

# OR/12/032 Geology

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The Lias (or in strict lithostratigraphical terminology the Lias *Group*) comprises those predominantly argillaceous sediments of latest Triassic and Early Jurassic age found in and around the United Kingdom, deposited between about 180 and 205 million years (my) ago. Onshore, the main outcrop of the Lias extends from the coast of Dorset (Lyme Regis to Burton Bradstock) to Yorkshire and Cleveland (Ravenscar to Redcar), with outlying areas in Somerset and South Wales, although parts are concealed beneath Quaternary (drift) deposits (Figure 2.1). Typically the strata dip very gently towards the east or southeast beneath younger beds, and so the Lias is present at depth eastwards (downdip) of the main outcrop other than in the London area (see below). This account will deal principally with these areas but in addition, it should be noted that small drift-covered outliers occur in Cheshire/Shropshire, and near Carlisle in Cumbria, and the Lias also occurs in central Skye and at various localities on the northwest coast of Scotland, and emerges here and there from beneath the Tertiary basalts of Northern Ireland. It also occurs offshore from the mainland outcrops and is also present beneath Cardigan Bay but does not crop out onshore there.



**Figure 2.1** Map showing outcrop and subcrop of the Lias Group in England and Wales with depositional basins, axes, and shelves.

## Tectonic setting

Over a long period of time during the latest part of the Palaeozoic era, a period of mountain-building (the Variscan Orogeny) produced by continuing movement of the earth's tectonic plates, uplifted the area of crust in what is now northwest Europe such that, by the beginning of the Permian Period (about 290 my), the area of Britain became dry land. During subsequent periods, these orogenic stresses relaxed, but were replaced by tensional forces associated with the beginning of continental rifting and creation of the North Atlantic Ocean basin on the western margins of Britain.

In combination, these effects produced a gradual subsidence of the region and the development of a number of fault-bounded basins (graben), where subsidence proceeded more rapidly than on the adjoining highs. These sedimentary basins are the Wessex, Bristol Channel, Worcester and Cleveland Basins in which great thicknesses of sediments accumulated during the Triassic Period (Sherwood Sandstone and Mercia Mudstone Groups) (Figure 2.1). By Rhaetian times, at the end of the Triassic period (c. 210 my) the sea flooded these basins, depositing the marine mudstone and limestones of the Penarth Group ('Rhaetic'). During the succeeding Jurassic (from c. 205 my) marine deposition continued, building up the Lias Group which typically lies on a somewhat eroded, commonly (trace fossil) bored surface of the Penarth Group. Subsidence continued in the basins,

albeit at a reduced rate and with some interruptions, again building up substantial thicknesses of Lias Group sediments; with 400 to 500 m in the Wessex, Worcester and Cleveland basins, and some 1300 m near Llanbedr on the margin of the mainly offshore Cardigan Bay Basin, the thickest Lias succession proved in Britain (Woodland, 1971<sup>[1]</sup>).

The basins were bordered by structural highs (Figure 2.1), including the small Mendip High, between the Wessex and Worcester basins, and the much more extensive London Platform, to the east. Because subsidence was less rapid on the highs than in the adjoining basins the successions there are substantially thinner and, because the sea lapped onto them progressively, the successions are less complete, with the older parts of the Lias missing. Thus the base of the Lias tends to be markedly diachronous, becoming younger when traced from the basins onto the highs (e.g. Donovan et al, 1979<sup>[2]</sup>). The highs were not inundated straight away and their interior parts remained land throughout the period of Lias deposition. Thus the London Landmass (i.e. the land area on the London Platform), diminished in size through the Early Jurassic, but some eastern parts probably remained dry land right through the Jurassic as (probably) did upland areas in Cornwall, Wales, Scotland and Ireland. However, the Pennines area was probably submerged early on.

Northwards, the London Platform merges into the East Midlands Shelf, a shallow marine area characterised by a more or less complete Lias succession of moderate thickness (typically 150 to 250 m). The smaller Bristol-Radstock Shelf is rather different, with thin and condensed successions, and could be regarded as the marginal area of the Mendip High. The Market Weighton High (or Axis) at the northern end of the East Midlands Shelf appears to have been an area of reduced subsidence throughout the Jurassic and, moreover, remained a high thereafter, such that Cretaceous rocks, which overlie the Jurassic unconformably throughout most of southern and eastern England, cut out all but the lowest part of the Lias Group there. The Vale of Moreton Axis, to the southwest of the East Midlands Shelf, was formerly perceived to have been an 'axis of uplift' similar to the Market Weighton High, but is now recognised merely as the hinge between the Worcester Basin and London Platform (Sumbler et al. 2000<sup>[3]</sup>).

The Lias Group is overlain non-sequentially by younger beds throughout southern and eastern England. Erosion prior to deposition of these younger beds cut into the Lias beneath so that the upper part of the succession is incomplete to a greater or lesser degree from place to place. It is most complete, with the youngest Lias beds preserved, in Dorset and Somerset and parts of the Cleveland Basin of Yorkshire. Conversely, the Lias is thinnest and least complete approaching the Market Weighton High and at depth on the interior of the London Platform. In these areas it is progressively overstepped by younger Jurassic and Cretaceous beds until it is cut out altogether.

## **Sediments, stratigraphy and nomenclature**

During the early Jurassic, the region that is now Britain lay somewhat closer to the equator than at present, probably at a latitude equivalent to the modern Mediterranean area. Accentuated by the presence of a large northern continental mass, and the lack of a major North Atlantic Ocean at that time, the climate and seas which gradually overwhelmed the region were warm. The seas were shallow; even in the basins, it seems that sedimentation generally kept pace with subsidence so that the water was generally no more than a few tens of metres in depth. Away from the contemporary shorelines, conditions were remarkably uniform over the whole area of deposition so that many beds can be traced across large areas of the country.

Sediments, mainly muds, were washed into the seas by rivers on the adjoining land areas, building up the succession of Lias strata. Much of the succession is more or less calcareous and limestone nodules or beds are developed at many levels most notably at the local base of the succession,

having been deposited when the seas were particularly shallow. In some areas these basal beds include pebbly and shelly limestones evidently laid down close to the contemporary shoreline. Sands and silts may represent climatic events, which washed coarser sediments into the sea, and are also associated with two main periods of basin infill and general shallowing (see below).

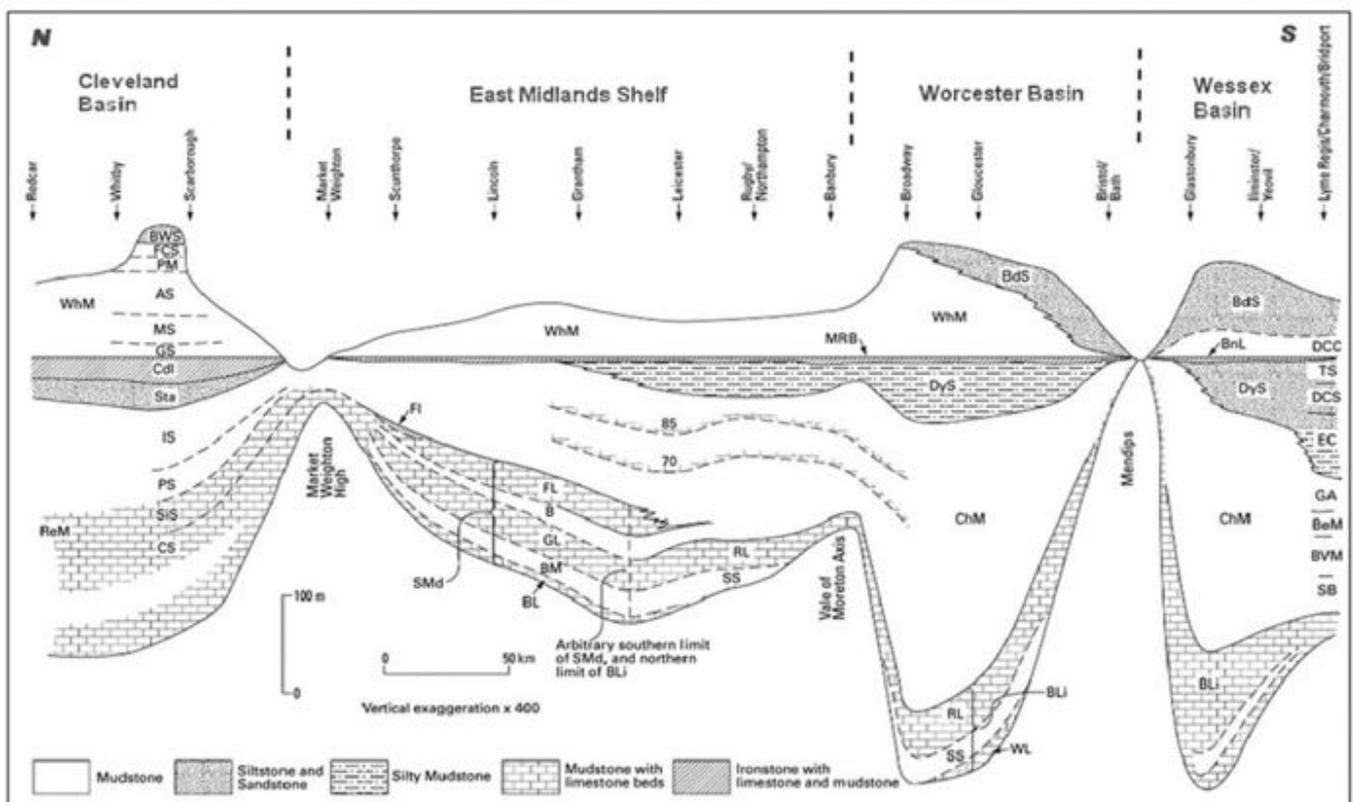
Life was abundant in the warm shallow sea, and much of the Lias is very fossiliferous, with rich and varied faunas dominated by molluscs, especially bivalves, gastropods, ammonites and belemnites, and with brachiopods also abundant in some beds. Bones of marine reptiles and fish also occur more rarely. For purposes of stratigraphy, the ammonites are the most important fossils of the Lias, providing the basis for chronostratigraphical (age-based) classification, enabling correlation on a worldwide scale. The Lias has been divided up into some twenty zones (and over 50 subzones) based on ammonites (Figure 2.2); a typical ammonite zone represents about 1 to 1.5 million years. Good exposures or cored boreholes are needed to apply ammonite zonation. However, microfossils such as ostracods, foraminifera and dinoflagellate cysts can also be used for zonation, and are particularly useful when dealing with borehole chipping samples. Unfortunately the stratigraphical resolution is, as yet, less precise than the ammonite-based standard.

**Stratigraphy** is the study of bedded (usually sedimentary) rocks, particularly in terms of their age and correlation with equivalent beds elsewhere. It has many different branches of which some of the most fundamental are:

**Lithostratigraphy**, the subdivision of the rock succession into units on the basis of its physical characteristics or lithology, and involves the differentiation, delineation, classification and formal definition of such units (Groups, Formations, Members, Beds) and their depiction on geological maps and sections.

**Biostratigraphy** is the subdivision and correlation of the rock succession based on its contained fossils. Particular [bio] zones may be recognised from the presence of a particular fossil or fossil assemblage.

**Chronostratigraphy** is the subdivision and classification of the rock succession into [chrono] zones, stages and systems according to its age.



**Figure 2.2** Section showing lithostratigraphy and depositional basins (refer to Figure 2.1 for locations and Table 2.2 for abbreviations).

Within the constraints provided by the fossil-based zonation, detailed, bed-by-bed correlation is generally best achieved by detailed comparison of lithological logs of boreholes and sections. For uncored boreholes, downhole gamma ray, sonic and other geophysical logs are valuable tools for correlation, being records of the physical properties of the rocks. Within the Lias, the gamma log essentially reflects the 'muddiness' (clay and silt content) of the rocks, and the sonic log measures the hardness of the sediments. Thus mudstones tend to have high gamma counts and low sonic velocities, whilst with limestones and sandstones the converse is true. Even at this basic level, it is often relatively easy to discern the characteristic lithological changes that define the formations and members of the Lias Group.

The rocks of the Lias Group were first studied systematically during the early and middle part of the nineteenth century. They became recognised as a distinct unit of strata, being largely dominated by clays and mudstones, yielding marine fossils, and contrasting with the red Triassic 'marls' below and the limestone and sand-dominated Middle Jurassic 'Oolites' and 'Estuarine' beds above. The Lias was split into a number of units and subunits based initially on lithological character. At the most basic level, it was perceived that the Lias could be divided into three parts, Lower, Middle and Upper Lias. In central England, for example, the succession comprised lower and upper divisions of mudstones separated by a middle division of sandy beds and ironstone. As geology progressed, and greater emphasis was placed on the importance of fossils for correlation, the traditional divisions Lower, Middle and Upper Lias became used variously as litho-, bio- or chronostratigraphical units and, as a result, positioning of their boundaries by different workers has been inconsistent. The same confusion of different disciplines of stratigraphy is inherent in the term 'Liassic', generally used in a quasi chronostratigraphic sense as a synonym of Lower Jurassic. Similar problems surround the usage of the numerous other stratigraphical terms, which have been used to describe subdivisions of the Lias Group.

In an attempt to rationalize the plethora of names, and clarify understanding, a revised scheme of lithostratigraphical classification for the Lias Group has recently been developed by the BGS with the support of the Geological Society of London. This scheme (Cox, Sumbler and Ivimey-Cook, 1999<sup>[4]</sup>), which divides the Lias Group into no more than 12 formations, is followed in this report, and is recommended that all workers should adopt it when describing rocks of the Lias Group. Terms such as Lower, Middle and Upper Lias, and Liassic should no longer be used in formal accounts. It should be noted that it will be some time before the recommended terminology is fully implemented on BGS geological maps.

Dealing with the main depositional areas of the Cleveland Basin, Wessex Basin and Bristol Channel Basin (Somerset and South Wales), Worcester Basin and East Midlands Shelf, the approach adopted is one of unification, emphasising similarities between areas rather than differences, whilst retaining well-established names where possible. The scheme used in these different geographical areas is shown in Table 2.1 and Figure 2.3 and the geographical limits of the various units are shown in Figure 2.2. Table 2.2 lists the current lithostratigraphic terms (in alphabetical order) with their former names or equivalents.

STAGE	Cleveland Basin				
		Coastal section	Rosedale	Other	
Upper TOARCIAN	Blea Wyke Sandstone F. 21m	Yellow Sandstone M. Grey Sandstone M.	Rosedale Ironstone Low Baring	?	
	Whitby Mudstone Formation 105 m	Fox Cliff M. 11.1m	High Grade Ironstone Wedge Ironstone		Whitby Mudstone (undifferentiated)
		Peak Mudstone M. 12.6 m			
		Alum Shale M. 37 m			
		Mulgrave Shale M. 31.5m			
Lower TOARCIAN					
		Grey Shale M. 13.5m			
Upper PLIENSBAKIAN	Cleveland Ironstone Formation 28 m				
	Staithes Sandstone F. 30m				
Lower PLIENSBAKIAN	Ironstone Shales and Pyritous Shales ~80m				
	Upper SINEMURIAN	Redcar Mudstone Formation 283 m	Siliceous Shales 32m		
Calcareous Shales 100m					
Lower SINEMURIAN					
HETTANGIAN					
RHAETIAN					

**Figure 2.3** Lias stages, formations and members showing regional variations.

Table 2.1 Lias Group 1:50 000 geological maps, thicknesses of Lias Formations.

<b>Cleveland Basin</b>						
Map Number	Map Name	Redcar Mudstone Formation (m)	Staithes Sandstone Formation (m)	Cleveland Ironstone Formation (m)	Whitby Mudstone Formation (m)	Blea Wyke Sandstone Formation (m)
35 + 44	Whitby and Scarborough	151	16.4 to 19.7	29.5 to 32.8	65.6 to 82	39.4 to 65.6
42	Northallerton	230	20 to 26	Up to 15	Up to 60	
52	Thirsk	Up to 200	20 to 25	9 to 13	40 to 43	
62	Harrogate	Up to 200	20	10	15 to 20	
<b>Wessex Basin including Somerset and South Wales</b>						
Map Number	Map Name	Blue Lias Formation	Charmouth Mudstone Formation (m)	Dyrham Formation (m)	Beacon Limestone Formation (m)	Bridport Sand Formation (m)
262	Bridgend	>146	--	--	--	--
263	Cardiff	Up to ~ 103	--	--	--	--
281	Frome	0 to 10?	Up to 46?	?	0 to 3	0 to 3
295	Taunton and Quantocks	100	100	--	--	--

296	Wincanton	23.8 to 52.3	~60 to 105?	5 to 40	1 to 6	0 to 83?
312	Yeovil	6.7 to 8.2	34.5 to 46	15 to 120	0.6 to 8.2	38 to 91
313	Shaftesbury	52 to 146	106 to 226	112 to 116	?	88 to 180
327	Tavistock		93 to 114	58.8 to 123	0 to 2	55 to 91
328	Dorchester	95 to 207	116 to 241	35 to 125	1 to 2	48 to 122?

### East Midlands Shelf

Map Number	Map Name	Scunthorpe Mudstone Formation (m)	Blue Lias Formation	Charmouth Mudstone Formation (m)	Brant Formation (m)	Dyrham Formation (m)	Marlstone Rock Formation (m)	Whitby Mudstone Formation (m)
80 + 89	Kingston upon Hull	45 to 90		35 to 100	35 to 85		1.9 to 7.6	10.6 to 28
90 + 91	Grimsby	45 to 90			70 to 79		3 to 11	13 to 38
126	Nottingham	28	--	--	--	--	--	--
127	Grantham	113 to 128			103 to 118	12 to 19	2.5 to 7.3	38 to 60
142	Melton Mowbray	124 to 136		110 to 130		15 to 25	1 to 5	55
171	Kettering		0 to 32	150 to 178		6 to 12	0 to 1	49 to 58
184	Warwick		24 to 35.3	150 to 170		21 to 26	2.5 to 4	Up to 38
185	Northampton					17 to 31	1 to 3	47 to 60
199	Worcester		Up to 85	Up to 250		Up to 60	0 to 6	Up to 105
200	Stratford-upon-Avon		6 to 85	61 to ~305		46 to 61	3 to 6.1	13 to 103?
201	Banbury		7.5 to 17	75 to 110		12 to 42	1.2 to 7.5	15 to 47
202	Towcester					12.5 to 16.7	0.3 to 3.3	14.8 to 49.2
216	Tewkesbury		96	225		60	Up to 5	Up to 76
218	Chipping Norton		0 to 11.2			7.5 to 30	0.3 to 7.6	7.5 to 60

### Worcester and Severn Basin

Map Number	Map Name	Blue Lias Formation	Charmouth Mudstone Formation (m)	Dyrham Formation (m)	Marlstone Rock Formation (m)	Whitby Mudstone Formation (m)	Bridport Sand Formation (m)
217	Moreton-in-Marsh	10 to 75	130 to ~290	15 to 60	0 to 6	25 to >110	0 to
235	Cirencester	8.7 to 57.8	120.6 to 284	15 to 54	0 to 5	9.6 to 98	7.8 to 75
236	Whitney	?	60 to 140	10 to 30	0 to 5	4 to 16	
251	Malmesbury	2 to 14	61 to 122	21 to 46	Up to 6.7	0 to 4.6	30 to 80?
264	Bristol	17 to 20	up to 122	Up to 9	Beacon Limestone Formation 1.4 m	Up to 23	

Table 2.2 Lias Group lithostratigraphic terms and former names

NOTE: where alternative abbreviations exist those used in cross-section (Figure 2.4) are shown in *italics*.

Current lithostratigraphic term	Former name
Alum Shale Member (AS)	Alum Shale Series/Formation, Hard Shales+Main Alum Shales+Cement Shales
Barnby Member (BM)	Angulatum/Angulata Clays, Barnby Clays
Barnstone Member ( <i>BL</i> )(Bst)	Strensham Series, Hydraulic Limestone (Series)
Barrington Member (BARB)	Barrington Beds, Upper Lias Limestone
Beacon Limestone Formation (BnL)	Junction Bed+Marlstone (Rock Bed)
Beckingham Member ( <i>B</i> )(Bkg)	Bucklandi Clays

Belemnite Marl Member (BeM)	Belemnite Marls/Beds, Stonebarrow Beds
Black Ven Marl Member (BVM)	Black Ven Beds/Marls, Black Marls [part]
Blea Wyke Sandstone Formation (BWS)	Blue Wick Sands, Blea Wick Sands/Beds/Series, Upper Lias (part)
Blue Lias Formation (BLi)	Blue Lias, Lyme Regis Beds, Hydraulic Limestones, Blue Lias Formation, marginal facies, White and Blue Lias [part]
Broadford Beds Formation (BfB)	Upper & Lower Broadford Beds
Bridport Sand Formation (BdS)	Bridport Sands, Midford Sands, Cotswold/Cotteswold Sands, Yeovil Sands, Upper Lias Sands
Calcareous Shale Member (CS)	Calcareous Shales
Charmouth Mudstone Formation (ChM)	Blue Marl, Lower Lias (Clay)(Formation), Brant Mudstone (Formation), Coleby Mudstone Formation (part), Pylle Clay Mbr+Spargrove Limestone Mbr+Ditcheat Clay Mbr
Cleveland Ironstone Formation (CdI)	Kettleness Beds, (Cleveland) Ironstone Series
Ditcheat Clay Member (DICL)	Lower Lias Marls (upper part), Belemniferous and Micaceous Marls (upper part)
Down Cliff Clay Member (DCC)	Down Cliff Clay
Down Cliff Sand Member (DCS)	Laminated Beds
Dyrham Formation (DyS)	Middle Lias Clays/Silts/Silts and Clays/Sandy Beds/Sands and Silts/Marls, Dyrham Silts, Dyrham Siltstone Formation, Pennard Sands (Member)
Eype Clay Member (EC)	Blue Clays, Eype Clay, Margaritatus Marls, Micaceous Beds, includes Three Tiers (Sandstone)
Eype Mouth Limestone Member	Junction Bed
Foston Member (FL)(Fst)	approximates to Ferruginous Limestone Series
Fox Cliff Siltstone Member (FCS)	Striatulus Shales
Frodingham Ironstone Member (FI)	Frodingham Ironstone
Granby Member (GL)(Gby)	Granby Limestones
Green Ammonite Member (GA)	Green Ammonite Beds, Wear Cliff Beds
Grey Sandstone Member	Grey Beds/Sands
Grey Shale Member (GS)	Grey Shales Series/Formation
Ironstone Shale Member (IS)	Ironstone Shales
Kettleness Member	Kettleness Beds
Lavernock Shale Member	Lavernock Shales, Lavernock Shale Formation
Marlstone Rock Formation (MRB)	Marlstone, Marlstone Rock, Marlstone Rock Bed
Marlstone Rock Member [of Beacon Lst Fm.] (MRWB)	Marlstone, Marlstone Rock
Mulgrave Shale Member (MS)	Jet Rock Series/Beds/Formation/Member, Jet Shales+Bituminous Shales
<i>Pabba Shales</i>	Pabba Beds
Peak Mudstone Member (PM)	Peak Shales
Penny Nab Member	<i>none</i>
Porthkerry Member (PO)	Porthkerry Formation
Portree Shale Formation (Pee)	Portree Shale
Pylle Clay Member (PYC)	Lower Lias Marls, Lower Lias Shales
Pyritous Shale Member (PS)	Pyritous Shales

Raasay Ironstone Formation (RASI)	none
Redcar Mudstone Formation (ReM)	Lower Lias
Rugby Limestone Member ( <i>RL</i> )( <i>RLs</i> )	Blue Lias, Lima Beds, Plagiostoma Beds
Saltford Shale Member ( <i>SS</i> )( <i>SaSh</i> )	Angulata Beds, Psiloceras Shales, Planorbis Beds (approx.), Lower Lias Clays (part), clays beneath Blue Lias
Scalpay Sandstone Formation (SCS)	Scalpa Sandstone Formation
Scunthorpe Mudstone Formation (SMd)	approximates to Hydraulic Limestones, Angulata Clays, Granby Limestones, Bucklandi Clays and Ferruginous Limestone Series/Frodingham Ironstone
Shales-with-Beef Member (SB)	Black Marl [part]
Siliceous Shale Member (SiS)	Siliceous Shales
St Mary's Well Bay Member	St Mary's Well Bay Formation
Staithe Sandstone Formation (Sta)	Staithe Beds/Formation, Marlstone Series, Sandy and Micaceous Beds, Sandy Series, Cleveland Sand Formation
Thorncombe Sand Member (TS)	Thorncombe Sands
Whitby Mudstone Formation (WhM)	Upper Lias (Clays/Clay Formation)
Wilmcote Limestone Member ( <i>WL</i> )( <i>Wct</i> )	combinations of Ostrea Beds, Pre-Planorbis Beds, Saurian Beds and Insect Beds
Yellow Sandstone Member	Yellow Beds/Sands

## Cleveland Basin

The succession in the Cleveland Basin is well displayed on the coast between Ravenscar, at the southern end of Robin Hood's Bay, and Redcar. It is classified in terms of the units traditionally recognised in these cliff sections:

- Blea Wyke Sandstone Formation
- Whitby Mudstone Formation
  
- Cleveland Ironstone Formation
- Staithe Sandstone Formation
  
- Redcar Mudstone Formation

Strictly, this nomenclature should be applied as far south as Market Weighton [SE 87 41] but in some contexts it may prove more convenient to take the southern limit a few kilometres farther north, at National Grid Line 450 or at the closely corresponding southern edge of BGS 1:50000 Sheets 63 and 64.

### Redcar Mudstone Formation

The Redcar Mudstone constitutes the 'Lower Lias' in the Cleveland Basin. The upper c.150 m, making up the greater part of the formation, is exposed at Robin Hood's Bay [NZ 9505 to NZ 9702] (Hesselbo and Jenkyns, 1995 <sup>[5]</sup>), which constitutes the type section. Some beds lower in the succession, although not the basal part of the formation, can be seen on the foreshore at Redcar,

Cleveland [NZ 60 24].

The Redcar Mudstone is typically about 225 to 250 m thick in the coastal area, and up to 280 m or more at depth inland, but thins to the west, being only 194 m in the Felixkirk borehole [SE 4835 8576] near Thirsk. The succession also thins dramatically southwards to the margin of the Cleveland Basin (Figure 2.1 and Figure 2.2) with perhaps only 30 or 40 m of strata at Market Weighton, although the thin succession there is partly due to the absence of the top part of the succession beneath the Cretaceous unconformity.

The Redcar Mudstone comprises grey, fossiliferous, fissile mudstones and siltstones with subordinate thin beds of limestone at some levels, and sporadic nodules of argillaceous limestone throughout.

The succession has been divided into several parts based on the excellent coastal sections. Approximately the lower half is assigned to the **Calcareous Shale Member**. It comprises mudstones with numerous thin beds of more or less shelly, argillaceous limestone, which tend to become more sandy up-sequence. Boreholes show that these limestones are particularly frequent and well developed in the lowest, poorly exposed part, forming a unit analogous to the Barnstone Member and Blue Lias elsewhere in England and Wales. Above, the **Siliceous Shale Member**, about 30 m thick on the coast, comprises silty mudstones with intercalations of strong calcareous siltstone and sandstone, often shelly, which represent storm-winnowed deposits. The topmost part of the Redcar Mudstone has been divided into the **Pyritous Shale Member** (c. 28 m), made up of mudstones with pyritic burrows and fossils, and the **Ironstone Shale Member** (c. 62 m) comprising mudstones with hard sideritic ironstone nodules. However, it is doubtful that these two units could be readily separated inland from their lithological characteristics alone. In the upper part of this succession, silty layers herald the transition to the succeeding Staithes Sandstone Formation.

### **Staithes Sandstone Formation**

This unit is well exposed in the cliffs of its type section at Staithes Harbour (Howarth, 1955<sup>[6]</sup>; Hesselbo and Jenkyns, 1995<sup>[5]</sup>) and also between Robin Hood's Bay and Hawsker Bottoms ([NZ 960 065] to [NZ 955 071]). In these sections it is about 26 m thick, and thicknesses of between about 24 and 30 m are recorded elsewhere in the Cleveland Basin, though it may be a little thicker in places, whilst thinning markedly to the south (Figure 2.1 and Figure 2.2). It comprises more or less argillaceous silty sandstone with some units of non-argillaceous fine-grained laminated sandstone, particularly in the middle and upper parts, and shows many types of bedding structures illustrating deposition in a shallow marine environment. The lower boundary lies within a transition from the underlying mudstones of Redcar Mudstone Formation; but for consistency is defined at base of 'Oyster Bed', a fossiliferous calcareous and ferruginous sandstone packed with fossil shells (including *Gryphaea*), which persists throughout the Cleveland Basin. The top is marked by a rapid transition to mudstones of the Cleveland Ironstone Formation.

Sands and silts are also developed at this level in the Lias elsewhere in England, and these strata indicate a widespread shallowing event, as the sedimentary basins became filled.

### **Cleveland Ironstone Formation**

The Cleveland Ironstone is well displayed at its type section on the coast near Staithes ([NZ 788 189] to [NZ 794 183]) (Howarth, 1955<sup>[6]</sup>; 1973; Hesselbo and Jenkyns, 1995<sup>[5]</sup>) and also at Hawsker Bottoms [NZ 953 073] and Kettle Ness [NZ 832 161]. About 29 m thick at Staithes, it generally falls within the range 20 to 35 m throughout the Cleveland Basin, though it thins markedly towards the margins to west and south, being only a few metres thick near Thirsk. This thinning is a result of a

more condensed sequence with some parts absent, notably one near the top which separates the **Penny Nab Member** from the succeeding **Kettleness Member** (Howard, 1985<sup>[7]</sup>). Whilst dominated by mudstone, argillaceous siltstone and silty sandstone, it characteristically contains beds of siderite and berthierine-rich, often somewhat nodular, ooidal ironstone which occurs at the tops of sedimentary rhythms. Where the succession is fully developed, there are six named ironstone bands, typically 0.3 to 1 m thick, the thickest and most persistent being the 'Main Seam' close to the top of the formation (in the Kettleness Member). The ironstone bands are best developed in the Guisborough-Loftus area near Middlesbrough, where they form up to 20 per cent of the thickness of the formation and once formed the basis of a thriving iron and steel industry ([see Iron](#)). There, the Main Seam, where not removed by mining, locally exceeds 3 m in thickness.

The base of the formation is clearly marked by a rapid downward transition from shaly mudstone with scattered sideritic nodules to the siltstone or sandstone of the Staithes Sandstone Formation. The top is similarly readily apparent, being taken at the top of the highest ironstone bed or nodule band, which is succeeded by grey mudstone of the Whitby Mudstone Formation.

### **Whitby Mudstone Formation**

The Whitby Mudstone, essentially the 'Upper Lias clays' of previous accounts, is well exposed in the cliffs between Hawsker Bottoms [NZ 951 077] and Whitby Harbour [NZ 901 114], which constitutes its type section (Howarth, 1962<sup>[8]</sup>, 1973<sup>[9]</sup>, 1992<sup>[10]</sup>). There it is about 115 m thick, but it thins to the west being about 40 m near Thirsk, principally due to the loss of the upper part by erosion beneath the succeeding Middle Jurassic beds. Southwards, towards Market Weighton, it is cut out altogether beneath the Cretaceous unconformity (Figure 2.1 and Figure 2.2).

The Whitby Mudstone is composed of medium and dark grey fossiliferous mudstone and siltstone, which at some levels is shaly and somewhat bituminous. It also includes thin siltstone or silty mudstone beds and hard nodules of argillaceous limestone are very common at some horizons. Both the base and top of the formation are marked by strong lithological changes, to the Cleveland Ironstone below and (generally) sandstones above. The Whitby Mudstone of the coast has been divided into five members. The **Grey Shale Member** at the base, about 15 m thick comprises silty, micaceous mudstones with bands of sideritic ironstone nodules. The succeeding **Mulgrave Shale Member**, about 32 m, is made up of finely laminated, bituminous and pyritic shales (*see* front cover photo). The lower c.7 m constitutes the Jet Rock, which is particularly rich in organic material, and includes very hard pyritic limestone nodules. Near the top of the Jet Rock, lenses of jet were formerly mined for making jewellery and ornaments ([see Jet](#)). Jet is essentially a black, lustrous, high-grade lignite, representing fossilised driftwood. Above the Mulgrave Shale, the **Alum Shale Member** comprises about 37 m of medium grey, relatively blocky or poorly laminated silty mudstone with sporadic limestone and ironstone nodules. The middle part of the member, the 'Main Alum Shales' is particularly low in calcium carbonate and partly for this reason proved suitable for the manufacture of alum (a potassium aluminium sulphate), and was extensively worked for this purpose until the late nineteenth century ([see Alum](#)). The topmost part of the formation comprises about 13 m of highly micaceous silty mudstone (**Peak Mudstone Member**) succeeded by 11 m of argillaceous siltstone and silty mudstone (**Fox Cliff Siltstone Member**). These beds are of rather restricted occurrence; over much of the Cleveland Basin they are cut out beneath younger strata.

### **Blea Wyke Sandstone Formation**

The Blea Wyke Sandstone, forming the youngest part of the Lias Group, is exposed only at the type section Blea Wyke Point [NZ 991 015], near Ravenscar (Knox, 1984<sup>[11]</sup>; Hesselbo and Jenkyns, 1995<sup>[5]</sup>), and is present only in the vicinity of this locality, elsewhere being cut out beneath the Middle Jurassic beds. It comprises 18–21 m of fine-grained, micaceous sandstones. The succession is

divisible into two parts, representing two coarsening upward cycles. The lower **Grey Sandstone Member** is markedly banded, and generally somewhat argillaceous, and the succeeding **Yellow Sandstone Member** is more massive, and generally better sorted.

## **Wessex Basin and Bristol Channel Basin**

The entire Lias succession is well exposed on the Dorset coast between Lyme Regis and Burton Bradstock (Callomon and Cope, 1995<sup>[12]</sup>; Hesselbo and Jenkyns, 1995<sup>[5]</sup>). As now classified (Cox et al., 1999<sup>[4]</sup>) it comprises:

Bridport Sand Formation  
Beacon Limestone Formation  
Dyrham Formation  
Charmouth Mudstone Formation  
Blue Lias Formation.

Inland from the Dorset coast, data (particularly cored boreholes) are limited. Whilst there is no doubt that the formational framework remains valid, details of the succession, and the degree of lateral persistence of the members recognised on the coast is not entirely clear, whilst other members have been recognised in some areas (e.g. Bristow and Westhead, 1993<sup>[13]</sup>).

### **Blue Lias Formation**

The Blue Lias is perhaps the best known, though not the most typical, part of the Lias Group, having been visited by generations of geologists at Lyme Regis [SY 320 908 to SY 333 914] (Lang, 1924<sup>[14]</sup>; Hallam, 1960<sup>[15]</sup>; Hesselbo and Jenkyns, 1995<sup>[3]</sup>; Callomon and Cope, 1995<sup>[12]</sup>), though its type area is between Bath and Bristol in Somerset (Torrens and Getty, 1980<sup>[16]</sup>). At Lyme Regis, the formation is about 25 m thick, and comprises thin (typically 0.10 m to 0.30 m) beds of argillaceous fine-grained limestones ('cementstones') interbedded with mudstones and silty mudstones, in beds of generally slightly greater thickness (Figure 2.4). The limestones make up about 40 per cent of the succession. In fact, viewed regionally, the Blue Lias at Lyme Regis is thin and condensed, as it thickens substantially northwards, probably being some 90 to 130 m inland and is typically developed on the coast east of Watchet, Somerset [ST 080 436 to ST 220 470] (Whittaker and Green, 1983<sup>[17]</sup>; Warrington and Ivimey-Cook, 1995<sup>[18]</sup>), where it is about 145 m thick. There, although more individual limestone beds are present, they are of comparable thickness with those in Dorset, whilst intervening mudstones are typically thicker, such that overall, limestone makes up a much smaller proportion of the total succession (perhaps only 20 per cent). Throughout the region, the top of the Blue Lias (i.e. the base of Charmouth Mudstone Formation) is marked by an upward decrease in abundance of limestone beds, sometimes associated with marked decrease in their individual thickness and lateral persistence. Particularly in more expanded successions, the level at which to take the boundary is somewhat arbitrary; guidelines intended to achieve some consistence are given by Cox et al. (1999)<sup>[4]</sup>.



**Figure 2.4** Blue Lias Formation at Ware Cliff, Lyme Regis.

On the opposite side of the Bristol Channel, about 150 m of Blue Lias are represented in Glamorgan, and well exposed on the coast (Waters and Lawrence, 1987<sup>[19]</sup>; Wilson et al., 1990<sup>[20]</sup>; Warrington and Ivimey-Cook, 1995<sup>[18]</sup>) where it is the only part of the Lias preserved (Figure 2.5). The Glamorgan Blue Lias laps onto a massif of Carboniferous Limestone and older rocks, which during Early Jurassic times, formed islands in the Lias sea, which were progressively submerged and buried by sediment. The near-shore location is reflected in the relatively high proportion of limestone in the succession; overall, about 50 per cent. The succession is readily divisible into three members, directly equivalent to those developed in the Worcester Basin and East Midlands Shelf. The basal **St Mary's Well Bay Member** comprises c.20 m of limestone and mudstone in approximately equal proportions. Above, some 9 to 12 m of shaly mudstone with very subordinate nodular limestones is known as the **Lavernock Shale Member**. The succeeding **Porthkerry Member**, of which about 120 m are preserved, is much like the St Mary's Well Bay Member, but includes some unusually thick limestones (over 1 m) albeit with thin mudstone partings. Locally the limestones are secondarily silicified, with the development of chert nodules and bodies. Close to the 'islands' of older rocks, a near-shore marginal facies of the Blue Lias is developed (the Sutton Stone and Southerndown Beds). This comprises massive or rubbly, often shelly and conglomeratic limestones and, as might be expected, is highly diachronous.



**Figure 2.5** View from Trwyn y Witch to Nash Point, Glamorgan Heritage Coast Blue Lias Formation (Porthkerry, Lavernock Shales, & Shelly Limestone Members) (Note: folds & faults on wave-cut platform), C. James 11/07/01.

### **Charmouth Mudstone Formation**

The Charmouth Mudstone is essentially equivalent to the Lower Lias clay of many earlier accounts, that is the 'Lower Lias' excluding the Blue Lias. At the Dorset coast type section (between Seven Rock Point [SY 327 909] and Golden Cap [SY 407 922]) it is about 136 m thick, but thickens substantially inland to perhaps as much as 290 m, and with c.235 m proved at Brent Knoll near Burnham on Sea, Somerset. The Charmouth Mudstone comprises mudstones of various types ranging from dark grey laminated mudstone to generally paler grey blocky mudstone. It contains sporadic, nodular limestone beds and nodule bands, and at many levels, particularly in the upper part, phosphatic or sideritic nodules and silty and finely sandy beds.

The Charmouth Mudstone of the Dorset coast has been divided into four members. Whilst these can be recognised inland on the basis of geophysical borehole log correlation (e.g. Whittaker et al., 1985) they have never been mapped at the surface and it is doubtful that they could be reliably identified on the basis of lithologies alone. The basal c. 36 m comprises dark shaly laminated mudstone with a few very thin limestone bands and is known as the **Shales-with-Beef Member**. Characteristically it contains lenticles of fibrous crystalline calcite (the 'beef' of the name). Although generally said to be an ancient diagenetic effect, this may alternatively be related to weathering in the landslipped coastal area, and may not occur elsewhere. Above, the **Black Ven Marl Member**, 42 m thick, is somewhat similar being made up of rather dark to medium grey mudstone, some parts pyritic or mottled with burrows, and with a few limestone bands. The succeeding **Belemnite Marl Member**, about 24 m thick, comprises alternating paler and darker, more carbonaceous mudstones. Apart from sporadic belemnites, fossils are rare. The cyclical nature of the succession is believed to be due to climatic variations affecting plankton abundance and the input of detrital clays. The top is marked by the Belemnite Stone, a thin belemnite-bearing limestone. The top part of the Charmouth Mudstone comprises the **Green Ammonite Member**, about 35 m thick, comprising mid grey mudstone. The curious name derives from the coloration of the calcite infill found in some fossils preserved in limestone nodules at certain levels. The succession becomes more silty up-sequence heralding the transition to the succeeding Dyrham Formation.

## **Dyrham Formation**

The Dyrham Formation comprises grey and greenish grey, silty and sandy mudstone, with interbeds of siltstone or fine-grained, often somewhat micaceous, calcareous sandstone. It is exposed on the Dorset coast between Seatown [SY 420 918] and Eype Mouth [SY 447 910] where it is about 122 m thick. It tends to thin northwards, in part through passage of the lowest part into less arenaceous beds (Figure 2.2). On the coast the succession has been divided into three members, but it is uncertain how readily these can be recognised further north. The lowest c.65 m comprises the **Eype Clay Member**, made up predominantly of bluish grey, silty and micaceous shaly mudstone with common small sideritic ironstone nodules. The base is marked by the Three Tiers, a fine sandy unit about 6 m thick in which the base, middle and top parts are cemented into sandstone beds separated by weaker material. This unit is known only in the coastal area, dying out inland. Above the Eype Clay, the **Down Cliff Sand Member** comprises 30 m of greyish brown, thinly interbedded, argillaceous sandstone and sandy mudstone. The succeeding **Thorncombe Sand Member** comprises 26 m of yellow-weathering silty and fine-grained sandstone. Inland, in north Dorset and Somerset, the Dyrham Formation, formerly known as the Pennard Sands in this area, is essentially equivalent to the Thorncombe Sand Member only.

## **Beacon Limestone Formation**

The Beacon Limestone is typically 0.6 to 1.5 m thick, equivalent to a much thicker succession farther north in England. The lower part, from zero to about 0.6 m thick, is the **Marlstone Rock Member**, made up of brown, or reddish, more or less ooidal limonitic ironstone, and is the equivalent of the Marlstone Rock Formation of the Worcester Basin and East Midlands Shelf. The upper part, the **Eype Mouth Limestone Member** is the so-called Junction Bed of most previous accounts. It comprises white, pinkish and yellowish nodular, conglomeratic and often highly fossiliferous limestone. It is a highly condensed unit incorporating many non-sequences, and is the equivalent of much of the Whitby Mudstone Formation as developed further north in England.

## **Bridport Sand Formation**

The Bridport Sand Formation includes the former 'Upper Lias sands' incorporating, within the Wessex Basin, both the Bridport Sand of south Dorset and the Yeovil Sands of North Dorset and Somerset. These units form a single somewhat diachronous sand body that becomes younger to the south. The succession can be examined in spectacular cliffs between Broadwindsor [ST 437 026] and Burton Bradstock [SY 488 895] (Wilson et al., 1958<sup>[21]</sup>) where it is c.62 m thick (P005794). The lower c.21 m constitutes the **Down Cliff Clay Member**, a uniform blue-grey fine sandy clay that weathers to a yellowish clay. The great bulk of the Bridport Sand Formation on the coast comprises grey, brownish yellow-weathering, micaceous silt and fine-grained sand, with calcite-cemented, more or less continuous into nodular sandstone beds occurring irregularly throughout the succession, typically every metre or so.



**P005794** Cliffs in Bridport Sand Formation capped by Inferior Oolite limestone at Burton Bradstock, Dorset [NGR 348500,189200].

The Bridport Sand Formation maintains its thickness into north Dorset and Somerset but may thicken locally to 90 m or more, and at depth in east Dorset, is more than double this thickness, with a much expanded Down Cliff Clay Member. In the Yeovil-Ilminster district, almost the whole of the succession is sands with nodular sandstones. A unit of brown-weathering shelly sandstone up to c.27 m thick in the upper part is known as the Ham Hill Stone, and has been extensively quarried for building stone. In north Somerset, the 60 m of Bridport Sand is generally present in the main outcrop, but this is cut out beneath Middle Jurassic beds as the Mendips are approached, near Shepton Mallet. Westwards, in the outlier of Glastonbury Tor, 11 m of silty mudstone occurs at the base in the lower part, and at Brent Knoll the mudstone succession thickens, and incorporates older zones than elsewhere in the Wessex Basin, in a succession somewhat like that in the Worcester Basin.

## **Mendip High and Bristol-Radstock Shelf**

This area encompasses the immediate vicinity of the Mendip Hills, and parts just to the north, between Bristol and Bath. As in South Wales, the Carboniferous Limestone and associated rocks that now form the Mendip Hills and Bristol area formed an up-standing massif during deposition of the Lias so that the succession that laps on to it is thin and incomplete, and there is no Lias preserved on the Mendips proper; any that may once have been present was removed by erosion in the Middle Jurassic. The Blue Lias and Charmouth Mudstone are thin; at Dundry Hill just south of Bristol, for example, the Blue Lias is about 20 m thick and the Charmouth Mudstone about 125 m. As the Mendip massif is approached, the succession thins still more and both Blue Lias and the lower part of the Charmouth Mudstone become increasingly dominated by limestones which form a diachronous near-shore facies including gritty, shelly and ferruginous limestones, to which a variety of local names have been applied (Donovan and Kellaway, 1984<sup>[22]</sup>). In the Radstock area south of

Bath, these units and the succeeding Dyrham Formation are cut out by erosion beneath the Beacon Limestone Formation, which comprises up to 1.5 m of marly and ferruginous limestone. This is succeeded by up to about 30 m of Bridport Sand Formation, which was formerly known as the Midford Sands.

## **Worcester Basin and East Midlands Shelf**

This extensive region stretches from the Bath area as far north as the Market Weighton High. The Worcester Basin, lying between the Malverns on the west, and the so-called Moreton Axis on the east, was an area of subsidence throughout the Triassic and Early Jurassic and the Lias succession is typically over 500 m thick, somewhat more than is usual in either the Wessex or Cleveland basins, and about twice the thickness typical on the adjoining East Midlands Shelf. Thinning at the eastern margin of the basin, i.e., the Vale of Moreton Axis, is gradual, but is concentrated in a zone a few kilometres wide, running approximately from Stratford-upon-Avon to Moreton-in-Marsh. The succession on the East Midlands Shelf thins to the southeast as the London Platform is approached, largely through progressive overlap of the basal beds. In the northern part of the East Midlands Shelf, the lower part of the succession changes in character such that different formational names are applied.

### **BLUE LIAS FORMATION**

The Worcester Basin is the type area of the Blue Lias with the type locality at Saltford railway cutting [ST 685 671 to ST 681 676], southeast of Bristol (Donovan, 1956<sup>[23]</sup>; Torrens and Getty, 1980<sup>[16]</sup>; Donovan and Kellaway, 1984<sup>[22]</sup>). In the basin, the formation is up to 90 m thick whilst on the East Midlands Shelf, 50 to 60 m is more typical. In lithological character it is much like the Blue Lias of the Wessex Basin, comprising mudstones with thin beds and nodule bands of pale grey, smooth-textured, more or less argillaceous limestones. These are seldom more than 0.2 to 0.3 m thick. Where fully developed it can be divided into three members. The **Wilmcote Limestone Member** at the base, present only in the Basin itself, comprises up to 8 m of mudstone with limestone interbeds, and is particularly limestone-rich at the base. It is succeeded by the mainly mudstone unit of the **Saltford Shale Member**, generally about 20 to 30 m thick, and of more widespread distribution than the Wilmcote Limestone, though possibly absent over the Vale of Moreton Axis. The uppermost part of the Blue Lias is known as the **Rugby Limestone Member**, which ranges from about 25 to 55 m in thickness. It is well exposed in quarries at Rugby (Figure 2.7) and elsewhere in Warwickshire, where it comprises about 36 m of alternating limestone and mudstone, the latter making up about 30 per cent of the succession. In the thicker, more expanded successions of the Basin, limestones form a somewhat lower proportion, of between 15 and 20 per cent.



**Figure 2.7** Quarry in Charmouth Mudstone Formation overlying Blue Lias Formation, Parkfield Road (East) quarry, Rugby, Warks.

### **Scunthorpe Mudstone Formation**

The outcrop of the Blue Lias can be traced northwards to Rugby, but there disappears beneath a thick cover of glacial drift. Where the Lias re-emerges in the Vale of Belvoir in north Leicestershire, the lower part of the Lias succession is substantially different and is termed the Scunthorpe Mudstone Formation. The precise details of the transition between the two stratigraphies are currently uncertain. Provisionally, the southern limit of the Scunthorpe Mudstone Formation is taken at the southern boundary of BGS sheet 142 or the nearby National Grid northing 315; that is, just south of Melton Mowbray.

The Scunthorpe Mudstone Formation comprises grey, variably calcareous mudstone with thin beds of argillaceous limestone of various types, particularly near the base and in the upper part in which sandy and ferruginous beds occur. It is some 110 to 120 m thick in the south, but thins substantially northwards, being only about 60 to 80 m thick in the type area around Scunthorpe, in north Lincolnshire and only 40 m just north of the Humber. It thins still further towards the Market Weighton High. In the Cleveland Basin, it is approximately equivalent to the Calcareous Shale Member (of the Redcar Mudstone Formation), which is similar in facies.

The type section of the Scunthorpe Mudstone Formation is the BGS Blyborough Borehole (SK 99 SW/79; [SK 9206 9428]; Gaunt et al., 1992<sup>[24]</sup>) near Scunthorpe, but it has been studied in greater detail in south Lincolnshire and north Leicestershire where it has been divided into five members (Brandon et al., 1990<sup>[25]</sup>). It seems probable, from borehole geophysics, that these are, in principle, recognizable in the north too. The **Barnstone Member** at the base comprises 5–10 m of alternating grey mudstone and limestone. The limestone beds are 0.1 to 0.3 m thick, and those in the basal 2–3 m are typically shelly. Argillaceous fine-grained limestones make up about 30 per cent of the succession, much like the Wilmcote Limestone Member of the Blue Lias in the Worcester Basin. Above, the **Barnby Member** comprises about 20 m of mudstone with sporadic limestone nodules and a few very thin limestone beds. It is essentially equivalent to the Saltford Shale. The succeeding **Granby Member**, 30 m thick, is, in terms of its age, approximately the equivalent the Rugby Limestone Member of the Blue Lias Formation. However, it contains considerably less limestone, making up only 10 to 15 per cent of the succession, and these limestones are generally coarser grained with much shell debris. They probably represent sediment winnowed by storms.

Above, the **Beckingham Member** comprises about 20 m of mudstone with rare thin limestones, and limestone nodules in the upper part. It is possible that this unit dies out northwards through development of additional limestones. The topmost unit of the Scunthorpe Mudstone Formation is the **Foston Member**. It comprises about 30 m of mudstones with shelly and somewhat sandy limestones. At the base in Leicestershire, the Stubton Limestone is a composite limestone about 1.5 m thick, characteristically containing ferruginous ooids in the upper part.

In a restricted area around Scunthorpe itself, the topmost unit of the Scunthorpe Mudstone Formation is the **Frodingham Ironstone Member**, up to about 10 m in thickness (Figure 2.2). It comprises more or less muddy or calcareous ooidal ironstone, and was formerly the basis of the Scunthorpe iron and steel industry. It dies out rapidly both north and south of that area and in Leicestershire the top of the Formation is drawn at a thin, composite conglomeratic bed (the Glebe Farm Limestone) which marks an important regional non-sequence which, however, is probably at a slightly higher horizon than the top of the Frodingham Ironstone of north Lincolnshire.

### **Charmouth Mudstone Formation**

The Charmouth Mudstone reaches almost 300 m in thickness in the Worcester Basin, though 250 m may be a more usual figure. On the East Midlands Shelf, thinner successions of about 100 to 150 m are typical. Northwards from the Leicester area, it is thinner still as a result of passage of the lower beds into the upper part of the Scunthorpe Mudstone Formation, and combined overall condensation towards the Market Weighton High. The Charmouth Mudstone is made up of grey mudstone with sporadic thin bands and nodules of limestone, some of which are markedly shelly. The upper part (say 50 to 70 m) is generally slightly more silty than the lower beds, and these higher beds may contain occasional sideritic ironstone nodules and beds, particularly in the north where the Dyrham Formation is absent. In this northern area, more or less coincident with the development of the Scunthorpe Mudstone Formation, the formation was formerly known as the Brant Mudstone (Brandon et al., 1990<sup>[25]</sup>). It includes one or more fine sandstone beds near the base (Sandrock or Brandon Sandstone) and this part of the succession resembles equivalent beds in the upper part of the Siliceous Shale Member of the Cleveland Basin.

Whilst the Charmouth Mudstone of this region has not been subdivided into members, study of boreholes, particularly downhole geophysical logs, shows a remarkably uniform internal stratigraphy throughout the region. Various more calcareous units form geophysical marker bands which are useful for correlation; these include the so-called 70 and 85 Markers indicated on Figure 2.2 (see for example Horton and Poole, 1977<sup>[26]</sup>; Horton et al., 1987<sup>[27]</sup>). At outcrop, these are seen as units of mudstone, several metres thick, bearing abundant limestone nodules, and lenticular, often very shelly limestones.

### **Dyrham Formation**

The Worcester Basin is the type area of this unit, named after the village of Dyrham [ST 741 758], to the east of Bristol (Kellaway, 1960<sup>[28]</sup>). It tends to form moderately steep slopes of an escarpment capped by the Marlstone Rock Formation. It is typically about 40 to 60 m thick in the Basin, though seldom more than 30 m thick on the Shelf. It can be traced as far north as the Grantham area, beyond which its characteristic sandy and silty lithologies do not appear to be developed and equivalent strata are included in the Charmouth Mudstone (Figure 2.2).

Overall, the succession is less sandy than in the Wessex Basin, being dominated by more or less silty, often finely micaceous mudstones which weather to a pale bluish grey, ochreous mottled clay. These beds were once favoured for brick making and there are several large, disused brickpits along the outcrop including the type section at Robin's Wood Hill, near Gloucester, Gloucestershire [SO 836

149] (Ager, 1956<sup>[29]</sup>, 1969<sup>[30]</sup>). Typically, the Dyrham Formation contains beds of fine-grained sand, which may be cemented into quite hard massive sandstones. These include the Subnodosus Sandstone, up to 1.5 m thick, which occurs near the top of the succession in the Gloucester to Moreton-in-Marsh area of the Cotswolds. The Capricornus Sandstone is a convenient marker for the base of the formation in this Cotswolds area, but where the sandstone is not well developed; the base of formation is gradational and hard to define.

### **Marlstone Rock Formation**

The Marlstone Rock Formation is restricted to this region, although a condensed representative is present as a member of the Beacon Limestone Formation in the Mendips and Wessex Basin areas. The Marlstone Rock is generally some 2 to 4 m in thickness and reaches a maximum of 7.5 m near Banbury. Up to 10 m are reported locally in Leicestershire, but this figure includes the so-called 'Sandrock' developed in much of the Midlands, which is a sandstone that strictly belongs to the Dyrham Formation (see above) but was not formerly mapped separately from the Marlstone Rock proper. The Marlstone Rock typically caps a prominent escarpment throughout the region, often forming an extensive shelf like dip-slope.

The Marlstone Rock is typically a more or less sandy, shell-fragmental, siderite and berthierine-bearing ooidal limestone, with calcareous sandstone and mudstone partings. It is commonly highly fossiliferous, particularly with belemnites and brachiopods (*Lobothyris* and *Tetrarhynchia*). In the Worcester Basin the formation is not generally especially ferruginous and may appear as a greenish-grey sandstone. However, on the Shelf, the iron concentration reaches 20 to 25% and the rock weathers to a rust-brown limonitic ironstone. This was formerly worked for iron ore particularly in the Banbury area and in Leicestershire and can still be seen in abandoned quarries in these areas and also at the type section, Tilton railway cutting, east of Leicester [SK 762 055] (Hallam, 1955<sup>[31]</sup>, 1968<sup>[32]</sup>; Howarth, 1980c<sup>[33]</sup>, 1992<sup>[10]</sup>).

The base of the Marlstone proper is an erosive non-sequence, and the basal bed is commonly conglomeratic enabling its identification in sections where the 'Sandrock' facies is present (e.g. in the type section). The top is also generally erosive, with mudstones or limestones of the Whitby Mudstone resting sharply on it.

### **Whitby Mudstone Formation**

The Whitby Mudstone exceeds 100 m in thickness in the northern part of the Worcester Basin, but thins to zero southwards due to replacement by the Bridport Sand Formation and Beacon Limestone Formation (see below). On the East Midlands Shelf thicknesses are very variable but 20 to 40 m are typical. The succession is incomplete compared with the type area in the Cleveland Basin, as the top beds are 'missing' beneath an erosive non-sequence at the base of the Middle Jurassic strata. The beds present are essentially equivalent to the Mulgrave Shale and Alum Shale members of the Cleveland Basin and are of similar lithology, being composed of generally rather dark to medium bluish grey, commonly shaly mudstone, with sporadic small dark grey limestone nodules. In the Worcester Basin and south-western part of the East Midlands shelf (Gloucestershire to Northamptonshire), brown to white thinly bedded or nodular limestones are developed in the basal few metres; these limestones are often highly fossiliferous with well preserved ammonites. Southwards, with increasing condensation of the succession these limestones become incorporated into the upper part (Eype Mouth Limestone) of the Beacon Limestone Formation.

Particularly in the Cotswold area and Leicestershire, the Whitby Mudstone typically forms a steep scarp slope capped by harder Middle Jurassic strata, and in this situation is very prone to landsliding (see Chapter 5).

## Bridport Sand Formation

The Bridport Sand Formation, formerly known in this region as the Cotswold Sands, is restricted to the Worcester Basin. It is made up of yellowish brown, fine-grained micaceous sands, which rarely may be cemented into a weak calcareous sandstone. First appearing near Broadway in the north Cotswolds, followed southwards it replaces the Whitby Mudstone from the top downwards such that near Wotton-under-Edge, Gloucestershire, most of the succession, about 60 m thick, may be assigned to the Bridport Sand Formation. From there southwards, any mudstones at the base may be most conveniently treated as a part of the Bridport Sand Formation. In this southern area, condensed, ferruginous, often highly fossiliferous marls and limestones often occur in the topmost part. This 'Cotswold Cephalopod Bed' is seldom more than 1 m thick but reaches 4.6 m near Dursley.

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