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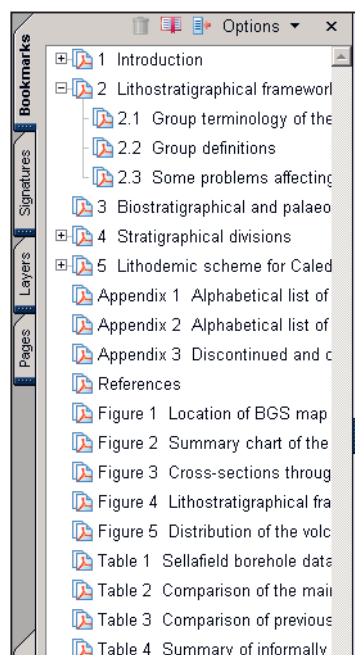
Research Report RR/09/01



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from each figure, plate or table caption to the first place that figure, plate or table is mentioned in the text and



from each page number back to the contents page.

[RETURN TO CONTENTS PAGE](#)

BRITISH GEOLOGICAL SURVEY

RESEARCH REPORT RR/09/01

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Front cover

View of the Upper Tawe Valley, South Wales Coalfield, showing Visean limestones of the Pembroke Limestone Group, exposed in prominent scarps. They are overlain by the Twrch Sandstone Formation (Marros Group) of Namurian age (P007583).

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A lithostratigraphical framework for the Carboniferous successions of southern Great Britain (onshore)

C N Waters, R A Waters, W J Barclay and J R Davies

Contributors: E C Freshney and B E Leveridge

Keyworth, Nottingham British Geological Survey 2009

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British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquires@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 0207 589 4090 Fax 0207 584 8270
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

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Foreword

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

The study draws upon an overview report for the Carboniferous of Great Britain (Waters et al, 2007). The overview report identifies a group framework based upon the identification of eight major lithofacies associations

across the UK. This framework report provides further, more detailed descriptions of group and formation nomenclature, specifically for the onshore area of southern Great Britain (essentially south of the Craven Fault System). The report covers central, southern and south-west England and Wales. 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, the report proposes a new nomenclature and provides a full description. This framework report is produced in conjunction with a framework report for northern Great Britain.

Acknowledgments

This report is the result of much discussion and lively debate within the BGS regarding the formulation of a comprehensive hierarchical lithostratigraphical scheme for the onshore successions of Great Britain. In 1999 Dr Peter Allen (Assistant Director, BGS) requested that the chairmen of the established Stratigraphical Framework Committee, Mike Browne (Midland Valley of Scotland), Nick Riley (Namurian of the Pennines) and Brian Young (Carboniferous of the Scottish Borders and northern England) investigate the possibility of producing a UK wide subdivision of Dinantian and Namurian lithostratigraphy at the group level. Following a meeting held on 11 June 1999 a top-down approach, defining groups by broad lithological facies was proposed, and schematic correlation figures were generated to indicate the distribution of these main lithofacies types. It was accepted that additional expertise was required to complete the lithostratigraphy of southwest England, so a further meeting was held on 21 October 2004. This proposal forms the basis of

the subsequent scheme published within an overview report for the entire UK onshore (Waters et al., 2007). The subsequent task, detailed in this report, was to complete a comprehensive lithostratigraphical description of southern Great Britain. The authorship of this report includes those who produced the Lexicon entries for all of the units described in this report. However, it is important to acknowledge the important contribution of E C Freshney and B E Leveridge in the compilation of Chapter 6 on South-West England.

The authors of the report acknowledge the contribution of many others in BGS who have offered constructive advice, especially D J Lowe in his role as Lexicon Manager. The comments of the BGS Stratigraphy Committee (Chaired by J H Powell) and the external reviewers, Dr Ian Somerville (University College Dublin) and Dr Sarah Davies (University of Leicester), are also acknowledged. Joanna Thomas is thanked for editing the report and Paul Lappage is thanked for the drafting of the figures.

Contents

Navigating the document *(follow link for information)*

Foreword	i
Acknowledgements	iv
Summary	vii
1 Introduction	1
1.1 Tectonic setting	1
1.2 Palaeogeography	1
2 Correlation and biostratigraphical framework	5
2.1 Chronostratigraphy	5
2.2 Biostratigraphy	7
3 Lithostratigraphical framework	11
3.1 Group framework	11
3.2 Formation framework	11
4 Central England and North Wales	13
4.1 Formations of continental and peritidal facies (ungrouped)	13
Craven Basin	13
East Midlands	16
North Wales	21
Shropshire	24
Carboniferous Limestone Supergroup	24
4.2 Bowland High Group	24
4.3 Trawden Limestone Group	27
4.4 Holme High Limestone Group	28
4.5 Peak Limestone Group	28
East Midlands Platform	29
Hathern Shelf	41
Market Drayton Horst	44
Shropshire	45
4.6 Clwyd Limestone Group	46
4.7 Craven Group	53
Craven Basin	53
Rossendale Basin, Gainsborough Trough and Holme High	64
Derbyshire High and Edale Gulf	64
Widmerpool Gulf	66
North Wales	68
4.8 Millstone Grit Group	70
Pennines	70
Staffordshire	77
Shropshire	77
North Wales	78
4.9 Pennine Coal Measures Group	78
North Staffordshire Coalfield	84
East Pennines Coalfield	85
4.10 Warwickshire Group	87
5 South Wales–Bristol	94
5.1 Avon Group	94
South Wales	94
Bristol	97
Shropshire	98
Berkshire Coalfield	99
Kent Coalfield	99
5.2 Pembroke Limestone Group	99
South Wales: South and East Crop	99
5.2A Black Rock Limestone Subgroup	99
5.2B Hunts Bay Oolite Subgroup	105
South Wales: North Crop	109
5.2C Abercriban Oolite Subgroup	109
5.2D Clydach Valley Subgroup	110
Bristol	116
5.2E Black Rock Limestone Subgroup	117
5.2F Burrington Oolite Subgroup	118
Shropshire	122
Berkshire	123
Kent Coalfield	123
5.3 Marros Group	123
South Wales	123
Bristol	126
Cannington Park, Somerset	127
5.4 South Wales Coal Measures Group	127
South Wales	127
Bristol	131
Berkshire Coalfield	131
Kent	131
5.5 Warwickshire Group	132
South Wales	132
Bristol	135
Forest of Dean	139
Newent Coalfield	140
Oxfordshire–Berkshire Coalfield	141
Kent Coalfield	143
6 South-west England	144
6.1 Exmoor Group	144
6.2 The Hyner Mudstone and Trusham Mudstone Formations	145
6.3 Tamar Group	145
6.4 Teign Valley Group	149
Northern margin and Northern Sub-basin	149
Central Sub-basin	154
Southern Sub-basin and Southern Margin	157
6.5 Carboniferous of the Tavy Basin	159
6.6 Chudleigh Group	160
6.7 Holsworthy Group	161
7 References	165
Appendix 1	Tables showing lithostratigraphical hierarchies 175
Appendix 2	Redundant lithostratigraphical names 182
FIGURES	
1	Tectonic framework for the Mississippian of Southern Britain 2
2	Palaeogeographical reconstruction for the Carboniferous of southern Britain. Adapted from Cope et al. (1992) 3
3	Extent of Carboniferous deposits in England and Wales 6
4	Central England and North Wales lithostratigraphical nomenclature 14
5	Correlation of selected deep borehole and geophysical logs through Tournaisian and Viséan strata from the Pennines of Lancashire and Yorkshire 15

- 6 Lithostratigraphical and chronostratigraphical relationships of Tournaisian and Viséan strata of the Peak District of Derbyshire and Staffordshire (based on Aitkenhead and Chisholm, 1982) 17
- 7 Correlation of selected deep borehole and geophysical logs from the East Midlands 18
- 8 North Wales lithostratigraphical nomenclature and correlations for Viséan strata 22
- 9 Correlation of selected deep borehole and geophysical logs from Merseyside and Cheshire 48
- 10 Schematic section (north–south) across the Namurian Central Pennine Sub-basin. Derived from Aitkenhead et al. (2002) 55
- 11 Correlation of selected deep borehole and geophysical logs through Namurian strata from the Pennines of Lancashire and Yorkshire 63
- 12 Coalfields of England and Wales (Powell et al., 2000b). Restored and generalised isopachs of the Pennine Lower and Middle Coal Measures formations within the Pennine Basin, modified from Calver (1968) and Kirby et al. (2000) 80
- 13 Generalised sections of the Pennine Coal Measures Group from the Lancashire to South Staffordshire coalfields (in part derived from Aitkenhead et al., 2002) 82
- 14 Generalised sections of the Pennine Coal Measures Group from East Pennines to Warwickshire coalfields (in part derived from Aitkenhead et al., 2002) 83
- 15 Generalised sections of the Warwickshire Group from the southern parts of the Pennine Basin and South Wales (from Powell et al., 2000) 89
- 16 South Wales and southern England lithostratigraphical nomenclature 96
- 17 South Wales and Bristol Tournaisian and Viséan lithostratigraphical nomenclature 97
- 18 Namurian stratigraphy of the Marros Group in South Wales (after George, 2000) 125
- 19 Generalised sections of the South Wales Coal Measures Group in the South Wales Coalfield (Thomas, 1974) 129
- 20 Generalised sections of the Warwickshire Group from the Somerset, Bristol, Severn and Forest of Dean coalfields (Green, 1992) 130
- 21 South-west England lithostratigraphical nomenclature 146

TABLES

- 1 Chronostratigraphical framework for the Carboniferous of England and Wales 5
- 2 Tournaisian and Viséan biostratigraphical zonations, derived from Riley (1993) 7
- 3 Summary of the chronostratigraphical units of the Namurian and the main biozones for the most important fossil groups 8
- 4 Westphalian chronostratigraphy and biostratigraphical zonations 10

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
- 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 Stratigraphical Lexicon for the areas of responsibility covered by the SFC

The economic importance of strata of Carboniferous age has resulted in 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. Consequently, a haphazard approach to the establishment of the hierarchy of units has resulted. From an early, relatively simple framework, subsequent surveys and publications have greatly added to the complexity of the nomenclature. Often this reflected the localised nature of research with a tendency to identify numerous local names for essentially the same unit. Also, end-Carboniferous and subsequent tectonic events have resulted in the isolation by faulting or erosion of laterally contiguous deposits. This complexity in nomenclature has, to an extent, hindered the regional understanding of the Carboniferous successions of the UK.

Two committees have reported on the Carboniferous succession of the Midland Valley of Scotland (Browne et al., 1999) and the Westphalian to Early Permian red-bed successions of the Pennine Basin (Powell et al., 2000a). Further committees were established to review the Carboniferous successions of the Scottish Borders and the Namurian successions of the Pennine Basin. In 2000, these committees were subsumed into a single committee that reviewed the entire Carboniferous Period throughout Great Britain.

This report summarises the SFC lithostratigraphical scheme for onshore Carboniferous successions of southern Great Britain. A further report summarises the scheme employed in northern Great Britain.

The first part of this report summarises the structural and palaeogeographical setting of southern Great Britain throughout the Carboniferous Period.

The second part describes the key techniques of correlation of successions, principally biostratigraphy and geophysical wireline log correlation.

The third part indicates the main principles for the development of the new lithostratigraphical scheme. This demonstrates how the group hierarchy has been linked to major lithofacies and the procedures for rationalisation of formation nomenclature.

The fourth and largest part of the report provides a full description of the group and formation framework for each of three palaeogeographic provinces; namely central England and North Wales, South Wales and southern England and south-west England. 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.

1 Introduction

The Carboniferous strata of the UK comprise a wide range of facies and depositional environments. This in part represents a northward drift of the UK across the Equator during the Carboniferous (Scotese and McKerrow, 1990). Both the beginning and end of the Carboniferous Period are marked by a climate that, at least seasonally, was in part arid. This led to widespread development of commonly red continental alluvial clastic-dominated facies during the Tournaisian and late Westphalian to Stephanian times. The intervening period was dominated by an equatorial climate.

The diverse lithofacies that developed throughout the Carboniferous were also the consequence of tectonic processes. A phase of Late Devonian to early Carboniferous rifting produced a marked palaeo-relief with numerous basins occupying subsiding grabens and half-grabens and emergent highs associated with horsts and tilt-block highs. Cessation of most rifting processes throughout large parts of the UK in the late Visean was followed by a period of regional subsidence and the resulting basins infilled by widespread deposits.

1.1 TECTONIC SETTING

The structural evolution of Southern Britain during the Carboniferous was primarily a consequence of an oblique (dextral) collisional orogenic belt between Gondwana and Laurussia (Warr, 2000). The Rhenohercynian Ocean opened during Early to Mid Devonian transtension between Avalonia and Armorica, possibly associated with northward-directed subduction along the southern margin of Armorica. Cessation of the subduction, associated with the Ligerian orogenic phase of central Europe, resulted from the collision of the Iberian and Armorican microplates. During the Late Devonian, transpressive closure of this restricted ocean, associated with the Bretonian orogenic phase, may have occurred in response to short-lived southward-directed subduction of the Rhenohercynian oceanic plate beneath Armorica.

1.1.1 Tournaisian and Visean

A return to northward-directed subduction of the Theic oceanic plate along the southern margin of Iberia/Armorica resulted in a Late Devonian to early Carboniferous phase of back-arc extension within the Avalonian part of the Laurussian plate. The resultant north-south rifting affected all of central and northern Britain, initiating development of a series of grabens and half-grabens, separated by platforms and tilt-block highs (Leeder, 1982, 1988).

To the south of the Craven Fault System the generally high subsidence rates created a province dominated by basinal facies. The Craven Sub-basin of Lancashire and the Harrogate Sub-basin of Yorkshire represent the northern examples of a series of linked narrow embayments. In the south of the basin the Gainsborough Trough and Widmerpool Gulf are separated by platform carbonate shelves such as the linked East Midlands Platform and Derbyshire High and the West Midlands Shelf and Central Pennine High (Figure 1). These shelfal areas represent the northern margin of the Wales–Brabant High, which

forms a persistent topographical feature throughout the Carboniferous. The block and basin margins commonly reflected reactivation of pre-existing basement lineaments (Fraser et al., 1990).

Along the southern margin of the Wales–Brabant High there is a gradual change southward from shelf/ramp carbonates into a deep marine basin of the Culm Trough of Cornwall and Devon. By the Late Devonian, Hercynian compressional deformation was beginning to affect southern parts of Cornwall and Devon; the deformation front migrated northwards during the Tournaisian and Visean (Selwood and Thomas, 1988). This deformation was dominated by the development of northward-verging recumbent folds and slaty cleavage.

1.1.2 Namurian to Stephanian

Cessation of rifting during the late Visean in the area between the Southern Uplands and the Wales–Brabant High resulted in a period dominated by thermally induced subsidence during Namurian and Westphalian times (Leeder, 1982). The Pennine Basin formed as part of this regional subsidence. The depocentre of the Pennine Basin was in south Lancashire/north Staffordshire; part of the Central Pennine Sub-basin, which extended between the Craven Fault System and the Wales–Brabant High. The thermal subsidence co-existed with small-scale, pulsatory phases of localised extension and compression, which reactivated basement lineaments (Waters et al., 1994). The sediment influx into the Pennine Basin changed from a dominantly northern provenance during the early Langsettian, to a western one during late Langsettian and early Duckmantian, and to a southern one from late Duckmantian and Bolsovian times (Hallsworth and Chisholm, 2000). Compressional deformation became increasingly influential during the Westphalian. Within the central parts of the Pennine Basin deformation is evident predominantly in the form of growth folds. At the basin margins, such as south Staffordshire, angular unconformities associated with folding and faulting are common.

Closure of the Theic Ocean and initial collision of Gondwana and Iberia/Armorica during the late Carboniferous resulted in Sudetian orogenic phase of crustal thickening, with foreland basin development along the northern margin of the orogenic belt, including south-west England and South Wales. The end Carboniferous late collisional stages, the Asturian orogenic phase, is associated with the northward advance of the Variscan thrust-fold belt into the foreland basin. In the Culm Basin this second phase of north-south compression was initiated no earlier than Bolsovian (Westphalian C) time forming mainly recumbent south-verging folds in the south and north-verging folds in the north.

1.2 PALAEOGEOGRAPHY

The palaeogeographical reconstructions presented for the Carboniferous of the UK (Figure 2) have been adapted from those illustrated by Cope et al. (1992).

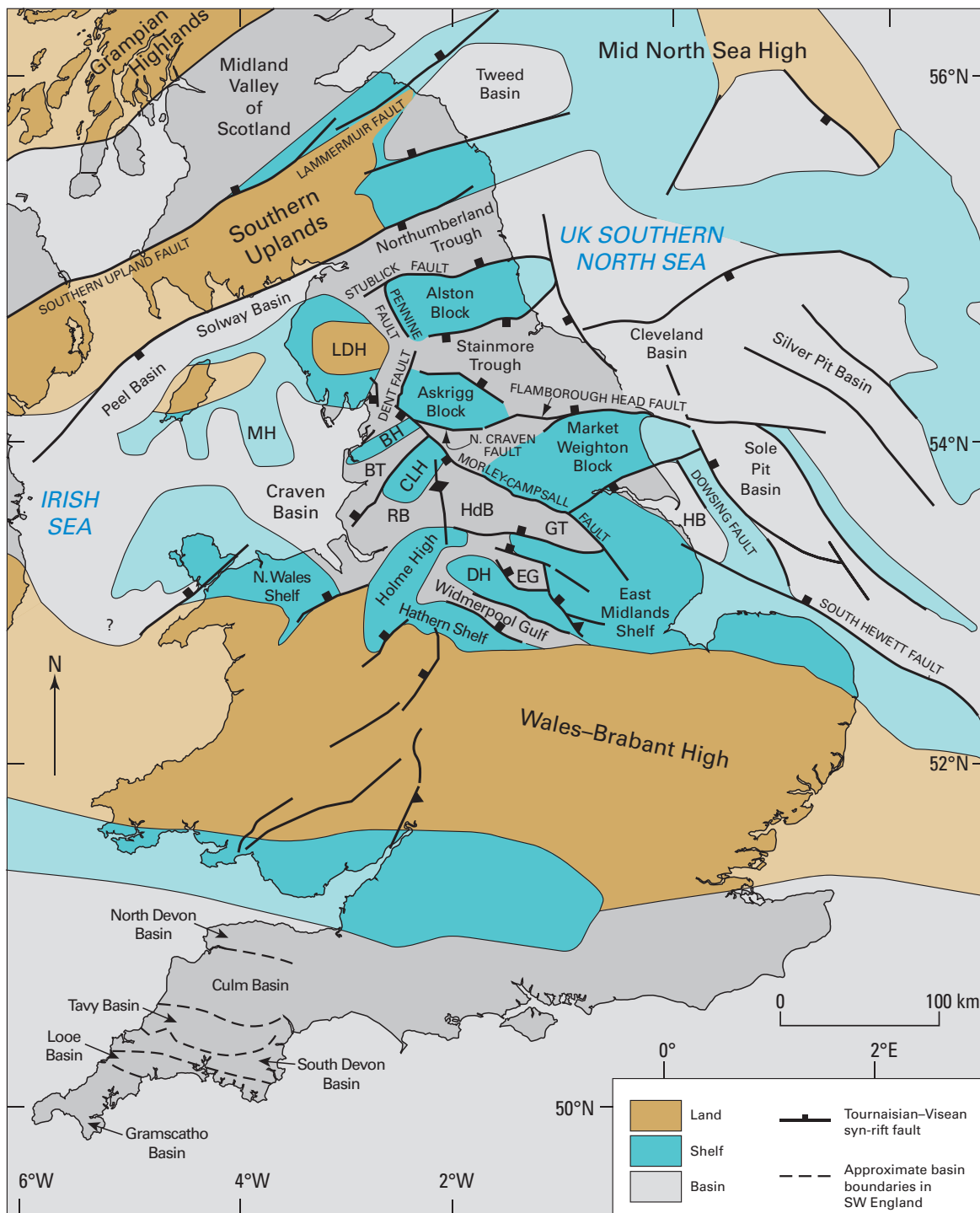


Figure 1 Tectonic framework for the Mississippian of Southern Britain. AB- Askrigg Block; BH- Bowland High; BT- Bowland Trough; CLH- Central Lancashire High; DF- Dent Fault; DH- Derbyshire High; EG- Edale Gulf; FHF- Flamborough Head Fault; GT- Gainsborough Trough; HdB- Huddersfield Basin; HB- Humber Basin; HH- Holme High and Heywood High; HS- Hathern Shelf; LDH- Lake District High; MCF- Morley-Campsall Fault; MH- Manx High; NCF- North Craven Fault; NT- Northumberland Trough; PF- Pennine Fault; RB- Rossendale Basin; SF- Stublick Fault; WG- Widmerpool Gulf.

1.2.1 Tournaisian

A marine influence is evident within the Craven Basin, where a carbonate-dominated succession formed at this time (Figure 2a). The open sea lay to the south of the Wales-Brabant High. Shelfal carbonates developed along the southern fringe of the Wales-Brabant High. In southern Cornwall and Devon there is a lateral transition into deep marine pelagic shales and thin limestones.

1.2.2 Visean

Rifting during the early Visean led to the initiation of basinal marine conditions in the Craven Basin (Figure 2b), which expanded with time into a series of linked embayments extending from the East Midlands to Ireland (Figure 2c). Throughout the Visean the Wales-Brabant High was probably emergent, flanked to both the north and south by shelf carbonates. In south-west England these carbonates pass southward

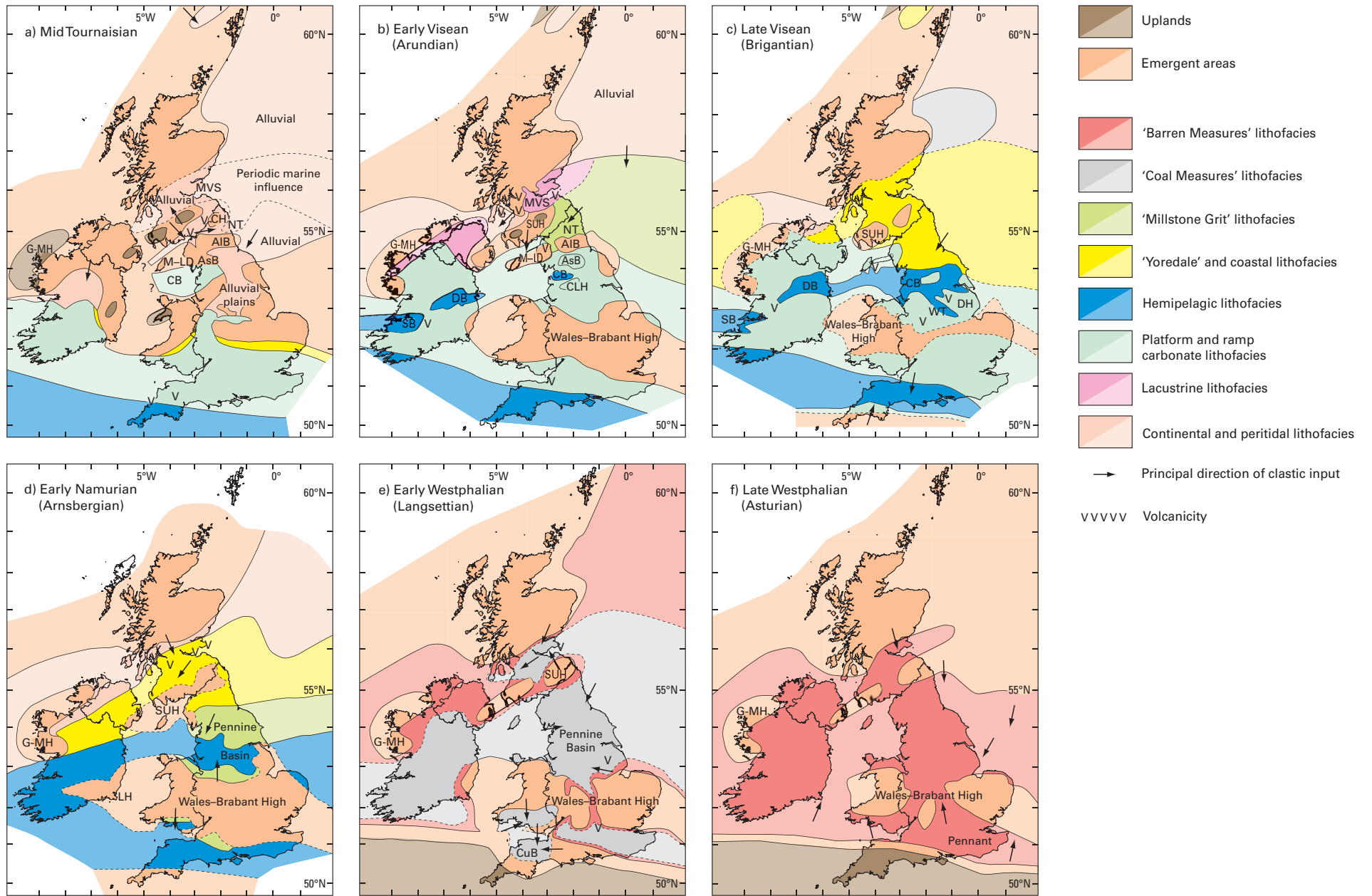


Figure 2 Palaeogeographical reconstruction for the Carboniferous of southern Britain. Adapted from Cope et al. (1992). AIB- Alston Block; AsB- Askrigg Block; CB- Craven Basin; CH- Cheviot High; CuB- Culm Basin; DB- Dublin Basin; LH- Leinster High; ML-D-Manx-Lake District High; MV- Midland Valley; NT- Northumberland Trough; RB- Rossendale Block; SB- Shannon Basin; SUH- Southern Uplands High.

into a deep marine Culm Basin associated with predominantly pelagic deposits. By the end of the Viséan, thin siliciclastic turbidites were being deposited, in part from a highland area developing to the south in response to Hercynian tectonics.

1.2.3 Namurian

During Pendleian times fluvio-deltaic ('Millstone Grit') successions started to feed siliciclastic sediment into the northern margin of the Central Pennine Sub-basin. Initial deposition into the basinal areas is marked by formation of thick turbidite-fronted delta successions. By Marsdenian times the deltas had prograded across and largely infilled the Central Pennine Sub-basin, resulting in a predominance of relatively thin, sheet-like deltaic sandstones and well-developed delta-top deposits. Meanwhile, erosion of the emergent Wales–Brabant High provided a source for more localised fluvio-deltaic successions, which prograded short distances both to the north and south of the high (Figure 2d).

1.2.4 Westphalian and Stephanian

From early in the Westphalian a coal-forming delta-top environment became established across the Pennine Basin and between South Wales, the Culm Basin and Kent. Although the 'Coal Measures' cyclic successions are lithologically similar, the two basinal areas were, at least in part, isolated by the upland area of the Wales–Brabant High. Marine incursions were relatively rare during deposition of these successions (Figure 2e). From Bolsovian (Westphalian) to Cantabrian (Stephanian) times fluvial sediments ('Pennant Measures') derived from the northward propagating thrust sheets of the Hercynian Highlands encroached northward across much of southern England and South Wales. Meanwhile, on the flanks of the Wales–Brabant High red-dened alluvial deposits accumulated. During the Asturian (Westphalian D) the 'Pennant Measures' breached the Wales–Brabant High and for a short period were deposited within the Pennine Basin (Figure 2f).

2 Correlation and biostratigraphical framework

2.1 CHRONOSTRATIGRAPHY

The Carboniferous System in western Europe has traditionally been defined as comprising two sub-systems, an older Dinantian and younger Silesian, corresponding to Lower Carboniferous and Upper Carboniferous, respectively (Table 1). The Dinantian–Silesian boundary was chosen to represent a regional facies transition in Britain from dominantly carbonate (Carboniferous Limestone Supergroup) to terrigenous clastic strata and does not reflect a global change in flora or fauna. The lower boundary of the Silesian was defined as the base of the ammonoid *Cravenoceras leion* Zone. The Mississippian and Pennsylvanian of the USA have become recognised internationally as sub-systems and strictly represent Lower and Upper Carboniferous, respectively, in international usage. The mid-Carboniferous boundary separating the two sub-systems occurs within the Chokierian Substage of the Namurian Regional Stage in western Europe (Table 1). Difficulties in direct comparisons between North America and western Europe has resulted in the UK maintaining usage of the regional western European chronostratigraphical nomenclature.

The Dinantian was subdivided into the Tournaisian and Visean Series, whereas the Silesian was subdivided into three series, Namurian, Westphalian and Stephanian (Table 1). These series do not represent global faunal or floral events, but were chosen to represent prominent facies variations in western Europe. In southern Britain, the Namurian broadly equates with the Millstone Grit lithofacies and the Westphalian with the Coal Measures lithofacies. The base of the Westphalian is taken at the base of the ammonoid *Gastrioceras subcrenatum* Zone, which broadly equates with the first incoming of thick coal seams. The Stephanian Series is of restricted to strata of limited geographical extent in onshore Southern Britain.

Internationally, the Dinantian and Silesian are now considered obsolete terms and the Tournaisian and Visean are now formally defined as stages (Heckel and Clayton, 2006). Work is in progress to define subsequent stages using nomenclatures defined in Russia (Table 1). However, until this work is complete it is prudent to maintain usage of the well-established chronostratigraphical nomenclatures established in Britain and western Europe, but with the Namurian, Westphalian and Stephanian downgraded to regional stages.

The western European stages names for the Visean, Namurian and Westphalian were based on

Table 1 Chronostratigraphical framework for the Carboniferous of England and Wales. Ages derived from Gradstein et al. (2004); Seismic sequences from Fraser et al. (1990); Mesothems from Ramsbottom (1973, 1977).

Age (Ma)	International Subsystems	International Stages	European Subperiods	European Stages (former Series)	Heerlen Classification	European Substages (former Stages)	Seismic Stratigraphy	Mesothems								
299	PENNSYLVANIAN	KASIM-OVIAN	SILESIAN (UPPER CARBONIFEROUS)	STEPHANIAN	C	BARRUELIAN CANTABRIAN	V1									
310					MOSCOVIAN				A	D	ASTURIAN					
		BASHKIRIAN							C	BOLSOVIAN						
					B				DUCKMANTIAN							
					A				LANGSETTIAN							
					NAMURIAN				C	YEADONIAN						
									B	MARSDENIAN						
										KINDERSCOUTIAN						
		A							ALPORTIAN							
CHOKIERIAN																
MISSISSIPPIAN	VISEAN	SILESIAN (LOWER CARBONIFEROUS)	VISEAN	NAMURIAN	A	ARNBERGIAN	LC 1	N11								
								N9-10								
								N6-8								
								N5								
								N4								
								N3								
								N2								
								N1								
								330	TOURNAISIAN	VISEAN	VISEAN	VISEAN	A	PENDLEIAN	LC 1	N1
																V3c
		EC5	D6a													
V3b	ASBIAN	EC4	D5b													
			D5a													
340	TOURNAISIAN	VISEAN	VISEAN	VISEAN	A	HOLKERIAN	EC3									D4
								V2b	ARUNDIAN	D3						
								V2a								
								V1b	CHADIAN	D2b						
350	TOURNAISIAN	VISEAN	VISEAN	VISEAN	A	IVORIAN	EC2	D2a								
								COURCEYAN	D1c							
										HASTARIAN	EC1	D1b				
												D1a				
359																

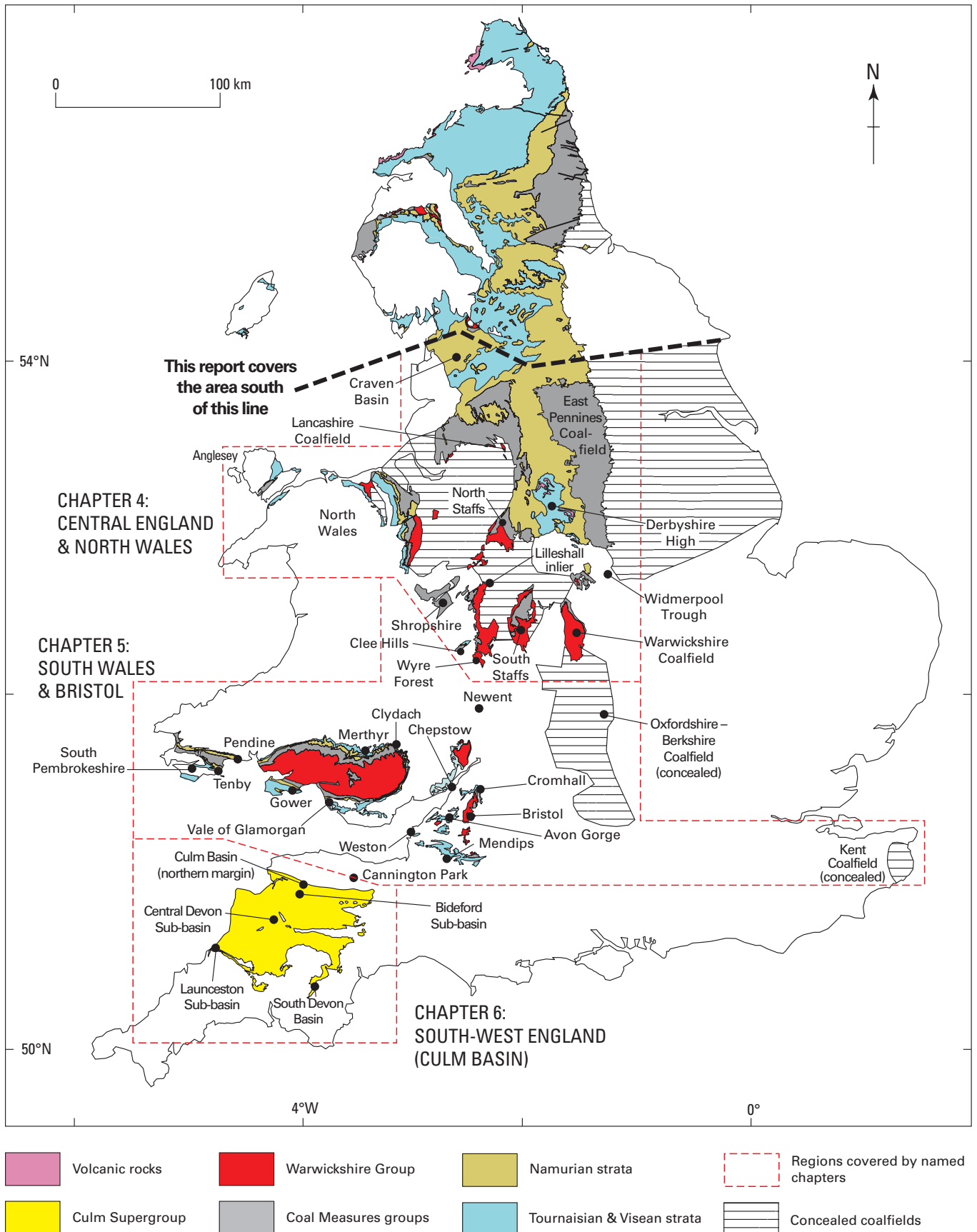


Figure 3 Extent of Carboniferous deposits in England and Wales, subdivided into main chronostratigraphical units, and location of areas discussed in text.

basal stratotypes defined by George et al. (1976) for the Visean, Ramsbottom (1981) for the Namurian and Owens et al. (1985) for the Westphalian, largely from localities in northern England. These stages are now downgraded to

regional substages (Heckel and Clayton, 2006). The distribution at outcrop of the main chronostratigraphical units and the location of the depositional areas discussed in this report is shown in Figure 3.

Table 2 Tournaisian and Visean biostratigraphical zonation, derived from Riley (1993). Grey shading indicates interzones (conodonts and miospores) or non-sequences (brachiopods). *anch.* *Scaliognathus anchoralis* – *Polygnathus bischoffi*; *Arnsb.* *Arnsbergites*; *B.* *Bollandoceras*; *bouc.* *Dollymae bouckaerti*; *bul.* *Eotaphrus bultyncki*; *bur.* *Eotaphrus burlingtonensis*; *c.* *Caninophyllum*; *coll.* *Gnathodus girtyi collinsoni*; *G.* *Goniatites*; *Gn.* *Gnathodus*; *has.* *Dollymae hassi*; *hom.* *Gnathodus homopunctatus*; *in.* *Polygnathus inornatus/Siphonodella*; *L.* *Lochriea*; *lat.* *Doliognathus latus*; *Lusit.* *Lusitanoceras*; *Lyrog.* *Lyrogoniatites*; *mono.* *monodosa*; *Neoglyph.* *Neoglyphioceras*; *Parag.* *Paraglyphioceras*; *prae.* *Mestognathus praebeckmanni*; *Ps.* *Pseudopolygnathus*; *S.* *Siphonophyllia*; *Siph.* *Siphonodella*; *spic.* *Polygnathus spicatus*; *V.* *Vaughania*; *Z.* *Zaphrentis*

Series	Stages	Conodonts	Ammonoids	Foraminifera	Coral / brachiopod			Miospores	Macroflora																		
					Mitchell (1981, 1989)	Vaughan (1905)	Garwood (1913)																				
Visean	Brigantian	<i>Gn.collinsoni</i>	<i>Lyrog. georgiensis</i> P2c	<i>Neoarchaediscus</i> Cf6 (part)	K	Horizon E	D _γ	NC (part)	<i>Lyginopteris berrudensis</i> / <i>Neuropteris antecessans</i>																		
		<i>L. mono</i>	<i>Neoglyph. subcirculare</i> P2b							J	D ₂	VF															
		<i>Gn.bilineatus</i>	<i>Lusit. granosus</i> P2a										I	D ₂	D ₂												
			<i>Parag. koboldi</i> P1d		H	D ₁	D ₁																				
			<i>Parag. elegans</i> P1c							G	D ₁	NM															
			<i>Arnsb. falcatus</i> P1b		α-β	D ₁	TC																				
	<i>G. crenistria</i> P1a	F	D ₁	TC																							
	<i>G. globostratus</i> B2b				B1	D ₁	TC																				
	<i>G. hudsoni</i> B2a	<i>Beyrichoceras</i>	F	TC																							
	Asbian				<i>Beyrichoceras</i>	B1	B1	F		TC																	
		Holkerian	<i>L. commutata</i>	<i>B. hodderense</i>							<i>Koskinotextularia-Pojar-kovella</i> Cf5	E	S ₂ (part)	S ₂	TS												
																Arundian	<i>Bollandites-Bollandoceras</i> BB	<i>Bollandites-Bollandoceras</i> BB	δ	D	S ₂ (part)	S ₁	Pu				
																								γ	C	C ₂ (part)	C ₂
																								Chadian late	<i>hom.</i>	<i>Fascipericyclus-Ammonellipsites</i> FA	<i>Eoparastaffella</i> Cf4
	early				<i>Polygnathus mehli</i>	<i>Pericyclus</i>	α ₁	S. <i>cylindrica</i>		C ₁																	
		Courceyan	<i>has. bul.</i>	<i>Pericyclus</i>							<i>Tetrataxis-Eotextularia</i> Cf3	C ₁	C ₁	CM													
	<i>cf. bul.</i>				<i>Paraendothyra</i> Cf2	<i>Chermysimella</i> Cf1	S. <i>patulum</i>	Z		Z?					PC												
<i>bul. bouc.</i>		<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>					K		BP	HD															
	<i>bul. bul.</i>				<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>	M		VI																	
<i>Ps. multistriatus</i>		<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>					K		BP	HD															
	<i>anch. bis.</i>				<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>	K		BP			HD														
<i>prae.</i>		<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>					K		BP	HD															
	<i>has. bul.</i>				<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>	K		BP			HD														
<i>in.</i>		<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>					K		BP	HD															
	<i>Siph. spic.</i>				<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>	K		BP			HD														
<i>Siph. spic.</i>		<i>Chermysimella</i> Cf1	<i>Chermysimella</i> Cf1	V. <i>vetus</i>					K		BP	HD															

The Stephanian Series (now defined as a stage) was originally defined in the Central Massif of France with three stages, referred as Stephanian A, B and C. The Stephanian A has been formally renamed the Barruelian Stage (now Substage). The recognition of a non-sequence in the Central Massif and identification of an additional Stephanian succession in Cantabria, northern Spain, led to the recognition of a Cantabrian Stage (now Substage), which is older than the Barruelian. Only strata of Cantabrian age have been recognised in England and Wales.

2.2 BIOSTRATIGRAPHY

Ammonoids (goniatites) are an integral component of Carboniferous biostratigraphy, notably within late Visean (Table 2), Namurian (Table 3) and early Westphalian (Table 4), when they provide the greatest biostratigraphical resolution. The nekto-pelagic habit of ammonoids allows biozones to be recognised across western Europe and some are applicable globally. Thick-shelled ammonoids occur within thin hemi-pelagic marine beds, ‘marine bands’,

Table 3 Summary of the chronostratigraphical units of the Namurian and the main biozones for the most important fossil groups.

STAGE	ZONE		WESTERN EUROPEAN MARINE BANDS		MIOSPORES	CONODONTS		
	Index	Ammonoid	Ammonoid	Index				
Yeadonian	G _{1b}	<i>Cancelloceras cumbriense</i>	<i>Ca. cumbriense</i>	G _{1b} 1	<i>Raistrickia fulva</i> – <i>Reticulatisporites reticulatus</i> (FR)	<i>Idiognathoides sinuatus</i> – <i>Idiognathoides primulus</i>		
	G _{1a}	<i>Cancelloceras cancellatum</i>	<i>Ca. cancellatum</i>	G _{1a} 1				
Marsdenian	R _{2c}	<i>Bilinguites superbilinguis</i>	<i>Verneulites sigma</i>	R _{2c} 2			— — — —	
			<i>B. superbilinguis</i>	R _{2c} 1				
	R _{2b}	<i>Bilinguites bilinguis</i>	<i>B. metabilinguis</i>	R _{2b} 5				
			<i>B. eometabilinguis</i>	R _{2b} 4				
			<i>B. bilinguis</i>	R _{2b} 3				
			<i>B. bilinguis</i>	R _{2b} 2				
	R _{2a}	<i>Bilinguites gracilis</i>	<i>B. gracilis</i>	R _{2a} 1				
Kinderscoutian	R _{1c}	<i>Reticuloceras reticulatum</i>	<i>R. coreticulatum</i>	R _{1c} 4			<i>Crassispora kosankei</i> – <i>Grumosisporites varioreticulatus</i> (KV)	<i>Idiognathoides corrugatus</i> – <i>Idiognathoides sulcatus</i>
			<i>R. reticulatum</i>	R _{1c} 3				
			<i>R. reticulatum</i>	R _{1c} 2				
			<i>R. reticulatum</i>	R _{1c} 1				
	R _{1b}	<i>Reticuloceras eoreticulatum</i>	<i>R. stubblefieldi</i>	R _{1b} 3				
			<i>R. nodosum</i>	R _{1b} 2				
			<i>R. eoreticulatum</i>	R _{1b} 1				
	R _{1a}	<i>Hodsonites magistrorum</i>	<i>R. dubium</i>	R _{1a} 5				
			<i>R. todmordenense</i>	R _{1a} 4				
			<i>R. subreticulatum</i>	R _{1a} 3				
			<i>R. circumplicatile</i>	R _{1a} 2				
			<i>Ho. magistrorum</i>	R _{1a} 1				
	Alportian	H _{2c}	<i>Vallites eostriolatus</i>	<i>Homoceratoides prereticulatus</i>	H _{2c} 2	<i>Lycospora subtriquetra</i> – <i>Kraeuselisporites ornatus</i> (SO)		
<i>V. eostriolatus</i>				H _{2c} 1				
H _{2b}		<i>Homoceras undulatum</i>	<i>H. undulatum</i>	H _{2b} 1				
H _{2a}	<i>Hudsonoceras proteum</i>	<i>Hd. proteum</i>	H _{2a} 1					
Chokierian	H _{1b}	<i>Homoceras beyrichianum</i>	<i>I. sp. nov.</i>	H _{1b} 2				
			<i>H. beyrichianum</i>	H _{1b} 1				
	H _{1a}	<i>Isohomoceras subglobosum</i>	<i>I. subglobosum</i>	H _{1a} 3				
			<i>I. subglobosum</i>	H _{1a} 2				
			<i>I. subglobosum</i>	H _{1a} 1				

Table 3 continued...

STAGE	ZONE		WESTERN EUROPEAN MARINE BANDS		MIOSPORES	CONODONTS	
	Index	Ammonoid	Ammonoid	Index			
Arnsbergian	E _{2c}	<i>Nuculoceras stellarum</i>	<i>N. nuculum</i>	E _{2c} 4	<i>Lycospora subtriquetra</i> – <i>Kraeuselisporites ornatus</i> (SO)	<i>Gnathodus bilineatus bollandensis</i>	
			<i>N. nuculum</i>	E _{2c} 3			
			<i>N. nuculum</i>	E _{2c} 2			
			<i>N. stellarum</i>	E _{2c} 1			
	E _{2b}	<i>Cravenocera-toides edalensis</i>	<i>Ct. nititoides</i>	E _{2b} 3			
			<i>Ct. nitidus</i>	E _{2b} 2			
			<i>Ct. edalensis</i>	E _{2b} 1			
	E _{2a}	<i>Cravenoceras cowlingense</i>	<i>Eumorphoceras yatesae</i>	E _{2a} 3			<i>Stenzonotriletes triangulus</i> – <i>Rotaspora knoxi</i> (TK)
			<i>C. gressinghamense</i>	E _{2a} 2a			
			<i>Eumorphoceras ferrimontanum</i>	E _{2a} 2			
<i>C. cowlingense</i>			E _{2a} 1				
Pendleian	E _{1c}	<i>Cravenoceras malhamense</i>	<i>C. malhamense</i>	E _{1c} 1	<i>Reticulatisporites carnosus</i> – <i>Bellisporites nitidus</i> (CN) <i>pars.</i>	<i>Kladognathus</i> – <i>Gnathodus girtyi simplex</i>	
	E _{1b}	<i>Cravenoceras brandoni</i>	<i>Tumulites pseudobilinguis</i>	E _{1b} 2			
			<i>C. brandoni</i>	E _{1b} 1			
E _{1a}	<i>Cravenoceras leion</i>	<i>C. leion</i> (= <i>Emstites leion</i>)	E _{1a} 1				

which developed during marine transgressions and typically comprise distinct ammonoid fauna. Ammonoid biozones are intervals defined by the successive first appearance of ammonoid taxa, with the base of the biozones coinciding with the bases of specific marine bands.

Foraminifera are of biostratigraphical importance within marine carbonates, particularly abundant in mid-ramp and platform settings, but also present within basinal deposits in limestone turbidites (Riley, 1993a). The formal foraminifera zonation for Belgium, established as the standard for north-west Europe, has been applied to British and Irish sequences by Conil et al. (1980) and Conil et al. (1991) (Table 2).

Conodonts are present within marine facies, notably carbonate turbidites and hemi-pelagic shales and conodont zones are particularly important for Tournaisian and Visean (Table 2) and Namurian (Table 3) correlation (Varker and Sevastopulo, 1985).

Palynomorphs (miospores) are present in both marine and terrestrial environments and have been used for biozonation up to and including the Cantabrian (Tables 2, 3

and 4). Recent advances in macrofloral zonation show the importance of plant fossil biostratigraphy, particularly for the Asturian and Cantabrian (Cleal, 1991).

Coral biozonation has been of historical importance in the classification of Tournaisian and Visean platform carbonates, though they are now considered strongly facies-controlled. However, the zonation nomenclature of Vaughan (1905) for Bristol and South Wales and Garwood (1913) are still widely used and are summarised by George et al. (1976) and (Riley, 1993a). The major rugose coral biozonation within the Visean is that of Mitchell (1989).

In the Tournaisian, Visean and Namurian, marine bivalves present within hemi-pelagic shales and occurring in association with ammonoids are of greatest stratigraphical importance (Riley, 1993a). In the Westphalian, it is the non-marine bivalves that assume greater biostratigraphical importance (Table 4). They tend to occur in association with fish and ostracodes. Estheriids ('Estheria'), a small crustacean that occupied brackish waters, can occur as prominent marker bands.

Table 4 Westphalian chronostratigraphy and biostratigraphical zonations.

Stage	Ammonoids	Conodonts	Palynomorphs		Non-marine bivalves		
			Index	Zone	Zone	Sub-zone	
Cantabrian			OT	<i>Thymospora obscura</i> – <i>T. thiessenii</i>	<i>Anthraconauta tenuis</i>		
Asturian							
Bolsovian			SL	<i>Torispora securis</i> – <i>T. laevignata</i>	<i>Anthraconauta phillipsi</i>		
Duckmantian			NJ	<i>Microreticulatisporites nobilis</i> – <i>Florinites junior</i>		'Upper similis-pulchra'	<i>adamsi-hindi</i>
						'Lower similis-pulchra'	<i>atra</i>
							<i>caledonica</i>
							<i>phrygiana</i>
Langsetian			RA	<i>Radiizonates aligerens</i>	<i>Anthraconaia modiolaris</i>	<i>ovum</i>	
						<i>Carbonicola communis</i>	<i>regularis</i>
	<i>cristagalli</i>						
	<i>pseudorobosta</i>						
	SS	<i>Triquitrites sinani</i> – <i>Cirratriradites saturni</i>	<i>Carbonicola lenisulcata</i>	<i>bipennis</i>			
				<i>torus</i>			
<i>proxima</i>							
<i>Gastrioceras listeri</i>	<i>Idiognathoides sulcatus parvus</i>			<i>extenuata</i>			
<i>Gastrioceras subcrenatum</i>	<i>Idiognathoides sinuatus</i> – <i>Idiognathoides primulus (pars.)</i>			<i>fallax-protea</i>			

3 Lithostratigraphical framework

The plethora of local group and formation names and the inconsistent application of lithostratigraphical hierarchies for the Carboniferous has, to an extent, hindered the regional understanding of the Carboniferous successions of the UK.

From an early, relatively simple framework, subsequent surveys and publications have greatly added to the complexity of the nomenclature. Much of this existing nomenclature has evolved from work carried out long before guidance was available for best practice in naming lithostratigraphical units. Consequently, a haphazard approach to the establishment of the hierarchy of units has resulted.

The local nomenclatures can be attributed to the following:

- restriction of deposits to individual basins
- isolation by faulting or erosion of once laterally contiguous deposits following end-Carboniferous and subsequent tectonic events
- the former BGS methodology of mapping geological sheets in isolation
- where a formal lithostratigraphical nomenclature has not been defined on BGS maps, scientific publications have created their own, often conflicting, schemes.

The Geological Society Special Reports for the Dinantian and Silesian (George et al., 1976; Ramsbottom et al., 1978) provided useful stratigraphical correlations between key sections across the United Kingdom and Eire. However, the reports did not give a unified lithostratigraphical framework. Their preference was to promote a unified approach to lithostratigraphy, biostratigraphy and chronostratigraphy (Holland et al., 1978, p.4).

In order to review the existing nomenclature it was decided to follow the guidance of the North American Stratigraphic Code (NASC) (Anon., 1983), as this is commonly accepted as a workable standard. The nomenclature chosen should aid communication of UK geology to others. However, it is acknowledged that many names are so entrenched in the literature that their replacement would result in confusion. As a consequence, it aims to use existing nomenclature where suitable, whilst providing full definitions consistent with the guidance from the NASC.

Formal definitions of all groups and formations present within Southern Britain are provided in Appendix 1. Redundant or obsolete names are listed in Appendix 2.

Note that where borehole records are used to determine thicknesses, the boreholes are vertical (unless otherwise stated) and the thicknesses are uncorrected down-the-hole measured thicknesses.

3.1 GROUP FRAMEWORK

It was decided to follow a ‘top-down’ approach by which the group nomenclature was based upon the recognition of major lithofacies. The committee discussed the possibility of having a single group name for each lithofacies applicable to the entire country. However, the lithofacies were often developed within distinct basinal areas and a single UK-wide group nomenclature would not aid the understanding of the

evolution of the basins. Hence, it was agreed that separate group names should be employed for each distinct depositional area (Waters et al., 2007). Where it was believed useful to provide a single term for a UK-wide lithofacies, it was recommended they should be defined as a super-group.

Eight major sedimentary lithofacies associations have been identified for the Carboniferous of the UK (Waters et al., 2007), of which six are recognised in southern Britain.

A *Continental and peritidal facies* occurs locally at the northern margin of the Craven Basin and northern flanks of the Wales–Brabant High, from Late Devonian to Visean times. A continental fluvial clastic sub-facies commonly forms the first basin infill and extends onto horst and tilt-block highs. The peritidal marine and evaporite sub-facies is generally limited to troughs associated with grabens and half-grabens.

A *clastic and non-marine carbonate facies* is restricted to the Midland Valley of Scotland and Northumberland Trough of Visean age, and is not found in southern Britain.

An *open marine, platform and ramp carbonate facies* accumulated upon platforms and ramps, which developed on horst-blocks and half-graben tilt-blocks during the Tournaisian and Visean on the northern and southern margins of the Wales–Brabant High. Isolated platform carbonates also developed on the Bowland High, Holme High and Central Lancashire High within a broadly basinal environment.

A *hemi-pelagic facies* was deposited in gulf areas of central England and North Wales during the Visean and Namurian. Similar deposits characterise the Culm Basin during the Late Devonian to Namurian.

A *mixed shelf carbonate and deltaic* (‘Yoredale’) *facies* is widespread across the Midland Valley of Scotland and northern England, in strata of Visean to Namurian age, but is typically absent south of the Craven Fault System.

A *fluvio-deltaic* (‘Millstone Grit’) *facies* extended across central England during the Namurian to early Westphalian. The main succession is of distant northerly provenance, although deposits of similar facies, locally derived from the Wales–Brabant High, occur immediately to the north and south of this upland area.

A *fluvio-deltaic* (‘Coal Measures’) *facies* extended across central England and North Wales, and to the south of the Wales–Brabant High in South Wales and the Bristol area in the west and in Kent to the east during the Westphalian.

An *alluvial* (‘Barren Measures’) *facies* occurs as two sub-facies. A ‘red-bed’ sub-facies comprises locally derived sediments located in central England and North Wales, southern fringes of the Wales–Brabant High, and the flanks of the Usk High in South Wales, deposited during the Westphalian and Stephanian. The ‘Pennant’ sub-facies comprises sediments of distant southerly provenance, present in South Wales, Bristol and Oxfordshire Coalfield, of Bolsovian to Cantabrian age. The sub-facies is locally present in the southern parts of the Pennine Basin, of Asturian age.

3.2 FORMATION FRAMEWORK

In most cases a nomenclature of formations, and to a lesser extent members, has been established. Those formations

present within areas of recent geological resurvey already have a full formal lithostratigraphical description, which is replicated in this report. In some circumstances, the definition of existing formations has been revised, with the new definition reproduced in this report. Some formations have been redefined as a group or member. Elsewhere, it was decided that there was a requirement to rationalise several local formation names into a single unit. The new forma-

tion name was generally an existing, widely used name, which conforms with the NASC criteria (Anon., 1983). In relatively few cases, formation names did not exist and have had to be established as part of this study.

Throughout the detailed descriptions of the lithostratigraphy in chapters 4–6 the heading for each defined lithostratigraphical unit is followed by the relevant BGS Lexicon code in brackets.

4 Central England and North Wales

This province includes basinal area between the Craven Fault System and the Wales–Brabant High (Figure 1). This includes a series of linked embayments, such as the Craven, Harrogate, Edale, Gainsborough and Widmerpool sub-basins and isolated structural highs, such as the Bowland, Holme and Central Lancashire highs. Each of the highs developed carbonate platforms, at least during the Tournaisian and early Visean. During the Namurian and Westphalian this province represents the Central Pennine Sub-basin, the area of greatest amount of thermal subsidence within the Pennine Basin.

To the south of the Central Pennine Sub-basin platform carbonates extend across North Wales and the East Midlands. The West Midlands Shelf extends northwards and westwards, forming platforms across North Wales (Figure 1). To the east, the nature of the sub-surface East Midlands Platform is based largely upon well records and geophysical information. A promontory of the East Midlands Platform forms the Derbyshire High. These carbonates are overlain by relatively condensed Namurian and Westphalian successions.

The lithostratigraphical succession is summarised in Figure 4.

4.1 FORMATIONS OF CONTINENTAL AND PERITIDAL FACIES (UNGROUPED)

The Late Devonian to Visean *continental and peritidal facies* is restricted to localised areas of deposition at the northern margin of the Craven Basin and northern flanks of the Wales–Brabant High (Figure 2). Within Central England deposits of this facies are mainly proved in boreholes and do not occur at crop. There is at present insufficient information to propose sub-surface correlations between these deposits. In North Wales the deposits are present in small isolated sub-basins and, as such, show no lateral connectivity. Consequently, the deposits have been attributed stand-alone formational names, with a geographical range limited to the known extent of the sub-basin. The SFC Committee did not consider these isolated deposits, with markedly different ages of deposition and clast composition, warranted group status.

CRAVEN BASIN

Borehole evidence indicates the localised presence of a succession of strata of *continental and peritidal facies* at the margin of the Craven Basin and Askrigg Block on the Settle sheet, the **Stockdale Farm Formation** (Arthurton et al., 1988) and above the Central Lancashire High (Figure 5), the **Roddlesworth Formation**. The two formations are similar in appearance, but poor biostratigraphical control and uncertainty of the lateral continuity prevents a direct correlation between the two formations.

4.1.1 Stockdale Farm Formation (STFA)

Name

The name was first proposed by Arthurton et al. (1988) for a succession proved in two boreholes (see type and reference sections) located on the Settle sheet.

Type section

Halsteads (Cominco Borehole S2) (SD86SW/6) [SD 8491 6345], shows the basal 37 m of the lower part of the formation.

Reference section

Stockdale Farm (Cominco Borehole S7) (SD86SE/6) [SD 8541 6378] from 170.00 to 309.4 m, proves the upper and middle part of the formation.

Formal subdivisions

Arthurton et al. (1988) proposed three members, in ascending order: the Halsteads Shales-with-Anhydrite, Stockdale Farm Sandstones and Shales and Stockdale Farm Limestones and Shales. This nomenclature is unacceptable as two of the members duplicate the name of the formation and the lithological epithets are unsuitable. As these units are recorded only in the subsurface, no attempt has been made during this study to formalise the definition of these units as members.

Lithology

A lower member comprises thinly interbedded laminated dolostones, dolomitic-siliciclastic siltstone, mudstone and laminated anhydrite. This is overlain by a middle member of interbedded sandstone, siltstone, mudstone and thin limestone. The sandstones are arkosic pale grey, fine-grained, micaceous and carbonaceous. Limestones are dark grey micrites with subordinate packstones and wackestones. The upper member comprises interbedded limestone, siltstone and mudstone, lithologically similar to the middle member, but lacking sandstones.

Lower and upper boundaries

The base is not seen, but possibly an angular unconformity above Lower Palaeozoic sandstone, siltstone and mudstone.

A deeply fissured top surface marking a significant non-sequence is overlain by conglomerates of the Chapel House Limestone Formation and underlain by limestone, siltstone and mudstone of the Stockdale Farm Formation.

Thickness

At least 165 m thick.

Distribution

At the southern margin of the Askrigg Block, in the transition zone to the Craven Sub-basin.

Regional correlation

Possibly equivalent to the Roddlesworth Formation of the Central Lancashire High.

Genetic interpretation

Alluvial plain and marginal marine flats subject to periodic desiccation and fluctuating salinity, in a semi-arid climate.

Biostratigraphical characterisation

Foraminifera from the topmost 11 m of the formation include the typical early Chadian (Tournaisian) forms

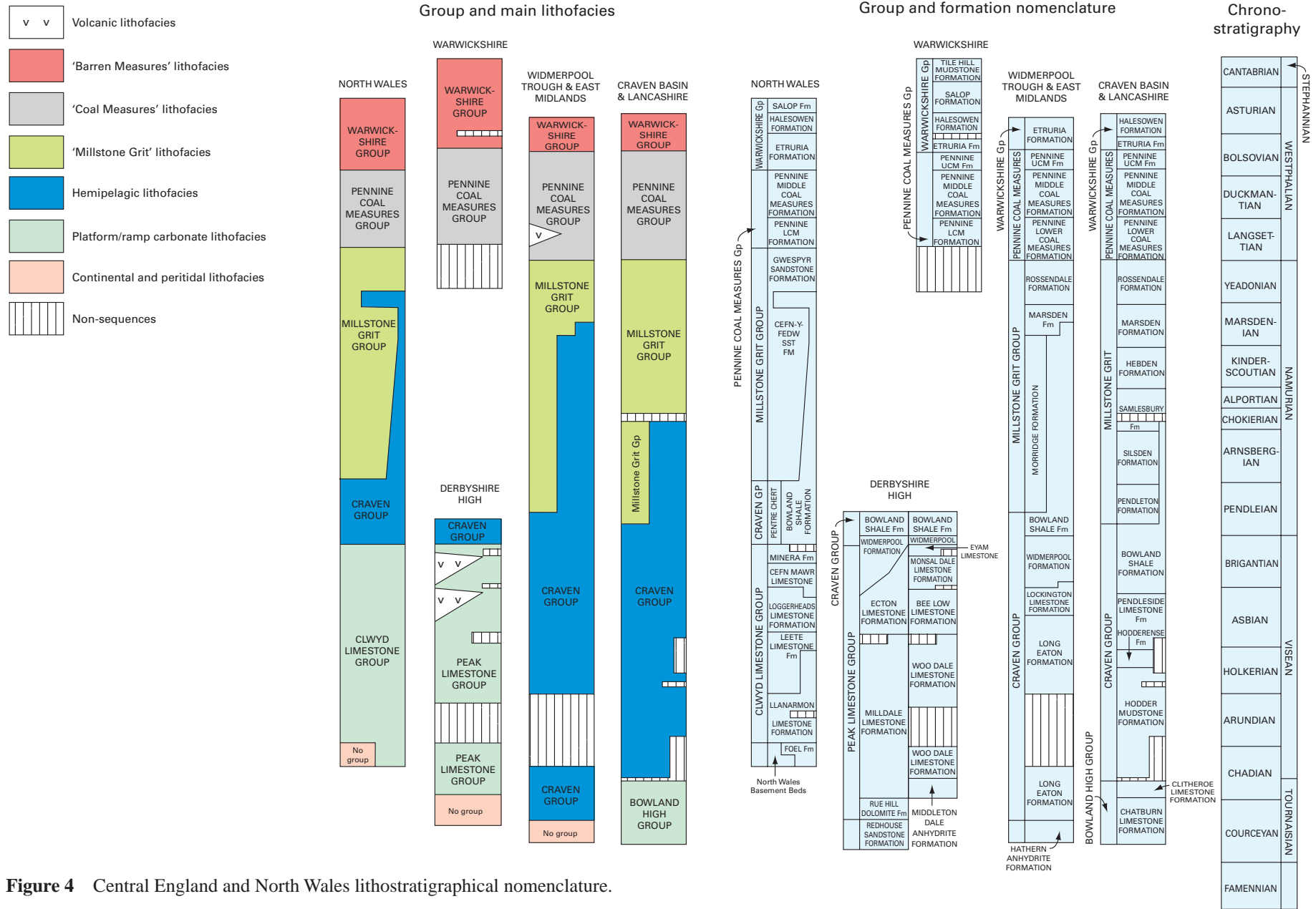


Figure 4 Central England and North Wales lithostratigraphical nomenclature.

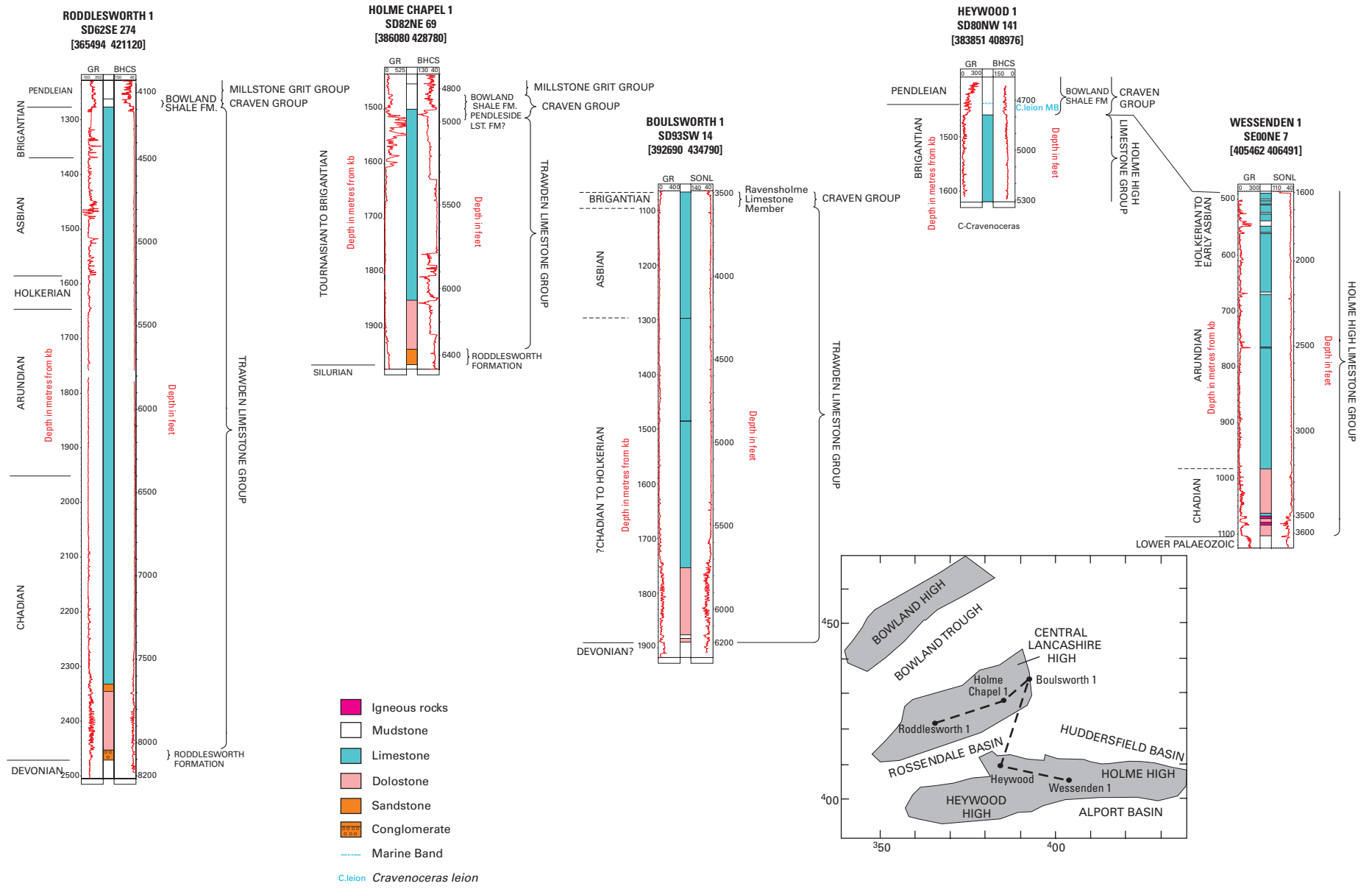


Figure 5 Correlation of selected deep borehole and geophysical logs through Tournaisian and Viséan strata from the Pennines of Lancashire and Yorkshire.

Palaeospiroplectammina mellina, *Endothyra danica*, *Lugtonia monilis* and *Spinoendothyra mitchelli* (Arthurton et al., 1988).

Age

Tournaisian to Chadian.

4.1.2 Roddlesworth Formation (RODD)

Name

This is a new name proposed for strata of *continental and peritidal facies* found only in the sub-surface above the Central Lancashire High (Figure 5). The unit has not been named previously.

Type section

Roddlesworth No.1 Borehole (SD62SE274) [SD 65494 21120], from a depth of 2470.6 m to 2452.6 m, which comprises the entire thickness of the formation (Figure 5).

Reference section

Holme Chapel No.1 Borehole (SD82NE69) [SD 8608 2878], from a depth of 1968.0 m to 1940.0 m, which comprises the entire thickness of the formation (Figure 5) (Riley and McNestry, 1988).

Lithology

At the stratotype, the formation comprises in ascending order: a pale green, grey and red conglomerate with quartz pebbles in a medium-grained chloritic sandstone matrix; medium to dark grey dolomitic siltstone, with beds of white to buff fine-grained dolostone, anhydrite and red siltstone; pale grey, medium-grained sandstone with siliceous and dolomitic cement, interbedded with medium to dark grey, fine-grained sandstone with an argillaceous and dolomitic matrix.

In the Holme Chapel No.1 Borehole the succession comprises a lower white, green and pink sandstone with a dolomitic cement and a basal conglomerate containing slate clasts and an upper pale green, dolomitic and silicic, fine-grained sandstone grading to siltstone (Riley and McNestry, 1988).

Lower and upper boundaries

At the base, conglomerate or sandstone overlies an angular unconformity above Lower Palaeozoic purple slates, or conformably upon white, pink to red and green, fine- to medium-grained sandstone of the Old Red Sandstone Group.

The pale to dark grey, green or red, fine- to medium-grained sandstone with siliceous and dolomitic cement of the Roddlesworth Formation is overlain unconformably by dolostone or limestone of the Trawden Limestone Group. The top of the formation is taken at the base of the lowermost limestone or dolostone of the predominantly carbonate succession of the Trawden Limestone Group.

Thickness

Some 18 m in the Roddlesworth Borehole, and 28 m in the Holme Chapel Borehole.

Distribution

Not proved at outcrop. Proved in the subsurface over the Central Lancashire High, a south-west to north-east structure extending from Chorley [SD 60 20] to Bradford [SE 10 30], bounded to the north-west by the Pendle Fault and the Bowland Basin, and to the south-east by the Rossendale Basin (Evans and Kirby, 1999).

Regional correlation

Possibly equivalent to the Stockdale Farm Formation of the Settle sheet.

Genetic interpretation

Alluvial fan, fluvial channel and floodplain overbank, deposited in a semi-arid climate.

Age

Tournaisian to Chadian

EAST MIDLANDS

The Tournaisian to early Visean *continental and peritidal facies* has been proved within a number of deep boreholes on the flanks of the Derbyshire High (Figures 6 and 7) and on the Hathern Shelf.

Adjacent to the Derbyshire High, these deposits include the **Redhouse Sandstone Formation** (Aitkenhead and Chisholm, 1982), and the **Middleton Dale Anhydrite Formation**, proved in separate boreholes (Figure 7). The concealed Hathern Shelf, on the southern flank of the Widmerpool Gulf (Figure 1), includes comparable formations to those present adjacent to the Derbyshire High. The **Calke Abbey Sandstone Formation** is overlain in the Ticknall Borehole by the Arch Farm Sandstone Formation (Carney et al., 2001). The **Hathern Anhydrite Formation** is proved in the Hathern Borehole. Further to the east the **Scalford Sandstone Formation** is proved in the Scalford No.1 Borehole.

4.1.3 Redhouse Sandstone Formation (RES)

Name

The unit was originally defined as the Redhouse Sandstones (Aitkenhead and Chisholm, 1982; Chisholm et al., 1988) and is here redefined as a formation.

Type section

Caldon Low Borehole (SK04NE/36) [SK 0804 4823], between 365.07 and 535.37 m (Figure 7) (Welsh and Owens, 1983).

Lithology

Pebbly sandstone, conglomerates especially near the base, fine- to medium-grained sandstone, siltstone and mudstone, typically red-brown with minor green mottling. The formation is broadly upward fining, with individual beds internally upward fining too, the cycles average 6.7 m thick, and diminish in thickness upwards. Carbonate concretions of calcrete may be present at the top of some cycles.

Lower and upper boundaries

The base is not seen, but is probably an unconformity upon pre-Carboniferous strata.

The top is a conformable passage, with the base of the overlying Rue Hill Dolomite Formation taken at the base of the lowest dolostone bed containing bioclasts, underlain by reddish-brown pebbly sandstone of the Redhouse Sandstone Formation.

Thickness

Measured as 170.3 m thick in the Caldun Low Borehole, although the base is not proved.

Distribution

Off-shelf to the Derbyshire High and Staffordshire Shelf, in the Ashbourne and Cheadle District, but in the subsurface only.

Regional correlation

The formation is lithologically comparable to the Calke Abbey Sandstone Formation of the Hathern Shelf, although

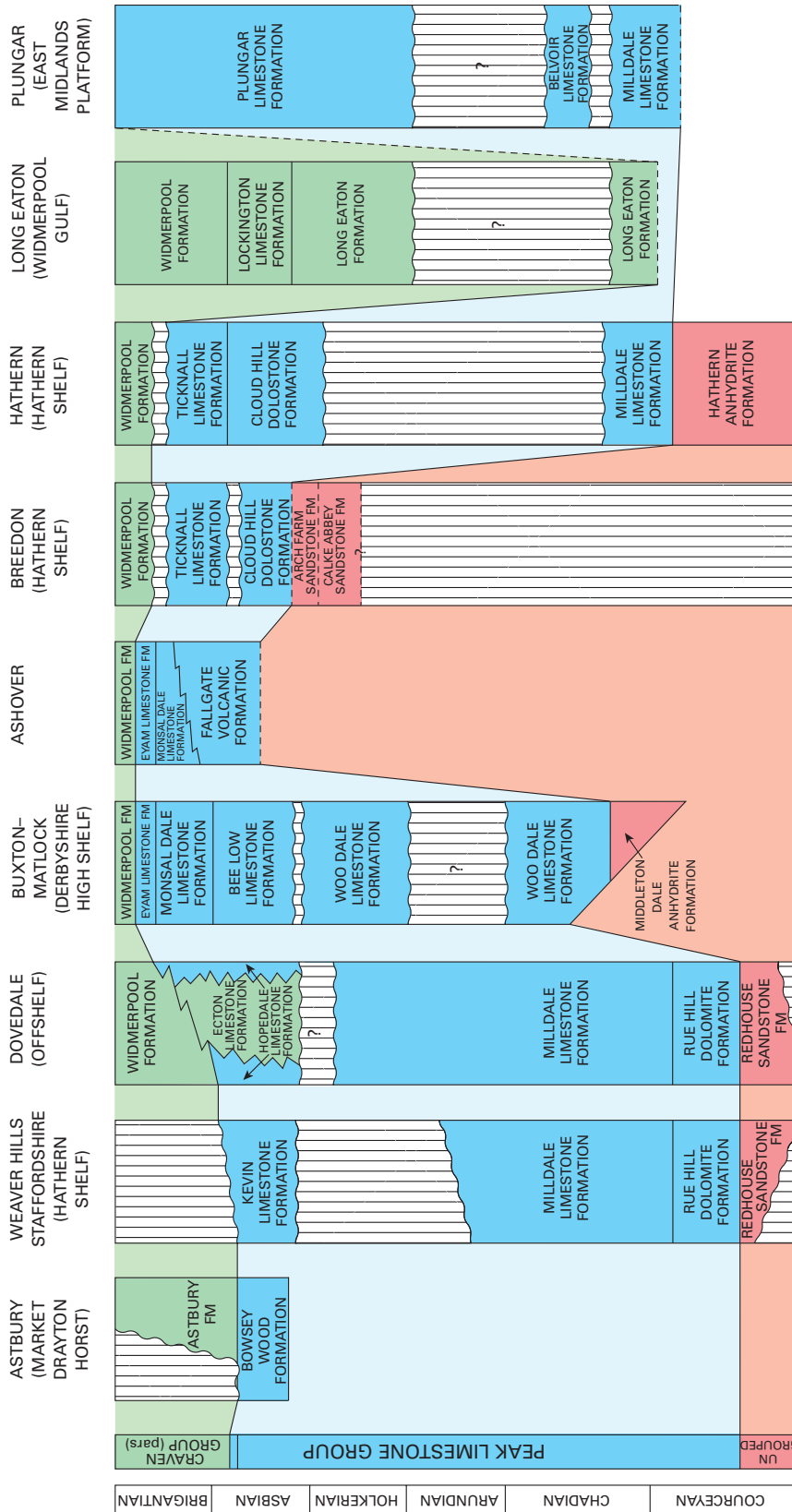
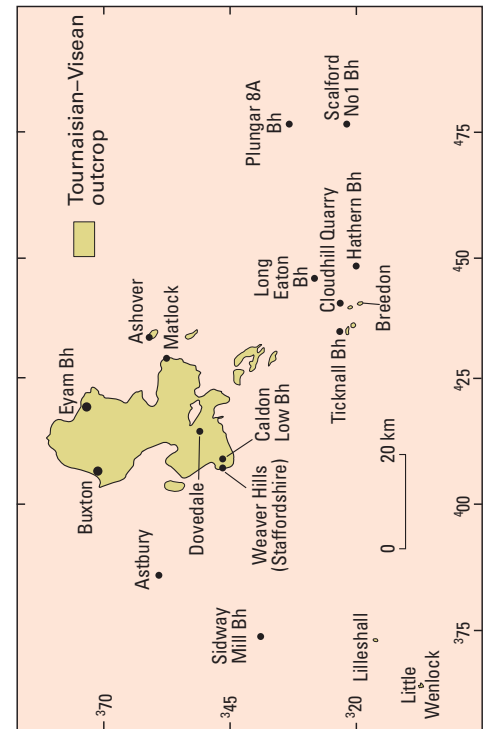


Figure 6 Lithostratigraphical and chronostratigraphical relationships of Tournaisian and Viséan strata of the Peak District of Derbyshire and Staffordshire (based on Aitkenhead and Chisholm, 1982).



no lateral continuity between the two formations has been demonstrated.

Genetic interpretation
Alluvial fan gravels.

Biostratigraphical characterisation
No biostratigraphical information available for the formation, but a Devonian to Courceyan age is assumed (Chisholm et al., 1988). Evidence from the overlying Rue

Hill Dolomite Formation shows the Redhouse Sandstone Formation to be no younger than Courceyan.

Age
Courceyan (Tournaisian)

4.1.4 Middleton Dale Anhydrite Formation (MIDA)

Name
The succession was described initially by Dunham (1973)

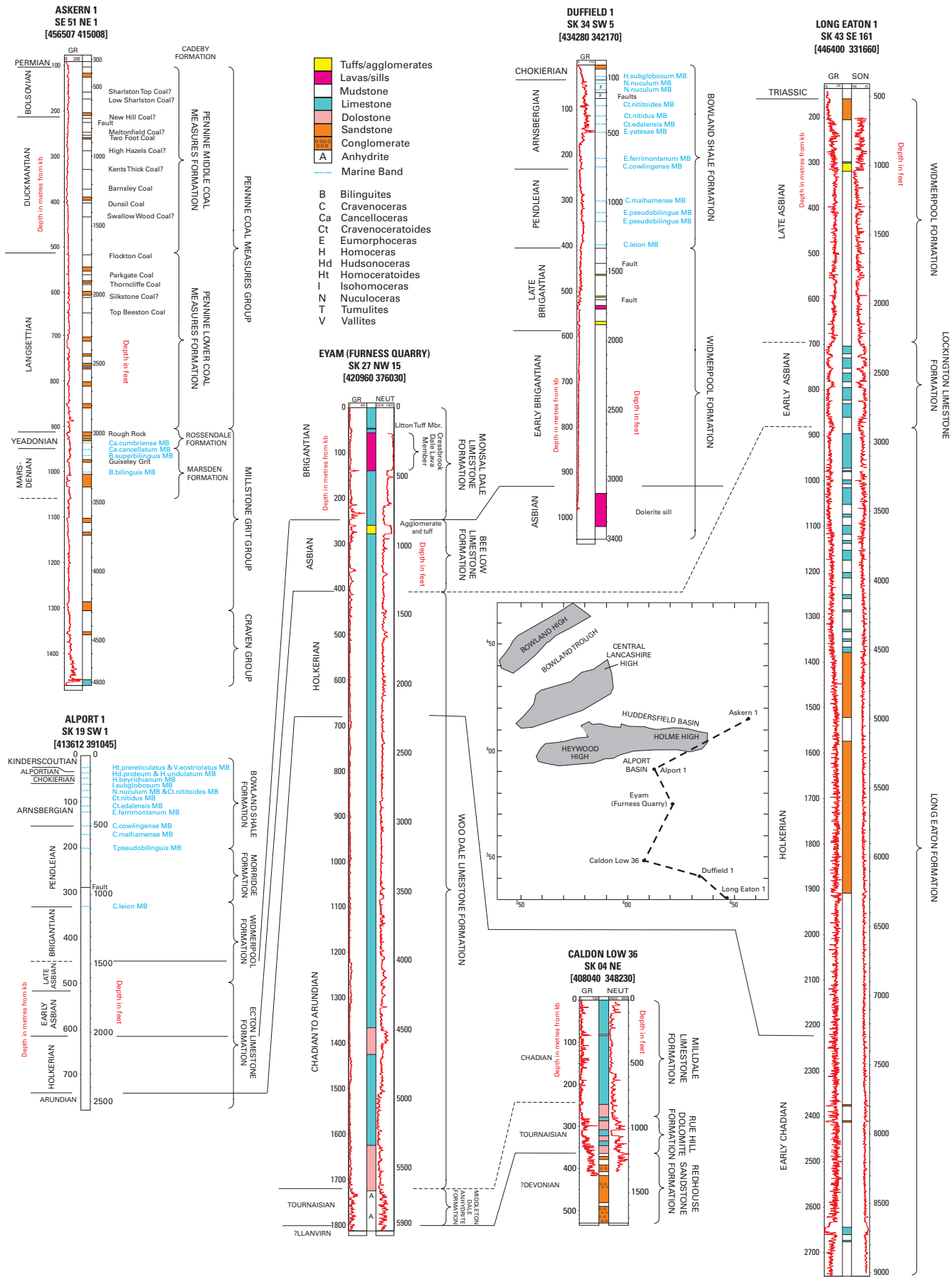


Figure 7 Correlation of selected deep borehole and geophysical logs from the East Midlands.

as an unnamed unit and is here formally defined as a formation. The name is derived from Middleton Dale, the location of the Eyam Borehole, the type locality.

Type section

The Eyam Borehole (SK27NW/15) [SK 2096 7603], located within the Furness Quarry, Middleton Dale, about 1.3 km south-south-west of Eyam, from a depth of 1803.25 to 1729.64 m (Figure 7).

Lithology

Bedded and nodular anhydrite interbedded with dark grey mudstone and thin beds of dolostone. A thin grey-green and red sandstone marks the base of the formation, with dark grey dolostone and thin dolomitic mudstone beds dominant in the lower part of the unit.

Lower and upper boundaries

The base is an unconformity, with grey-green and red sandstone of the Middleton Dale Anhydrite Formation overlying grey and purple mudstone of Ordovician age.

The top is sharply unconformable, and defined as the base of the lowermost thick, dark grey dolostone bed of the Woo Dale limestone Formation, overlying anhydrite of the Middleton Dale Anhydrite Formation.

Thickness

Measured as 73.6 m thick in the Eyam Borehole.

Distribution

Proved in the subsurface only, in the northern part of the Peak District [SK 27].

Regional correlation

The formation is lithologically and chronostratigraphically comparable to the Hathern Anhydrite Formation (Figure 6), although no lateral continuity between the two formations has been demonstrated.

Genetic interpretation

Evaporites deposited within a sabkha environment (Dunham, 1973).

Biostratigraphical characterisation

The sparse miospore assemblage of *Retusotriletes incohatatus*, *Verrucosporites nitidus*, *Baculatisporites fusticulus*, *Schopfites claviger*, *Vallatisporites vallatus* and *Grandispora echinata* indicate a late Tournaisian age (Dunham, 1973).

Age

Tournaisian

4.1.5 Calke Abbey Sandstone Formation (CAAS)

Name

The name was introduced by Ambrose and Carney (1997a) for a succession proved on the Hathern Shelf only in the Ticknall Borehole.

Type section

BGS Ticknall Borehole (SK32SE/103) [SK 3591 2363, between 101.3 m and 171.92 m depth, comprising the entire thickness of the formation.

Lithology

Brown to green-grey, medium to thick-bedded, medium- to coarse-grained sandstones, pebbly sandstones and con-

glomerates with low angle cross-bedding, with laminated to thinly bedded sequences of green or red mudstone and siltstone and thin, sharp-based and graded sandstone beds. Numerous reddened beds of poorly sorted structureless mudstone, siltstone and argillaceous sandstone with red to grey mottles along roots.

Lower and upper boundaries

The base is an unconformity with weathered, green mudstones of the Stockingford Shale Group, overlain by 13 m of thick basal conglomerate, commonly containing volcanic pebbles.

The top is defined by a marine flooding surface, overlain by green to grey, fine- to medium-grained sandstone with pebble-rich lenses and shelly lags of *Lingula* of the Arch Farm Sandstone Formation.

Thickness

Measured as 70.6 m thick in the Ticknall Borehole.

Distribution

Not present at outcrop, but seen in the subsurface in the area of Hathern Shelf, Loughborough District [SK 32].

Regional correlation

The formation is lithologically comparable to the Tournaisian Redhouse Sandstone Formation from adjacent to the Derbyshire High, although no lateral continuity between the two formations has been demonstrated (Figure 6). The formation may also be equivalent to the Asbian Caldon Low Conglomerate of the Ashbourne district or the proximal equivalent of the late Tournaisian Holly Bush Member of the Milldale Limestone Formation (Carney et al., 2001).

Genetic interpretation

Distal alluvial fan with episodic influxes of gravelly debris flows and sheetflood sands and quiescent periods associated with pedogenic modification of the alluvial deposits (Carney et al., 2001).

Biostratigraphical characterisation

The formation lacks dateable fossil remains. It is older than the Asbian (NM biozone) Cloud Hill Dolostone Formation proved higher in the Ticknall Borehole (Carney et al., 2001).

Age

Tournaisian or early Viséan

4.1.6 Arch Farm Sandstone Formation (ARFS)

Name

The name was introduced by Ambrose and Carney (1997a) for a succession proved on the Hathern Shelf in the Ticknall Borehole and not proved at outcrop.

Type section

BGS Ticknall Borehole (SK32SE/103), at between 101.3 m and 92.3 m depth, displaying the entire thickness of the formation.

Lithology

Green to grey, fine to medium-grained, laminated or cross-laminated sandstone in beds up to 1.7 m thick, with pebble-rich lenses and shelly lags with *Lingula* fragments and seams up to several centimetres thick, consisting of green mudstone and siltstone with *Lingula*. All lithologies are seen as rip-up clasts in the basal parts of the sandstone

beds. The upper part of the formation comprises coarse-grained, calcareous sandstone with pedogenic fabrics and conglomerate.

Lower and upper boundaries

A sharp, conformable base of green to grey, fine to medium-grained sandstone with *Lingula*, of the Arch Farm Sandstone Formation, above the brown to green-grey medium to coarse-grained sandstone and conglomerate of the Calke Abbey Sandstone Formation; seen as a prominent step on gamma-ray logs.

The top is taken at the top of a medium- to coarse-grained pebbly sandstone, overlain by green, slickensided, smectite-rich mudstone with about 4 mm ferruginous concretions of the Arch Farm Sandstone Formation, sharply overlain by pale grey to white calcareous sandstone of the Cloud Hill Dolostone Formation.

Thickness

Measured as 9 m thick in the Ticknall Borehole.

Distribution

Present in the subsurface in the area of Hathern Shelf, Loughborough District [SK32].

Genetic interpretation

The formation is interpreted as deposits associated with a major marine flooding surface, passing up into fluvial sands with palaeosol development (Carney et al., 2001).

Biostratigraphical characterisation

The formation lacks dateable fossil remains. It is older than the Asbian (NM biozone) Cloud Hill Dolostone Formation proved higher in the Ticknall Borehole (Carney et al., 2001).

Age

Tournaisian or early Viséan

4.1.7 Hathern Anhydrite Formation (HAA)

Name

Previously referred to as Hathern Anhydrite Series (Llewellyn and Stabbins, 1970) and redefined as a formation by Carney et al. (2001). The formation is named after the Hathern No.1 Hydrocarbon Borehole, taken as the type section.

Type section

Hathern No.1 Hydrocarbon Borehole (SK52SW/3) [SK 5158 2416], between 538 m and the base of the borehole at 635 m depth.

Lithology

Bedded and nodular anhydrite, interbedded with grey dolostone, mid-to-dark grey mudstone or calcareous mudstone, and massive to nodular limestone.

Lower and upper boundaries

The base is not proved in the Hathern No.1 Borehole, but probably an angular unconformity resting upon pre-Carboniferous rocks.

The top is defined at the top of the highest anhydrite or mudstone unit, and is overlain in the Hathern No.1 Borehole by thickly-bedded, grey, brown and black, fine-grained limestone with shaly beds, identified as the Milldale Limestone Formation. Anhydrites, possibly belonging to the Hathern Anhydrite Formation, are overlain by mudstone, siltstone and thin limestone beds of the Long Eaton

Formation in the Long Eaton No.1 Borehole (SK43SE/161) [SK 4640 3166].

Thickness

At least 97 m thick.

Distribution

Lies at depth within the Hathern Shelf and possibly the Widmerpool Half-Graben, in the Long Eaton No.1 Borehole (SK43SE/161) [SK 4640 3166].

Regional correlation

The formation is lithologically and chronostratigraphically comparable to the Middleton Dale Anhydrite Formation from the northern flank of the Derbyshire High (Figure 6), although no lateral continuity between the two formations has been demonstrated.

Genetic interpretation

Evaporites deposited within a sabkha environment.

Biostratigraphical characterisation

The formation has been constrained to the CM Miospore Zone (Llewellyn and Stabbins, 1970), indicating a Tournaisian age for the formation.

Age

Courseyan (Tournaisian)

4.1.8 Scafford Sandstone Formation (SFDS)

Name

The formation was first named by Carney et al. (2004) from the subsurface of the Melton Mowbray district.

Type sections

Scafford No.1 Borehole (SK72SE/30) [SK 7745 2299]; formation proved from 1069.54 to 945.8 m depth; base not proved.

Lithology

Reddish-brown, brown or green, fine- to medium-grained calcareous sandstones; brown, red and purple, blocky to fissile siltstones; and grey, blocky mudstones.

Lower and upper boundaries

The base has not been proved, but is likely to be an unconformity upon Lower Palaeozoic strata.

The top is taken at the type locality where the calcareous sandstone, siltstone and mudstone of the Scafford Sandstone Formation are in tectonic contact with the overlying mudstone and thin limestone of the Widmerpool Formation.

Thickness

At least 123.7 m.

Distribution

Only proved at the type locality, but may occupy other eastern parts of the Hathern Shelf.

Regional correlation

The formation is in an analogous structural position to the Calke Abbey Sandstone Formation of the Loughborough district (Carney et al., 2001).

Genetic interpretation

It may represent an early syn-rift fluvial or fan-delta association, containing material derived from young

escarpments formed by the initiation of rifting along the Normanton Hills or Sibley faults.

Age

Uncertain; assumed to be Late Devonian or early Carboniferous.

NORTH WALES

The 'basement beds' is an informal term used in North Wales to describe a number of isolated alluvial deposits. Formation names have been proposed for alluvial deposits present within what were distinct cuvettes, namely the **Lligwy Sandstone, Menai Straits, Ffernant, Penbedw, Fron-Fawr and Pant formations**. These formations are distinguished not only by their geographical isolation at time of deposition, but they also show different ages of deposition and clast composition, derived from local upland area that separated the cuvettes (Figure 8).

Locally, principally in the Vale of Clwyd, the basal part of the succession comprises up to 75 m of reddened alluvial breccias, conglomerates, sandstones, siltstones and mudstones. The Basement Beds are unfossiliferous but may range down into the Tournaisian. Replacive calcareous nodules ('cornstones'), and thin beds of variegated, red and green, argillaceous, nodular limestone or dolomite are present throughout the formation and record varying stages in the development of calcrete. The deposits record the infilling of an incised, but possibly fault-influenced topography. Welsh upland areas to the immediate west and south were the principal sediment source.

4.1.9 Lligwy Sandstone Formation (LGY)

Name

The unit was first described by Greenly (1919) and is here formally defined.

Reference sections

North-west facing slopes, east of Afon Lligwy, Anglesey [SH 485 860]: crags and small quarries provide intermittent exposures in the upper part of the formation (Greenly, 1919).

Lithology

Cross-bedded, sandstones, pebbly sandstones and conglomerates with subordinate siltstone and mudstone beds (Davies, 1983).

Lower and upper boundaries

The sandstone or conglomerate of the Lligwy Sandstone Formation rest unconformably on Devonian, Ordovician and Precambrian (Mona Complex) rocks.

The formation is overlain and passes laterally into thick-bedded limestones of the Loggerheads Limestone Formation.

Thickness

Up to 60 m

Distribution

Between Llangefni [SH 46 75] and Lligwy Bay [SH 50 87], Anglesey, North Wales.

Genetic interpretation

Records fluvial deposition along the margin of the North Wales Viséan platform throughout the late Asbian.

Age

Asbian

4.1.10 Menai Straits Formation (MEST)

Name

Previously named the Fanogle Sandstone (Greenly, 1919) and Bridges Sandstone Formation (Davies, 1983), the unit was defined by Howells et al. (1985).

Type section

Coastal cliffs between the Britannia Bridge [SH 5425 7090] and Menai Suspension Bridge [SH 5575 7125] (Greenly, 1928).

Lithology

Varied sequence of breccias, conglomerates, sandstones, siltstone and silty mudstones including variegated yellow and purple 'loam'. Spherical ferruginous (goethite) ooids are abundant in both the mudstones and the mudstone matrix of the breccias.

Lower and upper boundaries

The formation rests unconformably on Ordovician rocks (Nant Francon Formation) and Precambrian rocks of the Mona Complex.

The formation is conformably overlain by thick-bedded limestones of the Loggerheads Limestone Formation.

Thickness

Up to 43 m

Distribution

Menai Straits area [SH 55 71], North Wales.

Genetic interpretation

The formation records the accumulation of late Asbian terrestrial screes and alluvial deposits along the local margin of the Viséan carbonate platform. The goethite ooids are the product of pedogenic processes.

Biostratigraphical characterisation

Spores such as *Raistrickia nigra* of NM Biozone (Asbian) were reported by Hibbert and Lacey (1969) from the Menai Straits region.

Age

Asbian

4.1.11 Ffernant Formation (FANT)

Name

Formerly referred to as the Basement Beds (Warren et al., 1984), the unit is here formally redefined as the Ffernant Formation.

Type section

Ffernant Dingle, 400 m south-east of Ffernant [SH 8937 7520] formerly exposed the unconformable contact with underlying Silurian rocks and still provides a discontinuous section through the lower part of the formation (Warren et al., 1984).

Lithology

Red, purple and variegated silty mudstones, siltstones and sandstones with lenticular bodies of conglomerate. Breccias dominantly composed of weathered Lower Palaeozoic mudstone clasts occur at the base. The silty mudstones

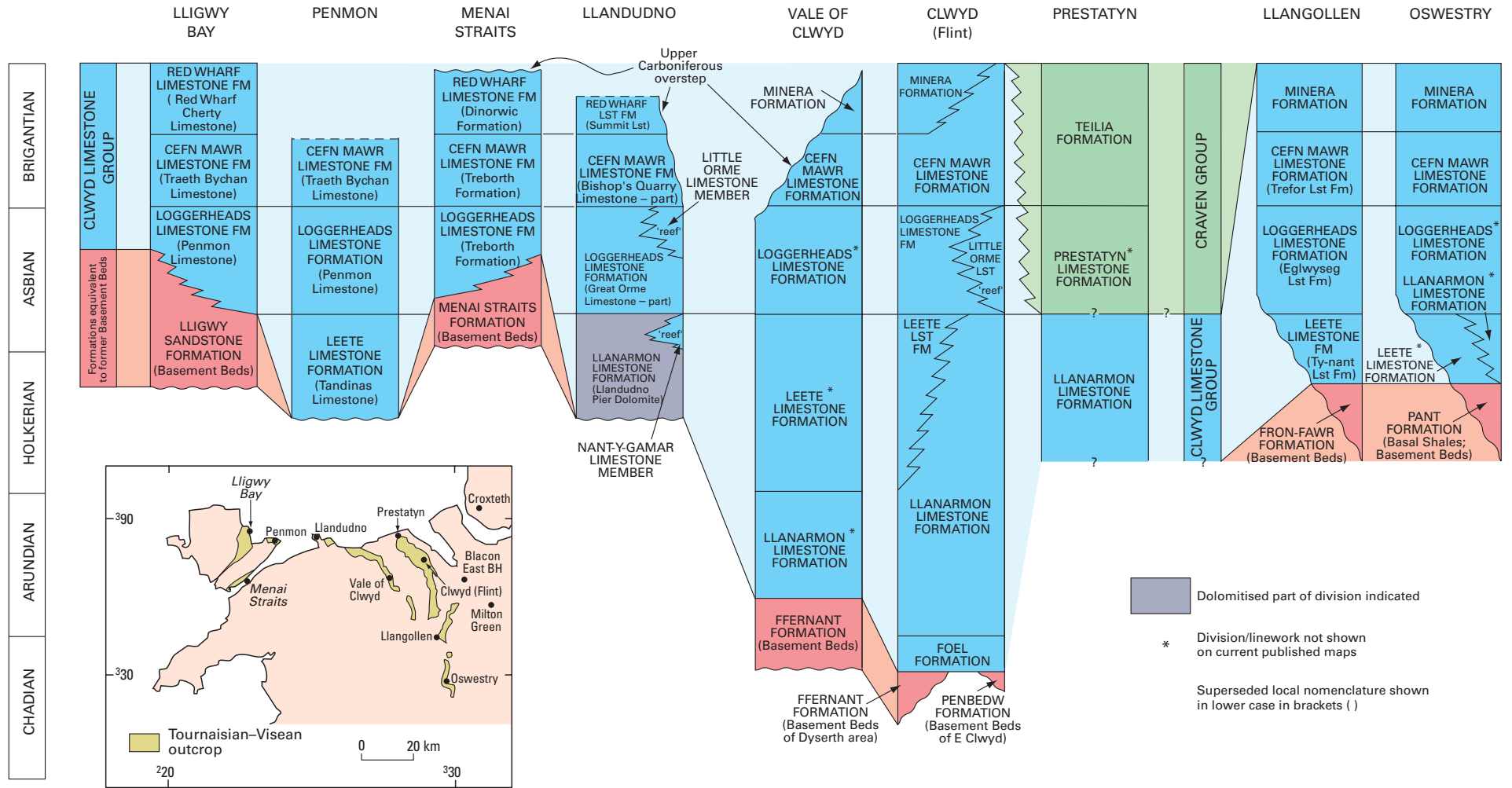


Figure 8 North Wales lithostratigraphical nomenclature and correlations for Visean strata.

locally display glaebular calcrite profiles including abundant calcareous nodules and thin units of nodular, locally dolomitised, limestone.

Lower and upper boundaries

The Ffernant Formation rests unconformably on cleaved and folded Silurian rocks (Elwy Formation).

The top of the formation is a sharp, erosive contact with limestones at base of Llanarmon Limestone Formation (Clwyd Limestone Group).

Thickness

Up to 330 m

Distribution

West side of the Vale of Clwyd [SH 89 76] and in the Dyserth area [SJ 06 78], North Wales.

Genetic interpretation

The formation records the accumulation, within palaeovalleys and embayments, of screes and alluvial sediments during the initial phases of Visean transgression, prior to the establishment of carbonate platform conditions of the Clwyd Limestone Group.

Age

Chadian to Arundian

4.1.12 Penbedw Formation (PDW)

Name

Formerly referred to as the Basement Beds (Strahan, 1890), the unit is here formally redefined as the Penbedw Formation.

Type section

Stream north of Penbedw Hall [SJ 1642 6877], near Nannerch: red 'shales' formerly exposed (Davies et al., 2004).

Reference section

Alyn Valley Borehole, Pistyll Gwyn Quarry (SJ15NE/8) [SJ 1889 5741]: the borehole penetrated a complete 3.5 m thick sequence of reddened breccias, conglomerates and sandstones, resting on weathered Silurian mudstones at a depth of 121.5 m (Davies et al., 2004).

Lithology

Red and green mottled mudstones, sandstones, conglomerates and basal breccias.

Lower and upper boundaries

The Penbedw Formation rests unconformably on cleaved and folded Silurian mudstones, siltstones and sandstones.

The top of the formation is a conformable contact with limestones of the Foel Formation.

Thickness

Up to 4 m

Distribution

The formation comprises a series of disconnected bodies occurring beneath the Clwyd Limestone Group along the eastern side of the Clwydian Range [SJ 17 67].

Genetic interpretation

The Penbedw Formation represents localised accumulations of terrestrial scree and alluvial deposits in palaeovalleys and

embayments along the margin of the North Wales Visean platform.

Age

Chadian

4.1.13 Fron-fawr Formation (FRFA)

Name

Formerly referred to as the Basement Beds, the unit is here formally redefined as the Fron-fawr Formation.

Type section

Eastern slope of Fron-fawr hill [SJ 212 452]: Intermittent exposures in red sandstone and conglomerate within the lower part of the formation (Wedd et al., 1927).

Lithology

Red, purple and variegated silty mudstones, siltstones and sandstones with lenticular conglomerates and basal breccias. The silty mudstones locally display glaebular calcrite profiles including abundant calcareous nodules and thin units of nodular limestone.

Lower and upper boundaries

The Fron-fawr Formation rests unconformably on Silurian (Elwy Formation and Dinas Bran Beds) rocks.

The top of the formation is a conformable contact with limestones of the overlying Leete Limestone Formation.

Thickness

Up to 90 m

Distribution

West of Eglwyseg Rocks escarpment [SJ 22 45], north of Llangollen, North Wales.

Genetic interpretation

Records the accumulation of terrestrial scree and alluvial deposits in a fault controlled embayment prior to the establishment of the Clwyd Limestone Group carbonate platform.

Age

?Arundian to early Asbian

4.1.14 Pant Formation (PANT)

Name

Formerly referred to as the Basal Shales, the unit is here formally defined as the Pant Formation.

Type area

Disused quarry west of Pant [SJ 265 216]: Grey and red 'shale' with beds of sandy limestone were formerly exposed (Wedd et al., 1929).

Lithology

Pale, greenish-grey mudstones, darker in uppermost 3 m, with thin beds of dark grey sandy limestone.

Lower and upper boundaries

The Pant Formation rests unconformably on Ordovician mudstones and tuffaceous sandstones of the Allt-tair-fynnon Formation.

The top of the formation is a conformable and gradational contact with porcellaneous or coarser grained limestones of the Leete Limestone Formation.

Thickness

Up to 90 m

Distribution

Pant area [SJ 28 22], south of Oswestry, North Wales.

Genetic interpretation

The formation records the accumulation of alluvial and lagoonal (restricted marine) muds along the local margin of the North Wales Viséan platform.

Age

?Arundian to early Asbian

SHROPSHIRE

The Tournaisian *continental and peritidal facies* has been proved in the Lilleshall inlier (Figure 3). A single **Village Farm Formation** is recorded from the succession (Bridge and Hough, 2002).

4.1.15 Village Farm Formation (VIFM)

Name

The name was first proposed in the Lilleshall inlier by Bridge and Hough (2002), and is retained here.

Type section

Lilleshall Borehole L8 (SJ71NW/34) [SJ 7348 1569] from 0 to 40.35 m below ground level (Riley, 1998.).

Reference section

Lilleshall Borehole L17 (SJ71NW/63) [SJ 73317 16483] from 37.9 m to 48.94 m below ground level.

Lithology

Polymictic conglomerate, sandstone and breccia.

Lower and upper boundaries

The lower boundary is taken at a sharp, well-defined unconformity. The base of the unit is taken at the lowermost pebbly sandstone unit overlying a pebble-free sandstone sequence. Rests on Lower Palaeozoic strata of the Lower Comley Sandstone or 'Dolgelly Beds'.

The upper boundary is assumed to be unconformable or transitional. It is taken at the uppermost sandstone below a sandstone and limestone-dominated sequence of the Jackie Parr Limestone Formation.

Thickness

Some 40.35 m maximum proved (incomplete thickness, top not present) from Lilleshall L8 Borehole (SJ71NW/34).

Distribution

Lilleshall Inlier, Lilleshall, North Shropshire.

Genetic interpretation

Alluvial fan sandstones and conglomerates with upward transition into supratidal carbonates, playa deposits and coastal plain sandstones (Bridge and Hough, 2002).

Age

Upper Devonian to Tournaisian

CARBONIFEROUS LIMESTONE SUPERGROUP (CL)

The *open marine, platform and ramp carbonate facies* has been attributed the status of Carboniferous Limestone

Supergroup for onshore Great Britain. The platform carbonates were deposited on geographically isolated horsts or tilt-block highs (Figure 1), with distinct group names applied for each development. Within Central England and North Wales province, the main developments of such carbonates are upon the Bowland High (Bowland High Group), Central Lancashire High (Trawden Limestone Group), Holme High (Holme High Limestone Group), East Midlands Platform and Hathern Shelf (Peak Limestone Group), North Wales and Shropshire (Clwyd Limestone Group).

4.2 BOWLAND HIGH GROUP (BOHI)

Platform carbonates accumulated on the Bowland High during the Tournaisian and until Chadian times, when the platform subsided and deposition was replaced by basal facies of the Craven Group. These exposed carbonates are newly defined as the **Bowland High Group**, comprising the Chatburn Limestone and Clitheroe Limestone formations (Figure 4). The **Chatburn Limestone Formation** (Fewtrell and Smith, 1980) is undivided. The **Clitheroe Limestone Formation**, defined by Riley (1990), includes the **Thornton Limestone**, **Coplow Limestone**, **Peach Quarry Limestone** and **Bellman Limestone** members.

4.2.1 Chatburn Limestone Formation (CHL)

Name

The succession was first referred to as the Chatburn Limestone (Parkinson, 1926), subsequently defined as the Chatburn Limestone Group (Earp et al., 1961) and redefined as a formation (Fewtrell and Smith, 1980).

Type area

Quarries west of Chatburn [SD765 443], upper 393 m of formation (Earp et al., 1961).

Reference sections

Chatburn Bypass road cutting (A59) east side, immediately east of Chatburn village [SD 773 441–SD 773 450]. For other sections, see (Whittard and Simpson, 1960) and (Earp et al., 1961).

Swinden No.1 Borehole (SD85NE/15) near Horton [SD 8597 5051]; a thickness of 682.5 m is proved from the lower part of the formation (Charsley, 1983).

Lithology

Well-bedded, mostly grey to dark grey packstone limestones with chert lenses and subordinate partings or thin beds of shaley calcareous mudstone and siltstone.

Lower and upper boundaries

The base of the formation is not exposed or proved.

The top is taken where the dominant lithology described above, passes conformably upwards into either the dark shale-with-limestone lithology of the undifferentiated Craven Group in basal areas, or into the paler, 'more coarsely bioclastic and cleaner washed' limestone of the Clitheroe Limestone Formation on the Bowland High.

Thickness

At least 838 m measured thickness (base not proved).

Distribution

Widespread across the Craven Basin from the Whitewell area [SD64] in the west to the Skipton/Broughton area [SD95] in the east.

Genetic interpretation

The formation was deposited in a relatively uniform and widespread shallow marine carbonate shelf environment with a significant contribution of fine terrigenous clastics.

Biostratigraphical characterisation

At Chatburn, the group has been attributed an age of Tournaisian (Courseyan) to Chadian (George et al., 1976) or entirely Tournaisian (Riley, 1990, 1993a). The apparent absence of the foraminifera *Eoparastaffella* from the formation suggests the formation is entirely Courseyan to early Chadian (Tournaisian) in age.

Age

Courseyan to Chadian (Tournaisian)

4.2.2 Clitheroe Limestone Formation (CLL)

Name

Referred to as the Clitheroe Limestone Complex (Miller and Grayson, 1972), subsequently redefined as a formation (Fewtrell and Smith, 1980; Riley, 1990). The Clitheroe Limestone Formation was formerly defined as the lowest formation of the largely basinal Worston Shale Group (Riley, 1990).

Type sections

The lowest 60 m or so are exposed at Coplow Quarry [SD 750 435], 1.8 km north-north-east of Clitheroe Castle (Fewtrell and Smith, 1980).

Middle of the formation: Salthill-Bellman Quarry [SD 762 429], 1.7 km north-east of Clitheroe Castle (Fewtrell and Smith, 1980).

Middle of the formation: exposure to the south of Coplow at Peach Quarry [SD 7640 4320], 2.7 km north-east of Clitheroe Castle (Fewtrell and Smith, 1980).

Good exposure in the A59 road-cut [SD 770 435 to SD 766 427], 3.2 km north-east of Clitheroe Castle (Fewtrell and Smith, 1980).

Formal subdivisions

In ascending order, the formation is subdivided into the Thornton Limestone, Coplow Limestone, Peach Quarry Limestone and Bellman Limestone members.

Lithology

Predominantly pale grey and commonly coarsely crinoidal, packstones, wackestones and subordinate grainstones and mudstones with Waulsortian mudmound reef limestones present at two levels (for detailed lithological description, see Miller and Grayson, 1972; Lees and Miller, 1985; Riley, 1990).

Lower and upper boundaries

The base is seen at Ings End [SD 8145 4455], where thin bedded, dark grey silty packstones and interbedded mudstones of the Chatburn Limestone Formation pass upwards conformably into paler, more coarsely bioclastic cleaner washed limestones of the Clitheroe Limestone Formation.

The top is seen as a sharp, unconformable boundary between the dominant limestone succession of the Clitheroe Limestone Formation and the overlying grey to dark grey, thin-bedded calcisiltites and calcareous mudstones with thin limestone interbeds of the Hodder Mudstone Formation. At the type section this upper boundary is equivalent to the base of the Limekilm Wood Limestone Member (Riley, 1990), identified as the 'Salthill Cap Beds' of Miller and Grayson (1972), and corresponds to a widespread unconformity.

Thickness

Up to 1500 m thick

Distribution

Craven Basin, Lancaster [SD 46] to Skipton [SD 95]; extent southward not defined.

Regional correlation

Carbonates of similar lithology and age are recognised on the Central Lancashire High, further to the south of the Craven Basin (Evans and Kirby, 1999).

Genetic interpretation

The Clitheroe Limestone Formation is associated with development of a carbonate ramp and northward retreat of shelf carbonates to be replaced by Waulsortian limestones (Aitkenhead et al., 1992). The build-up of Waulsortian limestones was briefly interrupted by a phase of shallowing and development of storm-generated carbonates (Peach Quarry Limestone Member).

Biostratigraphical characterisation

The Clitheroe Limestone Formation was considered early Chadian in age by Riley (1990), the absence of *Eoparastaffella* indicating a probable Tournaisian (Cf4α1 Subzone) age.

Age

Early Chadian

4.2.2.1 THORNTON LIMESTONE MEMBER (THTL)

Name

The Thornton Limestone was described in the Thornton and Broughton anticlines [SD 95] (Hudson and Dunnington, 1944) and recognised in Eshton-Hetton [SD 96] and Slaidburn [SD 75] anticlines (Arthurton et al., 1988). The unit was subsequently defined as a formation by Riley (1990).

Type sections

Marion Scar, Bank Newton, near Gargrave, disused quarries between [SD 8804 5193] and [SD8802 5312], 0.6 km west-north-west and 0.85 km north-west of Stainton Hall (Arthurton et al., 1988). Neither the base nor top is exposed.

Reference section

Middle part of member: Stream section at Lower Greystonely [SD 6435 4540], downstream from the ford, 2 km south-west of the Whitewater Hotel (Aitkenhead et al., 1992).

Lithology

Packstones, wackestones and subordinate grainstones predominantly wavy-bedded, muddy, pale to dark grey, bioclastic and locally cherty, interbedded with variable amounts of dark-grey calcareous mudstone and siltstone. Bioturbation is common.

Lower and upper boundaries

The base is seen at Ings End [SD 8145 4455], where thin bedded, dark grey silty packstones and interbedded mudstones of the Chatburn Limestone Formation pass upwards conformably into paler, more coarsely bioclastic cleaner washed limestones of the Thornton Limestone Member. Locally in the Broughton Anticline [SD 93 52], Swinden Anticline [SD 85 52], Slaidburn Anticline [SD 70 53] and Airton Anticline [SD 88 60], the member rests conformably upon dark grey calcareous mudstone, muddy limestone and

calcsiltites of the Clitheroe Limestone Formation (undifferentiated), formerly referred to as the Thornton Shales-with-Limestone (Arthurton et al., 1988).

Generally, the member is overlain unconformably by the Hodder Mudstone Formation of the Craven Group. In parts of the Slaidburn [SD 75] and Whitewell [SD 64] anticlines the upper limestone passes laterally into, and is overlain by Waulsortian limestones of the Coplow Limestone Member.

Thickness

Up to 200 m

Distribution

Craven Basin, restricted to the north and east of the Bowland High, including the Broughton [SD 95], Eshton-Hetton [SD 96], Slaidburn [SD 75], Gisburn [SD 85] and Cow Ark and Whitewell [SD 64] anticlines.

Regional correlation

The member has been proposed to occur in the subsurface on the Central Lancashire High, further to the south of the Craven Basin (Evans and Kirby, 1999).

Genetic interpretation

Shallow water carbonate deposition on the shallower part of a southward-dipping submarine ramp (Aitkenhead et al., 1992).

Age

Early Chadian

4.2.2.2 COPLOW LIMESTONE MEMBER (COPL)

Name

The unit was first referred to as the Coplow Knoll Series (Parkinson, 1926) and was first formally defined as a member by Riley (1990), the name derived from the type locality.

Type section

Coplow Quarry [SD 7505 4320], 1.8 km north-north-east of Clitheroe Castle; exposure of the base of the member.

Reference sections

Disused quarry at Hall Hill [SD 6675 4670], 0.9 km east-south-east of the Whitewell Hotel (Black, 1954; Aitkenhead et al., 1992) shows diachronous base of a Waulsortian limestone with underlying 4 m of thin-bedded packstones and thin shales.

Large quarry exposure at Leagram Knott [SD 6390 4470], 2.1 km north-east of Chipping Parish Church (Aitkenhead et al., 1992), with up to 8 m face in Waulsortian limestone.

Large quarry exposure at Knoll Wood [SD 6835 5010] 1.25 km west-south-west of Newton (Aitkenhead et al., 1992), with 15 m of massive Waulsortian limestone.

Lithology

Pure, massive and biohermal Waulsortian limestones with subordinate packstones, grainstones and thin fissile mudstones.

Lower and upper boundaries

The base of the member is taken at the base of the lowest Waulsortian limestone, which rests conformably upon shales of the 'Lower Coplow Shales' (Miller and Grayson, 1972).

Generally, Waulsortian limestones of the Coplow Limestone Member are overlain unconformably by mudstones of the Hodder Mudstone Formation. In the Clitheroe

Anticline the upper part of the Coplow Limestone Member is present, with Waulsortian limestones overlain conformably by poorly exposed dark grey fissile mudstones and packstones of the 'Upper Coplow Shales' (Miller and Grayson, 1972).

Thickness

Up to 300 m

Distribution

Craven Basin, generally to the south and west of the Bowland High, within the Ashnott and Clitheroe anticlines [SD 74], Slaidburn and Newton [SD 75], Swinden [SD 85], Thornley [SD 64] and Whitewell [SD 64] anticlines.

Regional correlation

The member has been proposed to occur in the subsurface on the Central Lancashire High, further to the south of the Craven Basin (Evans and Kirby, 1999).

Genetic interpretation

Deposition on the relatively deeper part of a southward-dipping submarine ramp (Aitkenhead et al., 1992).

Age

Early Chadian

4.2.2.3 PEACH QUARRY LIMESTONE MEMBER (PQL)

Name

The Peach Quarry Limestone was first recognised by Earp et al. (1961) and redefined as a member by Riley (1990).

Type section

Road cutting on the A59 Clitheroe By-pass between [SD 7700 4380] and [SD 7685 4392], 3.2 km north-east of Clitheroe Castle. The base and top of the member are not exposed.

Reference sections

Peach Quarry [SD 7640 4320], 1.7 km north-east of Clitheroe Castle, shows a deteriorating section with strata dipping 40° to the south-east.

Upper part of member: Northern side of Bellman Quarry [SD 7600 4290], in the old tramway cutting 2.25 km north-east of Clitheroe Castle.

Lithology

Packstone and grainstone, clean washed, fine- to coarse-grained, pale grey, with thin to thick, massive and multi-storey beds, wavy bedded and chert with abundant crinoid, algal and pellet grains, interbedded with subordinate dark to brownish grey, calcareous mudstones, platy with bedding planes crowded with brachiopods and ostracods. Many limestones contain intraformational lithoclasts and show erosive bases. Grading and cross-bedding occur, together with high-angle, imbricate shell-lags.

Lower and upper boundaries

The base of the member is a conformable passage from poorly exposed dark grey fissile mudstones and packstones of the 'Upper Coplow Shales' to packstones and grainstones of the Peach Quarry Limestone Member.

The top of the member is a gradational passage from the packstones and grainstones into the Waulsortian limestones of the Bellman Limestone Member.

Thickness

Up to 70 m

Distribution

Lenticular unit restricted to the southern limb of the Clitheroe Anticline [SD 74].

Regional correlation

The member has been proposed to occur in the subsurface on the Central Lancashire High, further to the south of the Craven Basin (Evans and Kirby, 1999).

Genetic interpretation

Associated with a phase of shallowing and development of storm-generated carbonates (Riley, 1990).

Age

Early Chadian

4.2.2.4 BELLMAN LIMESTONE MEMBER (BMNL)

Name

Defined as the 'Salthill Bank Beds' by Miller and Grayson (1972), the unit was named and defined as the Bellman Limestone Member by Riley (1990). The member is named after the type section.

Type section

Bellman Quarry [SD 7600 4290], north-east face, 3 km north-east of Clitheroe Castle (Earp et al., 1961). The top 21 m thickness of the member is seen in the southern part of this quarry.

Reference sections

Good exposure in the A59 road-cut [SD 7670 4300], 2.9 km north-east of Clitheroe Castle (Riley, 1990).

Large quarry at Twiston [SD 8075 4440], 7.2 km north-east of Clitheroe Castle: eastern part in thickly bedded crinoidal limestone passing to a dark, massive calcareous siltstone in the western part (Earp et al., 1961).

Lithology

Waulsortian limestones with subordinate packstones, wackestones and grainstones.

Lower and upper boundaries

The base of the member is taken at the base of the lowest Waulsortian limestone above the packstones and grainstones of the Peach Quarry Limestone Member. Where the latter is absent, the base of the member rests conformably upon dark grey fissile mudstones and packstones of the 'Upper Coplow Shales'.

The Waulsortian limestones at the top of the member are overlain unconformably by mudstones of the Hodder Mudstone Formation.

Thickness

Up to 800 m

Distribution

Craven Basin, limited to the Clitheroe Anticline [SD 74] and northern limb of the Whitewell Anticline [SD 64].

Regional correlation

The member has been proposed to occur in the subsurface on the Central Lancashire High, further to the south of the Craven Basin (Evans and Kirby, 1999).

Genetic interpretation

Deposition on the relatively deeper part of a southward-dipping submarine ramp (Aitkenhead et al., 1992).

Age

Early Chadian

4.3 TRAWDEN LIMESTONE GROUP (TRLI)

The concealed Chadian to Brigantian carbonates of the Central Lancashire High are recognised as distinct platform successions (Evans and Kirby, 1999). Seismic and geophysical logs have been used to identify a single lithofacies and no attempt has been made to divide the buried carbonates into formations. The informal name of **Trawden Limestone Group** is proposed. The Trawden Limestone Group is proved in several deep boreholes, including Roddlesworth No.1, Holme Chapel No.1 and Boulsworth No.1 (Figure 5).

Name

Not previously named, the Trawden Limestone Group is proved in the subsurface and is named after the Forest of Trawden [SD 93], Lancashire, located over the central part of the subsurface Central Lancashire High.

Type section

Roddlesworth No.1 Borehole (SD62SE/274) [SD 65494 21120], from about 2331 m to 1277 m, displaying the entire thickness of the group (Figure 5).

Reference section

Holme Chapel No.1 Borehole (SD82NE/69) [SD 8608 2878], from 1940 m to 1517.8 m, displaying the entire thickness of the group (Figure 5).

Lithology

A pale to dark grey, typically darker towards the base, micritic to crystalline limestone, with subordinate partings and thin beds of calcareous mudstone, locally abundant chert, crinoid and brachiopod debris. A pale grey, fine- to medium-grained dolostone is locally present, near the base of the group.

Lower and upper boundaries

A conformable base of argillaceous dolostone (Holme Chapel Borehole) or dark grey to black blocky claystone, grading upward into medium to dark grey micritic limestone of the Trawden Limestone Group, above pale grey medium-grained sandstone with siliceous and dolomitic cement, interbedded with medium to dark grey fine-grained sandstone, with an argillaceous and dolomitic matrix of the Roddlesworth Formation (Roddlesworth Borehole). The base is evident as a sharp change from highly serrated and high gamma responses below, and generally lower and more subdued gamma ray responses above the boundary.

The top of the group is marked by a conformable base of the overlying dark brown to black, calcareous and carbonaceous claystone to siltstone, of the Bowland Shale Formation above pale grey limestone of the Trawden Limestone Group.

Thickness

Thickest development of 1055 m in the type locality, and 422 m in the Holme Chapel Borehole.

Distribution

Not proved at outcrop, but proved in the subsurface over the Central Lancashire High, a south-west-north-east structure extending from Chorley [SD 60 20] to Bradford [SE 10 30], bounded to the north-west by the Pendle Fault and the

Bowland Basin, and to the south-east by the Rossendale Basin.

Regional correlation

Equivalent to the Holme High Group of the Holme High, located to the south and east of the Central Lancashire High. There is no evidence to suggest that there is any lateral connection between these two groups.

Genetic interpretation

Shallow water platform to ramp carbonates.

Biostratigraphical characterisation

Miospores of the *Lycospora pusilla* Zone are recorded in the Boulsworth No.1 borehole (SD93SW14) [92690 344790], indicating a Chadian to Arundian age, though as *L. pusilla* is rare in the assemblage, an early Chadian (Tournaisian) age is preferred (Riley and McNestry, 1988).

The lower part of the succession present in the Roddlesworth Borehole contains *Glomodiscus* and *Uralodiscus*, indicative of the Cf4 β - γ Subzones (early to mid Arundian, and the upper part contains *Asteroarchaediscus*, indicative of the Cf6 δ Subzone (Brigantian) (Riley, 1993b).

Age

Chadian to Brigantian

4.4 HOLME HIGH LIMESTONE GROUP (HOHI)

The concealed Chadian to Brigantian carbonates of the Holme High are recognised as distinct platform successions (Evans and Kirby, 1999). Seismic and geophysical logs have been used to identify a single lithofacies and no attempt has been made to divide the buried carbonates into formations. The informal name of **Holme High Limestone Group** is proposed. The Holme High Limestone Group is proved in the Wessenden No.1 Borehole (Figure 5), and the upper part of the group is also proved in the Heywood No.1 Borehole (Figure 5).

Name

Not previously named, the Holme High Group is named after the subsurface structure, the Holme High, above which these platform carbonates developed.

Type section

Not seen at the surface, but present in the Wessenden No.1 Borehole (SE00NE/7) [SE 05462 06491], from 1103.3 m to 489.5 m depth, displaying the entire thickness of the formation (Figure 5).

Reference section

Heywood No.1 Borehole (SD80NW141) [SD 83851 08976], from the base of the borehole at 1619 m to 1460.9 m, displaying the upper part of the group, of Brigantian age (Figure 5).

Lithology

A pale to dark grey, typically darker towards the base, micritic to crystalline limestone, with subordinate partings and thin beds of dark grey shale, and locally abundant chert, crinoid and brachiopod debris. A thin vesicular brecciated basalt is present near the base of the type locality, and dolostone or dolomitic limestone is predominant in the basal 120 m above this.

Lower and upper boundaries

The base of grey and grey-brown dolostone of the Holme High Limestone Group, rests unconformably upon Lower Palaeozoic green slate strata in the type locality.

The sharply conformable base of overlying dark grey, carbonaceous, fissile mudstone of the Bowland Shale Formation, occurs above the pale grey limestone of the Holme High Limestone Group.

Thickness

Seen as 613 m in the type locality, though seismic surveys over the high suggest that the group may be up to 1250 m thick (Evans and Kirby, 1999).

Distribution

Not seen at outcrop, but proved in the subsurface over the Holme High, a east-west structure extending from Heywood [SD 80 10] to Holmfirth [SE 20 10], bounded to the north by the Holme and Heywood faults, and to the south by the Alport Basin. The group is extended to include equivalent platform carbonates present on the Heywood High, which represents the westward continuation of the Holme High (Figure 5).

Regional correlation

Equivalent to the Trawden Limestone Group of the Central Lancashire High, located to the north and west of the Holme High. There is no evidence to suggest that there is any lateral connection between these two groups.

Genetic interpretation

Shallow water platform to ramp carbonates.

Biostratigraphical characterisation

The presence of the foraminifera *Archaediscus* sp. stage *angulatus* and the dasyclad alga *Koninckopora inflata* from the upper part of the group in the Wessenden Borehole indicate an Asbian (probably early Asbian) age (Riley, 1993c).

Age

Chadian to Brigantian

4.5 PEAK LIMESTONE GROUP (PKLM)

The main area of exposure is within the Peak District of Derbyshire, which during the Visean formed a promontory of the East Midlands Platform (Figure 1). The proposed lithostratigraphy of the **Peak Limestone Group** is shown on Figure 6, which is adapted from Aitkenhead and Chisholm (1982). An additional nomenclature has been described for parts of the Nottingham Shelf and part of the East Midlands Platform (Carney et al., 2001; 2004). The succession is proved in the subsurface only and there is insufficient information to allow correlation with the succession in the Peak District.

Across the East Midlands during Tournaisian to early Visean times there was a slow onlap of marine ramp carbonates, with some evaporites, onto an irregular palaeorelief, evident as the **Rue Hill Dolomite Formation**. At this time there is a distinction in the carbonate succession from comparatively massive and dolomitic, shallower water limestones of the northern part of the Peak District inlier (Buxton to Matlock) recognised as the **Woo Dale Limestone Formation** (including the **Iron Tors Limestone Member**) and relatively deeper water limestones with mudmounds present within the south-western part of the inlier (Dovedale and Manifold Valley), the **Milldale Limestone**

Formation. Bridges and Chapman (1988) suggest that the mud-mounds accumulated in water depths of 220 to 280 m. As the latter subfacies occurs as a belt extending north-west of the north-west-trending half-graben of the Widmerpool Gulf, it is tempting to recognise a structurally induced palaeorelief influencing deposition. On the Nottingham Shelf, the Milldale Limestone Formation is overlain, possibly unconformably, by the **Belvoir Limestone Formation**, in turn overlain, possibly unconformably, by the **Plungar Limestone Formation**.

By Asbian times a sea-level rise and syn-rift subsidence led to a clear differentiation between a shelf province, fringed by apron-reefs, and off-shelf facies (Craven Group). The shelf province includes the **Hopedale Limestone Formation**, **Bee Low Limestone Formation** (including the **Chee Tor Rock**, **Lower Miller's Dale Lava**, **Miller's Dale Limestone** and **Ravensdale Tuff members**), **Monsal Dale Limestone Formation**, **Fallgate Volcanic Formation** (including the **Lathkill Lodge Lava** and **Conksbury Bridge Lava members**), and **Eyam Limestone Formation**. The Monsal Dale Limestone Formation includes a complex stratigraphy of lavas and tuffs. The **Upper Miller's Dale Lava** present in the Castleton–Buxton–Tideswell region, the **Winstermoor Lava**, **Lower and Upper Matlock Lava** and **Shothouse Spring Tuff members** in the Matlock–Wirksworth region, the **Shacklow Wood Lava**, **Lees Bottom Lava members** of the Alport–Bakewell–Taddington Dale region, **Cressbrook Dale Lava** and **Litton Tuff members** of the Eyam–Longstone–Litton region.

The remainder of the shelf is largely known from subsurface borehole and seismic data. More than 500 m thickness of Peak Limestone Group is present on the East Midlands Platform. Chadian mud-mounds or bioherms and Asbian shelf-edge reefs are described by Strank (1987). The group generally rests unconformably upon deformed Lower Palaeozoic strata, or locally upon alluvial or peritidal facies strata (see Section 4.1). The top of the group is typically a conformable boundary marked by the transition into basal mudstones and siltstones of the Craven Group, though is locally truncated beneath Westphalian strata.

Localised tectonic uplift resulted in disconformities, particularly during the Chadian and Brigantian. Subaerial palaeokarstic dissolution hollows are common, particularly during the Asbian and Brigantian of Derbyshire (Walkden, 1974). In Derbyshire these surfaces are locally associated with subaerial and subaqueous basaltic lava flows and tuffs (Waters, 2003).

EAST MIDLANDS PLATFORM

4.5.1 Rue Hill Dolomite Formation (RHD)

Name

The Rue Hill Dolomites were first named by Aitkenhead and Chisholm (1982) after the locality near to the Caldron Low Borehole. It is here redefined as the Rue Hill Dolomite Formation.

Type section

Caldon Low Borehole (SK04NE/36) [SK 0804 4823] (Chisholm et al., 1988), displays the entire thickness of formation between 365.07 and 280.6 m (Figure 7).

Lithology

Grey, thinly bedded, very fine-grained dolostone, with subordinate beds of dark grey limestone comprising calcilitite and calcisiltite, mudstone, in which fenestral cavities are

common, breccias and several thin beds of coarse-grained quartzitic sandstone. The variably bedded argillaceous limestone or dolostone, has a marine fauna of crinoids and brachiopods, alternating with dolostone containing pencontemporaneous breccias and a sparse gastropod, serpulid and ostracod fauna.

Lower and upper boundaries

The base of the formation occurs at the top of a red-brown pebbly sandstone and conglomerate of the Redhouse Sandstone Formation, displaying a sharp passage into grey dolostone of the overlying Rue Hill Dolomite Formation.

The top of the formation is a conformable passage into medium grey biosparites or dark grey cherty micrites of the Milldale Limestone Formation, with the boundary at the top of unfossiliferous porcellaneous dolostone above the highest occurrence of the ostracod-gastropod fauna.

Thickness

Measured as 84.47 m thick in the Caldron Low Borehole.

Distribution

Proved only in the Caldron Low Borehole. Considered to be more widespread in the off-shelf area to the Derbyshire High and the Staffordshire Shelf, in the subsurface of the Ashbourne and Cheadle district.

Genetic interpretation

Repeated transitions from shallow subtidal environment to deposition on an intertidal or supratidal flat, during a broadly transgressive event (Chisholm et al., 1988).

Biostratigraphical characterisation

Miospores from the lower part of the formation were assigned to the VI Subzone to the PC Zone (Welsh and Owens, 1983). Foraminiferal assemblages from the upper part of the formation suggest a late Courceyan or Chadian age (Chisholm et al., 1988).

Age

Courceyan (Tournaisian)

4.5.2 Milldale Limestone Formation (MI)

Name

The name Milldale Limestones was introduced by Parkinson (1950) for bedded rocks of the C zone well developed in the neighbourhood of Milldale. The definition was extended to include the entire sub-D1 succession (Aitkenhead and Chisholm, 1982).

Type sections

Lower part: Caldron Low No.1 Borehole (SK04NE/36) [SK 0804 4823] (Chisholm et al., 1988), from 280.6 m to 2.59 m, showing the lower boundary with the underlying Rue Hill Dolomite Formation (Figure 7).

Top: Brownend Quarry, Waterhouses [SK 0910 5019–SK 0898 5027] (Chisholm et al., 1988), which exposes the top 82.15m of the formation and the junction with the Hopedale Limestone Formation.

Disused railway cutting [SK 0959 5501–SK 0949 5492], displaying about 28.4 m of discontinuously exposed strata below the knoll-reef at Thor's Cave, sections within the reef, and 49.02 m of discontinuously exposed strata above the reef, passing up into the Ecton Limestone Formation (Chisholm et al., 1988).

The bed of the River Manifold [SK 0988 5509–SK 0964 5500], exposes reef facies (Aitkenhead et al., 1985).

Raven's Tor, Dovedale [SK 1412 5385], exposes reef facies and lateral passage to inter-reef facies (Chisholm et al., 1988).

Reference sections

Breedon-on-the-Hill Quarry [SK 407 230], which shows a Waulsortian mud-mound reef, of up to 100 m thickness of unbedded dolostone, overlying about 280 m of well-bedded inter-reef facies (Ambrose and Carney, 1997b; Carney et al., 2001).

Cloud Hill Quarry [SK 413 211], new level; 4 m level and 24 m level (southern end of quarry). Comprises 130 m of well-bedded inter-reef facies with limestones, commonly bituminous clay, shaly mudstone and siltstone. The upper 61 m comprises the Holly Bush Member (Ambrose and Carney, 1997b; Carney et al., 2001).

Formal subdivisions

Holly Bush Member, restricted to the Hathern Shelf (see Section 4.5.11).

Lithology

In the type area, comprises well-bedded medium grey, crinoidal 'biosparites' and dark grey cherty micrites of an inter-reef facies, passing vertically and laterally into knoll reef mud-mounds of poorly bedded grey micrite, which are locally partially or completely dolomitised. In the Loughborough area, it comprises grey to buff, thin to thickly bedded, fine-to-coarse-grained, locally pebbly dolostones, whereas altered tuff and vesicular basaltic lava are recorded in the Gun Hill Borehole (SJ 96SE18) [SJ 9723 6182], between depths of 709 m and 770.5 m.

Lower and upper boundaries

The base of the formation is only seen in the Caldon Low borehole, where fine-grained pale grey-white dolostones comprising the Rue Hill Dolomite, of Tournaisian age, pass up rapidly into a predominantly limestone sequence of the Milldale Limestone Formation, with the base of the Milldale Limestone Formation taken at the base of a 2 cm thick black fissile mudstone overlying 2.35 m of very fine-grained dolostone. In the Hathern No.1 Hydrocarbon Borehole (SK52SW 3) [SK 5158 2416], limestones interpreted as the Milldale Limestone Formation are underlain by anhydrite, limestone and dolostone of the Hathern Anhydrite Formation.

The top is seen as a rapid upward transition, from dark cherty micritic limestones to: a) grey coarsely bioclastic conglomeratic limestones of the Hopedale Limestone Formation; b) to thicker bedded, paler peloidal and crinoidal bioclastic limestone of the Ecton Limestone Formation; c) poorly sorted conglomerate of reef limestone pebbles at the base of the Kevin Limestone Formation; or d) a sharp disconformity at the base of dark to pale brown, grey calcareous mudstone and thinly bedded argillaceous limestones of the Widmerpool Formation.

Thickness

From 305 m in the type area, 470 m in the Caldon Low Borehole (SK04NE 36) [SK 0804 4823], to at least 380 m at Breedon Hill, and 791.55 m recorded in the Gun Hill Borehole (SJ96SE 18) [SJ 9723 6182], located 13 km north-west of the Manifold Valley inlier.

Distribution

Deposited in the south-western part of the Peak District inlier in Staffordshire to Derbyshire, and at depth over the Hathern Shelf across north-west Leicestershire.

Regional correlation

Passes laterally to the north and east into the Woo Dale Limestone Formation (Figure 6) of the Derbyshire High (Aitkenhead and Chisholm, 1982).

Genetic interpretation

The formation was deposited within a comparatively deep marine ramp environment, with development of Waulsortian limestones, including mud-mounds and inter-reef facies.

Biostratigraphical characterisation

The Milldale Limestone Formation of the Peak District inlier includes Tournaisian conodont faunas, including *Scaliognathus anchoralis* and *Polygnathus communis carina* from the lower part of the formation, whereas the upper part contains coral and foraminifera assemblages of up to Arundian and Holkerian age, respectively (Aitkenhead et al., 1985).

In north-west Leicestershire foraminiferal assemblages at Cloud Hill Quarry are of Cf4a1 subzone and the ammonoid *Fascipericyclus fasciculatus* found at Breedon-on-the-Hill Quarry, both indicate an early Chadian (Tournaisian) age (Carney et al., 2001).

Age

Chadian to Asbian

4.5.3 Belvoir Limestone Formation (BVR)

Name

The formation was first named by Carney et al. (2004) from the subsurface of the Melton Mowbray District.

Type section

Plungar 8A Borehole (SK73SE/27) [SK 7745 3336]: the full thickness of the formation is proved between 1250 and 1130 m (Riley, 1992).

Lithology

Brown to white, dolomitic, locally ooidal limestone with rare thin volcanic beds of 'green ash'.

Lower and upper boundaries

The base of the formation is inferred to be an unconformity (Riley, 1992), with the dolomitic limestones of the Milldale Limestone Formation overlain by dolomitic, locally ooidal limestones of the Belvoir Limestone Formation.

The top of the formation is inferred to be an unconformity (Riley, 1992), with the dolomitic, locally ooidal limestones of the Belvoir Limestone Formation overlain by a grey, pebbly sandstone present at the base of the overlying Plungar Limestone Formation.

Thickness

Some 120 m thick in the type locality.

Distribution

Only proved at the type locality, but may occupy other parts of the Nottingham Shelf.

Genetic interpretation

Shallow to moderate depth waters occupying a carbonate ramp.

Biostratigraphical characterisation

A late Chadian age is assumed for the topmost part of the formation, as samples from above 1149 m in the type locality yielded bilaminar *Koninckopora*, with no archaeadiscids present (Riley, 1992).

Age
Chadian

4.5.4 Plungar Limestone Formation (PLLS)

Name

The formation was first named by Carney et al. (2004) from the subsurface of the Melton Mowbray District.

Type sections

Plungar 8A Borehole (SK73SE/27) [SK 7745 3336]; the full thickness of the formation is proved between 1131 and 932 m (Riley, 1992).

Lithology

The base of the formation comprises a 6 m-thick bed of grey, pebbly sandstone. This is overlain by dolomitic limestones with two thinner sandstones in a 15 m thickness of strata. White to buff, crystalline limestones, ooidal in places, occur above the youngest sandstone.

Lower and upper boundaries

The unconformable base is taken where dolomitic, locally ooidal limestone of the Belvoir Limestone Formation are overlain by grey, pebbly sandstone of the Plungar Limestone Formation.

The top of the formation is taken where the white to buff, crystalline limestone of the Plungar Limestone Formation is overlain by grey mudstone, siltstone or sandstone of the Millstone Grit Group.

Thickness

Some 199 m thick at the type locality.

Distribution

Only proved at the type locality, but may be represented by other limestone provings beneath the Namurian strata present in the north-east of the Melton Mowbray district.

Genetic interpretation

The formation is interpreted as a carbonate ramp or platform lithological association.

Biostratigraphical characterisation

Riley (1992) noted that faunal remains are sparse for this unit, with a late Arundian age regarded as tentative. This conflicts with the macrofauna obtained from 140 m below the top of the unit in the adjacent Plungar No.8 Borehole, which includes *Gigantoproductus*, indicative of a D1 (Asbian) age, possibly younging upwards into the Brigantian.

Age
?Arundian

4.5.5 Hopedale Limestone Formation (HP)

Name

The name Hopedale Limestones was introduced for the Hopedale area (Aitkenhead and Chisholm, 1982; Aitkenhead et al., 1985) and is here renamed the Hopedale Limestone Formation.

Type sections

Disused quarries east of Leehouse Farm, Waterhouses [SK 0868 5034–0851 5029], expose 80.8 m of beds in the upper part of the formation (Chisholm et al., 1988).

Brownend Quarry, Waterhouses [SK 0898 5027–0897 5026], exposes 8.26 m at the base of the formation, and

the boundary with the underlying Milldale Limestone Formation (Chisholm et al., 1988).

Disused quarry, north of Wetton [SK 1078 5570], shows 10.9 m of fossiliferous bioclastic and conglomeratic limestone near the flank of a knoll reef (Aitkenhead et al., 1985).

Lithology

A heterogeneous succession of typically medium grey, locally dark grey, fine- to coarse-grained calcarenites, with limestone clasts and coarse crinoid debris common at the base of the formation, and in the vicinity of knoll-reefs.

Lower and upper boundaries

The base is marked by a change from dark cherty micritic limestone of the underlying Milldale Limestone Formation, to grey coarsely bioclastic or conglomeratic limestones present at the base of the Hopedale Limestone Formation. The base of the formation is locally disconformable or gradational.

The upper part of the formation, seen as mostly calcarenites, is overlain with a sharp boundary to darker mudstones at the base of the Widmerpool Formation.

Thickness

Seen as 60 m thick in Hopedale [SK 129 549], up to 300 m around Gag Lane, to the north-north-east of Thorpe [SK 16 51].

Distribution

Southern part of the Peak District, in a broad synclorium between the Manifold and Dove valleys.

Regional correlation

The formation is believed to pass laterally (Figure 6) toward the north into the Bee Low Limestone Formation and to the south into the deeper water, off-shelf Ecton Limestone Formation (Craven Group) (Aitkenhead et al., 1985).

Genetic interpretation

The formation includes knoll-reefs and inter-reef facies, the latter including graded beds interpreted as storm-surge deposits or turbiditic influxes off knoll-reef slopes. A shallow water origin of these reefs may be indicated by the presence of reef-derived clasts in the off-reef beds, possibly reflecting wave brecciation

Biostratigraphical characterisation

The lower part of the Hopedale Limestone Formation includes ammonoid fauna indicative of the B_{2b} Subzone and Brigantian coral and brachiopod fauna in the upper part (Aitkenhead et al., 1985).

Age
Asbian to Brigantian

4.5.6 Woo Dale Limestone Formation (WDL)

Name

The name Wood Dale Beds was introduced by Stevenson and Gaunt (1971) for the S2 Zone beds of the Wye Valley and was extended to include the entire Tournaisian to Visean sequence proved in the Woo Dale Borehole (Cope, 1973). The unit is here redefined as the Woo Dale Limestone Formation.

Type section

Woo Dale [SK 097 726]: shows 24.16 m of brown, granular dolostone with subsidiary beds of pale grey and grey brown limestone (Aitkenhead et al., 1985).

Reference sections

Woo Dale Borehole (SK07SE/24) [SK 0985 7248]: unconformable base above pre-Carboniferous volcanic rock, overlain by 27.7 m of ?Tournaisian grey and dark grey limestone and shale partings, and 243.2 m of grey, dark grey and brown dolostone (Cope, 1973).

Cutting by A6, near Topley Pike [SK 1076 7243–SK 1115 7246] exposes the top 31.7 m of the formation and the boundary with the overlying Bee Low Limestone Formation (Aitkenhead and Chisholm, 1982).

Eyam Borehole (SK27NW/15)[SK 2096 7603] from 1729.64 m to 405.12 m (Figure 7), with boundaries between the underlying Middleton Dale Anhydrite Formation and the overlying Bee Low Limestone Formation (Dunham, 1973).

Formal subdivisions

Single Iron Tors Limestone Member representing the lower 107 m of the formation in Wolfscote Dale.

Lithology

In the Woo Dale Borehole, the base of the formation comprises a basal breccia of lava and pyroclastic rock fragments, overlain by grey and dark grey limestone, including thin calcilutite beds and shale partings. These are typically overlain by pale or medium grey crinoidal biosparites and pelsparites. However, at the type locality of Woo Dale, the overlying succession is dominated by dark grey to grey-brown and mainly dolomitised limestone, with subordinate limestone beds. The upper part of the formation is characterised by irregular beds of medium to pale grey and grey-brown micritic limestone, interbedded with peloidal calcarenitic limestone, comprising biopelsparites and pelsparites.

Lower and upper boundaries

The base of the formation is taken at the bottom of the basal breccia of the limestone sequence in the Woo Dale Borehole, marking a prominent unconformity above pre-Carboniferous volcanic rocks. The conformable boundary in the Eyam Borehole (Figure 7), with anhydrite and thin mudstone and dolostone beds of the Middleton Dale Anhydrite Formation, is overlain by dolostone of the Woo Dale Limestone Formation.

The top of the formation is taken at the base of the lowest pale grey limestone of the Bee Low Limestone Formation above the dark grey micrite or calcilutite beds of the Woo Dale Limestone Formation.

Thickness

Measured as 402.26 m thick in the Woo Dale Borehole and Woo Dale outcrop, with 1324.52 m in the Eyam Borehole.

Distribution

The East Midlands, notably across the northern part of the Peak District inlier (Buxton to Matlock).

Regional correlation

The formation passes laterally to the south and west (Figure 6) into the slightly deeper-water Milldale Limestone Formation (Aitkenhead and Chisholm, 1982).

Genetic interpretation

The formation was deposited within a comparatively shallow water part of a carbonate ramp. The basal breccia in the Woo Dale Borehole probably represents a marine shoreline deposit associated with marine transgression (Aitkenhead et al., 1985). The presence of ‘birdseye’ structures and rare coals suggests a regressive event associated

with development of an intertidal or supratidal environment during Holkerian times.

Biostratigraphical characterisation

A Chadian age has been attributed to the base of the Woo Dale Limestone Formation and a late Holkerian to early Asbian age for the top (Aitkenhead et al., 1985); Arundian strata have not been proved within this formation.

Age

Courseyan to Asbian

4.5.6.1 IRON TORS LIMESTONE MEMBER (IT)

Name

The name Iron Tors Limestone was first used by Parkinson (1950) to include a lower biosparite and upper micrite unit in Wolfscote Dale. The unit was redefined as a member, including only the lower biosparites by Aitkenhead and Chisholm (1982).

Type sections

Isolated crags, up to 12 m high at Iron Tors [SK 1439 5647; 1448 5648; 1458 5643] (Aitkenhead et al., 1985).

Lithology

Massive, pale grey to grey-brown peloidal calcarenites.

Lower and upper boundaries

The base of the member is not proved in exposures, but it is conjectured to rest conformably upon thin-bedded limestones of the undivided Woo Dale Limestone Formation.

The top is marked by a passage from the massive, pale grey to grey-brown peloidal calcarenites of the Iron Tors Limestone Member to grey to pale grey calcarenites, commonly laminated and including biopelsparites, and subordinate thinly interbedded calcilutites of the Woo Dale Limestone Formation (undivided).

Thickness

Estimated to be 107 m thick.

Distribution

Northern part of the Peak District inlier, limited to Iron Tors [SK 15] in Wolfscote Dale.

Regional correlation

The member passes laterally to the south and west into the slightly deeper-water Milldale Limestone Formation (Aitkenhead et al., 1985).

Genetic interpretation

Relatively strong current action, either in tidal channels or above the storm wave base.

Age

Chadian to Arundian

4.5.7 Bee Low Limestone Formation (BLL)

Name

The name Bee Low Limestones was introduced by Stevenson and Gaunt (1971) for the sequence around Bee Low and Eldon Hill, but was extended to include all stratigraphical equivalents in the northern part of the Peak District inlier (Buxton to Matlock) (Aitkenhead and Chisholm, 1982). The unit is here defined as a formation.

Type sections

Bee Low Quarry [SK 0922 7915], shows 89.76 m of formation, with the highest part about 24.38 m below the top of formation (Stevenson and Gaunt, 1971).

Duchy Quarry [SK 0938 7681], exposes the top 33.63 m of the Chee Tor Rock Member (Stevenson and Gaunt, 1971).

The A6 near Topley Pike [SK 1076 7243–1115 7246], exposes the basal 10.3 m of formation, and the boundary with the underlying Woo Dale Limestone Formation (Aitkenhead and Chisholm, 1982).

Station Quarry, Miller's Dale [SK 1327 7340], exposes the top 18.11 m of the Miller's Dale Limestone Member, and the boundary with the overlying Monsal Dale Limestone Formation (Aitkenhead et al., 1985).

Eyam Borehole (SK27NW 15), proves the formation in full, as 161.94 m thick, with 18.58 m of fragmented lava and tuff in the upper part (Dunham, 1973) (Figure 7).

Formal subdivisions

The formation includes two volcanic members, the Lower Miller's Dale Lava and Ravensdale Tuff members. In the Wye Valley, the Lower Miller's Dale Lava Member separates an underlying Chee Tor Rock Member from an overlying Miller's Dale Limestone Member.

Lithology

Pale grey, pale brownish grey to grey, fine- to medium-grained calcarenites, thick-bedded with scattered crinoid debris; mainly biosparites, but biopelsparites and pelsparites also occur. Peloidal calcarenites are present in the lower part and the back reef facies. Pedogenic crusts and palaeokarst features are common on many of the major bedding planes and are often overlain by red-brown and grey-green volcanic clays (bentonites) up to 0.5 m thick. Towards the apron reef, the limestones become increasingly micritic and poorly bedded, with more peloids and ooids and the local development of conglomeratic limestones. Thick basaltic lavas and tuffs are locally developed, including two volcanic members, namely the Ravensdale Tuff and the Lower Miller's Dale Lava.

Lower and upper boundaries

The base of the formation is taken at the top of the highest dark micritic or calcilutitic bed, of the Woo Dale Limestone Formation, overlain conformably by pale grey limestone of the Bee Low Limestone Formation.

The top of the formation is taken at the base of the lowest dark limestone bed of the Monsal Dale Limestone Formation above the pale grey limestone of the Bee Low Limestone Formation.

Thickness

From 68 to 213 m in the Buxton district, with 161.94 m measured in the Eyam Borehole (Figure 7).

Distribution

The northern part of the Peak District inlier (Buxton to Matlock).

Regional correlation

The formation passes laterally to the south and west into the Hopedale Limestones (Aitkenhead and Chisholm, 1982).

Genetic interpretation

The formation was deposited in a shallow shelf sea, with repeated sea-level fluctuations resulting in periodic emergence and development of palaeosols and palaeokarstic surfaces.

Biostratigraphical characterisation

The Bee Low Limestone Formation contains Asbian coral and foraminifera assemblages, with the upper part containing *Davidsonina septosa* and ammonoid fauna indicative of the B2b Subzone (Aitkenhead et al., 1985).

Age

Late Asbian

4.5.7.1 CHEE TOR LIMESTONE MEMBER (CT)

Name

The name Chee Tor Rock was introduced by Green et al., (1869) after the type locality, and was subsequently defined and described by Cope (1933). The unit is defined here as a member.

Type sections

Chee Tor [SK 1229 7331] comprises a 47 m cliff of massive limestone from the basal part of the member (Aitkenhead et al., 1985).

Below Cowdale Quarry [SK 0807 7246] 12.88 m-thick basal section of the member, overlying the Woo Dale Limestone Formation (Aitkenhead et al., 1985).

Cowdale Quarry [SK 0818 7227–0802 7216], 50.48 m-thick section entirely within member (Aitkenhead et al., 1985).

Tunstead Quarry (Stevenson and Gaunt, 1971) consists of a 116 m thick succession of the member, overlying the Woo Dale Limestone Formation.

Lithology

A homogeneous, massive to thickly bedded, pale grey to grey calcarenite. Bed boundaries are typically defined by stylolitic or clay partings, with beds generally ranging from 0.5 to 5.0 m, up to a maximum of 10.2 m thick. Rare calcilutites or very fine calcarenites occur in the basal 13 m, where beds tend to be thinner.

Lower and upper boundaries

The base of the member is a conformable transition from the top of the highest dark micritic or calcilutitic bed, of the Woo Dale Limestone Formation to the pale grey to grey calcarenite with rare calcilutites or very fine calcarenites of the Chee Tor Limestone Member.

At the top of the member, calcarenites of the Chee Tor Limestone Member are overlain by basaltic lavas of the Lower Miller's Dale Lava Member.

Thickness

The estimated thickness is 120 m.

Distribution

The member is restricted to the area around Buxton and the valley of the River Wye.

Regional correlation

Where the Lower Miller's Dale Lava Member, the equivalent of the Chee Tor Rock Member is represented by undivided Bee Low Limestone Formation.

Genetic interpretation

The member was deposited in a shallow shelf sea, with repeated sea-level fluctuations resulting in periodic emergence and development of palaeosols and palaeokarstic surfaces.

Biostratigraphical characterisation

The upper part of the member include the Upper and Lower *Davidsonina septosa* bands, important faunal beds used

in regional correlation of the succession (Stevenson and Gaunt, 1971). Fossil assemblages are detailed by Stevenson and Gaunt (1971).

Age
Asbian

4.5.7.2 LOWER MILLER'S DALE LAVA MEMBER (LMB)

Name

The name Lower Miller's Dale Lava was introduced by Stevenson and Gaunt (1971) and is here formally defined as a member.

Type section

Ashwood Dale [SK 0675 7293–0666 7300] section in a railway cutting shows full thickness of 7.62 m of vesicular lava (Aitkenhead et al., 1985).

Lithology

Olivine basalt, usually very amygdaloidal with calcite-, zeolite- and chlorite-filled vesicles. The central parts of flows may be non-vesicular. The lava is typically very weathered. Intervening beds of clay, tuff and limestone are locally present.

Lower and upper boundaries

The base of the Lower Miller's Dale Lava Member, evident at Tideswell Dale [SK 154 740], is rubbly, resting directly upon about 1 m of red clay with columnar or prismatic structures up to 6 cm in diameter, possibly representing weathered basalt, believed to rest upon thermally altered limestone of the Bee Low Limestone Formation (Waters, 2003).

The top of the vesicular lava of the Lower Miller's Dale Lava Member is overlain by limestone of the Miller's Dale Limestone Member.

Thickness

About 30 m thick at Wormhill [SK 123 741], decreasing in thickness rapidly to the north.

Distribution

Northern part of the Peak District inlier, south-east of a line between Dove Holes [SK 08 77] to Ox Low [SK 12 80], and north-west of a line from Grin Low [SK 05 71] to Tideswell Dale [SK 15 73]. Also, there is an isolated area to the north at Cave Dale [SK 14 82]. The southern outcrops tend to be lenticular in plan.

Regional correlation

The Ravensdale Tuff Member, which is present east of the outcrop of the Lower Miller's Dale Lava Member [SK 17 73], occurs slightly below the latter.

Genetic interpretation

Lenticular lava-bodies in the southern part of the outcrop suggest emplacement in a series of discrete tongue-like flows (Aitkenhead et al., 1985). To the north, the outcrop is more continuous, suggesting more sheet-like flows.

Age
Asbian

4.5.7.3 MILLER'S DALE LIMESTONE MEMBER (MDA)

Name

Referred to as the Miller's Dale Beds (Cope, 1933; Stevenson and Gaunt, 1971) and subsequently redefined as the Miller's Dale Limestones (Aitkenhead et al., 1985), this unit is here formally defined as a member.

Type section

Ashwood Dale [SK 0675 7293–0666 7300] section in a railway cutting shows the lower part of the member, including the *Davidsonina septosa* Bed (Aitkenhead et al., 1985).

Reference section

Higher Buxton [SK 0621 7321–0631 7348] section in a railway cutting includes the upper 8.2 m of the member and the upper boundary with the Monsal Dale Limestone Formation (Aitkenhead et al., 1985).

Lithology

A massive, pale grey to grey, fine-grained calcarenite with common fossils, particularly corals, brachiopods and crinoid debris. Rare cherts occur locally in the middle part of the member. Locally the limestones are pure white and have a more bedded character. Ooidal beds are locally present. The Dove Holes Tuff, 2.2 m thick, occurs about 15 m above the base of the member and comprises pyritous greenish grey clay with limestone lapilli, resting on a palaeokarstic surface.

Lower and upper boundaries

At the base, limestone of the Miller's Dale Limestone Member overlies vesicular lava of the Lower Miller's Dale Lava Member. Locally, the basal part of the limestone can be tuffaceous.

At the top, the pale grey, massive limestone of the Miller's Dale Limestone Member is separated from the limestones of the Monsal Dale Limestone Formation by a palaeokarstic surface.

Thickness

Up to 43 m near Dove Holes [SK 08 77].

Distribution

Only recognised where the underlying Lower Miller's Dale Lava Member is present, restricting the Miller's Dale Limestone Member to the Wye Valley area near Buxton, north of the Peak District inlier.

Regional correlation

Outside of the limited outcrop of the Lower Miller's Dale Lava Member, the equivalent limestones are identified as Bee Low Limestone Formation (undivided).

Genetic interpretation

The member was deposited in a shallow shelf sea, with repeated sea-level fluctuations resulting in periodic emergence and development of palaeokarstic surfaces.

Biostratigraphical characterisation

The lower part of the member includes a *Davidsonina septosa* band, an important faunal bed used in regional correlation of the succession (Stevenson and Gaunt, 1971). Fossil assemblages are detailed by Stevenson and Gaunt (1971).

Age
Asbian

4.5.7.4 RAVENSDALE TUFF MEMBER (RDT)

Name

Initially described by Arnold-Bemrose (1894) and named the Ravensdale Tuff (Aitkenhead et al., 1985), the unit is defined here as a member.

Type section

Stream section near Ravensdale Cottages [SK 1724 7393]

shows 2.44 m of banded tuff with lapilli (Aitkenhead et al., 1985).

Lithology

Banded tuff with lapilli, with some of the lapilli including vesicles infilled with analcite.

Lower and upper boundaries

The base is not seen, but defined as a transition from tuffs of the Ravensdale Tuff Member to underlying limestones of the Bee Low Limestone Member.

The top is not seen, but defined as transition from tuffs of the Ravensdale Tuff Member to overlying limestones of the Bee Low Limestone Member.

Thickness

Up to 20 m

Distribution

Restricted to the lower part of Cressbrook Dale [SK 17 74], northern part of the Peak District inlier.

Regional correlation

The member may have developed from the same volcanic event that produced lavas and tuffs in the Litton Dale Borehole [SK 1599 7498] (Stevenson and Gaunt, 1971). It occurs in the lower part of the Bee Low Limestone Formation, at a level equivalent to the Chee Tor Rock Member.

Genetic interpretation

Volcanic ash deposits from a localised eruptive event, probably derived from the Tunstead Centre [SK 11 75] (Aitkenhead et al., 1985).

Age

Asbian

4.5.8 Monsal Dale Limestone Formation (MO)

Name

The original name of Monsal Dale Beds was given by Hudson and Cotton (1945a) to the lower beds of the limestones with chert of the Wye Valley. This unit was extended to include all strata of D2 Zone of the Shelf Province of the Peak District inlier (Stevenson and Gaunt, 1971), which they referred to as the Monsal Dale Group, with component Monsal Dale Beds at various levels. The unit was redefined as the Monsal Dale Limestones (Aitkenhead and Chisholm, 1982) and extended to the south and east to replace the Matlock Group (Smith et al., 1967). It is here formally defined as the Monsal Dale Limestone Formation.

Type sections

Cressbrook Dale [SK 1716 7437–SK 1788 7550]: composite section of full 143 m thickness of formation (Stevenson and Gaunt, 1971).

Furness Quarry [SK 2085 7596–SK 2100 7608]: shows the uppermost 56.92 m of the formation and the boundary with the overlying Eyam Limestone Formation (Stevenson and Gaunt, 1971).

Reference sections

Station Quarry, Miller's Dale [SK 1327 7340]: exposes the basal 12.4 m, and the boundary with the underlying Bee Low Limestones Formation (Aitkenhead et al., 1985).

Railway cutting between Cressbrook and Litton tunnels [SK 1661 7269–SK 1676 7261]. The base of the formation rests upon an erosion surface with palaeokarstic solu-

tion hollows on top of the Bee Low Limestone Formation (Cope, 1937; Walkden, 1977; Waters, 2003).

Formal subdivisions

The Monsal Dale Limestone Formation includes a complex stratigraphy of lavas and tuffs. The Upper Miller's Dale Lava present in the Castleton–Buxton–Tideswell region, the Winstermoor Lava, Lower and Upper Matlock Lava and Shothouse Spring Tuff members in the Matlock–Wirksworth region, the Shacklow Wood Lava and Lees Bottom Lava members of the Alport–Bakewell–Taddington Dale region, the Cressbrook Dale Lava and Litton Tuff members of the Eyam–Longstone–Litton region.

Lithology

Pale to medium grey, thickly-bedded and bioturbated well-sorted biosparites and pelsparites, to poorly sorted biomicrites. The limestone contains sporadic chert nodules, and emergent surfaces are marked by pedogenic tubes and crusts of brown laminated micrite. The lower part at Cressbrook Dale–Millers Dale and all around Litton, comprise dark grey thinly-bedded, cherty limestone containing dark argillaceous partings, the limestone being typically a poorly sorted bioclastic calcisiltite with a micritic matrix, and includes several volcanic members of basaltic lava and tuff.

Lower and upper boundaries

The base of the formation is taken at a sharp unconformable boundary with the lowest bed of dark limestone, commonly marked by abundant *Girvanella* or *Saccamminopsis*, above the pale grey limestones of the Bee Low Limestone Formation. Elsewhere, the boundary is marked by the base of the Upper Millers Dale Lava, Winstermoor Lava or Lower Matlock Lava members.

The top of the formation is taken at the base of the dark grey to grey-brown limestones of the overlying Eyam Limestone Formation, which locally overlies an erosive surface and clay wayboard, above the pale to medium grey limestone, of the Monsal Dale Limestone Formation.

Thickness

Appears 143 m thick in the Cressbrook Dale section (200 m at Ashford on the Water [SK 19 69], and 359 m at Longstone Edge [SK 20 73]).

Distribution

Northern and eastern parts of the Peak District.

Regional correlation

The Monsal Dale Limestone Formation passes to the south and west of the shelf margin into the Hopedale Limestone Formation (Figure 6).

Genetic interpretation

Marked facies variations within the formation indicate localised changes in environment (Aitkenhead et al., 1985). The pale and medium grey bioturbated limestones were deposited in a very shallow marine environment and shows evidence of intermittent subaerial emergence. The dark facies contains relatively few emergent surfaces and graded bedding, suggesting deposition in comparatively deeper water below the wave base.

Biostratigraphical characterisation

Girvanella or *Saccamminopsis* are of particular stratigraphical value, tending to occur in thin beds near the base of the formation. Fossil assemblages are detailed by Stevenson and Gaunt (1971) and Aitkenhead et al. (1985).

Age
Brigantian

4.5.8.1 UPPER MILLER'S DALE LAVA MEMBER (UMB)

Name

The Upper Miller's Dale Lava of Stevenson and Gaunt (1971) and Aitkenhead et al. (1985) is here formally defined as a member.

Type section

Litton Mill disused railway cutting [SK 157 730]: the member is 5.18 m thick (Cope, 1937; Walkden, 1977; Waters, 2003).

Reference section

Two small quarries [SK 134 731 and 134 730] west of the disused Lime Works Quarry: exposure of 10 m of non-vesicular lava, part of the 35 m succession formerly exposed at the Lime Works Quarry (Walters and Ineson, 1981).

Lithology

Amygdaloidal olivine basalt with calcite and chlorite infilling vesicles. At the type locality the lava is brown-weathered with a flow banding and degraded lava blocks up to 0.6 m diameter. In Miller's Dale, where the member is thickest, the member was subdivided into a 5.2 m thick tuff with a thin amygdaloidal basalt, overlain by a 30 m thick lava, at least in part comprising non-vesicular, holocrystal-line basalt with spheroidal weathering (Walters and Ineson, 1981).

Lower and upper boundaries

At the type section, basalt of the Upper Miller's Dale Lava Member rests upon dark grey, thinly bedded, fine-grained limestone of the Monsal Dale Limestone Formation. Outside of Miller's Dale the member rests disconformably upon pale grey limestones of the Bee Low Limestone Formation.

At the type locality, an irregular upper surface of the lava is overlain by grey, fine-grained, irregularly bedded limestones of the Monsal Dale Limestone Formation, including rounded and decomposed fragments of lava immediately above the boundary.

Thickness

Up to about 35 m thick in Miller's Dale [SK 140 730], decreasing markedly to the east toward the type locality.

Distribution

Nearly continuous outcrop from Hurdlow Town [SK 112 669] and Miller's Dale [SK 134 731] and an isolated outcrop at Harpur Hill [SK 066 713] and Cressbrook Dale [SK 173 724].

Regional correlation

The member passes toward the east and amalgamates with other volcanic members to form a single Fallgate Volcanic Formation in the Ashover area [SK 35 62].

Genetic interpretation

At the type section the lava appears to have flowed across an eroded surface into a lagoonal embayment, with the flow front shattered and brecciated as a consequence of the contact with water (Waters, 2003).

Age
Brigantian

4.5.8.2 WINSTERMOOR LAVA MEMBER (WMB)

Name

The member was first recognised and named the Winster Moor Lava by Shirley (1950) and subsequently referred to as the Winstermoor Lava (Aitkenhead et al., 1985). The unit is here defined as the Winstermoor Lava Member.

Type area

Sacheveral Farm [SK 228 593]: There are no exposures, but the member is recognised by lava fragments in the soil (Aitkenhead et al., 1985).

Aldwark Borehole (SK25NW22) [SK 2125 5815]: 4.4 m thick clay with altered basalt fragments (Aitkenhead et al., 1985).

Lithology

Dark grey basaltic lava, locally altered to green and brown clay with basalt fragments.

Lower and upper boundaries

Basalt of the Winstermoor Lava Member rests upon pale grey, massive limestones of the Bee Low Limestone Formation.

The basalt of the Winstermoor Lava Member is overlain by grey to dark grey, bituminous limestones of the Monsal Dale Limestone Formation.

Thickness

Up to 4.4 m thick proved in the Aldwark Borehole.

Distribution

Restricted to the area between Gratton Dale, Winster and Bonsall Moors and the workings of Millclose Mine. Boreholes show the lavas to be lenticular in distribution and locally absent.

Regional correlation

Probably equates with the Upper 129 Toadstone of the Millclose Mine (Walters and Ineson, 1981).

Age

Brigantian

4.5.8.3 LOWER MATLOCK LAVA MEMBER (LRB)

Name

Referred to as the Matlock Lower Lava (Smith et al., 1967) and the Lower Matlock Lava (Aitkenhead et al., 1985), it is here formally defined as the Lower Matlock Lava Member.

Type section

Via Gellia Valley, small quarry [SK 2880 5728]: 6.1 m of dark green basalt with some amygdaloids in the upper 1.8 m (Smith et al., 1967).

Reference section

Hoptonwoodstone Quarry [SK 277 557]: full thickness of 19.8 m of basalt and clay (thoroughly weathered basalt) (Smith et al., 1967).

Lithology

Dark green, grey or brown basalt lava with interbedded tuff and locally in the Masson Hill [SK 286 587] to Bonsall area [SK 2758] interdigitations of limestone and tuffaceous limestone (Walters and Ineson, 1981; Chisholm et al., 1983). At Masson Hill three distinct lava flows are recognised, characterised by vesicular upper and lower surfaces, separated by tuff or decomposed clay (Walters and

Ineson, 1981), with the lower two flows containing abundant marmorised limestone and angular basaltic fragments. Typically amygdaloidal toward the top of lava flows and may include hematite veinlets. Locally, the lavas include vertical wedges of clay representing partial weathering of the basalt (Smith et al., 1967). In places the weathering of the basalt to a grey or brown clay is complete, although the presence of amygdaloids indicates the origin as a lava.

Lower and upper boundaries

Generally, the basalt lava of the Lower Matlock Lava Member rests upon thickly bedded limestones of the Monsal Dale Limestone Formation. At Hoptonwoodstone Quarry [SK 277 557] the basal approximately 3 m comprises amygdaloidal basalt, thoroughly altered to grey and yellow clay, with lenses of pink limestone (Smith et al., 1967). The base of the lava here has been interpreted as a palaeokarstic surface with pits up to 10 m deep filled by weathered blocks of lava, tuff and limestone in a clay matrix (Walters and Ineson, 1981). South of Bonsall the formation thins markedly and around Golconda Mine [SK 249 551] a thin lava rests upon pale grey calcarenites of the Bee Low Limestone Formation.

Lavas and tuffs of the Lower Matlock Lava Member are overlain by thickly bedded limestones of the Monsal Dale Limestone Formation. At Hoptonwoodstone Quarry [SK 277 557] the uppermost 0.3 m thick bed of the member comprises brecciated limestone in a matrix of clay with vestiges of amygdaloids (weathered basalt).

Thickness

Maximum thickness of about 99 m at Masson Hill [SK 286 587] (Walters and Ineson, 1981), where lavas and tuffs interdigitate with limestone. The member is about 50 m thick in boreholes north of Winster e.g. Whiteholmes Borehole (SK26SW54) [SK 2349 6126].

Distribution

The member has a poorly exposed outcrop from west of Gratton Dale [SK 198 604] to Masson Hill [SK 286 587] and the Bonsall area [SK 27 58]. Present as inliers in the Derwent Valley at Matlock [SK 294 589] and Matlock Bath [SK 293 579]. Also outcrops around Aldwark [SK 23 57] in the Buxton District, where exposures are rare. From Aldwark the member thins toward the west and south and cannot be traced beyond Minninglow Hill [SK 209 573], Curzon Lodge [SK 234 560] and Golconda Mine [SK 249 551].

Regional correlation

North-east of Aldwark [SK 23 57] the member passes laterally into the Shothouse Spring Tuff Member.

Age

Brigantian

4.5.8.4 UPPER MATLOCK LAVA MEMBER (URB)

Name

Referred to as the Matlock Upper Lava (Smith et al., 1967) and the Upper Matlock Lava (Aitkenhead et al., 1985), it is here formally defined as the Upper Matlock Lava Member.

Type section

Railway cutting south of High Tor [SK 2967 5875]: 14 m of basalt, amygdaloidal in upper 4.9 m, possibly overlain and underlain by clay (weathered basalt) (Smith et al., 1967).

Lithology

Mainly vesicular and non-vesicular basalts. At Groaning

Tor adit, Via Gellia [SK 283 572] the member is seen as a 1 m thick clay wayboard (Walters and Ineson, 1981).

Lower and upper boundaries

The basalt lava (or clay derived from weathered lava) of the Upper Matlock Lava Member rests upon thickly bedded limestones of the Monsal Dale Limestone Formation.

The basalt lava (or clay derived from weathered lava) of the Upper Matlock Lava Member is overlain by thickly bedded limestones of the Monsal Dale Limestone Formation.

Thickness

The thickest development is recorded at Masson Hill [SK 286 587], variously estimated at 35 m (Worley, 1978) or 21.5 m thickness (Dunham, 1952). The member is also recorded as 36 m thick in boreholes at Cawdor Quarry, Matlock [SK 285 605] (Smith et al., 1967).

Distribution

The member has a more restricted outcrop in comparison with the Lower Matlock Lava Formation, extending from Tearsall Mine [SK 262 600] in the west to Masson Hill [SK 286 587] and the Derwent Valley [SK 296 587] in the east. The southern most extent is Groaning Tor adit, Via Gellia [SK 283 572].

Regional correlation

The extent of the member toward the east is unknown, but is possible that it passes toward the east and amalgamates with other volcanic members to form a single Fallgate Volcanic Formation in the Ashover area [SK 35 62].

Genetic interpretation

The source of the lava flows is believed to be north of Matlock (Walters and Ineson, 1981).

Age

Brigantian

4.5.8.5 SHOTHOUSE SPRING TUFF MEMBER (ST)

Name

The name Shothouse Spring Tuff (Smith et al., 1967; Aitkenhead et al., 1985) is here formally defined as a member.

Type area

Shothouse Spring [SK 242 589]: series of poor exposures 1 km south-west and south-east of Shothouse Spring.

Lithology

Green tuff with beds of coarse lapilli in a calcareous cement. To the east of Grangemill [SK 244 578] the tuffs interdigitate with limestone in the Bottom Leys Farm Borehole (SK25NE/41) [SK 2587 5795]. In the latter, the tuffs include medium- to coarse-grained, angular to subrounded fragments of mudstone and limestone in a fine-grained grey to dark grey or green matrix.

Lower and upper boundaries

The tuffs of the Shothouse Spring Tuff Member rest upon thickly bedded limestones of the Monsal Dale Limestone Formation.

The tuffs of the Shothouse Spring Tuff Member are overlain by thickly bedded limestones of the Monsal Dale Limestone Formation.

Thickness

Unknown in the type area. Seen as three leaves, in ascend-

ing order 6.90, 0.32 and 4.93 m thick, in a succession of limestone and mudstone 36 m thick.

Distribution

Outcrop is localised to the vicinity of Shothouse Spring [SK 242 589]. Proved in a borehole at Bottom Leys Farm, Bonsall (SK25NE/41) [SK 2587 5795].

Regional correlation

South-west of Aldwark [SK 23 57] the member passes laterally into the Lower Matlock Lava Member (Smith et al., 1967).

Genetic interpretation

Located close to the tuff-filled Grangemill volcanic neck, regarded to be the source of the member (Arnold-Bemrose, 1907; Walters and Ineson, 1981).

Age

Brigantian

4.5.8.6 LEES BOTTOM LAVA MEMBER (LSBB)

Name

Referred to as the Lees Bottom Lava (Walters and Ineson, 1981; Aitkenhead et al., 1985), the unit is here formally defined as a member.

Type sections

Lees Bottom, near A6, Taddington Dale [SK 1699 7050]: 8.5 m thickness of vesicular basalt (Walters and Ineson, 1981; Aitkenhead et al., 1985).

Lithology

Vesicular and non-vesicular basalt.

Lower and upper boundaries

Basalt lava of the Lees Bottom Lava Member is underlain by pale and medium grey limestone, locally tuffaceous, of the Monsal Dale Limestone Formation.

Basalt lava of the Lees Bottom Lava Member is overlain by pale and medium grey limestone of the Monsal Dale Limestone Formation.

Thickness

A thickness of 8.5 m proved at the type locality.

Distribution

Restricted to the area west of Ashford [SK 19 69], Peak District inlier.

Genetic interpretation

The lava is believed to have emanated from the Alport Centre [SK 25 65], toward which it thickens (Aitkenhead et al., 1985).

Biostratigraphical characterisation

No faunal evidence for the member. At the type locality the lava is overlain by limestones with Brigantian coral-brachiopod faunas (Aitkenhead et al., 1985).

Age

Brigantian

4.5.8.7 SHACKLOW WOOD LAVA MEMBER (SWB)

Name

Referred to as the Shacklow Wood Lava (Walters and Ineson, 1981; Aitkenhead et al., 1985), the unit is here formally defined as a member.

Type section

Great Shacklow Wood, cliff by the A6, Taddington Dale [SK 1794 6975]: 17 m exposure of compact and doleritic lavas (Aitkenhead et al., 1985).

Lithology

Basalt, dark greenish grey, locally purplish grey, variably amygdaloidal or compact, locally doleritic, in part autobrecciated.

Lower and upper boundaries

Basalt lava of the Shacklow Wood Lava Member is underlain by pale and medium grey limestone of the Monsal Dale Limestone Formation.

Basalt lava of the Shacklow Wood Lava Member is overlain by mainly dark and medium grey limestone, thinly bedded and cherty, of the Monsal Dale Limestone Formation.

Thickness

Up to 20 m thick at outcrop and at least 50 m thick in the Mogshaw Borehole (SK16NE19) [SK 1889 6778] (Aitkenhead et al., 1985).

Distribution

Restricted to the area west of Ashford [SK 19 69], Peak District inlier.

Regional correlation

A thin but persistent lava proved in boreholes at Longstone Edge [SK 22 73] is correlated with this member (Aitkenhead et al., 1985).

Genetic interpretation

The lava is believed to have emanated from the Alport Centre [SK 25 65], toward which they thicken (Aitkenhead et al., 1985).

Age

Brigantian

4.5.8.8 CRESSBROOK DALE LAVA MEMBER (CBDL)

Name

The name Cressbrook Dale Lavas was used by Stevenson and Gaunt (1971) and subsequent authors (Walters and Ineson, 1981; Aitkenhead et al., 1985), and is here defined as a member.

Type section

Eyam Borehole (SK27NW15) [SK 2096 7603]: includes a 76.59 m thickness of basalt and brecciated basalt (Figure 7) (Dunham, 1973).

Lithology

The member typically comprises hyaloclastite, basalt and tuff, the latter locally well bedded with some limestone grains. At Cressbrook Dale the member is dominated by amygdaloidal basalt. At the type locality the lower part comprises brecciated lavas, with oxidised angular fragments of vesicular or non-vesicular basalt and a matrix of silica and chlorite, interdigitated with non-brecciated basalt lavas. At this locality, the top of the member is a 0.75 m thick pale green, pyritic tuff.

Lower and upper boundaries

At the type locality, the basalt at the base of the member is underlain by dark grey cherty limestones of the Monsal Dale Limestone Formation.

At the type locality, the pale green tuff at the top of the member is overlain by dark grey biomicrosparite limestones of the Monsal Dale Limestone Formation.

Thickness

Maximum thickness of 80.88 m proved in the Longstone Edge Borehole (SK27SW/5) [SK 2088 7335]. The member is only 10 m thick at Cressbrook Dale.

Distribution

The member has a limited, poorly exposed outcrop at Cressbrook Dale [SK 17 74], with a thicker and extensive development in the subsurface to the north and east of this locality.

Regional correlation

The extent of the member toward the east is unknown, but is possible that it passes toward the east and amalgamates with other volcanic members to form a single Fallgate Volcanic Formation in the Ashover area [SK 35 62].

The member occurs between 19 and 47 m below the Litton Tuff Member in the Longstone Edge boreholes and above the Shacklow Wood Lava Member. At the type area the member lies about 5 m below the Litton Tuff Member.

Genetic interpretation

In addition to basaltic lavas and tuffs, the member shows the presence of hyaloclastites, indicative of rapid quenching and brecciation of lavas flowing into water.

Age

Brigantian

4.5.8.9 LITTON TUFF MEMBER (LT)

Name

The name Litton Tuff was used by Stevenson and Gaunt (1971) and subsequent authors (Walters and Ineson, 1981; Aitkenhead et al., 1985), and is here defined as a member.

Type area

Slopes north and east of Litton, includes roadside exposures [SK 1682 7518] of 3.6 m of brown-weathered tuff from the upper part of the member (Stevenson and Gaunt, 1971).

Lithology

At the type locality the member is dominated by a volcanic breccia (agglomerate) with clasts, including some limestone, up to 13 cm diameter (Stevenson and Gaunt, 1971). In the Longstone Edge boreholes [e.g. SK 2144 7367] the member comprises one to three leaves of grey and green banded tuff with some limestone grains. The thickest development in these boreholes is associated with a well-sorted tuff, with coarser bands of fine lapilli (Aitkenhead et al., 1985). In the Eyam Borehole (Figure 7) the member is a 1.1 m thick, fine-grained, grey-green, pyritic tuff (Dunham, 1973).

Lower and upper boundaries

The tuff at the base of the member is underlain by dark to medium grey limestones of the Monsal Dale Limestone Formation.

The tuff at the top of the member is overlain by dark grey cherty limestones of the Monsal Dale Limestone Formation.

Thickness

Maximum thickness of in excess of 30 m to the north-east of Litton.

Distribution

The member can be traced from Tideswell Moor [SK 152 766], Litton [SK 168 751], Cressbrook Dale [SK 172 749] and Wardlow Hay Cop [SK 180 738].

Regional correlation

The extent of the member toward the east is unknown, but is possible that it passes toward the east and amalgamates with other volcanic members to form a single Fallgate Volcanic Formation in the Ashover area [SK 35 62].

The member occurs between 19 and 47 m above the Cressbrook Dale Lava Member in the Longstone Edge boreholes.

Genetic interpretation

The member represents a low-angle tuff-mound with peripheral slopes of about 1° (Walters and Ineson, 1981). The tuff is coarsest and thickest in the vicinity of Litton.

Age

Brigantian

4.5.9 Fallgate Volcanic Formation (FV)

Name

The name was introduced by Aitkenhead and Chisholm (1982) for a thick sequence of volcanic rocks initially described by Ramsbottom et al. (1962) in the Ashover area (Figure 6). It is applied only where the proportion of volcanic rocks in the sequence exceeds that of limestone.

Type sections

Fallgate Borehole (SK36SE/25) [SK 3542 6219]: commences close to the top of the formation and proves a thickness of 293 m (Smith et al., 1967). The base of the formation is not reached.

Reference section

Haddon Fields Borehole (SK26NW25) [SK 2372 6577]: a thickness of 228 m of tuffs, basalts and hyaloclastites are proved (Aitkenhead et al., 1985). The top, but not the base of the formation is present.

Formal subdivisions

The Lathkill Lodge Lava and Conksbury Bridge Lava Members are recognised for the upper part of the formation in the Lathkill Dale area [SK16 66–SK 24 66].

Lithology

Basaltic lavas, commonly amygdaloidal and locally brecciated, hyaloclastites and tuffs with thin beds of limestone.

Lower and upper boundaries

The base of the formation is not proven.

The top of the formation is overlain sharply and conformably by the lowest bed of dark limestone, commonly containing Girvanella or Saccaminopsis of the Monsal Dale Limestone Formation.

Thickness

Measured as 293 m in the Fallgate Borehole, base not reached.

Distribution

The eastern margin of the Derbyshire Dome, in the Peak District, around Ashover [SK 36]. This locality occurs

at the eastern end of an elongate magnetic anomaly that extends ESE from Bakewell [SK 26] to Ashover, which may represent a large volcanic centre (Aitkenhead et al., 1985).

Regional correlation

It is possible that the formation passes toward the west with increasing thicknesses of limestone partings and may be equivalent to the numerous lava and tuff members recognised in the Bee Low Limestone and Monsal Dale Limestone formations.

Genetic interpretation

The formation includes both subaqueous and subaerial lava flows and volcanoclastic deposits.

Biostratigraphical characterisation

The Brigantian coral *Diphyphyllum lateseptatum* is present in limestones within the formation, immediately beneath the Lathkill Lodge Lava Member member in the Haddon Fields Borehole (Aitkenhead et al., 1985). The volcanic rocks beneath this limestone are assumed to be Asbian.

Age

Asbian to Brigantian

4.5.9.1 LATHKILL LODGE LAVA MEMBER (LOB)

Name

Referred to as the Lathkill Lodge Lavas (Walters and Ineson, 1981; Aitkenhead et al., 1985), this unit is here formally defined as a member of the Fallgate Volcanic Formation.

Type sections

Lathkill Dale [SK 2041 6617]: Section of 3.8 m of weathered vesicular basalt, representing much of the thickness in this area (Aitkenhead et al., 1985).

Haddon Fields Borehole (SK26NW25) [SK 2372 6577]: the entire thickness of 85.5 m of tuffs, basalts and hyaloclastites is proved in this confidential borehole (Aitkenhead et al., 1985).

Lithology

At Lathkill Dale basalt lava includes marmorised limestone fragments. In the Haddon Fields Borehole the member mainly comprises, in upward sequence: 20 m of bedded tuff, 8 m of partly brecciated basalt, 40 m of hyaloclastite and 17.5 m of amygdaloidal basalt.

Lower and upper boundaries

The base of the member is not seen at outcrop. In the Haddon Fields Borehole, tuffs of the Lathkill Lodge Lava Member rest upon grey and dark grey bioclastic limestone, included within the Fallgate Volcanic Formation.

In the Haddon Fields Borehole, basalt of the Lathkill Lodge Lava Member is overlain by pale grey and cherty limestones with some calcilutites, included within the Fallgate Volcanic Formation.

Thickness

In the Haddon Fields Borehole the member is 85.5 m thick. At Lathkill Dale there is about 5 m of lava visible at outcrop.

Distribution

Present at outcrop in the lower part of Lathkill Dale, north of Alport. Also proved in boreholes at Alport [SK 23 65]. Occurs about 27 m (Shirley, 1950) or 19 m (Aitkenhead et al., 1985) below the Conksbury Bridge Lava Member.

Regional correlation

Equates with the Lower Alport Lava of the Alport area (Walters and Ineson, 1981), now attributed to the Fallgate Volcanic Formation (Aitkenhead et al., 1985).

Genetic interpretation

The sequence in the Haddon Fields Borehole is interpreted as the progressive infilling of a body of water by volcanic material, eventually leading to subaerial lava flows (Aitkenhead et al., 1985).

Biostratigraphical characterisation

No faunal evidence for the member. The Brigantian coral *Diphyphyllum lateseptatum* is present in limestones immediately beneath the member in the Haddon Fields Borehole (Aitkenhead et al., 1985).

Age

Brigantian

4.5.9.2 CONKSURRY BRIDGE LAVA MEMBER (CBB)

Name

Referred to as the Conksbury Bridge Lava (Walters and Ineson, 1981; Aitkenhead et al., 1985), this unit is here formally defined as a member of the Fallgate Volcanic Formation.

Type sections

Conksbury Bridge [SK 2098 6600]: 3.8 m of vesicular lava (Aitkenhead et al., 1985).

Haddon Fields Borehole (SK26NW25) [SK 2372 6577]: the entire thickness of 51.71 m made up of three flows (Aitkenhead et al., 1985).

Lithology

In the Haddon Fields Borehole the member comprises three flows of compact and amygdaloidal basalt. At Conksbury Bridge the member includes two flows: the upper flow includes a vesicular basalt at the top and base and a central non-vesicular dolerite; the lower flow has a highly vesicular and slightly hematized upper margin, which grades down into a non-vesicular dolerite (Walters and Ineson, 1981).

Lower and upper boundaries

In the Haddon Fields Borehole, basalt of the Conksbury Bridge Lava Member is underlain by pale grey and cherty limestones with some calcilutites, included within the Fallgate Volcanic Formation.

At Conksbury Bridge, limestone of the Monsal Dale Limestone Formation rests upon a vesicular upper margin of a 5 m thick lava flow of the Conksbury Bridge Lava Member (Walters and Ineson, 1981).

Thickness

Thickest development is 51.71 m, proved in the Haddon Fields Borehole. At Conksbury Bridge the member is about 30 m thick.

Distribution

Present at outcrop in the lower part of Lathkill Dale, north of Alport. Also proved in boreholes at Alport [SK 23 65]. Occurs about 27 m (Shirley, 1950) or 19 m (Aitkenhead et al., 1985) above the Lathkill Dale Lava Member. The member is not seen west of Over Haddon [SK 203 663].

Regional correlation

Equates with the Upper Alport Lava of the Alport area (Walters and Ineson, 1981), now attributed to the Fallgate

Volcanic Formation (Aitkenhead et al., 1985). May equate with a thick clay wayboard at Mandale Mine [SK 196 662] (Walters and Ineson, 1981).

Age
Brigantian

4.5.10 Eyam Limestone Formation (EYL)

Name

The name Eyam Limestones was introduced for limestones in the Eyam area, which lie upon D₁-D₂ limestones with a marked lithostratigraphical break (Shirley and Horsfield, 1945). The unit, referred to as the Eyam Group (Stevenson and Gaunt, 1971) was redefined by Aitkenhead and Chisholm (1982) to include parts of the obsolete Ashford Beds around Bakewell and the Cawdor Group around Lathkill Dale, Matlock and Wirksworth.

Reference sections

Wardlow Mires No.2 Borehole (SK17NE10) [SK 1825 7586]: proves entire thickness at 9.18 m, upper boundary with Widmerpool Formation and lower boundary with Monsal Dale Limestone Formation (Stevenson and Gaunt, 1971).

Furness Quarry, Middleton Dale [SK 2085 7596–SK 2100 7608]: displays basal 4.65 m of formation, with a clay bed up to 0.38 m at the base resting above the Monsal Dale Limestone Formation (Stevenson and Gaunt, 1971).

Eyam Dale [SK 2199 7621–SK 2200 7634]: shows 19.51 m of strata, starting about 3.05 m above the base of the formation (Stevenson and Gaunt, 1971).

Stoney Middleton [SK 2279 7560–SK 2300 7550]: shows reef facies passing down into bedded unit 10.9 m thick, resting upon the Monsal Dale Limestone Formation (Stevenson and Gaunt, 1971).

Lithology

A thinly bedded, dark grey, cherty, bioclastic limestone with fossiliferous beds of brachiopods, corals and crinoids and a few dark mudstone intercalations, which is overlain by massive pale reef limestone in the south. The reef facies occur at the base in the central and southern parts, and in the upper part in the north, and is typically a core of massive biomicrite with a distinctive brachiopod fauna, passing laterally and downward into well-bedded, coarsely crinoidal biomicrites and biosparites.

Lower and upper boundaries

At the base, dark grey to grey brown basal limestone, resting upon clay or mudstone partings of the Eyam Limestone Formation, lie on a potholed surface above pale to medium grey limestone of the Monsal Dale Limestone Formation. The disconformity at the base of the formation may also be marked by a coal and seatearth. Around Ashford-in-the-Water [SK 19 69], where both formations are dark grey, the boundary is taken at the top of the laminated beds of the Monsal Dale Limestone Formation.

A gradational top is marked by a transition from dark grey, bioclastic limestone or pale grey massive reef limestone of the Eyam Limestone Formation, to dark grey, calcareous mudstone of the Widmerpool Formation.

Thickness

At Eyam Dale, 54 m thick including 30 m of reef facies; at Wardlow Mires No.2 borehole, it is 9.18 m, and contains no reef facies.

Distribution

Restricted to the northern and central part of the Peak District (shelf province) of the East Midlands [SK].

Regional correlation

The formation passes laterally toward the south and west into the relatively deeper water off-shelf Widmerpool Formation (Figure 6).

Genetic interpretation

Shallow marine deposits comprising a more widespread bedded inter-reef facies and a reef facies, which forms small buildups. A caliche crust on two knoll reefs suggests emergence.

Biostratigraphical characterisation

The coral-brachiopod assemblages are comparable with the underlying Monsal Dale Limestone Formation, though the rare presence of the ammonoid *Sudeticeras* sp. indicates a Upper *Posidonia* (P2) age (Stevenson and Gaunt, 1971).

Age

Late Brigantian

HATHERN SHELF

The Peak Limestone Group of the Hathern Shelf occurs largely in the sub-surface, with isolated exposures within inliers present in Leicestershire and the south-western part of the Peak District inlier in Staffordshire. During the Tournaisian to early Viséan ramp phase in the evolution of the platform carbonates, the Hathern Shelf comprises the same comparatively deeper water limestones with mud-mounds developed in the Dovedale–Manifold Valley part of the East Midlands Platform to the north. By Asbian and Brigantian times a shelf carbonate succession accumulated over the Hathern Shelf, with a deeper water off-shelf facies separating the Hathern and East Midlands Platform.

The **Milldale Limestone Formation**, present within the both the Leicestershire and Staffordshire inliers includes a single laterally impersistent **Holly Bush Member**. A prominent unconformity is present at the top of the Milldale Limestone Formation, with strata of Arundian and Holkerian age largely absent (Figure 6). The unconformity is overlain in Staffordshire by the **Kevin Limestone Formation** and in Leicestershire by the **Cloud Hill Dolostone Formation**. The lower part of the latter formation includes the laterally impersistent **Cloud Wood and Scot's Brook members**. The uppermost unit of the Peak Limestone Group on the Hathern Shelf is the **Ticknall Limestone Formation**.

4.5.11 Milldale Limestone Formation (MI)

See full formal definition in Section 4.5.2.

The Milldale Limestone Formation is present within the both the Leicestershire and Staffordshire inliers and represents a lateral continuation of the same formation present on the East Midlands Platform. Within the Staffordshire outcrop the formation differs little from the succession present on the East Midlands Platform (Chisholm et al., 1988). In Leicestershire, the main exposures are at the quarries of Breedon on the Hill [SK 407 235] and Cloud Hill [SK 413 215], where the formation is at least 380 m and 130 m thick, respectively (Carney et al., 2001). The formation comprises both the typical deeper-water mud-mound subfacies and a fine- to coarse-grained, bioclastic, ooidal and peloidal grainstone sub-facies, deposited within a high-energy, storm-

dominated shelf environment (Carney et al., 2001). At Cloud Hill Quarry a laterally impersistent Holly Bush Member is identified.

4.5.11.1 HOLLY BUSH MEMBER (HYBH)

Name

Initially defined at Cloud Hill Quarry as the Holly Bush Member (Ambrose and Carney, 1997b).

Type section

Cloud Hill Quarry [SK 413 211], southern face of 4 m quarry level: entire thickness of member, up to 61 m thick, is proved in the section (Ambrose and Carney, 1997b).

Lithology

Fine to coarsely crystalline sandy dolostone, dolomitic sandstones and dolomites with thin stylolitic shaley mudstone and clay partings. The top 5 m of the member contain fine- to coarse-grained sand and scattered to common, generally well-rounded pebbles. The pebbles, around 1 cm and up to 5 cm diameter, include mainly vein quartz, with some quartzite, intraformational clasts and volcanic clasts.

Lower and upper boundaries

The base of the member is marked by the incoming of common beds of sandy dolostone/dolomitic sandstone in the Milldale Limestone Formation.

In the type section the top is taken at the top of the highest sandy dolomite, here additionally containing derived pebbles. The member is succeeded by grey, medium to thickly bedded dolostones of the undivided Milldale Limestone Formation.

Thickness

Up to 61 m thick in the Cloud Hill Quarry, though is impersistent, dying out northwards over 200 m within the quarry (Carney et al., 2001).

Distribution

Only known in southern part of Cloud Hill Quarry.

Genetic interpretation

The member was deposited during storm events on a carbonate platform.

Age

Early Chadian (Tournaisian)

4.5.12 Kevin Limestone Formation (KV)

Name

The Kevin Limestones were introduced for a sequence of pale, thickly bedded limestones in and around Kevin Quarry [SK 087 461] (Aitkenhead and Chisholm, 1982). The unit is here redefined as a formation.

Type sections

Kevin Quarry [SK 0837 4612–SK 0877 4616]: a 131 m thick section, although the base and top of the formation are not seen (Chisholm et al., 1988).

Lithology

Pale grey, thickly bedded, internally massive, fine- to coarse-grained biosparite limestone, with prominent bedding planes, some with brown pedogenic crusts and bentonite clay partings. The formation includes two areas of knoll-reefs.

Lower and upper boundaries

The base of the formation is marked by a disconformity above the well-bedded, grey to dark grey, medium- to fine-grained limestones of the Milldale Limestone Formation. The disconformity is locally overlain by a localised, poorly sorted conglomerate with pebbles of reef limestone and sparse quartz grains. Elsewhere the base of the formation is taken at the base of the lowermost thickly-bedded, pale grey limestone above the disconformity.

At the top of the formation a disconformity is overlain sharply by dark grey, siliceous mudstones of the Craven Group, with local erosional scouring into the top of the formation.

Thickness

At least 150 m thickness in the type area, although poorly constrained, and thins northward of the type area to 80–150 m in the Hopten's Cross area [SK 072 481], and to the east of the type locality, the formation is cut out by Namurian overstep.

Distribution

Seen in outcrop in the Weaver Hills [SK09 46], and probably present in the subsurface part of the Hathern shelf of Staffordshire.

Regional correlation

The formation is of comparable age and similar lithology as the Bee Low Limestone Formation of the Peak District inlier (Figure 6). The two formations are given distinct nomenclatures because of their separation by off-shelf facies in the intervening area of Dovedale.

Genetic interpretation

Two masses of fossiliferous reef limestones are interpreted as apron reefs (Aitkenhead and Chisholm, 1982).

Age

Asbian

4.5.13 Cloud Hill Dolostone Formation (CLHD)

Name

The unit was initially defined as the Cloud Hill Dolomite Formation (Monteleone, 1973) and was subsequently redefined as the Cloud Hill Dolostone Formation (Ambrose and Carney, 1997b).

Type section

Cloud Hill Quarry [SK 413 215]: At least 125 m thickness, displaying basal unconformity and mud-mound reef dolostone (Ambrose and Carney, 1997b).

Reference sections

Top: BGS Ticknall Borehole (SK32SE/103) [SK 3591 2363], between 55.4 m and 92.3 m.

Old quarries, Barrow Hill [SK 4217 2000]: displaying well exposed mud-mound reef dolostones (Ambrose and Carney, 1997b).

Formal subdivisions

The lower part of the Cloud Hill Dolostone Formation is recognised as the Cloud Wood Member at Cloud Hill Quarry [SK 413 215] and Scot's Brook Member in the Ticknall Borehole.

Lithology

Grey, pale buff and reddish grey, finely to coarsely crystalline, thin to very thickly bedded dolostones, with shaly

mudstone or clay partings and beds. Bioclastic grainstones interbedded with mudstones and dolostones are defined as the Cloud Wood Member, calcareous mudstones seen where undolomitised. The mud-mound reef dolostones, which form the bulk of the formation, are typically buff to grey, massive, fine grained and fossiliferous with common brachiopods, crinoids, corals, gastropods, nautiloids and ammonoids.

Lower and upper boundaries

The lower boundary is an unconformity, possibly in part a shear surface, with biosparites and micrites of the Milldale Limestone Formation of early Asbian age below, locally marked by the incoming of mudstone-dominated sediments, such as the Cloud Wood Member, and may be crowded with *Thalassinoides* trace fossils.

The top is taken at the incoming of the first palaeosol of friable siltstone and sandstone, displaying carbonate nodules of the overlying Ticknall Limestone Formation.

Thickness

At least 125 m thickness proved at type section.

Distribution

The outcrop is restricted to inliers at Barrow Hill, Cloud Hill and Breedon Hill across south Derbyshire and north-west Leicestershire; the subcrop extends at least to the Ticknall area [SK 35 24].

Regional correlation

Broadly equivalent in age and lithology to the Kevin Limestone Formation of the Staffordshire part of the Hathern Shelf.

Genetic interpretation

The formation comprises bedded dolostones, which probably represented bioclastic grainstones, subsequently heavily dolomitised, and a mud-mound reef facies (Carney et al., 2001).

Biostratigraphical characterisation

The ammonoid genus *Goniatites*, found in the mud-mound facies indicates a late Asbian age for the upper part of the formation (Ambrose and Carney, 1997b). A ?Holkerian to Asbian age for the lower part of the formation is derived from palynological determinations from the Cloud Wood Member.

Age

Holkerian to Asbian

4.5.13.1 CLOUD WOOD MEMBER (CLWD)

Name

Formerly referred to as the Lower Red Bed and Pebble Bed Group (Mitchell and Stubblefield, 1941) or Red Bed Member (Monteleone, 1973), the unit was defined as the Cloud Wood Member by Ambrose and Carney (1997b).

Type section

Cloud Hill Quarry [SK 412 217], north face 24 m, 47 m, 54 m levels: 36 m succession with lower two levels mudstone-dominated, upper level is limestone-dominated (Ambrose and Carney, 1997b).

Lithology

Dark grey mudstones with thin dolostone and dolomitic siltstones, passing up into dolostones with common, thin grey and red mudstone beds and partings.

Lower and upper boundaries

The base of the member is marked by an unconformity/shear surface with sheared mudstone resting on dolostone of the Milldale Limestone Formation.

The top is marked by an abrupt change from thinly bedded dolostone with common mudstone partings to massive, finely crystalline dolostone.

Thickness

Up to 36 m

Distribution

Known only in Cloud Hill Quarry.

Regional correlation

Present in the basal part of the Cloud Hill Dolostone Formation in Cloud Hill Quarry.

Genetic interpretation

The member was deposited in relatively deep water, dominated by mud deposition in relatively quiet conditions, indicated by sparse fauna and the presence of Chondrites-type burrows. The interbedded carbonates represent storm deposits, some with a proximal source of sand and pebbles (Ambrose and Carney, 1997b; Carney et al., 2001).

Biostratigraphical characterisation

Mudstone samples from this member indicate an abundant and moderately diverse palynological assemblage indicating a late Holkerian to early Asbian age (Turner, 1996).

Age

Holkerian to Asbian

4.5.13.2 SCOT'S BROOK MEMBER (SCBR)

Name

The name was first proposed by Ambrose and Carney (1997a).

Reference sections

Ticknall Borehole (SK32SE103) [SK 3591 2363]: between 92.3 m and 88.8 m depth.

Lithology

Green to grey, medium to coarse-grained pebbly argillaceous sandstones with subordinate calcareous mudstones and layers of white, nodular, micritic limestone. The member contains marine fossils (brachiopods and algae).

Lower and upper boundaries

The base of the member is taken at the top of a medium- to coarse-grained pebbly sandstone, overlain by green, slickensided, smectite-rich mudstone with about 4 mm ferruginous concretions of the Arch Farm Sandstone Formation, sharply overlain by pale grey to white calcareous sandstone of the Scot's Brook Member.

The top of the member is sharply overlain by grey, nodular limestone of the Cloud Hill Dolostone Formation.

Thickness

Some 3.4 m in the Ticknall Borehole

Distribution

Not identified at surface. Proved only in the Ticknall Borehole.

Regional correlation

Present in the basal part of the Cloud Hill Dolostone Formation in the Ticknall Borehole.

Genetic interpretation

There are common horizons of pedogenic modification, mainly grey in colour and carbonate-rich. The presence of a basal micritic carbonate facies within the palaeosol horizons is comparable with that seen in alluvial calcretised palaeosols developed under hydromorphic, reducing conditions (Ambrose and Carney, 1997a; Carney et al., 2001). A possible peritidal environment is proposed by these authors.

Age

Tournaisian to Viséan

4.5.14 Ticknall Limestone Formation (TIL)

Name

This unit was named by Monteleone (1973) and further defined by Carney et al. (2001).

Type area

Top: disused limestone quarries at Ticknall, south Derbyshire [SK 3626 2370–SK 3573 2422].

Reference sections

BGS Ticknall Borehole (SK32SE/103) [SK 3591 2363]: displays 55 m of continuous cored sequence from a probable unconformity at the base, to just below the top of the formation (Ambrose and Carney, 1997a).

BGS Worthington Borehole (SK42SW/204) [SK 4045 2104]: displays a continuous cored sequence through the upper of 43 m of the formation (base not seen).

Base: south-west corner of Cloud Hill Quarry [SK 413 215], about 14 m thick at the topmost part of the face (Ambrose and Carney, 1997a).

Lithology

Buff to pale grey, fine- to medium-grained massive to thinly bedded dolostone and limestones, with shaly mudstone interbeds, common palaeosols and karstic surfaces with green clayey drapes, and bioclastic grainstones and calcareous mudstones where undolomitised. Some sandy dolostones and dolomitic sandstones are present at the base of the formation.

Lower and upper boundaries

The lower unconformable boundary is taken at the base of the lowest palaeosol, recognised by 1–2 m of heterogeneous, friable siltstone and sandstone with carbonate nodules, above fine- to coarse-grained dolostones containing shaly mudstone partings, of the Cloud Hill Dolostone Formation.

At the top of the formation, the highest bed of limestone or dolostone in the Peak Limestone Group, is overlain rapidly by grey mudstone, siltstone or sandstone of the Millstone Grit Group or red-bed Permo-Triassic breccia of the Moira Formation.

Thickness

Estimated to be 60 m thick in the type area, and possibly up to 90 m between the Worthington Borehole and Cloud Hill Quarry.

Distribution

South Derbyshire to north-west Leicestershire, between Ticknall [SK 35 24] and Thringstone, near Grace Dieu [SK 42 17].

Genetic interpretation

Palaeosols and karstic surfaces with green clayey drapes are typical of the formation, indicative of periodic emergence.

Biostratigraphical characterisation

Foraminiferal determinations and macrofossils are consistent with a Brigantian age (Riley, 1997a). This supports faunal lists for the outcrops at Ticknall and Calke Park (Parsons, 1918; Monteleone, 1973).

Age

Brigantian

MARKET DRAYTON HORST

The Peak Limestone Group of the Market Drayton Horst occurs largely in the sub-surface within the Stoke-on-Trent District, with an isolated exposure within a small inlier near Limekiln Farm, Astbury [SJ 86 59], within the Macclesfield District. The lower limestone-dominated part of the succession is here defined as the **Bowsey Wood Formation**. The overlying mudstone-dominated **Astbury Formation** was deposited in shallow marine conditions, intermittently emergent and is included within the Peak Limestone Group rather than the relatively deep basinal argillaceous deposits of the Craven Group.

4.5.15 Bowsey Wood Formation (BOWO)

Name

The formation was initially defined as the Astbury Limestone (Evans et al., 1968). However, as the name was similar to the overlying Astbury Limestone-Shales, it has been necessary to rename the unit as the Bowsey Wood Formation, named after the type locality.

Type section

Bowsey Wood Borehole (SJ74NE/9) [SJ 7695 4643] cored 13.5 m thickness of the top of the formation (Earp and Calver, 1961).

Reference section

Bittern's Wood Borehole (SJ74SE/92) [SJ 7662 4286]: cored 1.5 m thickness of the top of the formation (Rees and Wilson, 1998).

Lithology

Pale grey, massive and thickly bedded limestone. At the type locality the formation comprises very fine- to very coarse-grained, slightly dolomitised packstones containing shell fragments with micritic (cyanobacterial) coatings, and calcareous mudstones.

Lower and upper boundaries

The base of the formation is not proved and the underlying succession is unknown.

At Astbury [SJ 86 59] the top of the formation is taken at the conformable base of the mudstone-rich succession, with subordinate limestone, of the Astbury Formation above the limestone-dominated succession of the Bowsey Wood Formation. In the Bowsey Wood and Bittern's Wood boreholes the top of the formation is an unconformity, overlain by mudstone of the Bowland Shale Formation.

Thickness

Some 13.5 m thickness at the type locality; this is a minimum thickness as the base of the formation is not proved.

Distribution

The formation occurs above the northern part of the Market Drayton Horst. The formation is limited in outcrop to a small inlier (about 1 km long and 300 m wide) at Limekiln

Farm, Astbury [SJ 86 59]. The formation is also present in the subsurface within the Stoke-on-Trent district, proved in the Bowsey Wood and Bittern's Wood boreholes.

Regional correlation

The formation probably passes laterally northwards and eastwards into the relatively deeper water carbonates of the Ecton Limestone Formation of the North Staffordshire Basin. The formation is comparable to and is probably contemporaneous with the Bee Low Limestone Formation of the Peak District and the Kevin Limestone Formation of the Hathern Shelf.

Genetic interpretation

Coral and brachiopod faunas suggest association with the 'reef' (mud-mound) facies of the Peak District inlier.

Biostratigraphical characterisation

The diverse fauna from the Astbury inlier, listed by Evans et al. (1968) and for the Bowsey Wood Borehole, described by Rees and Wilson (1998), indicate an Asbian or late Asbian age, respectively.

Age

Asbian

4.5.16 Astbury Formation (AYLS)

Name

The formation was initially defined as the Astbury Limestone-Shales (Evans et al., 1968) and is here formally redefined as the Astbury Formation.

Type section

Small disused quarry near Limekiln Farm, Astbury [SJ 8619 5921]: The section, seen to be 10.3 m thick (Evans et al., 1968), is from the lower part of the formation, below the Astbury Sandstone.

Lithology

Mudstones, interbedded with limestones, sandstones and tuffs and subordinate coals and seatearths. At the type locality the basal 43 m of the formation is dominated by grey or brown calcareous mudstone with several thin beds of impure grey or dark grey limestone and in the upper part thin beds of yellow-brown tuff and tuffaceous limestone and mudstone. Above this, a 52 m thick succession comprises brown mudstone and calcareous mudstone and includes at least three coals and a 21 m thick succession of white or pale yellow coarse-grained and feldspathic sandstones with thin interbeds of siltstone or mudstone, informally referred to as the Astbury Sandstone.

Lower and upper boundaries

The base of the formation is taken at the conformable base of the mudstone-rich succession with subordinate limestone above the limestone-dominated succession of the Bowsey Wood Formation.

The top of the formation is taken at the top of the mudstone-dominated succession with subordinate limestones and sandstones, overlain conformably by the dark grey mudstone of the Bowland Shale Formation.

Thickness

Up to 100 m

Distribution

The formation occurs above the northern part of the Market

Drayton Horst. The formation is limited in outcrop to a small inlier (about 1 km long and 300 m wide) at Limekiln Farm, Astbury [SJ 86 59].

Regional correlation

The formation passes laterally to the north and east into the Widmerpool Formation (former Mixon Limestone-Shales) of the North Staffordshire Basin (Rees and Wilson, 1998).

Genetic interpretation

The presence of coals and seatearths suggests that the formation was deposited partly under emergent conditions. The intimate association between fossiliferous strata and tuffs indicates that the volcanic material was ejected into the sea (Evans et al., 1968).

Biostratigraphical characterisation

Fossil collections from the basal part of the formation at the type locality do not permit a confident biozonal determination, but the fossils are consistent with an Asbian age (Evans et al., 1968). The two highest coals contain miospores thought to be indicative of a late Brigantian age (Evans et al., 1968).

Age

Asbian to Brigantian

SHROPSHIRE

Platform carbonates are present in a faulted succession at Little Wenlock [SJ 648 069]. These geographically isolated outcrops have distinct ages and have been given unique lithostratigraphical nomenclatures.

In the Little Wenlock outcrop the succession, of Asbian to Brigantian age, comprises the **Lydebrook Sandstone Formation**, overlain by the **Sylvan Limestone Formation** and a component **Little Wenlock Basalt Member**. These units are included within the Peak Limestone Group, assuming lateral continuity with the succession present on the Market Drayton Horst (see Sections 4.5.15 and 4.5.16). The group rests upon the Jackie Parr Limestone Formation (see section 5.1.5). Inferred to be the northernmost development of the Avon Group (Mitchell and Reynolds, 1981).

4.5.17 Lydebrook Sandstone Formation (LYS)

Name

The name Lydebrook Sandstone was used in the Doseley district by (Whitehead et al., 1928) and subsequently by other authors (Pocock et al., 1938; Hamblin and Coppack, 1995), formally defined as a formation by (Bridge and Hough, 2002).

Type section

Disused building stone quarries and natural waterfalls in Lydebrook Dingle [SJ 65 06].

Reference section

Lilleshall Borehole L18 (SJ71NW/64) [SJ 7354 1639], near New House Farm: formation recorded between 61.51 and 37.00 m depth.

Lithology

Orange-brown, fine- to coarse-grained sandstone, locally pebbly, with subordinate mudstones.

Lower and upper boundaries

The base of the formation occurs at the base of sandstone of the Lydebrook Sandstone Formation, resting unconformably

on, and overstepping, Tournaisian limestone (Jackie Parr Limestone Formation), and Silurian and Cambrian strata.

The top of the formation occurs at the base of calcreted limestones of the overlying Sylvan Limestone Formation.

Thickness

Between 20 and 37 m. The maximum thickness was recorded at Pitchcroft Mine [SJ 7392 1720].

Distribution

Coalbrookdale Coalfield, Shropshire.

Genetic interpretation

Vertically and laterally stacked fluvial channels, interspersed with alluvial plain palaeosols.

Biostratigraphical characterisation

Bivalve and brachiopod casts found at Wenlock Wood indicate an Asbian (D1 Subzone) age (Bracewell, 1925). Palynological studies from the Ironbridge Gorge area yield spores indicative of an Asbian to Brigantian age (Turner et al., 1995).

Age

Holkerian to Asbian

4.5.18 Sylvan Limestone Formation (SYLV)

Name

Referred to as Carboniferous Limestone by (Whitehead et al., 1928), and subdivided into an Upper and Lower Limestone separated by the Little Wenlock Basalt, this terminology was used by subsequent authors (Hamblin and Coppack, 1995). The unit was named and formally defined as a formation by (Bridge and Hough, 2002).

Type area

Little Wenlock, west of Little Wenlock Fault (Sheet 152).

Reference section

Lilleshall Borehole L18 (SJ71 NW/64) [SJ 73345 16395], New House Farm, Lilleshall 1.94 m–34.44 m depth (Riley, 1998).

Formal subdivisions

Little Wenlock Basalt Member

Lithology

Limestone (typically rubbly calccrete) with subordinate mudstone and sandstone, and basaltic lava(s) including the Little Wenlock Basalt.

Lower and upper boundaries

The lower boundary is taken at the base of lowermost limestone resting, probably unconformably, on sandstone/mudstone sequence of the Lydebrook Sandstone Formation.

The upper boundary is taken at the conformable base of the lowermost sandstone of the overlying Pennine Lower Coal Measures Formation (where present). Elsewhere, it is an unconformable junction with overlying mudstone and sandstone of the Pennine Lower Coal Measures Formation.

Thickness

Full thickness of 19.68 m at stratotype but c.105 m in expanded section of Little Wenlock Basalt at Little Wenlock [SJ 6470 0700].

Distribution

Lilleshall [SJ 73 15], Coalbrookdale [SJ 64 08], Little Wenlock, [SJ 6470 0700].

Genetic interpretation

Shallow subtidal and peritidal carbonates with the presence of ooids indicating raised salinity.

Biostratigraphical characterisation

An Asbian age for the limestone present below the Little Wenlock Basalt Member is supported by the presence of *Davidsoninia septosa* (Bridge and Hough, 2002).

Age

Asbian to Brigantian

4.5.18.1 LITTLE WENLOCK BASALT MEMBER (LWKB)

Name

Referred to as basalt of Little Wenlock by (Whitehead et al., 1928) and Basalt Lava by (Pocock et al., 1938), it was named the Little Wenlock Basalt by Hamblin and Coppack (1995) and formally defined a member by (Bridge and Hough, 2002).

Type section

Doseley Quarry [SJ 6750 0680]: up to 60 m of basalt with columnar joints (Hamblin and Coppack, 1995).

Lithology

Microporphyrritic olivine-basalt lava of Dalmeny type. Olivine phenocrysts with a groundmass of labradorite laths, granules and prisms of augite and fine grains of magnetite (Pocock et al., 1938).

Lower and upper boundaries

At the base there is a sharp junction between basalt of the Little Wenlock Basalt Member and the underlying limestone of the Sylvan Limestone Formation.

The basalt is overlain by sandstone, limestone or mudstone (formerly 'Upper Limestone') of the Sylvan Limestone Formation. The upper part of the Little Wenlock Basalt is locally marked by a weathered bole.

Thickness

Between 25 and 60 m in the Little Wenlock area.

Distribution

Little Wenlock, [SJ6470 0700], Lilleshall [SJ73 15] and Coalbrookdale [SJ64 08].

Genetic interpretation

The presence of pillow structures indicates a local shallow submarine origin.

Age

Brigantian

4.6 CLWYD LIMESTONE GROUP (CLWYD)

The Visean succession of North Wales comprises a sequence of dominantly shallow marine ramp and platform carbonates defined as the **Clwyd Limestone Group**. The group, up to 900 m thick, rests locally upon several formations formerly collectively known as 'Basement Beds' (see Sections 4.1.9 to 4.1.14), or elsewhere with marked unconformity on Silurian rocks. The sequence was thought to comprise only Asbian and Brigantian strata (George et al., 1976). However, earlier Chadian, Arundian and Holkerian strata were subsequently discovered (Somerville and Strank, 1984a, and Strank, 1984b; Davies et al., 1989). The formation nomenclature is summarised in Figure 8.

The succession comprises the **Foel Formation**, overlain by the **Llanarmon Limestone Formation**, which includes

the **Llwyn-y-Fran Sandstone Member** and **Nant-y-Gamar Limestone Member**. This is overlain by the **Leete Limestone Formation** and in turn by the **Loggerheads Limestone Formation**, with the component **Graig Fawr Limestone Member** and **Little Orme Limestone Member**. The upper part of the group comprises the **Cefn Mawr Limestone Formation**, with a component **Craig Rofft Sandstone Member**. This is locally overlain by the **Red Wharf Limestone Formation** or **Minera Formation**.

The eastward continuation of the Clwyd Limestone Group below the Permo-Triassic strata of the Cheshire Basin is proved in the Croxteth No.1 Borehole and Blacon East No.1 Borehole (Figure 9). The former comprises a 151.5 m-thick carbonate succession. The uppermost 15 m of the group comprises pale to dark grey, massive, bioclastic limestone with common brachiopods and breccia beds of limestone clasts in a dark grey argillaceous matrix. Below this, a thin shale contains ammonoids indicative of the P_{2a} Biozone of the Late Brigantian (Magraw and Ramsbottom, 1956). The underlying succession ranges from dark to pale grey, micritic to coarse-grained crinoidal limestone of Asbian and possibly Holkerian age. The Blacon East Borehole contains a 345.6 m thickness of Clwyd Limestone Group comprising pale to dark grey, predominantly micritic limestone with subordinate beds of medium to dark grey siltstone within the upper part of the group. The details from both deep boreholes are insufficient to allow correlation with the formational nomenclature defined in the exposed successions of North Wales. The Clwyd Limestone Group is also present in the Milton Green No.1 Borehole (Earp and Taylor, 1986), with a 322 m-thick succession of Asbian to Brigantian age.

4.6.1 Foel Formation (FOF)

Name

Previously referred to as the Lower Brown Limestone (Strahan, 1890), the unit was subsequently renamed the Foel Formation by Warren et al. (1984).

Type section

Northern of two quarries on western side of Moel Hiraddug at Tan-y-Foel [SJ 0607 7834]: section through the upper 12.9 m of the formation (Warren et al., 1984).

Lithology

Heterolith of dark grey peloidal limestones, shelly, oncolitic and locally oolitic limestones, porcellanous limestones, and fossil plant-bearing calcareous siltstones and calcareous sandstones. The limestones are locally dolomitised.

Lower and upper boundaries

Locally, limestone of the Foel Formation conformably overlies reddened 'Basement Beds' (Ffernant or Penbedw formations), but elsewhere rests unconformably on Silurian rocks of the Clwydian Range (Nantglyn Flags and Elwy formations).

The top of the formation is a conformable contact with thicker bedded limestones of the Llanarmon Limestone Formation.

Thickness

Up to 88 m in thickness, apparently thinning and dying out southwards.

Distribution

Confined to the north and east of the Clwydian Range in north-east Wales, between Moel Hiraddug [SJ 07 78] and Gelli Gynan [SJ 18 54].

Genetic interpretation

The Foel Formation records peritidal and shallow lagoonal deposition during the onset of the Visean transgression of North Wales (Davies et al., 1989).

Biostratigraphical characterisation

The formation is entirely late Chadian, containing the foraminifera diagnostic of the Cf4α2 Subzone. Mudstones provide well-preserved miospore assemblages of the *Lycospora pusilla* (Pu) Biozone (Davies et al., 2004). The biostratigraphy of the type section has been fully described (Somerville et al., 1989).

Age

Late Chadian

4.6.2 Llanarmon Limestone Formation (LNML)

Name

Variouly known as the Llandudno Pier Dolomite, Llysfaen Limestone and Ochr-y-Foel Limestone (Warren et al., 1984) and the Dyserth Quarry Limestone, Moel Hiraddug Limestone and Gop Hill Limestone (Somerville et al., 1986), the formation was originally described by Somerville and Strank (1984b), modified by Davies et al. (1989) and by Davies et al. (2004).

Type section

Alyn Valley Borehole (SJ15NE/8) [SJ 1900 5750] and Pistyll Gwyn Quarry, Llanarmon-yn-Ial: the conformable contact with the fine-grained argillaceous limestones of the underlying Foel Formation is encountered at a depth of 29.79 m in the borehole; which together with the quarry provides an unbroken section through the lower 85 m of the formation (Davies et al., 2004).

Formal subdivisions

The formation includes the Llwyn-y-Fran Sandstone Member of the Llanarmon-yn-Ial area [SJ 1958], and Nant-y-Gamar Limestone Member of the Nant-y-Gamar area near Llandudno [SH 80 81].

Lithology

Predominantly pale, thick-bedded, locally cross-stratified, shelly limestones (packstones and grainstones), subordinate thinner bedded dark grey limestones (packstones) and ooidal limestones. Upper parts (of early Asbian age), which interdigitate with the Leete Limestone Formation, include limestones rich in pelloids, plates of dasycladacean algae, oncoids and reworked micrite intraclasts. On the Great Orme, the formation is extensively dolomitised.

Lower and upper boundaries

East of the Clwydian Range, the base is taken at lowest massive, thick-bedded packstones and grainstone above thinner bedded, heterolithic sequences of the Foel Formation. West of the Clwydian Range, the Llanarmon Limestone Formation rests conformably on red beds of the Ffernant Formation, or sits unconformably on older Silurian rocks.

Where overlain by the Leete Limestone Formation, the top is taken at the lowest porcellaneous limestone diagnostic of this formation; however, east of the Clwydian Range, the Leete Limestone Formation passes laterally northwards into the Llanarmon Limestone Formation, so that north of Nannerch the top of the latter is taken at the entry of pseudobrecciated and mottled packstones typical of the Loggerheads Limestone Formation.

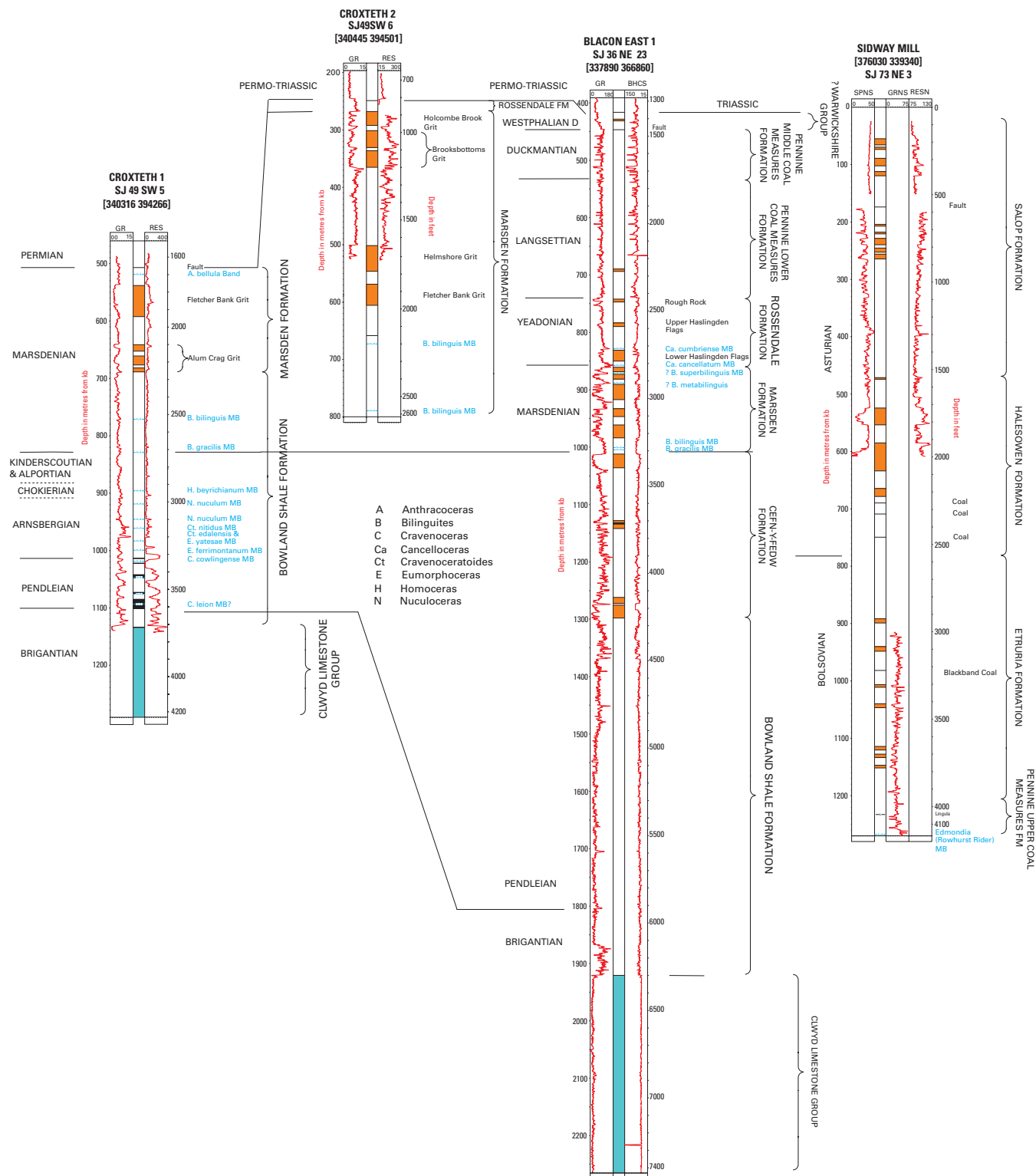


Figure 9 Correlation of selected deep borehole and geophysical logs from Merseyside and Cheshire. See Figures 6 and 8 for locations of boreholes.

Thickness

The Llanarmon Limestone ranges from 75 m thick in the Vale of Clwyd to 280 m in the Dyserth–Caerwys area.

Distribution

Crops out on the Great Orme at Llandudno [SH 76 83], and along the west side of the Vale of Clwyd [SJ 10 60]; in fault slices along the Vale of Clwyd Fault [SJ 12 67]; in its type area east of the Clwydian Range between Dyserth [SJ 07 79] and Llandegla [SJ 18 52].

Regional correlation

The upper part of the formation, intertongues with, and is progressively replaced by, the Leete Limestone towards the south (Figure 8).

Genetic interpretation

The Llanarmon Limestone Formation records the introduction of carbonate depositional environments across North Wales during a major and sustained Arundian marine transgression (Somerville et al., 1989). The initial

distribution of facies suggests a ramp-like setting, with darker offshore limestones deposited in the north and east (of the Clwydian Range) and shallower, inner ramp facies to the west (Vale of Clwyd). Subsequently, during the late Arundian, these high energy, inner ramp limestones prograded northwards and eastwards to establish a low-gradient carbonate platform. During the early Asbian, these shoal facies withdrew to the outer edge of the platform to form a protective barrier to the peritidal facies of the Leete Limestone Formation.

Biostratigraphical characterisation

A commonly rolled coral assemblage is indicative of an Arundian age (Somerville and Strank, 1984b). The basal few metres of the formation locally contain foraminiferal assemblages indicative of the Cf4 α 2 Subzone (Davies et al., 1989). The upper levels of the thicker northern sequence are considerably younger, containing Cf5 Biozone and Cf6 α Subzone assemblages, which confirm the presence of Holkerian and early Asbian strata, respectively (Davies et al., 2004).

Age

Holkerian to Early Asbian

4.6.2.1 LLWYN-Y-FRÂN SANDSTONE MEMBER (LYFS)

Name

The member was defined by Davies et al. (1989).

Type section

Alyn Valley Borehole (SJ15NE/8) [SJ 1889 5741] and Pistyll Gwyn Quarry: base of member proved at 16.72 m depth in the borehole; top of member located c.14 m above the base of the quarry section (Davies et al., 2004).

Lithology

Calcareous sandstones and sandy limestones (grainstones), locally cross-bedded and dolomitised.

Lower and upper boundaries

The base of the member is marked by the entry of calcareous sandstone 13 m above the base of the Llanarmon Limestone Formation in the Alyn Valley Borehole.

The top of the member is marked by the entry of dark brown-grey, less sandy, crinoidal limestones (packstones) of overlying parts of the Llanarmon Limestone Formation.

Thickness

Between 20 and 30 m

Distribution

Llanarmon-yn-Ial area [SJ 19 58], east of the Clwydian Range, north-east Wales.

Genetic interpretation

Records high energy, near shore bar deposition during the early stages of the Arundian transgression of North Wales, at a time when siliciclastic detritus was still actively being supplied to the developing carbonate ramp margin (Davies et al., 2004).

Age

Arundian

4.6.2.2 NANT-Y-GAMAR LIMESTONE MEMBER (NYGL)

Name

The unit, described by (Nichols, 1965) and (Bancroft et al., 1988) is here defined formally as a member.

Type section

Quarry at Nant-y-Gamar, Llandudno [SH 8012 8165]: section in upper 35 m of the bryozoan-rich limestones of the member (Bancroft et al., 1988).

Lithology

Massive, bryozoan-rich reef limestone (bafflestone/framestone).

Lower and upper boundaries

The base of the member is not seen, but presumed to be a contact between massive, bryozoan-rich, reef limestones and underlying well bedded, extensively dolomitised limestones (peloidal and skeletal grainstones) of the Llanarmon Limestone Formation.

The top of the member is at the boundary between massive 'reef' limestones and well bedded, extensively dolomitised limestones (peloidal and skeletal grainstones) of the Llanarmon Limestone Formation.

Thickness

At least 35 m

Distribution

Nant-y-Gamar, Llandudno [SH 80 81]

Genetic interpretation

Early Asbian build-up of trepostome bryozoan-rich limestones at the margin of North Wales Visean carbonate platform (Bancroft et al., 1988).

Age

Early Asbian

4.6.3 Leete Limestone Formation (LEEL)

Name

Formerly known as the Lower Brown Limestone, the Careg-Onen Limestone and Tandinas Limestone formations in Anglesey (Davies, 1983), Dulas Limestone of Rhyll (Warren et al., 1984), Ty-Nant Limestone of Llangollen (Somerville, 1977) and Sychtyn Member of Oswestry (Grey, 1981). The formation, named after Leete Country Park [1985 6280] at Loggerheads, was first defined by Somerville (Somerville, 1977, 1979), who included in it the whole of the limestone sequence below the Loggerheads Limestone. Following the recognition of earlier Arundian formations, the base has subsequently been redefined by Somerville and Strank (1984b) and again by Davies et al. (1989). The unit was formally defined by Davies et al. (2004).

Type section

Scarp east of River Alyn in Leete Country Park at Loggerheads [SJ 1978 6284]: section through upper 65 m of the formation (Davies et al., 2004).

Lithology

Lithologically varied, comprising diagnostic porcellanous and fenestral limestones (wackestones and calcite mudstones) interbedded with dark, foetid, argillaceous limestones (packstones), and pale skeletal peloidal limestones (packstones and grainstones) including beds rich in oncoids. Thin grey and green mudstone beds and rare coals are present locally. Lithologies are arranged in shoaling-upwards rhythms each capped by a porcellaneous limestone.

Lower and upper boundaries

The base of the formation is taken at the lowermost porcellanous limestone overlying the coarser grained and thicker bedded limestones of the Llanarmon Limestone Formation.

The top of the formation is taken at the uppermost porcellanous limestone underlying the rubbly and pseudo-brecciated limestones of the Loggerheads Limestone Formation.

Thickness

Between 150 and 175 m

Distribution

Crops out on Anglesey [SH 59 82] in north-west Wales; at Llandulas [SH 90 78] and along the western side of the Vale of Clwyd [SJ 12 52]; along the eastern side of the Vale of Clwyd in fault slices along the Vale of Clwyd Fault [SJ 12 67]; in its type area east of the Clwydian Range between Nannerch and Llanelidan [SJ 18 52]; and south of the Bala Fault Zone between Minera and Oswestry [SJ 27 22].

Regional correlation

Lateral passage northwards into the Llanarmon Limestone Formation (Figure 8).

Genetic interpretation

The formation marks an Holkerian to early Asbian interval of widespread peritidal and lagoonal facies deposition across the North Wales Viséan carbonate platform. In detail, the shoaling upwards rhythms testify to a succession of progradational events during a period of sustained and steady rise in sea level (Somerville, 1979c; Davies et al., 2004).

Biostratigraphical characterisation

The presence of thick-shelled brachiopod *Daviesiella llan-gollensis* is indicative of a Holkerian to early Asbian age for the formation (Somerville and Strank, 1984b). The foraminifera *Holkeria* sp., indicative of the Cf5 Biozone (Holkerian) is present at the base of the formation. The upper part of the formation and its northern tongues contain foraminifera of the Cf6 α - β Subzone (early Asbian).

Age

Holkerian to Early Asbian

4.6.4 Loggerheads Limestone Formation (LGHL)

Name

Various referred to as the Middle White Limestone (Morton, 1878), Eglwyseg Limestone (Somerville, 1979), Llandulas Limestone (Warren et al., 1984), and on the Llandudno (94) Sheet as the Penmon Limestone Formation, Great Orme Limestone Formation and Great Orme Limestone. The unit was referred to as the Loggerheads Limestone Formation by Somerville (1979a) and Davies et al. (2004).

Type section

Base exposed in scarp east of River Alyn in the Leete Country Park at Loggerheads [SJ 1995 6328] taken above highest porcellanous limestone of underlying Leete Limestone (Somerville, 1979).

Formal subdivisions

The formation includes the Graig Fawr Limestone Member in the Dyserth area [SJ 06 80] and Little Orme Limestone Member in the Llandudno area [SH 816 827].

Lithology

Thickly bedded, massive, pale grey shelly limestones (packstones and grainstones), locally mottled and pseudo-brecciated, arranged in shoaling upwards cycles capped by calcretes, hummocky palaeokarstic surfaces and associated thin bentonitic clay seams (palaeosols) and rare coals. The limestone is locally dolomitised and with scattered chert nodules.

Lower and upper boundaries

The base of the formation is taken at the top of highest porcellanous limestone of the underlying Leete Limestone Formation.

The top of the formation is taken at the base of lowest sequence of thinly interbedded dark grey limestones and mudstones of overlying Cefn Mawr Limestone Formation.

Thickness

Up to 275 m

Distribution

North Wales between Anglesey [SH 50 80] and Oswestry [SJ 27 23]; including the Corwen Outlier [SJ 05 42].

Genetic interpretation

The formation records late Asbian platform carbonate deposition on the North Wales Viséan shelf. Each cyclic sequence records a shoaling upwards unit developed in response to transgressive and regressive movements in sea level (Somerville, 1979c). Many regressions culminated in emergence of the platform surface and the formation of calcrete and karstic dissolution features. During these periods of emergence, wind-blown volcanic ash accumulated on the platform surface to form thin bentonitic soils.

Biostratigraphical characterisation

The formation displays a sparse, but diverse coral and brachiopod assemblages including *Davidsonina septosa*, consistent with the late Asbian D1 Subzone (George et al., 1976).

Age

Late Asbian

4.6.4.1 LITTLE ORME LIMESTONE MEMBER (LOLS)

Name

Previously referred to as 'Knoll reef limestones' (Warren et al., 1984), is here formally defined as the Little Orme Limestone Member.

Type area

Little Orme, Llandudno [SH 816 827]: extensive, but largely inaccessible cliff and quarry sections through massive 'reef' limestones (Warren et al., 1984). The lateral (southwards) transition into bedded limestones of the Loggerheads Limestone Formation is well displayed on the south side of the Little Orme.

Lithology

Knoll reef limestones comprising highly fossiliferous, massive, pale, fine-grained, recrystallised and locally dolomitised limestones with abundant calcite-lined former cavities with internal geopetal sediment (stromatactis). Contains a rich brachiopod and goniatite fauna.

Lower and upper boundaries

The base of the member is taken at the entry of massive 'reef' limestones above well-bedded Loggerheads

Limestone Formation; also passes laterally into Loggerheads Limestone Formation.

The top of the member is not seen, but was once probably unconformably overlain by red beds of the Warwickshire Group, or by Permo-Triassic strata (?Kinnerton Sandstone Formation).

Thickness
50 m

Distribution
Little Orme, Llandudno [SH 81 82], North Wales

Genetic interpretation
During the time of late Asbian carbonate platform development in North Wales, a series of knoll reefs formed along, and serve to define the platform margin. The knoll reef facies interdigitate with platformal facies on one side, and resedimented basinal facies of the Craven Group on the other.

Biostratigraphical characterisation
A rich coral and diverse brachiopod assemblage of late Asbian (B2) age (Warren et al., 1984).

Age
Late Asbian

4.6.4.2 GRAIG FAWR LIMESTONE MEMBER (GFLS)

Name
Previously referred to as Reef limestone (Warren et al., 1984) and knoll reef, the unit is here newly defined as the Graig Fawr Limestone Member.

Type section
Disused railway quarry (Station Quarry) at Meliden [SJ 0612 8064], near Dyserth: 1.4 m of fossiliferous 'reef' limestone near the base of the member (Warren et al., 1984).

Lithology
Knoll reef limestones comprising highly fossiliferous, massive, pale, fine-grained, recrystallised and locally dolomitised limestones with abundant calcite-lined former cavities with internal geopetal sediment (stromatactis). Contains a rich brachiopod and goniatite fauna.

Lower and upper boundaries
The base of the member is taken at the entry of massive 'reef' limestones above well-bedded Loggerheads Limestone; also passes laterally southwards into the Loggerheads Limestone, and passes laterally northwards into the Prestatyn Limestone Formation (Craven Group).

At the top of the member the massive 'reef' limestones are overlain by dark grey mudstones and thin argillaceous limestones of the Teilia Formation.

Thickness
About 100 m

Distribution
Dyserth area [SJ 06 80], North Wales

Genetic interpretation
During the time of late Asbian carbonate platform development in North Wales a series of knoll reefs formed along, and serve to define the platform margin. The knoll reef facies interdigitate with platformal facies on one side, and resedimented basinal facies of the Craven Group on the other.

Biostratigraphical characterisation
The ammonoids *Goniatites crenistria* and *Bollandoceras micronotum* from Meliden Quarry, in the flank beds of mud mounds are interpreted as indicative of late Asbian (B2) age (Neaverson, 1930; 1943; 1965; Warren et al., 1984), but are more likely to be latest Asbian (P_{1a}) age (see Riley, 1993a). Austin and Aldridge (1973) also recorded *Gnathodus bilineatus* and *Mestognathus neddensis* from the same locality, suggesting a horizon close to the Asbian/Brigantian boundary (see Riley, 1993a).

Age
Late Asbian

4.6.5 Cefn Mawr Limestone Formation (CFML)

Name
The formation was first defined by Somerville (1979). This name replaces the Upper Grey Limestone or D2 limestones, the Traeth Bychan Limestone of Anglesey (Davies, 1983), the Bishop's Quarry and Summit limestones of the Great Orme (Warren et al., 1984) and the Trefor Limestone of the Llangollen and Oswestry areas (Somerville, 1977).

Type section
Cefn Mawr Quarry [SJ 200 634]: exposes the conformable contact with the underlying pale, massive limestones of the underlying Loggerheads Limestone Formation and the lower 80 m of the Cefn Mawr Limestone Formation (Davies et al., 2004).

Formal subdivisions
Craig Rofft Sandstone Member at Llandudno [SH 775 831].

Lithology
Thinly interbedded dark grey argillaceous limestones (wackestones and packstones) and mudstones, with intercalated thick-bedded to massive pale shelly limestones (packstones and grainstones) and lenticular, cross-bedded, coarsely crinoidal limestone (rudstone) bodies. Lithologies are arranged in cyclic sequences. Limestones at the top of each cycle commonly display calcrete and palaeokarstic features locally overlain by bentonitic clay palaeosols. Black, replacive chert nodules are common. Thin chert beds and nodules are present in the upper part; rare sandstone beds.

Lower and upper boundaries
The base of the formation is taken at the uppermost palaeokarstic surface/palaeosol of the Loggerheads Limestone Formation, overlain by the lowest sequence of thinly interbedded, dark grey, limestones and mudstones of the Cefn Mawr Limestone Formation.

Where overlain by Minera Formation, top taken at base of lowest sandstone within latter; where overlain by Pentre Chert Formation, top taken at disconformable base of latter.

Thickness
Between 40 and 275 m, with thickness increasing southwards.

Distribution
Crops out on Anglesey [SH 50 80] and the Great Orme [SH 74 83] (Llandudno) in north-west Wales, in its type area to the east of the Clwydian Range [SJ 20 63], and at

Llangollen [SJ 23 45], and near Oswestry [SJ 28 25] in north-east Wales. Also present in the Corwen outlier [SJ 05 43].

Genetic interpretation

The formation records principally Brigantian platform carbonate deposition on the North Wales Visean shelf. Each cyclic sequence records a shoaling upwards unit developed in response to transgressive and regressive movements in sea level. Many regressions culminated in emergence of the platform surface and formation of calcrete and karstic dissolution features. The sequences of thinly interbedded dark grey limestone and mudstone, diagnostic of the formation, record deposition during marine transgressions which repeatedly established deeper platformal conditions than ever prevailed during the preceding and similarly cyclic Loggerheads Limestone Formation (Somerville, 1979a; Davies, 1983).

Biostratigraphical characterisation

The rich coral faunas detailed by Somerville (1979) are typical of the D2 Biozone of the Brigantian Stage. Ammonoids include forms indicative of the mid-Brigantian P1c Biozone, and from near the top of the formation of the P2b Biozone. The conformable base of the formation is markedly diachronous; in the north the base of the formation was taken by Somerville and Strank (1984a) to represent the local Asbian/Brigantian boundary, whereas to the south strata of late Asbian age are present.

Age

Asbian to Brigantian

4.6.5.1 CRAIG ROFFT SANDSTONE MEMBER (CRRS)

Name

The Craig Rofft Sandstone was first named by Warren et al. (1984) and shown on Sheet 94 within the Great Orme Limestone, a redundant Asbian formation now superseded by the Loggerheads Limestone Formation. However, unpublished foraminiferal dating by BGS has shown that limestones underlying the sandstone member are Brigantian in age. These limestone therefore equate with the Cefn Mawr Limestone Formation and their lithology (dark grey packstones) confirms that they should be included in that formation, as must the Craig Rofft Sandstone.

Type section

Disused sandstone quarry on Craig Rofft, 180 m east of tram shed, on the Great Orme [SH 7755 8315]: exposure in upper 3.4 m of the member (Smyth, 1925).

Lithology

Red and purple, fine to medium-grained, sandy limestone (grainstone) and calcareous sandstone with scattered quartz pebbles and lenses of coarse shell material. Lower part is bioturbated and mottled; upper 2 m are cross-stratified.

Lower and upper boundaries

The base of the member is not exposed, but should be taken at entry of sandy limestones and calcareous sandstones above underlying sand-free limestones of the Cefn Mawr Limestone Formation.

In the type section, the top of the member is an undulating surface above calcareous sandstone of the Craig Rofft Sandstone Member, overlain by a thin, impersistent, calcareous porcellaneous limestone bed of the Red Wharf Limestone Formation.

Thickness

From 4 to 5 m

Distribution

Great Orme at Llandudno [SH 76 83], North Wales.

Genetic interpretation

The sandstone forms the upper part of a Brigantian shoaling-upwards cycle and formed in a shallow water, upper shoreface setting.

Biostratigraphical characterisation

Unpublished foraminiferal dating by BGS has shown that limestones underlying the sandstone member are Brigantian in age.

Age

Brigantian

4.6.6 Red Wharf Limestone Formation (REL)

Name

Previously referred to as the Red Wharf Chert Limestone on the Llandudno (94) Sheet, it is here formally defined as a formation.

Type section

Cliffs north of Red Wharf, Anglesey [SH 532 822 to 531 815]: exposure in upper 55 m of the formation above a faulted base (Davies, 1983).

Lithology

Massive or irregularly bedded skeletal limestones (packstones and grainstones), commonly sandy, with abundant chert nodules. The formation comprises a series of shoaling upwards cycles capped by palaeokarstic surfaces commonly overlain by beds of sandstone infilling karstic pipes, or by channel-filling sequences of conglomerate, sandstone and silty mudstone.

Lower and upper boundaries

The base of the formation is not exposed, but assumed to be a contact between massive sandy limestones with abundant chert nodules of the Red Wharf Limestone Formation and the lithologically more varied limestone sequence of the underlying Cefn Mawr Limestone Formation. The contact is likely to be taken at a palaeokarstic surface developed at the top of the uppermost Cefn Mawr Limestone cycle.

In its type section, the Red Wharf Limestone Formation is overlain by a 6 m-thick unit of bedded cherts which was previously included in the formation as the Castell Mawr Chert Member, but which may now be viewed as a local representative of the Pentre Chert Formation.

Thickness

About 55 m

Distribution

Western side of Red Wharf Bay on Anglesey [SH 53 81], and Great Orme at Llandudno [SH 74 83], North Wales.

Genetic interpretation

The Red Wharf Limestone Formation records late Brigantian, mixed carbonate-siliciclastic shallow marine deposition at a time of increased supply of siliciclastic detritus to the North Wales Visean platform. Each cycle represents a shoaling upwards sequence formed in response to transgressive and regressive movements in sea level. Many regressions culminated in emergence of the platform surface and the

formation of karstic dissolution features, and of channels which were filled by fluvial conglomerates and sandstones and estuarine mudstones (Walkden and Davies, 1983).

Age
Brigantian

4.6.7 Minera Formation (MRF)

Name

Previously referred to as the Sandy Limestone, Arenaceous Limestone or Sandy Passage Beds (Morton, 1878; Strahan, 1890; Wedd et al., 1927), the unit was first referred to as the Minera Formation by Brown (1960) and formally defined by Davies et al. (2004).

Type area

Crags and stream sections on the north flank of Ruabon Mountain, west of Wrexham [SJ 254 515 to 270 510] (Brown, 1960).

Lithology

Interbedded limestones and calcareous sandstones. Limestone components compare with those of the underlying Cefn Mawr Limestone Formation and include both thick-bedded, massive pale grey limestones (packstones and grainstones), and sequences of thinly interbedded dark grey limestone (packstones and wackestones) and mudstone arranged in shoaling upwards cycles with the calcareous sandstones typically forming the upper parts of the cycles. The sandstones include ooidal units composed of radial fibrous ooids with sand grain cores. Chert beds and nodules are common at some levels, and coral biostromes are present locally.

Lower and upper boundaries

The base of the formation is taken at the base of the lowest, laterally extensive and mappable sandstone above the Cefn Mawr Limestone Formation, but diachronous as the formation passes laterally into Cefn Mawr Limestone Formation in north Flintshire.

The top of the formation is taken at the top of the highest laterally extensive and mappable limestone beneath thick, sandstone-dominated sequences of the Cefn-y-fedw Sandstone Formation.

Thickness

In its type area the formation is c.50 m thick, thickening north of the Bala Lineament up to 180 m.

Distribution

North-east Wales between Oswestry [SJ 28 25] and Halkyn Mountain [SJ 19 70].

Genetic interpretation

The Minera Formation records late Brigantian, mixed carbonate-siliciclastic shallow marine deposition at a time of increased supply of siliciclastic detritus to the North Wales Visean platform. Each cycle represents a shoaling upwards sequence formed in response to transgressive and regressive movements in sea level. The diagnostic calcareous sandstones principally record the progradation of nearshore siliciclastic facies over transgressive, offshore limestone facies. Many regressions culminated in emergence of the platform surface, but, since sandstones commonly occupy the tops of the cycles, calcrete and karstic dissolution features are only poorly developed (Davies et al., 2004).

Biostratigraphical characterisation

The Minera Formation is considered to be entirely late

Brigantian in age, yielding colonial rugose corals of the D2 Biozone and foraminifera of the Cf6δ Subzone (Davies, 1983).

Age
Brigantian

4.7 CRAVEN GROUP (CRAV)

The **Craven Group** is introduced to replace numerous geographically localised group names for Chadian to Yeadonian age strata deposited in a range of environments from slope carbonate turbidites to a hemipelagic basinal setting. A number of former groups have been redefined as constituent formations of the Craven Group. During Visean times the Craven Group of the Craven Basin type area was dominated by deposits of calcareous mudstones, interbedded with limestones and subordinate limestone breccias, conglomerates and sandstones. The limestones are typically pale and coarsely bioclastic towards the base and more argillaceous towards the top. The top of the group is defined by the base of the Millstone Grit Group, which is highly diachronous, ranging from Pendleian in age in the north to Yeadonian age in the south of the province (Figure 10).

The Craven Group blankets the palaeotopographies associated with the development of the Visean platform carbonate. Hence, the thickest and oldest developments are in the basinal areas, such as the Craven Basin, Rossendale Basin, Gainsborough Trough, Edale Gulf and Widmerpool Gulf (Figure 1). Thinner and younger successions occur above the drowned platform carbonates associated with the Central Lancashire High, Holme High and Derbyshire High.

CRAVEN BASIN

In the type area of the Craven Basin the formations of the Craven Group comprise in ascending order the Hodder Mudstone, Hodderense Limestone and Pendleside Limestone formations, all formally defined by Riley (1990) for the now redundant Worston Shale Group, and the redefined Bowland Shale Formation that formerly had group status (Figure 4). The group onlaps onto and eventually covers the Central Lancashire High at the southern margin of the basin (Evans and Kirby, 1999).

The **Hodder Mudstone Formation** consists in broadly ascending stratigraphical order: the **Limekiln Wood Limestone**, **Phynis Mudstone**, **Whitemore Limestone**, **Hetton Beck Limestone**, **Leagram Mudstone**, **Buckbanks Sandstone**, **Embsay Limestone**, **Rain Gill Limestone**, **Chaigley Limestone** and **Twiston Sandstone members** (Riley, 1990).

The overlying Holkerian succession includes the **Hodderense Limestone Formation** and the Holkerian to Asbian **Pendleside Limestone Formation**, with a constituent **Rad Brook Mudstone Member**. The youngest, Asbian to Pendleian, part of the Craven Group is represented by the **Bowland Shale Formation**, with component **Ravensholme Limestone**, **Park Style Limestone** and **Pendleside Sandstone members**.

4.7.1 Hodder Mudstone Formation (HOM)

Name

Previously referred to as the Worston Shales (Earp et al., 1961; Fewtrell and Smith, 1980), the name Hodder Mudstone Formation was first named and defined by Riley (1990) after the type section.

Type section

The lowermost exposed beds are on the north bank of the River Hodder 1.8 km east-north-east of Doeford Bridge [SD 6680 4330]. The top of the formation is seen 4.8 km to the south-east on the south-west bank of the river, 0.5 km south-east of Higher Hodder Bridge [SD 7007 4070] (Riley, 1990; Aitkenhead et al., 1992).

Formal subdivisions

A basal limestone boulder conglomerates, packstone and grainstone is identified as the Limekiln Wood Limestone Member. Subsequent deposition is dominated by hemipelagic mudstones interbedded with bioclastic limestone turbidites. The Phynis Mudstone and Leagram Mudstone members are locally recognised within the Chadian part of the succession. Limestone-dominated intervals have been defined as members, including the Whitmore Limestone, Hetton Beck Limestone, Emsay Limestone, Rain Gill Limestone and Chaigley Limestone members. Local developments of pale to dark grey, thin to thick bedded, siliceous and calcareous sandstone have been recognised as the Buckbanks Sandstone and Twiston Sandstone members.

Lithology

Predominantly grey to dark grey mudstone, with subordinate and variable detrital limestone, siltstone and sandstone. Mud-mound reef (Waulsortian) limestones, limestone boulder conglomerates and breccias locally, near the base. Soft sediment deformation, slumps, debris flows and gravity slides are widespread.

Lower and upper boundaries

The contact with the underlying Clitheroe Limestone Formation is unconformable and shows considerable regional overstep. Many sections show a sharp lithological change from pale grey wackestone limestone of the Clitheroe Limestone Formation to grey mudstone, or locally limestone conglomerate.

The top of the formation is taken where grey mudstone with subordinate limestone, siltstone and sandstone, passes up into the pale olive and blue-grey to cream coloured porcellanous mottled wackestone, of the Hodderense Limestone Formation.

Thickness

Up to 900 m thick

Distribution

Craven Basin, Lancaster [SD 46] to Skipton [SD 95]

Genetic interpretation

The basal unconformity marks submarine erosion during the break-up of the carbonate ramp during a phase of extension. Basal limestone boulder conglomerates, packstones and grainstones initially fill the depositional lows. Subsequent deposition is dominated by hemipelagic mudstones interbedded with bioclastic limestone turbidites derived from the carbonate shelves and platforms (Riley, 1990). Local unconformities are recognised at the base of the Emsay Limestone and Twiston Sandstone members. Relatively steep slopes are evidenced by the common presence of slumps, debris flows and gravity slides. Eventually, carbonate turbidites cease as the highs become smothered by hemipelagic mudstones.

Biostratigraphical characterisation

The first appearance of the foraminifera *Eoparastaffella* occurs at the base of the Hodder Mudstone Formation

(Riley, 1990). This diagnostic fauna marks the base of the Cf4 α 2 Subzone, also taken as the base of the Viséan Series, and indicates a Chadian age for the base of the formation. Holkerian (Cf5 Zone) foraminiferal assemblages are recognised above the Chaigley Limestone Member in the west and above the Twiston Sandstone Member in the east of the basin (Riley, 1990).

Age

Chadian to Holkerian

4.7.1.1 LIMEKILN WOOD LIMESTONE MEMBER (LMKL)

Name

The unit was first recognised informally in the Thornley Anticline [SD 60 40] and mapped as the Thornley reef conglomerate (Parkinson, 1926). In the Clitheroe Anticline [SD 80 45] the unit was described informally as the Salthill Cap Beds (Miller and Grayson, 1972). The Limekiln Wood Limestone Member was first named and defined by Riley (1990) after the type section.

Type section

River Hodder, continuous exposure in the core of the Plantation Farm Anticline at Limekiln Wood [SD 6630 4330 to SD 6715 4330], 1.25 to 2.1 km east-north-east of Doeford Bridge (Riley, 1990; Aitkenhead et al., 1992).

Lithology

Packstones, floatstones, grainstones, Waulsortian limestone, limestone-mudstone lithoclast breccias and boulder beds, thin to thick-bedded, interbedded with mudstones, some of which are lithoclastic. Laminated, erosive-based, graded beds occur at the type locality. Crinoidal debris is very conspicuous.

Lower and upper boundaries

The base of the member is not seen at the type locality. It is taken at the base of the succession of lithoclast breccias and boulder beds, packstones, floatstones, grainstones resting unconformably upon mainly pale grey packstones, wackestones and floatstones of the Clitheroe Limestone Formation.

At the top of the member there is, typically, a conformable passage from the succession of lithoclast breccias and boulder beds, packstones, floatstones, grainstones into the overlying dark grey mudstones of the Phynis Mudstone Member.

Thickness

Up to 120 m maximum thickness at the type locality.

Distribution

Western part of the Craven Basin, including Cow Ark [SD 65 46], Plantation Farm [SD 66 43], Thornley [SD 60 40] and Slaidburn [SD 71 53] anticlines and the southern limb of the Whitewell Anticline [SD 64 47].

Regional correlation

The member shows lateral passage to the Phynis Mudstone, Whitmore Limestone and Leagram Mudstone members on the northern limb of the Whitewell Anticline.

Genetic interpretation

Limestone boulder conglomerates, packstones and grainstones are derived from depositional highs and infill the depositional lows, deposited from debris flows and gravity slides.

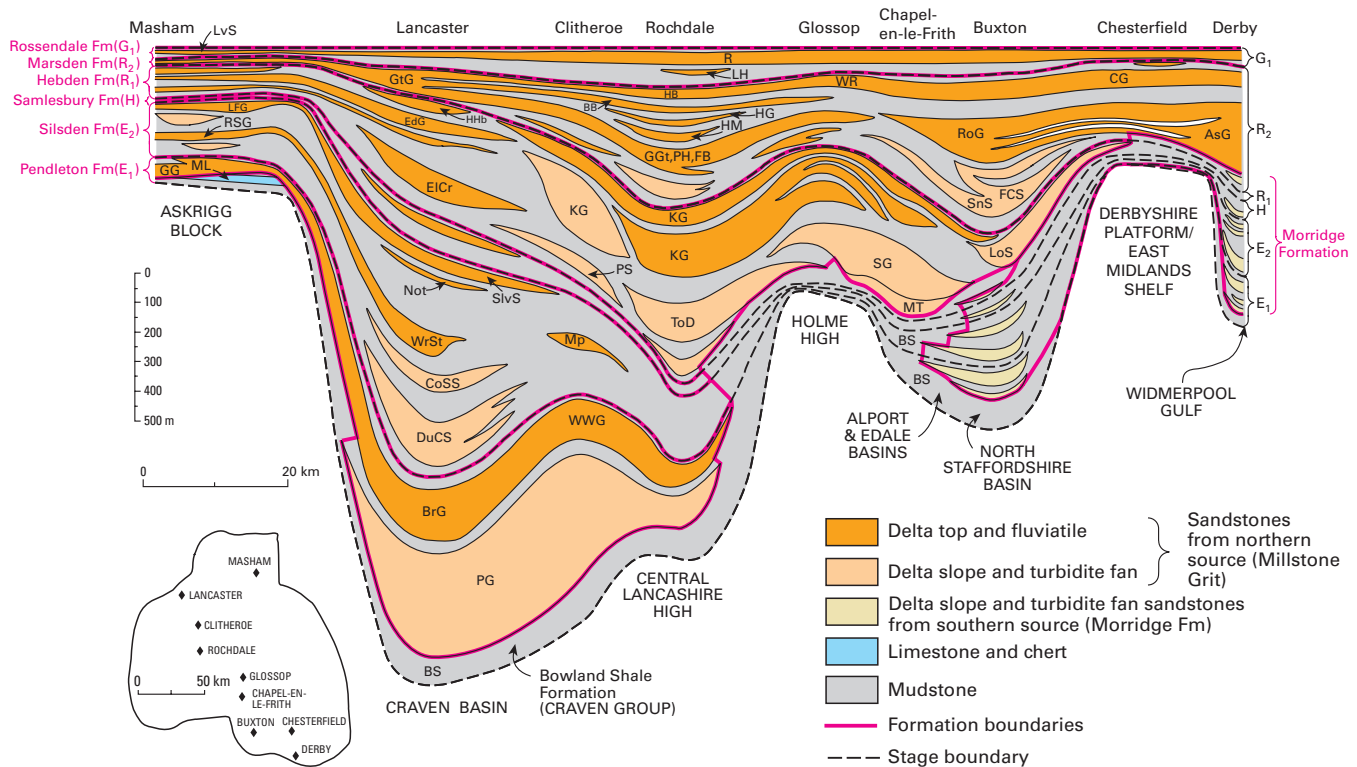


Figure 10 Schematic section (north–south) across the Namurian Central Pennine Sub-basin. Derived from Aitkenhead et al. (2002).

Biostratigraphical characterisation

Reworked foraminifera and algae indicative of the late Tournaisian Cf4α1 Subzone are present in the Cow Ark and Plantation Farm anticlines (Aitkenhead et al., 1992).

Age

Chadian

4.7.1.2 PHYNIS MUDSTONE MEMBER (PHS)

Name

Informally referred to as the Phynis Shales (Parkinson, 1936), the member was formally defined by Riley (1990).

Type section

Phynis Beck [SD 7152 5429], 0.16 km south-east of Phynis Farm, Slaidburn: the lowest beds lie about 2 m above the crinoidal packstones of the Clitheroe Limestone Formation, the boundary is not exposed. The thickness of the succession exposed is not recorded (Arthurton et al., 1988).

Lithology

Dark grey, laminated mudstones, finely micaceous, silty and calcareous, interbedded with laminated siltstones, dark grey, blocky and calcareous.

Lower and upper boundaries

At the type locality and also in the Whitewell Anticline, the dark grey mudstones of the Phynis Mudstone Member rest conformably upon crinoidal packstones of the Clitheroe Limestone Formation. Elsewhere, the mudstones are underlain conformably by lithoclast breccias and boulder beds, packstones, floatstones and grainstones of the Limekiln Wood Limestone Member.

In the Slaidburn and Whitewell anticlines the dark grey mudstones of the Phynis Mudstone Member are overlain conformably by pale blue-grey wackestones and pack-

stones of the Whitmore Limestone Member. Elsewhere, the mudstones are overlain by non-micaceous, laminated mudstones interbedded with laminated calcisiltites of the Hodder Mudstone Formation (undifferentiated).

Thickness

Up to 350 m, with thickest development in the Plantation Farm Anticline; elsewhere typically less than 50 m thick.

Distribution

Western part of the Craven Basin, including Cow Ark [SD 65 46], Plantation Farm [SD 66 43], Slaidburn [SD 71 53] and Whitewell [SD 64 47] anticlines.

Regional correlation

The member passes laterally into, and locally overlies, the Limekiln Wood Limestone Member.

Genetic interpretation

Hemipelagic mudstones interbedded with distal siltstone turbidites.

Biostratigraphical characterisation

Conodonts assemblages from the Cow Ark Anticline indicate correlation with the *Gnathodus pseudosemiglaber* Subzone and the ammonoid *Ammonellipsites* indicates correlation with the upper part of the *Fascipericyclus-Ammonellipsites* Zone (Aitkenhead et al., 1992).

Age

Chadian

4.7.1.3 WHITEMORE LIMESTONE MEMBER (WML)

Name

The member was first formally defined by Riley (1990), named after the type locality.

Type section

Stream section at Whitmore Knott, Whitewell [SD 6475 4793], 1 km west of Burholme Bridge: the section includes the base of the member and all but the uppermost 10 m of the member (Aitkenhead et al., 1992).

Lithology

Wackestones and packstones, pale blue-grey, thin-bedded, bioclastic, fine- to coarse-grained, graded, often erosive-based and containing intraformational lithoclasts, interbedded with similar amounts of pale blue-grey calcareous mudstone, commonly platy and blocky.

Lower and upper boundaries

The base of the member is defined at the base of the first pale blue-grey wackestones of the Whitmore Limestone Member overlying conformably the dark grey mudstones of the Phynis Mudstone Member.

In the Whitewell Anticline, the top of the member is taken at the base of the dark grey blocky mudstone interbedded with thin wackestones of the Leagram Mudstone Member, overlying conformably the pale blue-grey wackestones and packstones of the Whitmore Limestone Member. In the Slaidburn Anticline, the limestones of the Whitmore Limestone Member are overlain by non-micaeous, laminated mudstones interbedded with laminated calcisiltites of the Hodder Mudstone Formation (undifferentiated).

Thickness

Up to 80 m

Distribution

Limited to the Slaidburn [SD 71 53] and Whitewell [SD 64 47] anticlines and the northern limb of the Plantation Farm Anticline [SD 66 43], from the western part of the Craven Basin.

Regional correlation

At the type locality there is lateral passage of the member into the Limekiln Wood Limestone Member. The Whitmore Limestone Member is in part coeval with the Hetton Beck Limestone of the Eshton-Hetton Anticline.

Genetic interpretation

Bioclastic limestone turbidites derived from the carbonate ramp to the north (Hetton Beck Limestone Member), deposited on the lower part of a submarine ramp or upper part of a slope.

Biostratigraphical characterisation

The member is richly fossiliferous, with ammonoids indicative of a high horizon within the *Fascipericyclus-Ammonellipsites* Zone and foraminifera indicative of the Cf4 α 2 Subzone (Aitkenhead et al., 1992).

Age

Chadian

4.7.1.4 HETTON BECK LIMESTONE MEMBER (HBEL)

Name

The unit was first recognised informally by Booker and Hudson (1926) and described by Arthurton et al. (1988). The member was formally defined by Riley (1990).

Type section

Hetton Beck [SD 9592 5793 to SD 9607 5828], 1.5 km south-west of Rylstone Parish Church: the base and top are not exposed (Arthurton et al., 1988).

Formal subdivisions

None

Lithology

Packstones, wackestones and floatstones with a variety of thick, thin, wavy and nodular bedding, interbedded with subordinate grainstones, limestone, lithoclasts, possible in situ Waulsortian limestones and thin mudstones. Silicification and dolomitisation is common, with slumps and gravity slides present locally (Gawthorpe and Clemmey, 1985).

Lower and upper boundaries

The Park Laithe Borehole (SD95NE1) [SD 9629 5813] shows wackestones with a basal conglomerate 0.3 m thick of the Hetton Beck Limestone Member, resting unconformably upon medium to dark grey wackestones and packstones of the Thornton Limestone Member (Clitheroe Limestone Formation) (Arthurton et al., 1988).

In the Eshton-Hetton Anticline the packstones and wackestones of the Hetton Beck Limestone Member are overlain, probably disconformably, by wackestones, laminated calcisiltites, mudstones and boulder beds of the Hodder Mudstone Formation (undifferentiated).

Thickness

Up to 130 m

Distribution

Present in the northern part of the Craven Basin, within the Eshton-Hetton [SD 95 60], Catlow [SD 72 60] and Sykes-Brennand [SD 63 54] anticlines.

Regional correlation

The member is in part coeval with the Whitmore Limestone and Limekiln Wood Limestone members from the west of the Craven Basin.

Genetic interpretation

The sea was sufficiently shallow and extensive in the northern margins of the Craven Basin for a carbonate ramp to accumulate.

Biostratigraphical characterisation

Profuse foraminifera *Eoparastaffella* are present within the coarse-grained limestones of the member and indicate a Chadian Cf4 α 2 Subzone age (Riley, 1990; Aitkenhead et al., 1992; Brandon et al., 1998).

Age

Chadian

4.7.1.5 LEAGRAM MUDSTONE MEMBER (LEAM)

Name

This unit was named and defined by Riley (1990) and is equivalent to the Prolecanites compressus Beds of Parkinson (1926).

Type section

Leagram Brook, meander cliff on east bank [SD 6375 4450], 1.97 km north-east of Chipping Parish Church. The base of the member is not exposed; discontinuous exposures occur upstream to the top of the member exposed at a stream confluence [SD 6357 4457] (Aitkenhead et al., 1992).

Lithology

Mudstone, dark grey, blocky, pyritic and calcareous, interbedded with thin, dark wackestones with diffuse bed boundaries.

Lower and upper boundaries

The dark grey blocky mudstone of the Leagram Mudstone Member lies conformably upon limestones of the Limekiln Wood Limestone Member in the Clitheroe Anticline or upon the Whitmore Limestone Member of the Whitewell Anticline.

At the type locality, the top of the member is taken where there is a change from the dark grey blocky mudstone of the Leagram Mudstone Member to the overlying thin-bedded, laminated calcisiltites and dark grey, fissile mudstones of the Hodder Mudstone Formation (undifferentiated).

Thickness

Up to at least 50 m

Distribution

The member is restricted to the Clitheroe [SD 75 45], Slaidburn [SD 71 53] and Whitewell [SD 64 47] anticlines.

Genetic interpretation

Hemipelagic mudstones interbedded with distal wackestone turbidites.

Age

Chadian

4.7.1.6 BUCKBANKS SANDSTONE MEMBER (BNKS)

Name

The unit was first named and defined by Riley (1990), named after Buckbanks Wood, near the type locality.

Type section

Leagram Brook, west bank of gorge [SD 6380 4435], 1.9 km east-north-east of Chipping Parish Church: base of the member is exposed; the top of the member is exposed upstream at [SD 6355 4472] (Aitkenhead et al., 1992).

Lithology

Sandstone, dark grey, brown weathered, massive, thick- to thin-bedded, fine- to medium-grained, calcareous, quartzitic, bioclastic (crinoid and brachiopod debris), finely micaceous, interbedded with thin, dark grey, calcareous, laminated mudstones and siltstones.

Lower and upper boundaries

The base of the member is taken at the base of the first sandstone bed above laminated calcisiltites and mudstones of the Hodder Mudstone Formation (undifferentiated).

The top of the member is taken at the passage of sandstone into the overlying laminated mudstones and thin-bedded calcisiltites of the Hodder Mudstone Formation (undifferentiated).

Thickness

Maximum thickness of 11.5 m in the Thornley Anticline.

Distribution

The member is present in the western part of the Craven Basin, in the western closure of the Whitewell Anticline [SD 64 47] and the northern limb of the Clitheroe [SD 75 45], Thornley [SD 62 40] and Throstle Nest [SD 63 44] anticlines.

Genetic interpretation

The member represents terrigenous sands, which entered the western part of the Craven Basin probably through the by-pass of the carbonate shelf of the South Lake District High during a phase of erosion (Riley, 1990).

Age

Chadian

4.7.1.7 EMB SAY LIMESTONE MEMBER (EML)

Name

The name Emsay Limestone was first used informally by Hudson and Mitchell (1937). In the Lothersdale Anticline the unit was informally termed the Main Limestone (Bray, 1927) and interpreted by Earp et al. (1961) as part of the Chatburn Limestone Formation. The correlation with the Emsay Limestone Formation was first made by Fewtrell and Smith (1980).

Type section

Emsay Beck [SE 0030 5390], Emsay, near Skipton, North Yorkshire: full thickness of the member present (Hudson and Mitchell, 1937; Metcalfe, 1981).

Reference sections

Large quarry exposure at Dowshaw Delf [SD 9340 4480], near Skipton, North Yorkshire (Riley, 1990).

Large quarry exposure at Ray Gill Delf [SD 9400 4520], near Skipton, North Yorkshire (Riley, 1990).

Lithology

Pale packstones and grainstone, frequently pelley or ooidal and locally cherty, interbedded with dark, calcareous, silty mudstones, calcisiltites, conglomerates and breccias.

Lower and upper boundaries

The base of the member is drawn at the base of boulder beds of the Emsay Limestone Member where it rests unconformably on mudstones ('Halton Shales with Limestone' of Hudson and Mitchell, 1937).

The top is taken at the conformable upward passage from limestone of the Emsay Limestone Member to shaly calcisiltites and mudstones ('Skibeden Shales with Limestone' of Hudson and Mitchell, 1937).

Thickness

Up to 100 m

Distribution

Eastern part of the Craven Basin, including the Lothersdale [SD 95 45] and Skipton [SE 05 55] anticlines.

Regional correlation

The member is at least partly coeval with the Rain Gill Limestone and Chaigley Limestone members present in the western part of the Craven Basin.

Genetic interpretation

The member comprises fine detrital carbonate that was derived from the Askrigg carbonate shelf and gravitationally fed into the eastern part of the Craven Basin, interbedded with hemipelagic muds.

Biostratigraphical characterisation

The first entry of the primitive archaetid foraminifera of the *Eoparastaffella* Cf4 β Subzone occurs at the type locality some 9.7 m above the base of the member (Riley, 1990).

Age

Chadian to Arundian

4.7.1.8 RAIN GILL LIMESTONE MEMBER (RNGL)

Name

The unit was first recognised informally as the Middop

Limestone in the Middop Anticline (Earp et al., 1961). The unit was named the Rain Gill Limestones in the Slaidburn Anticline (Arthurton et al., 1988) and the unit was formally defined and extended geographically by Riley (1990).

Type section

Quarry [SD 7288 5417], 0.45 km south-west of Rain Gill, Slaidburn: 170 m thick with the base and top of the unit not exposed (Arthurton et al., 1988).

Reference sections

In the Ashnott area the unit is exposed in Bonstone Brook [SD 6955 4868], downstream from the track to Ashnott Farm, 1.75 km south of Newton (Earp et al., 1961).

The best exposure in the Middop Anticline is in old quarry [SD 8390 4520], 0.5 km east-south-east of Middop Hall (Earp et al., 1961).

Lithology

Wackestones, floatstones and subordinate packstones, fine to coarse-grained, cherty, muddy, dark-grey, thin to thick-bedded, commonly with diffuse bed boundaries, interbedded with thin mudstones. Slumping is common.

Lower and upper boundaries

The base of the member is not seen at the type locality. The boundary is taken as the passage of wackestones and floatstones of the Rain Gill Limestone Member into underlying laminated calcisiltites and mudstones of the Hodder Mudstone Formation (undifferentiated).

The top of the member is not seen at the type locality. The boundary is taken as the passage of wackestones and floatstones of the Rain Gill Limestone Member into overlying laminated calcisiltites and mudstones of the Hodder Mudstone Formation (undifferentiated).

Thickness

Up to 170 m

Distribution

Restricted to the Ashnott [SD 69 48], Middop [SD 83 45], Slaidburn [SD 71 53] and Whitewell [SD 64 47] anticlines.

Genetic interpretation

The member comprises fine detrital carbonate that was derived from the Askrigg carbonate shelf and gravitationally fed into the eastern part of the Craven Basin, interbedded with hemipelagic muds.

Biostratigraphical characterisation

A foraminiferal assemblage in the Slaidburn Anticline of *Glomodiscus miloni*, *G. oblongus*, *Rectodiscus sp.* and *Tubispirodiscus settlensis* indicate an Arundian age (Arthurton et al., 1988).

Age

Arundian

4.7.1.9 CHAIGLEY LIMESTONE MEMBER (CHGL)

Name

The member was first named and formally defined by Riley (1990).

Type sections

River Hodder, north bank at Paper Mill Wood [SD 6790 3217], 1.65 km west-south-west of Bashall Eaves: base of member exposed; exposure continues to foot of a meander

cliff on the west bank [SD 6800 4255], 0.65 km downstream (Aitkenhead et al., 1992).

Lithology

Packstones and floatstones, bioclastic, mainly medium- to coarse-grained, dark grey, thin- to medium-bedded, commonly graded and laminated. May show soft-sediment deformation structures such as slump folds and convolute ripples. Many beds display erosive, tool-marked and fluted basal surfaces and some beds contain coarse-grained lags and mudstone lithoclasts. The interbedded mudstones are dark grey, fissile, pyritic and sometimes sideritic and mainly barren of macrofauna. Dark sandy ferruginous siltstones with plant debris also occur.

Lower and upper boundaries

The base of the member is taken at the first coarse-grained packstone which lies above a succession of thin-bedded, laminated calcisiltites and mudstones of the Hodder Mudstone Formation (undifferentiated).

The top is taken where packstones and floatstones of the Chaigley Limestone Member are overlain by slumped, blocky, calcareous mudstones of the Hodder Mudstone Formation (undifferentiated).

Thickness

Up to 180 m

Distribution

Restricted to the western part of the Craven Basin, including the Dinckley [SD 70 35] and Thornley [SD 62 40] anticlines, southern limb of the Plantation Farm Anticline [SD 66 43] and the northern limb of the Clitheroe Anticline [SD 75 45].

Regional correlation

The member is slightly younger than the Rain Gill Limestone Member and the two members are geographically exclusive.

Genetic interpretation

The member comprises fine detrital carbonate that was derived from carbonate shelves to the north and gravitationally fed into the eastern part of the Craven Basin, interbedded with hemipelagic muds.

Biostratigraphical characterisation

The distinctive Dunbarella Bed is present in the lower part of the member in the Plantation Farm Anticline. This 0.3 m-thick dark fissile mudstone crowded with *Dunbarella* and *Pteronites* can be traced beyond the extent of the Chaigley Limestone Member. Ammonoids characteristic of the *Bollandites-Bollandoceras* Zone and foraminifera from the base of the member indicate Cf4 β - γ Subzone age (Aitkenhead et al., 1992).

Age

Arundian

4.7.1.10 TWISTON SANDSTONE MEMBER (TTS)

Name

The sandstone was mapped, but not named in the Clitheroe and Lothersdale Anticline (Earp et al., 1961). The member was named and formally defined by Riley (1990).

Type section

Stream section [SD 8202 4407], 0.23 km north-west of Clough Head, Twiston, near Clitheroe, Lancashire: full thickness seen (Riley, 1990).

Reference sections

Disused Quarry at Dowshaw Delf [SD 9350 4482], near Skipton, North Yorkshire: Angular unconformity above the Embsay Limestone Member seen in the section (Riley, 1990).

Embsay Beck [SE 0033 5414], near Skipton, North Yorkshire: Sandstone underlain by shale of the Hodder Mudstone Formation (undifferentiated) (Riley, 1990).

Lithology

Pale to dark grey, locally bioclastic siliceous, calcareous, thin- to thick-bedded, fine- to medium-grained sandstone. Lower and upper boundaries

The sharp base of sandstone of the Twiston Sandstone Member rests conformably on mudstones and thin calcisiltites of the Hodder Mudstone Formation (undifferentiated) and unconformably on the limestones of the Embsay Limestone Member in the Lothersdale Anticline.

The top is taken at the conformable upward passage from sandstone of the Twiston Sandstone Member to mudstones and thin calcisiltites of the Hodder Mudstone Formation (undifferentiated). Upper boundary taken at base of lowermost mudstone in a succession dominated by mudstone.

Thickness

Up to 4 m

Distribution

Southern limb of the Clitheroe Anticline [SD 82 44], Lothersdale [SD 93 44] and Skipton [SE 00 54] anticlines of the Craven Basin, north-west England.

Genetic interpretation

The member represents terrigenous sands, which entered the Craven Basin probably through the by-pass of the carbonate shelf to the north during a phase of erosion (Riley, 1990).

Age

Holkerian

4.7.2 Hodderense Limestone Formation (BOH)

Name

The formation was first recognised informally as the *Beyrichoceras hodderense* Bed (Parkinson, 1926). Revision of the eponymous fauna to *Bollandoceras hodderense* led to a change in the informal name (Earp et al., 1961), which was subsequently revised to the Hodderense Limestone Formation, formally defined by Riley (1990).

Type section

East bank of the River Hodder, Great Falls [SD 7035 3999], near Stonyhurst, near Clitheroe, Lancashire: base and top of the formation is seen in the section (Earp et al., 1961).

Reference sections

South of the old limekilns the Visitor Centre at Scarlett, Isle of Man [SC 2580 6620]: base of the formation is seen

Cliff section at Scarlett Point, Isle of Man [SC 2583 6633]: top of formation is seen.

Lithology

Pale olive and blue-grey, to cream-coloured porcellanous wackestones with characteristic dark blue, micritic nodules, interbedded with occasional packstones, frequent mudstones. Thin beds of medium-grained, muddy, dark grey sandstone occur in the Cow Ark Anticline (Wadge et al., 1983). Chert is common in the Isle of Man sections, where some beds are multistorey and display lag horizons composed of reworked

micrite nodules, inadunate crinoids, bellerophontid gastropods, cephalopods, trilobites and sponges (Chadwick et al., 2001). Also present is the trace fossil *Helminthoides*.

Lower and upper boundaries

In the Craven Basin the base of the formation is drawn at the base of the first cream-coloured wackestone with dark blue micritic nodules of the Hodderense Limestone Formation, where it rests conformably on grey or dark grey mudstone and calcisiltite of the Hodder Mudstone Formation. In the south of the Isle of Man, at the Visitor Centre at Scarlett, south of the old lime kilns, the wackestones and packstones of the underlying Knockrushen Formation are overlain by the massive lime mudstones of the Hodderense Limestone Formation. The base of the latter 'is taken at the lowest mottled horizon' (Dickson et al., 1987), and this mottling is a result of the presence of blue or grey micrite nodules up to 3 cm in size.

In the Craven Basin, the top is drawn at the conformable upward passage from the highest nodule bearing cream-coloured wackestone bed of the Hodderense Limestone Formation, to the first grey mudstone of the Pendleside Limestone Formation. In the south of the Isle of Man, at Scarlett Point [SC 2583 6633] the upper boundary of the Hodderense Limestone Formation occurs below the lowest black claystone of the wackestones, lime-mudstones and interbedded claystones of the Scarlett Point Member, Bowland Shale Formation.

Thickness

Up to 15 m in north-west England and 14 m in the Isle of Man.

Distribution

Craven Basin, north-west England, although removed beneath the unconformity in the Skipton area; south of the Isle of Man.

Genetic interpretation

The facies represents a deep-marine hemipelagic carbonate, deposited in a setting that was mainly starved of clastic supply and lay below storm wave base. *Helminthoides* is a deep-water trace fossil.

Biostratigraphical characterisation

The ammonoid assemblage, including *Bollandoceras hodderense*, is indicative of the upper part of the *Bollandites-Bollandoceras* Zone (Aitkenhead et al., 1992). In the south Isle of Man, Scarlett Quarry [SC 258 662] is the type locality of the ammonoid *Merocanites henslowi*.

Age

Holkerian

4.7.3 Pendleside Limestone Formation (PDL)

Name

The formation was recognised informally by Parkinson (1926) and Earp et al. (1961). Fewtrell and Smith (1980) provided the first attempt at a formal definition, which was subsequently redefined by Riley (1990) as a stratigraphically more restricted unit. The latter definition is retained here.

Type section

Pendle Hill, Burst Clough, seen on the lower slopes [SD 7808 4220], 0.16 km south-east of Angram Green Farm, 1.38 km east-south-east of Worston: almost complete section is exposed, together with lower beds of the overlying Bowland Shale Formation (Riley, 1990).

Reference sections

Composite section in Cutlers Quarry [SD 6239 4007] and Dale House Quarry [SD 6253 4022] (both disused), about 2.5 km north-east of Longridge (Aitkenhead et al., 1992).

Red Syke [SD 812 431], Twiston Moor, near complete section (Earp et al., 1961).

Formal subdivisions

A single Rad Brook Mudstone Member is present in the lower part of the formation.

Lithology

Grey, fine- to coarse-grained, bioclastic, commonly graded, erosive-based and bioturbated cherty packstones, interbedded with wackestone, sporadic intraformational and extraformational limestone conglomerate, and especially in the lower part, dark to pale olive- and blue-grey mudstone (Rad Brook Mudstone Member). Locally dolomitised, especially in the packstones, and rare sandstones.

Lower and upper boundaries

In the type section, the base is defined at the base of the first grey mudstone bed, lying above the pale olive and blue-grey nodule-bearing wackestones, that characterise the Hodderense Limestone Formation. At the northern basin margin an unconformity is present at the base of the formation with the underlying Hodderense Limestone removed by erosion.

The junction with the overlying Bowland Shale Formation is marked by the absence of bioturbation, and by a colour change from pale olive- and blue-grey, to dark blue and black, as mudstones and interbedded limestones become fetid and petroliferous, and this colour change commonly corresponds to the entry of limestone breccias.

Thickness

Up to 300 m thick

Distribution

Occurs throughout the Craven Basin, roughly between Lancaster [SD46], Skipton [SD95] and Preston [SD52].

Regional correlation

A 17.7 m-thick succession of thinly bedded pale grey shelly crinoidal limestone and shale in the Holme Chapel Borehole (Figure 5) may represent the southern attenuated extension of the Pendleside Limestone upon the Trawden Limestone Group of the Central Lancashire High.

Genetic interpretation

The formation represents a return to deposition of limestone turbidites and debris flows derived from adjacent platforms.

Biostratigraphical characterisation

The earliest *Neoarchaediscus* foraminiferal Zone occurs near the base of the formation, with the subzones Cf6 α - γ recorded (Aitkenhead et al., 1992).

Age

Late Holkerian to Asbian

4.7.3.1 RAD BROOK MUDSTONE MEMBER (RKM)

Name

The unit was mapped as an unnamed unit (Earp et al., 1961) and subsequently named informally the Rad Brook Beds

(Metcalf, 1981). The unit was formally defined by Riley (1990).

Type section

Pendle Hill, stream section in Rad Brook [SD 7890 4275], 2 km east of Worston: complete section is exposed (Riley, 1990).

Lithology

Mudstone, dark to pale olive- and blue-grey, calcareous, bioturbated, interbedded with dark, laminated, micromicaceous, calcareous siltstones and sporadic fine-grained, grey-blue packstones and wackestones.

Lower and upper boundaries

The base of the member is defined at the base of the first mudstone above the characteristic pale noduliferous wackestones of the Hodderense Limestone Formation.

The top of the member is taken at the base of the lowest packstone of the Pendleside Limestone Formation with less than 50 per cent interbedded mudstone.

Thickness

Up to 100 m. In the Ashnott Anticline [SD 70 48] the member is the sole representative of the Pendleside Limestone Formation, reduced to 0.6 m thickness.

Distribution

Limited to the southern part of the Craven Basin; absent north of the Clitheroe [SD 82 44] and Whitewell [SD 64 47] anticlines.

Genetic interpretation

Hemipelagic shales.

Age

Holkerian

4.7.4 Bowland Shale Formation (BSG)

Name

The Bowland Shale Group of Earp et al. (1961) was subdivided into Lower and Upper Bowland Shale formations, the division between the two taken at the base of the Cravenoceras leion Marine Band. The equivalent succession was referred to as the Bowland Shale Formation by Fewtrell and Smith (1980). The formation is formally redefined, with the term extended to replace other dark grey euxinic shales in North Wales (Holywell Shales) (Davies et al., 2004) and the East Midlands (Edale Shales), which were in lateral continuity with the deposits of the Craven Basin at the time of deposition.

Reference sections

River Ribble at Dinckley [SD 689 366 to SD 686 366], on the south bank of the River Ribble between Dinckley Hall and the suspension footbridge, about 300 m to the west downstream (Earp et al., 1961).

Little Mearley Clough [SD 779 414 to SD 785 411], 400 m to 1100 m south-east and upstream from Little Mearley Hall (Earp et al., 1961; Fewtrell and Smith, 1980).

Coed Pen-y-Maes stream section at Holywell [SJ 1939 7650 to SJ 1962 7687] shows typical lithologies present in North Wales as intermittent exposure; base and top not seen (Davies et al., 2004).

Duffield Borehole, near Derby (SK34SW/5) [SK 3428 4217], from 0.86 m to 405.78 m depth (Figure 7), from the H1a marine band to the base (Aitkenhead, 1977).

Roosecote Borehole, Barrow-in-Furness (SD26NW/19) [SD 2304 6866], includes an entire thickness of the formation from 158.13 to 613.31 m depth (Rose and Dunham, 1977; Johnson et al., 2001).

Shellag Point Borehole, north Isle of Man [NX 4565 9965] cored from 100.60 m to 128.15 m, with neither the base or top proved (Chadwick et al., 2001).

Formal subdivisions

The Ravensholme Limestone and Park Style Limestone members are present at or near the base of the formation. Sandstone-dominated turbidites are locally common, including the Pendleside Sandstone Member. In the south of the Isle of Man, the Scarlett Point and Scarlett Volcanic members occur at the base and top of the formation, respectively (described fully by Dean et al., in press).

Lithology

Mainly dark grey fissile and blocky mudstone, weakly calcareous with subordinate sequences of interbedded limestone and sandstone, fossiliferous in more-or-less discrete bands.

In the Furness and Settle areas the formation comprises thick-bedded, blocky to sub-fissile, dark grey and black, organic-rich mudstone, with subordinate beds of dark grey siltstone, sandstone and pale brown dolomitic limestone. Marine bands are also present. The formation shows an upwards decrease in carbonate turbidites and a concomitant increase in siliciclastic sandstone turbidites (see Rose and Dunham, 1977; Johnson et al., 2001; Arthurton et al., 1988).

In the south Isle of Man, the Bowland Shale Formation includes black claystone with localised deposition of carbonate turbidites, debris flows, olistoliths, volcanoclastic deposits and lavas (see Chadwick et al., 2001; Dickson et al., 1987). At the base of the formation, the Scarlett Point Member comprises cherty and pyritous tabular beds of pale wackestone and lime mudstone (dolomitised in places), which display gradational boundaries with interbedded black, fissile, blocky claystone. The limestone is burrowed and has inadunate crinoidal lags and scattered ammonoids. At the top of the formation, the Scarlett Volcanic Member is dominated by a series of volcanoclastic debris flows and gravity slides. Claystone rafts and megaclasts are entrained within the volcanoclastic rocks, and carbonate olistoliths and pillow lavas also occur. Between the members, where the Bowland Shale Formation oversteps the Balladoole Formation (Great Scar Limestone Group), coarse-grained detrital carbonates and debris beds are common. These include erosively based, graded packstone beds, conglomerate, megaclasts and large olistoliths (with reef limestone and spectacularly preserved ammonoid faunas) derived from the Balladoole Formation. The middle part of the exposed part of the formation comprises black, calcareous, platy claystone with subordinate beds (up to 2 m thick) of dark wackestone, and dark detrital packstone debris.

In the north Isle of Man, the Shellag Point Borehole (see below) cored through 27.55 m of siltstone, claystone and ironstone. These included two marine bands.

Lower and upper boundaries

The conformable base upon the Pendleside Limestone Formation in the Craven Basin, on the Widmerpool Formation in the East Midlands, and the Pentre Chert and Cefn-y-Fedw Sandstone Formation in North Wales, on the Hodderense Limestone Formation in the south of the Isle of Man, is taken at the first appearance of black mudstone above variegated mudstones or fine-grained limestones.

In south Cumbria the lower boundary of the formation is taken at the base of the *Cravenoceras leion* Marine Band, where the dark grey to black marine mudstone rests upon thinly interbedded limestones, mudstones and subordinate sandstones of the Alston Formation. The Bowland Shale Formation onlaps onto, and eventually by Pendleian times extends over, the carbonates of the Central Lancashire High (Trawden Limestone Group). In the Craven Reef Belt, in the Malham Cove–Gordale Scar area, the fissile mudstones with nodules and thin beds of ironstone and limestone of the Bowland Shale Formation, rest unconformably and diachronously on the Malham Formation (Great Scar Limestone Group), or Yoredale Group.

The top of the formation is taken at the base of the Millstone Grit Group over most of the Pennine Basin and at the base of the Morridge Formation in Staffordshire and the East Midlands. The formation shows complex inter-tonguing with the Morridge and Cefn-y-Fedw Sandstone formations. It is seen as a conformable boundary defined by the base of the lowermost thick feldspathic sandstone of the Millstone Grit Group, or quartzitic sandstone of the Morridge and Cefn-y-Fedw formations, above thick dark grey mudstone of the Bowland Shale Formation.

Thickness

Generally between 120 m and 620 m thick. The formation thickens north-eastwards along the axis of the Central Lancashire High, from about 22 m in the Roddlesworth Borehole (SD62SE/274), 68 m thick in the Holme Chapel Borehole (SD82NE/69), and 102 m in the Boulsworth Borehole (SD93SW/14) (Figure 11). The underlying Trawden Limestone Group shows a thinning in the same direction (Evans and Kirby, 1999), suggesting the thickening of the Bowland Shale Formation reflects available accommodation space.

In the Craven Reef Belt the Bowland Shale Formation is perhaps 30 m to 200 m thick (see Arthurton et al., 1988, figure 22). In south Cumbria, the Roosecote Borehole (SD26NW/19) (see above) proved the formation to be 130 m thick (see Johnson et al., 2001; Rose and Dunham, 1977). On the Isle of Man, the Bowland Shale Formation may be at least 186 m thick. In the north Isle of Man, the Shellag Point Borehole [NX 4565 9965] proved only a part of the formation 27.55 m thick.

Distribution

Widespread in the Craven Basin (the type area), including Lancaster, Garstang, Settle, Clitheroe, Harrogate districts, south Cumbria and the Isle of Man, but also in North Wales, Staffordshire and the East Midlands.

Regional correlation

The upper part of the Bowland Shale Formation passes northward into the Millstone Grit Group and to the south into the Morridge Formation (Figure 10).

Genetic interpretation

The mudstones accumulated as hemipelagic deposits, predominantly from suspension in moderately deep water largely below the storm wave base. For much of the time the water was brackish or fresh and occurred in the photic zone (Collinson, 1988). Marine bands developed during periods of higher salinity when connections with the open ocean were established. The thin limestones and sandstones were introduced by storms and/or as turbidites; the limestones sourced from active carbonate shelves, the siliciclastic sediments from active deltas accumulating on the margins of the Central Pennine Basin. In the south of the Isle of

Man, lavas, volcanoclastic debris flows and gravity slides are apparently submarine. In the north Isle of Man, the siltstone, claystone and ironstone of the Shellag Point Borehole was mostly of marine origin.

Biostratigraphical characterisation

In the type area of the Craven Basin the formation ranges from late Asbian (Cf6 γ Zone) to early Pendleian (E_{1c} Zone). The top of the formation ranges to younger ages toward the south of the Pennine Basin, with Yeadonian strata present in North Wales. The Bowland Shale Formation of south Cumbria and the Craven Reef Belt is Pendleian. On the Isle of Man, the formation is Asbian to late Arnsbergian. In the south of the island, the Scarlett Point Member is of (possibly early) Asbian age and includes in the limestone the deep water trace fossil *Helminthoides* sp., and the ammonoid genera *Beyrichoceras* and *Bollandoceras*. In the north of the island, the Shellag Point Borehole (see above) includes the two latest Arnsbergian marine bands with the ammonoid *Nuculoceras nuculum*, an associated shelly fauna and the trilobite *Paladin*.

Age

Asbian to Yeadonian

4.7.4.1 RAVENSHOLME LIMESTONE MEMBER (RL)

Name

The unit was first named in its type area in the Clitheroe district (Earp et al., 1961) and is here formally defined as a member.

Type section

Possible type section in a stream section at Red Syke [SD 812 431], east of Ravens Holme, Pendle Hill, Lancashire; the member shows its maximum measured development of 34.7 m (Earp et al., 1961).

Lithology

Coarsely bioclastic, shelly and crinoidal limestone, conglomeratic in places, with subordinate shaly mudstone beds and partings.

Lower and upper boundaries

The limestone of the Ravensholme Limestone Member is underlain conformably by either the dark mudstone of the Bowland Shales Formation (undifferentiated) or resting directly on the relatively fine-grained limestones of the Pendleside Limestone Formation.

The member is overlain conformably by the predominantly mudstone sequence of the Bowland Shales Formation (undifferentiated).

Thickness

Up to about 35 m

Distribution

Occurs at scattered localities in the Craven Basin, including the northern slopes of Pendle Hill [SD 81 43] and the Brennand inlier [SD 65 54].

Regional correlation

The member is broadly coeval with the lower part of the Park Style Limestone Member of the Garstang district.

Genetic interpretation

Carbonate clastic grains derived from platform margins, intrabasinal highs and slope regions and redeposited from turbidity currents and debris flows.

Age

Asbian to Brigantian

4.7.4.2 PARK STYLE LIMESTONE MEMBER (PKSL)

Name

The member was first delineated in the Garstang district by Aitkenhead et al., (1992).

Type section

Leagram Brook [SD 6294 4514 to 6280 4526], near Park Style: full thickness of member at crop (Aitkenhead et al., 1992).

Lithology

Packstones and wackestones predominate, interbedded with dark grey fissile and blocky mudstone. At the type locality, the lower 17 m comprises equal proportions of limestone and mudstone. The limestone is dark bluish grey, typically with sharp bases and flute and groove casts. The limestones form graded beds (8 to 70 cm thick), with medium- to coarse-grained packstone fining upwards to calcisiltite and argillaceous wackestone. The beds have an undulatory parallel lamination. The interbedded mudstones are cherty, calcareous and platy or fissile. Thin beds of bioclastic debris, mainly crinoid, brachiopod and coral fragments, occur in places. The upper 67 m has a proportion of 70 to 90 per cent limestone to mudstone. The limestones are grey wackestones, locally weathering to pale brownish grey. Beds range from 8 to 80 cm thickness, with sharp, slightly undulatory bases and tops. Faint parallel lamination is visible in some beds. The interbedded mudstone is dark grey, calcareous, blocky and strongly bioturbated.

Lower and upper boundaries

The base of the member is taken at the base of the lowermost normal-graded packstone overlying a black mudstone-dominated succession of the Bowland Shale Formation (undifferentiated).

The top of the member is taken at the top of the uppermost wackestone in a limestone-dominated succession, overlain by black mudstones and siltstones of the Bowland Shale Formation (undifferentiated).

Thickness

At the type locality the member is 84 m thick. At Hell Clough [SD 6353 4640], 1.3 km to the north-east of the type locality, the member is only 6.3 m thick.

Distribution

The member is mainly found in the Garstang district, located in the western part of the Craven Basin.

Regional correlation

The lower part of the member is broadly coeval with the Ravensholme Limestone Member of the Clitheroe district.

Genetic interpretation

Carbonate clastic grains derived from platform margins, intrabasinal highs and slope regions and redeposited from turbidity currents and debris flows.

Biostratigraphical characterisation

In the Saunders Anticline [SD 61 43] ammonoids recorded from the lower part of the member represent B_{2a} and P_{1a} Subzone ages. In the Thornley Anticline [SD 60 41] mudstones in the upper part of the member contain *Posidonia becheri*, suggestive of a P_{1b-c} Subzone age (Aitkenhead et al., 1992).

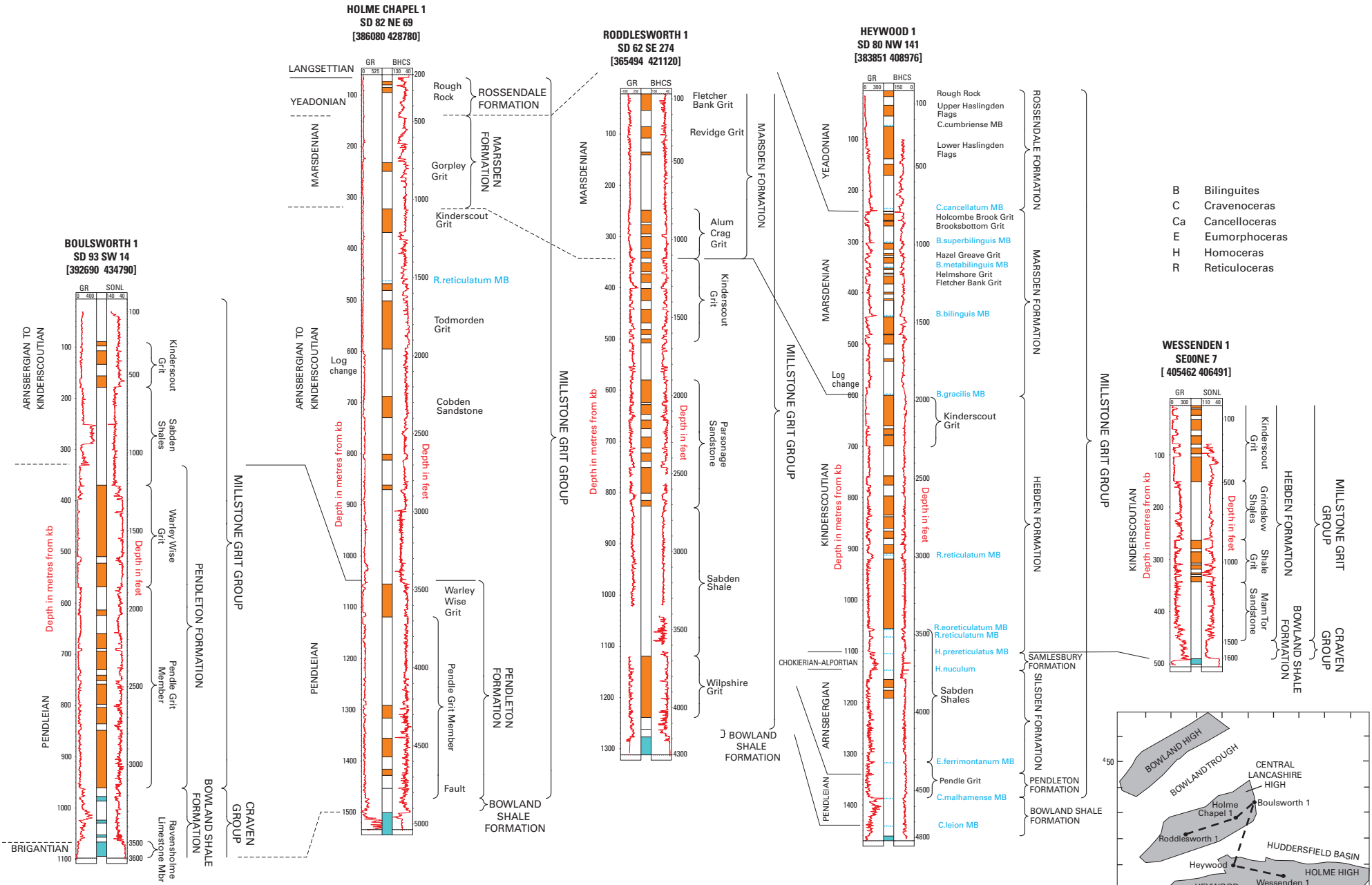


Figure 11 Correlation of selected deep borehole and geophysical logs through Namurian strata from the Pennines of Lancashire and Yorkshire.

Age

Late Asbian to early Brigantian

4.7.4.3 PENDLESIDE SANDSTONE MEMBER (PNDS)

Name

Formerly referred to as the Pendleside Grit during the primary survey and by Parkinson (1926), it was renamed the Pendleside Sandstone (Parkinson, 1936; Earp et al., 1961) and Pendleside Sandstones (Arthurton et al., 1988). The unit was redefined as a member by Aikenhead et al. (1992).

Type area

Slopes to the north and north-east of Pendle Hill, Lancs; numerous stream sections and small disused building and wall stone quarries (Earp et al., 1961). Stratotype sections: Red Syke [SD 8103 4300] and Pendle Hill Brook [SD 8095 4230], stream section about 0.6 km south-south-east of Ravens Holme.

Reference section

Little Mearley Clough [SD 7815 4140 to SD 7825 4130], stream section 200–400 m upstream from Little Mearley Hall (Earp et al., 1961).

Lithology

Sandstone turbidite facies comprising mainly fine- to medium-grained, thin to thickly bedded, grey to pale brown sandstones, interbedded with shaly mudstones and siltstones, calcareous in part.

Lower and upper boundaries

The base of the member is taken at the position where, going up sequence, sandstones start to dominate the Bowland Shale Formation.

The top of the member is taken at the position where, going up sequence, sandstones cease to dominate the Bowland Shale Formation.

Thickness

About 300 m maximum

Distribution

Widely, but discontinuously cropping out in the Craven Basin in Clitheroe, Settle, Lancaster and Garstang districts and probably farther afield.

Genetic interpretation

Terrigenous siliciclastic grains redeposited from turbidity currents, sourced from the north or north-east. The stacked sequences of beds are interpreted as turbidite submarine fans deposited in relatively deep water.

Biostratigraphical characterisation

In the Pendle Hill Brook section, in the type area, a shale interbed within the member includes ammonoids indicative of the P1d Ammonoid Subzone (Earp et al., 1961). In the Thornley Anticline [SD 64 41] mudstones up to 24 m above the top of the member include *Lusitanoceras granosus* and *Lusitanites subcircularis*, indicative of a horizon high in the P_{2a} Ammonoid Subzone (Aitkenhead et al., 1992).

Age

Brigantian

ROSSENDALE BASIN, GAINSBOROUGH TROUGH AND HOLME HIGH

The Rossendale Basin and Gainsborough Trough are laterally contiguous, largely separated from the Craven Basin to

the north by the Central Lancashire High. The succession is typically only found in the subsurface and is mainly known from deep boreholes. Consequently, no formal lithostratigraphy has been developed for the basins. Commonly, deep boreholes penetrating the Craven Group in this area have attempted to relate the succession to formations within the Craven Basin (Evans and Kirby, 1999).

The Rossendale Basin succession is proved by the Fletcher Bank No.1 Borehole (SD81NW3 [SD 8053 1644], which penetrates a 383.4 m thick succession from the upper part of the group. The lowermost 253 m comprises dark grey calcareous mudstone overlain by 12.2 m of dark grey limestone, thinly interbedded with dark grey calcareous mudstone of Brigantian age. This lower part of the succession is attributed to Craven Group (undifferentiated). This is overlain by strata attributed to the **Bowland Shale Formation** (see definition in Section 4.7.4). A late Brigantian succession, 38.4 m thick, consists of dark grey calcareous mudstone with thin beds of dark grey limestone. The uppermost 79.9 m comprises dark grey shale and calcareous mudstone with marine bands indicating a Pendleian (E_{1a-c}).

The Gainsborough Trough formed a half-graben, with the syn-rift Tournaisian and Visean succession thickening toward the north-east, with a maximum thickness of fill adjacent to the north-west–south-east oriented bounding fault, the Askern–Spittal Fault (Fraser et al., 1990). The syn-rift fill succession is poorly known with record of a Brigantian interbedded clastic/carbonate succession representing the only well data (Strank, 1987). This succession is attributed to the Craven Group (undifferentiated) until more detailed information becomes available.

The Holme High succession is proved in the Wessenden No.1 and Heywood No.1 boreholes (Figure 11). The Bowland Shale Formation was deposited over the high during late Brigantian and early Pendleian times in the Heywood Borehole and are some 75 m thick, whereas in the Wessenden Borehole the formation is of Kinderscoutian age and only 30 m thick.

DERBYSHIRE HIGH AND EDALE GULF

During the Visean comparatively deep-water basinal facies developed to the south-west (Dovedale and Manifold Valley) and to the north (Alport/Edale basins) of the Derbyshire High. The two basinal areas are commonly shown as linked by the Goyt Trough or Staffordshire Basin to the west of the Derbyshire High. The Dovedale–Manifold Valley succession is known in detail and the lithostratigraphy is summarised by Aitkenhead and Chisholm (1982). The Edale Gulf succession is less well known, the main source of information being the Alport Borehole (Figure 7), which provides a 778.7 m thick succession of the Craven Group ranging from Arundian to Kinderscoutian age. The Visean part of the succession is described in detail by Gutteridge (1991). Similarities in the successions of the two areas, reflecting pulses of carbonate turbidites derived from the same shelf area of the Derbyshire High, allows a common lithostratigraphy to be applied. The description below is largely derived from Aitkenhead and Chisholm (1982).

The initial relatively deeper water deposits between the Derbyshire High and Hathern Shelf are represented by the **Ecton Limestone Formation**. The overlying **Widmerpool Volcanic Member** (Chisholm et al., 1988). In the late Brigantian carbonate production ceased over the Derbyshire High and was replaced by a mudstone-dominated succession, the **Bowland Shale Formation** (formerly Edale Shales).

4.7.5 Ecton Limestone Formation (ECL)

Name

The term was introduced for limestones exposed around Ecton [SK 096 583] (Hudson and Cotton, 1945b) and given as an alternative name for the Mixon Limestones of the Mixon Anticline [SK 045 572]. Formally defined as the Ecton Limestones (Aitkenhead and Chisholm, 1982), it is here redefined as a formation.

Type section

Manifold Light Railway track (disused) near Ecton [SK 0950 5818–SK 0910 5794]: proves basal 108 m of succession (Aitkenhead et al., 1985).

Reference section

Grindon Borehole (SK05SE/19) [SK 0933 5410]: the entire depth of borehole (0 to 124 m) is in lower part of formation, base not proved (Chisholm et al., 1988).

Lithology

The lower part of the formation is dominated by thinly to thickly bedded, brownish-grey, finely bioclastic and peloidal to conglomeratic limestone, containing chert nodules and mudstone partings, in sharp-based, poorly graded turbiditic beds. In the middle, thinly bedded and laminated dark grey micritic limestone passes up into thicker bedded limestone. The upper part of the formation, includes dark grey, fine-grained limestone, and coarser-grained, sharp-based graded beds of turbiditic origin.

In the Alport Borehole (Figure 7) the formation comprises 262 m of fine- to medium-grained, thickly bedded, bioclastic grainstone/packstone limestones, locally slumped, with typically thin shale partings or beds.

Lower and upper boundaries

The base is taken at the base of thicker-bedded, paler grey peloidal and crinoidal bioclastic limestone of the Ecton Limestone Formation, above dark grey, thinly-bedded, fine-grained limestones of the Milldale Limestone Formation.

A transitional conformable top is taken at the lowest thick grey mudstone of the Widmerpool Formation, above grey limestones of the Ecton Limestone Formation.

Thickness

From 225 m thick in the type area, increasing to a maximum of 258 m proved around Grindon [SK 093 541].

Distribution

The Dovedale–Manifold Valley, and the south-western part of the Peak District inlier [SK 09 60 to SK 13 48].

Regional correlation

The formation passes laterally to the east and south-west into the shallower water shelf carbonates of the Hopedale Limestone Formation, Peak Limestone Group (Figure 6).

Genetic interpretation

Proximal turbiditic, sharp-based limestone beds, deposited within the relatively deeper water environment between the Derbyshire High and Hathern Shelf.

Biostratigraphical characterisation

Foraminiferal assemblages indicate an Arundian to early Asbian age for the formation (Aitkenhead et al., 1985).

Age

Arundian to Asbian

4.7.6 Widmerpool Formation (WDF)

The formation is defined fully in its type area of the Widmerpool Gulf (see Section 4.7.10).

In the Dovedale–Manifold Valley the formation comprises up to 193 m of interbedded turbiditic, sharp-based, fining upwards limestone beds and black mudstones. The formation ranges from limestone-mudstone interbeds of equal proportions (former Mixon Limestone-Shales) to mudstone with subordinate limestone interbeds (former Longstone Mudstone Formation). The formation is late Asbian to Brigantian age with a diachronous conformable base and passes laterally to the east into the Hopedale Limestone of the Peak Limestone Group. In the Alport Borehole (Figure 7) the formation is 188 m thick. In the borehole the formation comprises thickly bedded, bioclastic grainstone/packstone limestones interbedded with dark grey shale thin calcarenite and calcisiltite beds. Beds of reworked volcanoclastic grains and bedded tuffs are also present. The formation represents gradations from comparatively proximal to distal carbonate turbidites deposited within a predominantly low-energy, deep-water environment.

4.7.6.1 TISSINGTON VOLCANIC MEMBER (TIVO)

Name

The unit was first named by Chisholm et al. (1988).

Type section

Lees Farm Borehole (SK 15 SE/12) [SK 1818 5016]: partial section, between 182.02 m and 152.46 m (Chisholm et al., 1988).

Reference sections

Near Woodeaves Farm [SK 1899 5115]: 4.2 m thick (Arnold-Bemrose, 1894).

Tissington No.2 Borehole (SK 15 SE/14) [SK 1901 5189]: section between 26.4 m and 42.8 m (Chisholm et al., 1988).

Lithology

Mainly a hyaloclastite, composed of highly amygdaloidal and partly carbonated basaltic rock fragments. Minor basaltic lavas also occur.

Lower and upper boundaries

The base of the member is taken at the first bed of slumped, laminated dark grey to grey dolomitised limestone containing angular lapilli of amygdaloidal basalt lava (in Lees Farm Borehole, SK 15 SE/12); depth 182.02 m.

The top is taken at the uppermost occurrence of calcitic igneous rock and mudstone, or of hyaloclastite. This is overlain by calcareous mudstones and thin limestones of the Widmerpool Formation (in Tissington 1 & 2 Boreholes, SK 15 SE/13 & 14).

Thickness

Up to 44 m recorded

Distribution

The principal outcrop extends from a locality 250 m north-west of Pethills [SK 207 493] to about 100 m south-east of Crakelow Farm [SK 177 535].

Genetic interpretation

The hyaloclastite was probably produced by the ejection of magma into water, accumulating on a southward-facing submarine slope.

Biostratigraphical characterisation

In the Lees Farm Borehole the member lies in the range of late P_{1c} to early P₂, probably in the P_{1d} Zone (Chisholm et al., 1988).

Age
Brigantian

4.7.7 Bowland Shale Formation (BSG)

The Bowland Shale Formation (formerly Edale Shales) is defined fully from its type area in the Craven Basin (see Section 4.7.4).

The Bowland Shale Formation of the Edale Gulf is approximately 356 m thick and ranges from the base of the Cravenoceras leion Marine Band (base Pendleian) to the *Reticuloceras reticulatum* (R_{1c}) Biozone of late Kinderscoutian age. The formation comprises mainly dark grey shale and mudstone with disseminated pyrite and limestone and ironstone nodules. In the lower part of the formation a succession of grey-green calcareous shale with very thin beds of calcareous quartzose siltstones (known as the Crowstones) may represent the distal delta-slope equivalent of the Morridge Formation (see Section 4.8.7).

WIDMERPOOL GULF

Within the half-graben of the Widmerpool Gulf the Craven Group has a distinct formational nomenclature to that present within the north-western continuation of the trough exposed in the Peak District inlier (Dovedale–Manifold Valley). Despite their concealment beneath younger Carboniferous and Triassic strata, the succession is well constrained by deep hydrocarbon boreholes, such as the Long Eaton No.1 and Duffield boreholes (Figure 7) and seismic lines. The Tournaisian and Visean succession, described by Carney et al. (2001), is in ascending order; the **Long Eaton, Lockington Limestone** and **Widmerpool formations** (Figure 6). The Widmerpool Formation includes subaqueous tuffs, lavas and hyaloclastites recorded from the upper part of the formation (P_2 Zone), including the **Ratcliffe Volcanic Member**. The **Bowland Shale Formation** (formerly the Edale Shales), of Namurian age, is the youngest formation of the Craven Group within the Widmerpool Gulf.

4.7.8 Long Eaton Formation (LOE)

Name

The formation was named after the succession proved in the Long Eaton No.1 Hydrocarbon Borehole (Brandon, 1996). Reference sections

Long Eaton No.1 Borehole (SK43SE/161) [SK 4640 3166], partially cored, from 2747 m to 880 m depth (Figure 7) (Brandon, 1996).

Ratcliffe on Soar Borehole (SK52NW/72) [SK 5081 2913], from 1832 m to 1157 m depth (Carney and Cooper, 1997; Carney et al., 2001).

Lithology

Dark grey or brown calcareous mudstones and siltstones, with thin beds of bioclastic limestone, graded calcisiltite, packstone and grainstone (description from borehole chip samples). Anhydrite pseudomorphs after gypsum are present in the lower part of the formation.

Lower and upper boundaries

The base is not proved by borehole, although known to locally pass down to nodular anhydrite and interbedded dolostone in the Long Eaton No.1 Borehole, possibly a lateral equivalent of the Hathern Anhydrite Formation.

The top of the formation is taken at the base of lower, thickly bedded turbiditic limestone of the Lockington Limestone Formation.

Thickness

At least 1867 m thick in the Long Eaton Borehole (Figure 6). Seismic interpretations suggest the formation thickens south-westwards within the Widmerpool half-graben to a maximum of 4000 m.

Distribution

Does not appear at outcrop, and is limited to the Widmerpool half-graben in the sub-surface.

Regional correlation

The formation is similar in nature to the Hodder Mudstone Formation of the Craven Basin, which was deposited broadly at the same time.

Genetic interpretation

Deposition of these strata was probably by sediment gravity flow mechanisms and the beds are interpreted as carbonate turbidites. The anhydrite pseudomorphs may imply periodic exposure to surface evaporation, but may also be due later tectonic activity, which caused ponding of saline groundwaters (Carney et al., 2001). The internal unconformity may relate to a late Holkerian phase of basin inversion, also seen on the margin of the Wales–Brabant High (Fraser and Gawthorpe, 1990).

Biostratigraphical characterisation

Microfaunas show the formation ranges in age from early Chadian to Asbian age. However, the apparent absence of strata of late Chadian and Arundian age in the Long Eaton Borehole suggests the presence of a depositional hiatus within the formation (Riley, 1997b).

Age

Chadian to Asbian

4.7.9 Lockington Limestone Formation (LOCL)

Name

The formation was named after the succession proved in the Long Eaton No.1 Hydrocarbon Borehole (Brandon, 1996).

Reference sections

Long Eaton No.1 Borehole (SK43SE/161) [SK 4640 3166], between 880 m and 695 m depth (Figure 7) (Brandon, 1996).

Ratcliffe on Soar Borehole (SK52NW/72) [SK 5081 2913], between 1157 m and 1300 m depth (uncored) (Carney and Cooper, 1997; Carney et al., 2001).

Lithology

Packages between 15 and 30 m thick of pale brown, argillaceous to sandy limestone, displaying turbiditic facies, normal graded with sharp bases, interbedded with thinner sequences of pyritic and carbonaceous mudstone and thin sandstone beds. The formation is notable for the presence of a serrated wireline signature.

Lower and upper boundaries

The base of the formation is taken at the base of the lowest thick, pale brown turbiditic limestone package, where it rests on grey-brown calcareous mudstones and limestones of the Long Eaton Formation.

The top of the formation is taken at the top of the uppermost thick limestone of the pale brown Lockington Limestone Formation, with the base of the overlying Widmerpool Formation, consisting of grey-brown mudstones with thin argillaceous limestones.

Thickness

From 143 m to 185 m thick; maximum thickness in the Long Eaton Borehole (Figure 7).

Distribution

Does not appear at outcrop; limited to the Widmerpool half-graben in the subsurface [SK 53].

Regional correlation

The formation is of comparable Asbian age and depositional environment with the Pendleside Limestone Formation of the Craven Basin.

Genetic interpretation

The formation is interpreted as a deep-water turbidite deposit.

Age

Asbian

4.7.10 Widmerpool Formation (WDF)

Name

The name was first applied to the late Visean basinal succession proved in the Duffield Borehole (Aitkenhead, 1977) and named after a borehole near Widmerpool [SK 6366 2958] (Falcon and Kent, 1960). The formation was formally defined by Aitkenhead and Chisholm (1982). The geographical extent of the formation has been extended to include Dovedale and Manifold Valley, with the Mixon Limestone Shales by Aitkenhead and Chisholm (1982) here redefined as Widmerpool Formation.

Type section

Duffield No.1 Borehole (SK34SW/5) [SK 3428 4217], Derbyshire: from 1047.5 to 41.2 m; base of formation not proved (Aitkenhead, 1977) (Figure 7).

Reference sections

Lees Farm Borehole (SK15SE/12) [SK 1818 5016]: 251.49 to 12.7 m, base not seen; includes Tissington Volcanic Member (Chisholm et al., 1988).

Stream, south-west of Brookhouse Farm, Kniveton [SK 2066 4939 to 2027 4939]: 72 m succession exposed in lower part of the section, including Tissington Volcanic Member (Chisholm et al., 1988).

Formal subdivisions

Lavas and hyaloclastites are common in the Widmerpool Formation, with two named members formally defined, the Ratcliffe Volcanic Member present in the Widmerpool half-graben and the Tissington Volcanic Member in Dovedale/the Manifold Valley (see Section 4.7.6).

Lithology

Dark to pale brown or grey, calcareous and locally carbonaceous, pyritic, fissile mudstone, thinly interbedded with turbidite, argillaceous cherty limestone and thin beds of quartzose siltstone, calcareous or quartzose sandstone and tuff. The proportion of limestone to mudstone increases northwards, with the formation passing laterally into the Hopedale Limestone Formation of the Derbyshire platform.

Lower and upper boundaries

The base of the formation is only seen in Ratcliffe-on-Soar and Long Eaton boreholes (Carney et al., 2001), where

it is taken at the top of the uppermost thick bed of pale brown argillaceous to sandy limestone, of the Lockington Limestone Formation. Overlain by dark green mudstone of the Widmerpool Formation, which may be unconformable on other units, such as the Milldale Limestone Formation.

The top of the formation is taken at the base of dark grey fossiliferous, fissile mudstone of the Cravenoceras leion Marine Band where present. Otherwise taken at start of a dark grey mudstone and siltstone sequence lacking limestones of the Bowland Shale Formation, present above the top of the uppermost limestone bed of the Widmerpool Formation.

Thickness

From 741 m thick in the Ratcliffe-on-Soar Borehole (SK52NW/72) at [SK 5081 2913] (Carney and Cooper, 1997), within the Widmerpool half-graben, or attenuated development of 110–130 m on the Hathern Shelf and northern margin of the Wales–Brabant High.

Distribution

Crops out discontinuously north-westwards from Wardgate to Kniveton [SK 20 50], Grindonmoor Gate and Butterton [SK 07 56] in Derbyshire; restricted to the Widmerpool half-graben [SK53] and Hathern Shelf [SK52] at subcrop (Figure 6).

Regional correlation

The formation passes laterally into the Hopedale Limestone Formation of the Derbyshire platform

Genetic interpretation

The formation is interpreted as deep-water turbidite deposits.

Biostratigraphical characterisation

The lowermost part of the formation in the Ashbourne district (former Mixon Limestone Shales) includes ammonoids indicative of the B2 Zone, of late Asbian age (Chisholm et al., 1988). The top of the formation is taken at the base of the Namurian *Cravenoceras leion* Biozone.

Age

Late Asbian and Brigantian

4.7.10.1 RATCLIFFE VOLCANIC MEMBER (RAVO)

Name

The name was first proposed from the description of the Ratcliffe-on-Soar borehole (Carney and Cooper, 1997; Carney et al., 2001).

Type section

Ratcliffe on Soar borehole (SK52NW/72) [SK 5081 2913]; full thickness between 507 m and 631 m depth (not cored) comprising five tuff beds intercalated with mudstone (Carney and Cooper, 1997; Carney et al., 2001).

Lithology

Chip samples indicate a sequence of olive green to brown silty carbonaceous mudstones and limestones with beds of bluish grey, pyritous tuff.

Lower and upper boundaries

The base of the member is taken at the base of the lowest tuff bed at 631 m depth in Ratcliffe-on-Soar borehole.

The top is taken at the top of the highest tuff bed, at 507 m depth in Ratcliffe on Soar borehole.

Thickness

Measured as 124 m in the Ratcliffe on Soar borehole.

Distribution

Does not crop out. Proved in the Ratcliffe on Soar borehole.

Regional correlation

The member is correlated with similar tuffaceous beds of P₂ age in the Duffield Borehole (Aitkenhead, 1977) and the Tissington Volcanic Member of the Ashbourne district.

Genetic interpretation

Submarine volcanic ashfall deposits.

Age

Brigantian

4.7.11 Bowland Shale Formation (BSG)

The Bowland Shale Formation (formerly the Edale Shales), of Namurian age, is the youngest formation of the Craven Group within the Widmerpool Gulf. The formation is defined fully from its type area in the Craven Basin (see Section 4.7.4).

The Bowland Shale Formation of the East Midlands comprises dark grey calcareous mudstone with thin turbiditic sandstones. The base of the formation is taken at the base of the Cravenoceras leion Marine Band. The top of the formation occurs generally at the base the Millstone Grit Group, a highly diachronous boundary that is considerably younger in the southern part of the province (Figure 10). The formation is 166m thick in the Duffield Borehole (Figure 7), ranging from Pendleian to Chokierian age. Despite the chronostratigraphical significance as the boundary between the Visean and Namurian, the base of the formation is justified lithostratigraphically by the decrease in carbonate turbidites and concomitant increase in siliciclastic sandstone turbidites derived from the Wales–Brabant High. The Bowland Shale Formation passes laterally southwards into the siliciclastic sandstone-dominated Morridge Formation of the northern margin of the Wales–Brabant High.

NORTH WALES

In North Wales the nomenclature of Dyerth and Gronant groups of Warren et al. (1984) was essentially chronostratigraphical, distinguishing pre-Brigantian and Brigantian strata. This nomenclature took no account of the prominent facies variation within these groups between shelf carbonates and slope turbidites. The basinal facies has been redefined by the SFC Committee as comprising the **Prestatyn Limestone** and **Teilia formations** of the Craven Group (Figure 8). These formations consist of carbonate turbidites comparable to and synchronous with the Mixon Formation of Derbyshire and Widmerpool Formation of the Widmerpool Gulf. During the Namurian the basinal facies of North Wales consists of the **Pentre Chert Formation**, a succession of cherts and cherty mudstones comparable to cherts developing at the same time on the Askrigg Block, to the north of the Pennine Basin. The Pentre Chert Formation is overlain by the **Bowland Shale Formation**, a succession of marine, brackish and non-marine mudstones. The Pentre Chert and Bowland Shales intertongue with, and pass laterally southwards into, the Cefn-y-fedw Sandstone Formation, a fluvio-deltaic succession discussed in the section on the margins of the Wales–Brabant High. By late Namurian to early Westphalian times, the upper part of the Bowland Shale Formation interdigitates and is succeeded by the Gwespyr Sandstone of the Millstone Grit Group.

The eastward continuation of the Craven Group below the Permo-Triassic strata of the Cheshire Basin is proved in the Croxteth No.1 Borehole and Blacon East No.1 Borehole (Figure 9). The Croxteth Borehole comprises a 36 m thick succession of late Brigantian dark grey shales, locally calcareous, with subordinate thin grey limestone beds, overlain by 410 m of Pendleian to early Marsdenian dark grey shale and mudstone, with thin shelly limestone beds with crinoid and brachiopod debris present in the lower part of the formation (Magraw and Ramsbottom, 1956). The Blacon East Borehole contains a 627 m thickness of dark grey calcareous siltstone, occasionally pyritic and carbonaceous, with the base of Brigantian age and the top poorly constrained to Pendleian to Kinderscoutian age. The successions present within both boreholes probably equate with the Bowland Shale Formation.

4.7.12 Prestatyn Limestone Formation (PRL)

Name

Previously referred to as the Prestatyn Limestone (Warren et al., 1984), the unit is here formally redefined as a formation.

Type sections

Series of adjoining disused quarries, Prestatyn [SJ 0707 8178 to SJ 0718 8212]: exposure of about 120 m of the formation, but with the base faulted (Warren et al., 1984).

Lithology

Thin-bedded limestone turbidites (packstones and wackestones), occurring as fining-upwards graded beds, with mudstone interbeds; local thick-bedded units of resedimented fine-grained limestone (grainstones) and isolated rolled blocks of knoll reef limestone; scattered chert nodules.

Lower and upper boundaries

The base is not exposed, but presumed to be a conformable contact between thicker-bedded limestones (packstones and grainstones) of the underlying Llanarmon Limestone Formation and thinner-bedded Prestatyn Limestone facies.

The top of the formation is a conformable contact with interbedded mudstones and dark argillaceous limestones of the overlying Teilia Formation.

Thickness

Over 120 m

Distribution

Prestatyn area of North Wales [SJ 07 81]

Genetic interpretation

The formation formed as an apron of late Asbian limestone turbidites, resedimented carbonate detritus and fallen blocks of 'reef' limestone derived from the adjacent North Wales Clwyd Limestone Group platform to the south (Davies et al., 2004).

Biostratigraphical characterisation

Aldridge et al. (1968) recorded a late Asbian conodont assemblage including *Gnathodus bilineatus* and *G. girtyi*, and Reynolds (1970) recorded the same taxa and *Mestognathus bipluti* from a horizon just below the top of the formation in the Gronant Borehole (SJ08SE/22) at about 110 m depth.

Age

Late Asbian

4.7.13 Teilia Formation (TLB)

Name

The formation was previously referred to as the Black Limestone on the Rhyll (95) Sheet. However, the Teilia Formation of Hind and Stobbs (1906) was preferred by Warren et al. (1984). The definition of the formation is here redefined.

Type section

Disused quarry, west-south-west of Teilia [SJ 0793 8137]: now largely degraded, the quarry formerly exposed an approximately 8 m section close to the base of the formation (Warren et al., 1984).

Lithology

Interbedded calcareous mudstones and dark grey, tabular-bedded, argillaceous limestones containing a pectinoid bivalve and goniatite fauna.

Lower and upper boundaries

The base of the formation is marked by the entry of thicker mudstones and dark limestones above conformable contact with thin-bedded limestones of the underlying Prestatyn Limestone Formation; locally rests on 'knoll reef' limestones.

The top of the formation is a conformable contact with bedded cherts of the Pentre Chert Formation.

Thickness

Between 40 and 90 m

Distribution

Prestatyn area, north-east Wales [SJ 07 81]

Genetic interpretation

The Teilia Formation represents a basinal, turbiditic and hemipelagic marine mudstone facies which overlapped the northern margin (including knoll reefs) of the North Wales Visean platform during the Brigantian.

Biostratigraphical characterisation

The formation contains a typical assemblage of *Dunbarella persimilis*, *Posidonia becheri*, and *Arnsbergites sphaericostratus*, indicative of a Brigantian (P_{1c}) age (Warren et al., 1984).

Age

Brigantian

4.7.14 Pentre Chert Formation (PECH)

Name

Originally referred to as the Chert Beds, the unit was called the Pentre Cherts by Warren et al. (1984) and subsequently redefined as the Pentre Chert Formation by Davies et al. (2004).

Type sections

Pentre Quarry [SJ 095 828] and Gronant Borehole drilled in the floor of the quarry (SJ08SE/22) [SJ 0950 8279], Gronant: together the quarry and borehole provide a continuous section through the basal 83 m of the formation (Warren et al., 1984).

Lithology

Banded glassy cherts and siliceous (cherty) mudstones with subordinate thin siltstone and silicified crinoidoidal lime-

stone beds, and scattered beds of pebbly quartzose sandstone, arranged in thickening-upwards cycles. Petrographic studies suggest that recrystallised radiolaria tests and rod-shaped sponge spicules are locally abundant in some of the cherts.

Lower and upper boundaries

The base is a conformable or disconformable contact between chert lithologies of the Pentre Chert Formation and mudstones of the underlying Teilia Formation around Prestatyn, or, to the south, with limestones of the Cefn Mawr Limestone Formation.

The top of the formation is taken at the chert/mudstone contact at the base of the Bowland Shale Formation.

Thickness

The formation shows marked lateral thickness variation from about 40 m in the north to 180 m in the south.

Distribution

North-east Wales between Prestatyn [SJ 09 83] and Halkyn Mountain [SJ 21 69].

Genetic interpretation

The Pentre Chert Formation represents an offshore to basinal early Namurian facies deposited across the northern sector of former Visean limestone platform. The formation accumulated predominantly from suspension in moderately deep water, largely below the storm wave-base, in a setting isolated from coarser grade siliclastic contamination, but in which sponges and radiolaria were abundant. Thin sandstone and crinoidal limestone beds were possibly introduced by storms and/or as turbidites. The formation also exhibits the effects of extensive secondary silicification.

Biostratigraphical characterisation

The age of the formation is no older than the late Brigantian P_{2b} Subzone and no younger than the Pendleian E1b Subzone (Ramsbottom, 1974).

Age

Pendleian

4.7.15 Bowland Shale Formation (BSG)

The **Bowland Shale Formation** (formerly Holywell Shale Formation) is fully defined from the type area of the Craven Basin (see Section 4.7.4).

In North Wales the formation comprises mudstones with subordinate thin sandstones, impure limestones and impersistent coal seams. The mudstones are typically dark grey or olive brown, weathering to buff or reddish-brown hues, finely micaceous and fissile to blocky (Davies et al., 2004). Marine bands, comprising highly fossiliferous, black, fissile mudstone occur up to several metres thickness. The strata between the marine bands are generally unfossiliferous apart from scattered fish and plant debris. Sideritic bands and nodules and small phosphate nodules are sporadically developed. Grey, blocky mudstones with sideritised rootlets, locally developed beneath rare thin coal seams, represent seatearths. The interbedded sandstones are fine- to medium-grained, quartzose and generally 0.01 to 0.05 m thick, although beds up to 1.5 m occur in places. They are locally micaceous and contain small amounts of carbonaceous material, disseminated or concentrated in thin laminae. Cross-lamination is common, with locally developed flaser bedding and bioturbation structures. At Holywell the formation is 152 m thick. The formation exhibits complex

intertonguing with the Cefn-y-fedw Sandstone. The age of the Bowland Shales in North Wales is established from the ammonoid-bearing marine bands (Ramsbottom, 1974), which demonstrate that all the Namurian stages are present. The Pendleian *Cravenoceras malhamense* Marine Band (E_{1c}) is the lowest recognised ammonoid horizon. The formation accumulated in a pro-delta environment, showing increased marine influence to the north.

4.8 MILLSTONE GRIT GROUP (MG)

The Millstone Grit Group was deposited by repeated progradation of deltas. The heterolithic succession of grey sandstone, siltstone and mudstone with subordinate coal and seatearth is characterised by the commonly coarse-grained nature of the sandstone (formerly referred to as grit), typically an arkosic or sub-arkosic arenite in the northern part of the Central Pennine Sub-basin and protoquartzitic arenites in the south. Similar strata present along the southern flanks of the Wales–Brabant High (Figure 2) have been historically referred to as Millstone Grit. However, as the succession was deposited in the South Wales Basin, isolated from the Pennine Basin to the north, it is considered to be distinct from the Millstone Grit Group and is now referred to as the Marros Group south of the Wales–Brabant High (see Section 5.3).

Historically, the Millstone Grit of the northern part of the Central Pennine Sub-basin has been divided chronostratigraphically into the Namurian stages bounded by widespread marine bands. Where these marine bands cannot be recognised it will be necessary to leave the group undivided. This is comparable to the system used to subdivide the cyclical Coal Measures. Along the southern margins of the Pennine Basin isolated outcrops of Millstone Grit Group are given distinct formation names: the Morridge Formation of north Staffordshire, the Cefn-y-fedw Formation of North Wales and Cornbrook Sandstone Formation of Shropshire.

The cyclic clastic sequences show a broad upwards coarsening. Marine bands are common, representing transgressive events. These consist typically of dark grey to black, calcareous, shaly mudstone about 0.5 m, but ranging up to 15 m thick. Distinct ammonoid fauna and the extensive correlation of the marine bands makes them of primary stratigraphical importance. A total of 46 ammonoid bearing marine bands are recognised and named after the species present (Table 3), whereas 3 marine bands lacking diagnostic ammonoids have been named after geographical type localities.

PENNINES

The thickest development of the Millstone Grit Group is in the northern part of the Central Pennine Sub-basin, where 1225 m is recorded in Wharfedale (Ramsbottom et al., 1978). The southward thinning of the group is accounted for by the diachronous nature of the base of the group, which is younger towards the south (Figure 10).

There are two main types of delta sub-facies recognised in the Central Pennine Sub-basin (Figure 10):

- Deep-water deltaic sequences are commonly several hundred metres thick, e.g. Pendle Grit Member (550 m), Lower Kinderscout Grit (570 m), Roaches and Ashover grits (360 m). They comprise a lower turbidite sequence, a middle upwards-coarsening succession dominantly of siltstone and an upper part of erosive channels filled with pebbly coarse-grained

sandstones (Walker, 1966b; Collinson, 1969; McCabe, 1978). These represent deltas fed by large distributaries in which coarse sands were transported in feeder channels, by-passing the delta slope to be deposited in a delta-front apron of coalescing turbidite lobes.

- Shallow-water deltaic sequences are commonly tens of metres thick. They comprise a lower succession which coarsens upwards from mudstone to sandstone, overlain by laterally extensive sandstones and commonly capped by seatearths and thin coals. These deltas lacked significant transport of sediment by turbidity currents. The lower part of the succession is dominated by mouth-bar deposits that are overlain by distributary sands. These are mostly sheet-like and laterally extensive, e.g. Guiseley Grit, Chatsworth Grit, Rough Rock. However, elongate deltas are locally developed, e.g. East Carlton Grit, Haslingden Flags.

Although it is broadly the case that the deep-water deltaic succession occurs in the lower part of the group and the shallow-water deltaic succession in the upper part (Figure 10), the complex interdigitation of the two sub-facies along the northern margin of the Pennine Basin hinders use of these sub-facies to define a truly lithostratigraphical formational scheme.

The SFC Committee concluded that formations within the Millstone Grit Group should be based upon key basin-wide marine bands, similar to the subdivision of the overlying Coal Measures Group. The historical precedence was established in the Bradford district (Stephens et al., 1953) where six groups were defined using ammonoid biozones, which broadly correspond to the modern stages of the Namurian. Each of the seven Namurian Stage successions has been assigned a distinct formation name, with the exception of the thin, often mudstone-dominated successions of the Chokierian and Alportian, which have been joined to form a single formation (Figure 4). Key boreholes and geophysical logs for the Millstone Grit Group are presented in Figures 9 and 11.

The new name **Pendleton Formation** is proposed to identify all Millstone Grit Group strata of Pendleian age and supersedes previous terms such as Pendle Grit Formation and Brennand Grit Formation, used in the Lancaster district for components of the Pendleton Formation (Brandon et al., 1998). The thick turbiditic succession of the **Pendle Grit Member** is the only formally defined member of the Pendleton Formation. The new name **Silsden Formation** is proposed to identify all Millstone Grit Group strata of Arnsbergian age. Some of the former formations identified in the Lancaster district are downgraded to member status, e.g. **Roeburndale** and **Cloughton members**. Thick mudstones are present in Lancashire, including the Caton Shales of E_{2b} age, 70 m thick, and the Sabden Shales of E_{2b} to Kinderscoutian age, 600 m thick. The new name **Samlesbury Formation** is proposed to identify all Millstone Grit Group strata of Chokierian and Alportian age. The new name **Hebden Formation** is proposed to identify all Millstone Grit Group strata of Kinderscoutian age. Former formations identified in the Lancaster district are downgraded to informal bed status. The new name **Marsden Formation** is proposed to identify all Millstone Grit Group strata of Marsdenian age. The new name **Rosendale Formation** is proposed to identify all Millstone Grit Group strata of Yeadonian age.

4.8.1 Pendleton Formation (PENDL)

Name

The new name Pendleton Formation is proposed to identify all Millstone Grit Group strata of Pendleian age.

Pendleton Formation supersedes previous terms such as Pendle Grit Formation and Brennand Grit Formation, used in the Lancaster district for components of the Pendleton Formation (Brandon et al., 1998). The formation coincides with the Skipton Moor Grits of the Bradford district, defined by Stephens et al. (1953).

Type sections

Pendleton Moor on the western flank of Pendle Hill between Light Clough [SD 7516 3764], the basal stratotype for the Pendleian Stage, and the excellent section of Mearley Clough [SD 785 411]: exposure of the base of the formation (Earp et al., 1961).

Faugh's Delph [SD 820 392]: the upper part of the formation is exposed with about 30 m of very coarse-grained, massive sandstone of the Warley Wise Grit (Earp et al., 1961).

Formal subdivisions

The widespread Pendle Grit Member.

Lithology

Fine to very coarse-grained and pebbly, feldspathic sandstone, interbedded with grey siltstone and mudstone, with subordinate marine black shales, thin coals and seatearths.

Lower and upper boundaries

The base of the formation is taken at the base of the first thick quartz-feldspathic sandstone of Pendleian age, present above the dark grey, carbonaceous, fissile mudstone of the Bowland Shale Formation, which in the north Lancashire area and Bradford–Harrogate districts, is at the base of the Pendle Grit Member, and on the Askrigg Block, taken at an unconformity of E_{1c} age at the base of the Bearing or Lower Howgate Edge Grit (Brandon et al., 1995), overlying the mixed shelf carbonate and deltaic succession of the Yoredale Group. The base is taken at the point in the sequence where sandstone becomes predominant.

The top of the formation occurs at the sharp conformable base of the dark grey, fissile mudstone of the Cravenoceras cowlingsense Marine Band with eponymous fauna, which is commonly underlain by a thin, fine-grained, calcareous and phosphatic sandstone of the Pendleton Formation. Locally, in the absence of the Cravenoceras cowlingsense Marine Band, the top of the formation is taken at the top of the Warley Wise Grit (north Lancashire area and Bradford–Harrogate districts), the base of the Mirk Fell Ironstones (Stainmore Trough) or the top of the Lower Howgate Edge Grit (northern part of the Askrigg Block).

Thickness

Lancaster 800 m; Bradford 600 m; southern part of the Askrigg Block up to 45 m thick with a condensed succession, about 30 m thick present in the Great Shunner Fell area, dominated by the Lower Howgate Edge Grit.

Distribution

The Craven Basin of north Lancashire and north Yorkshire between Lancaster [SD 47 61], Pendle Hill [SD 80 41], Skipton Moor [SE 00 50] and Harrogate [SE 30 55], and also present across the southern part of the Askrigg Block, and in the Masham district [SE 29] (Dunham and Wilson, 1985).

Regional correlation

The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Genetic interpretation

During the Pendleian the fluvial succession of the Bearing Grit crossed the Askrigg Block occupying an incised valley (Figure 10). On reaching the Craven Fault System the marked slope into the Central Pennine Sub-basin resulted in deep-water turbidite-fronted deltas prograding into the northern part of the sub-basin, forming the Pendle Grit Member. The deposits typically comprise background sedimentation of thinly interbedded silty mudstones, siltstones and fine-grained sandstones deposited on the submarine pro-delta slope. These are cut by massive, laterally imper-sistent, coarse-grained, pebbly sandstones filling turbidite channels (Aitkenhead et al., 2002). The great thickness of sediments was sufficient to infill the northern part of the basin by late Pendleian times and allow a shallow-water fluvio-deltaic coarse-grained, cross-bedded successions of the Warley Wise Grit to extend several kilometres southwards into the basin.

Biostratigraphical characterisation

The top of the formation is defined at the base of the *Cravenoceras cowlingsense* Ammonoid Zone.

Age

Pendleian (E_1)

4.8.1.1 PENDLE GRIT MEMBER (PG)

Name

The name Pendle Grit was first used by R H Tiddeman on the Geological Survey One-inch Old Series Sheet 92SE, published in 1878, for the grit capping Pendle Hill. In the Bradford district the name was not used by Stephens et al. (1953), the interval equating with the lower part of the Skipton Moor Grits. The unit was first defined as the Pendle Grit Formation in the Settle district (Arthurton et al., 1988) and used by subsequent authors (Aitkenhead et al., 1992; Brandon et al., 1998; Waters, 1999). Brandon et al. (1998) included the mudstone-dominated Surgill Shale Member within the formation. The redefined Pendle Grit Member includes the Surgill Shales, as proposed by Brandon et al. (Brandon et al., 1998).

Type section

Little Mearley Clough, Pendle Hill, Lancashire [SD 785 411], stream section south-east of Little Mearley Hall at top and highest slope of Pendle Hill escarpment: continuous succession c.152 m thick (Earp et al., 1961).

Reference sections

Trough of Bowland, Lancashire: banks of stream immediately west of the Trough of Bowland road [SD 613 537].

Left bank of the River Ribble, [SD 6790 3631 to 6775 3595], 450 to 820 m northeast of Salesbury Hall: shows top 46 m and the junction with the overlying Warley Wise Grit (Aitkenhead et al., 1992).

Lithology

Medium- to coarse-grained feldspathic sandstone with subordinate interbedded siltstone and mudstone. Commonly in sharp-based, massive beds from 0.2 to 4.5 m thick.

Lower and upper boundaries

Commonly a gradational coarsening upwards change from the underlying Bowland Shale Formation means that the base is taken at the point in the sequence where sandstone becomes predominant. The top of the member is taken at the point in the sandstone succession where cross-bedded sandstones become evident.

Thickness

From about 200 m at northern margin of the Lancaster district to about 475 m on Longridge Fell, and an average of 457 m in the Clitheroe district.

Distribution

Widespread in Craven Basin in Lancaster, Settle, Garstang, Clitheroe, Bradford sheet areas.

Genetic interpretation

The deposits typically comprise background sedimentation of thinly interbedded silty mudstones, siltstones and fine-grained sandstones deposited on the submarine pro-delta slope. These are cut by massive, laterally impersistent, coarse-grained, pebbly sandstones filling turbidite channels (Aitkenhead et al., 2002).

Biostratigraphical characterisation

Fossils are generally rare in the member. The member occurs above the *Cravenoceras malhamense* (E_{1c1}) Marine Band and below the *Cravenoceras cowlingsense* (E_{2a1}) Marine Band, indicating a late Pendleian E_{1c} Ammonoid Subzone age.

Age

Pendleian (E_1)

4.8.2 Silsden Formation (SILS)

Name

The new name Silsden Formation is proposed to identify all Millstone Grit Group strata of Arnsbergian age. Silsden was chosen as the name had been used in the Bradford district for the Silsden Moor Grit Group (Stephens et al., 1953). The base of the Silsden Moor Grit Group was defined at the base of the *C. cowlingsense* Marine Band, but the top of the group was taken as the base of the *Nuculoceras nuculum* Marine Band, resulting in part of the Arnsbergian succession falling within the overlying Middleton Grit. The newly defined formation is named after Silsden village [SE 040 470], to distinguish it from Silsden Moor Grit Group, named after the upland area to the west of Silsden. Silsden Formation supersedes previous terms such as Roeburndale, Ward's Stone Sandstone, Caton Shale, Claughton, Silver Hills Sandstone and Crossdale Mudstone formations, used in the Lancaster district for components of the Silsden Formation (Brandon et al., 1998).

Type area

The newly defined formation is named after Silsden village [SE 040 470], West Yorkshire, to distinguish it from Silsden Moor Grit Group, named after the upland area to the west of Silsden.

Basal exposures at Lister Gill [SE 0091 4946], overlain by interbedded turbiditic sandstone, micaceous mudstone, Marchup Grit and by dark grey fossiliferous mudstones of the *Eumorphoceras yatesae* and *Cravenoceras edalensis* marine bands along Bracken Hill Gill [SE 0304 4686 to 0324 4697] (Addison, 1997).

Formal subdivisions

Roeburndale and Claughton members

Lithology

Fine- to very coarse-grained pebbly feldspathic sandstone, interbedded with grey siltstone and mudstone and subordinate marine black shales, thin coals and seatearths. The lower part of the formation is dominated by thinly bedded

sandstone, siltstone and mudstone forming sharp-based, normal graded beds of interpreted turbiditic origin.

Lower and upper boundaries

The base is taken at a sharp base of dark grey fissile claystones of the *Cravenoceras cowlingsense* Marine Band with diagnostic eponymous fauna, commonly underlain by a thin, fine-grained, calcareous and phosphatic sandstone of the Pendleton Formation. Elsewhere the boundary is taken at the base of the first thick quartz-feldspathic sandstone of Arnsbergian age, present above the dark grey, carbonaceous mudstone of the Bowland Shale Formation. It is taken at the base of the Mirk Fell Ironstones in the Stainmore Trough or the top of the Lower Howgate Edge Grit in the northern part of the Askrigg Block.

The top of the formation is taken at the base of the dark grey fissile claystones of the *Isohomoceras subglobosum* Marine Band, with diagnostic eponymous fauna. Where the marine band is not proven, the boundary is taken at the base of thick, medium or dark grey mudstone succession, with numerous marine bands of the Samlesbury Formation. It is taken at the top of the Lower Follifoot Grit in the southern part of the Askrigg Block, or the base of a mudstone succession with *Lingula* in the Stainmore Trough.

Thickness

Lancaster 1000 m; Bradford 400 m; Askrigg Block and Stainmore Trough up to 190 m.

Distribution

Craven Basin of north Lancashire and north Yorkshire, between Lancaster [SD 47 61], Pendle Hill [SD 80 41], Skipton Moor [SE 00 50] and Harrogate [SE 30 55]. Also present across the southern part of the Askrigg Block, Masham district [SE 29] (Dunham and Wilson, 1985).

Regional correlation

The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Genetic interpretation

The succession is dominated by a great thickness of turbiditic siltstones and thin sandstones with periodic progradation of shallow-water lobate deltas about 10–15 km south into the Central Pennine Basin (Waters, 1999).

Biostratigraphical characterisation

Entirely of Arnsbergian age with base taken at base of the *Cravenoceras cowlingsense* Marine Band and top at the base of the lowermost *Isohomoceras subglobosum* Marine Band.

Age

Arnsbergian (E_2)

4.8.2.1 ROEBURNDALE MEMBER (RBL)

Name

The Roeburndale Grit Group of Moseley (1954) was renamed the Roeburndale Formation and the boundaries redefined by Arthurton et al. (1988). The unit is here formally redefined as a member.

Type area

Lancaster Fells [SD 56]

Reference sections

Snab Beck, Aughton [SD 560 687]: section commences 600 m upstream from The Snab, with exposure of the

uppermost part of the member above the Close Hill Siltstone (Brandon et al., 1998).

Some 230 m upstream of confluence of Sapling Clough and Round Hill Water [SD 6284 5580]: discontinuous section including the Dure Clough Sandstone, *E. ferrimontanum* Marine Band, Sapling Clough Sandstone, *E. yatesae* Marine Band and upper boundary (Brandon et al., 1998).

Lithology

Predominantly grey, sandy, micaceous, shaly siltstones with packets of interbedded, generally fine-grained, sharp-soled sandstones; includes three thin marine bands; rare clean quartzitic sandstones.

Lower and upper boundaries

The base of the member is taken at the top surface of the Brennand Grit where present; this is typically a rootlet bed (ganister). Where the Brennand Grit is absent, the lower boundary is gradational above the Pendle Grit Member; the boundary occurs where siltstones of the Roeburndale Member become predominant.

The top is taken at the base of Ward's Stone Sandstone, typically sharp and erosional, resting upon siltstones of the Roeburndale Member (NB previously defined at base of Caton Shale Formation).

Thickness

About 600–700 m

Distribution

Lancaster, Garstang and Settle sheets.

Genetic interpretation

The member is dominated by delta-slope siltstones and sandstones deposited from density currents and from suspension. There are subordinate pro-delta sideritic mudstones and impersistent delta-top sandstones (Brandon et al., 1998).

Biostratigraphical characterisation

The member includes the *Cravenoceras cowlingsense* ($E_{2a}1$), *Eumorphoceras ferrimontanum* ($E_{2a}2$), *C. gressinghamense* ($E_{2a}2a$) and *E. yatesae* ($E_{2a}3$) marine bands.

Age

Pendleian to Arnsbergian (E_1 – E_2)

4.8.2.2 CLAUGHTON MEMBER (CLAU)

Name

Previously defined as the Claughton Flags (Moseley, 1954), comprising the delta slope sequence between the Caton Shales and the Crossdale Grit (now Silver Hills Sandstone). The succession was redefined as the Claughton Formation (Brandon et al., 1998) and here redefined as a member. Moseley (1956) used Keasden Flags for the same unit in the Keasden area, west of Settle. Keasden Flags is a synonym for the Claughton Member.

Type section

Greenholes Beck [SD 5688 6314 to 5737 6340]: basal 72 m completely exposed in faulted section. Incised stream gully repeatedly affected by small north-west–south-east faults, commencing 650 m upstream from road bridge (Brandon et al., 1998).

Reference sections

Westend Beck [SD 5620 6591 to 5665 6566]: basal 200 m exposed in incised beck and old brickpits (Brandon et al., 1998).

Claughton Beck and brick pit [SD5650 6617 to 5685 6577]: exposure in basal part of member (Brandon et al., 1998).

Lithology

Predominantly sandy grey micaceous shaly siltstones with irregular interbeds of fine- to medium-grained micaceous, plant-rich sandstone; very variable thickness and bedding commonly syndepositionally slumped.

Lower and upper boundaries

The base is a sharp boundary between the fossiliferous, fissile, clayey, blue-grey mudstones with limestone nodules and thin sideritic lenses of the Caton Shales below with siltstones with sandstones of the Claughton Member above.

The top of the member is not seen; believed to be a sharp boundary at the erosional base of the coarse-grained sandstone of the Silver Hills Sandstone, resting upon the siltstone-dominated succession of the Claughton Member.

Thickness

About 200–300 m in the Claughton area, but the upper part is not represented.

Distribution

Lancaster Fells and Keasden, west of Settle.

Genetic interpretation

Typical delta slope facies (Brandon et al., 1998).

Age

Arnsbergian (E_2)

4.8.3 Samlesbury Formation (SAML)

Name

The new name **Samlesbury Formation** is proposed to identify all Millstone Grit Group strata of Chokierian and Alportian age. The term Middleton Grit Group of Bradford (Stephens et al., 1953) is unsuitable as there is a sandstone already called Middleton Grit, and it is Arnsbergian in age. The new name was chosen from Samlesbury Bottoms [SD618 291] where a complete basinal succession in the Chokierian and Alportian is exposed.

Type sections

Composite section in the River Darwin at Samlesbury Bottoms [SD 618 291]: shows dark grey mudstones and common marine shales, including the marine bands, which define the base and top of the formation (Moore, 1930; Price et al., 1963).

Stonehead Beck, Cowling, North Yorkshire [SD 9473 4330]: comprising a continuously exposed 40 m succession including the base Chokierian stratotype, which equates to the base of the Samlesbury Formation, and defines the position of the mid Carboniferous boundary (Riley et al., 1995).

Lithology

A dark grey mudstone, common thin shaly mudstones, subordinate sandstone and siltstone, and locally in the Bradford area, a thick, coarse-grained, cross-bedded sandstone (Brocka Bank Grit) (Waters, 1999).

Lower and upper boundaries

The sharply conformable base of the formation is taken at the base of the dark grey shaly mudstone of the *Isohomoceras subglobosum* Marine Band with eponymous fauna, where the formation overlies the interbedded sandstone, siltstone and mudstone succession of the Silsden Formation. Where

the marine band is absent from the interval, the base of the formation is taken at the top of the Lower Follifoot Grit in the southern part of the Askrigg Block, or the base of a mudstone succession with *Lingula* in the Stainmore Trough. In the southern part of the Central Pennine Basin, taken at the base of the first thick quartz-feldspathic sandstone of Chokierian to Alportian age, present above the Bowland Shale Formation.

The top is taken at the sharp conformable base of the dark grey shaly mudstone of the Hodsonites magistrorum Marine Band, including eponymous fauna, overlain by the siltstone-dominated lower part of the Hebden Formation. The marine band is underlain by the mudstone-dominated succession of the Samlesbury Formation. Where the marine band is absent from the interval, the top of the formation equates with the base of the Cayton Gill Shale in the south of the Askrigg Block (Wilson, 1977) and the base of the Mousegill Marine Beds in the Stainmore Trough (Owens and Burgess, 1965).

Thickness

In Lancashire there are 58 m of Chokierian and 6 m of Alportian strata, entirely within shaly mudstones (Brandon et al., 1998). In Bradford the succession including the Brocka Bank Grit is 75 m thick (Waters, 1999). The formation is less than 30 m thick along the southern part of the Askrigg Block, and in the Stainmore Trough, the thin Chokierian succession is no more than 20 m thick.

Distribution

The Craven Basin of north Lancashire and north Yorkshire, between Lancaster [SD 47 61], Pendle Hill [SD 80 41], Skipton Moor [SE 00 50] and Harrogate [SE 30 55] and the southern part of the Askrigg Block and the Stainmore Trough.

Regional correlation

The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Genetic interpretation

During the Chokierian and Alportian there appears to be little clastic input into the Pennine Basin. The succession is condensed with some hemipelagic marine shales. A shallow-water lobate delta, the Brocka Bank Grit prograded about 15 km into the Harrogate Sub-basin (Waters, 1999).

Biostratigraphical characterisation

Of Chokierian and Alportian age, although part or all of the Alportian succession may be missing regionally due to a mid Carboniferous unconformity (Riley et al., 1995). The *Isohomoceras subglobosum* Marine Band occurs at the base of the formation and the top is taken at the base of the Hodsonites magistrorum Marine Band.

Age

Chokierian to Alportian (H₁–H₂)

4.8.4 Hebden Formation (HEBD)

Name

The new name Hebden Formation is proposed to identify all Millstone Grit Group strata of Kinderscoutian age. The term Kinderscout Grit Group of Bradford (Stephens et al., 1953) is unsuitable as there is a sandstone already called Kinderscout Grit, and the name has also been used for the stage. The new name was chosen from Hebden Bridge [SD990 270] and Hebden Water, which provide excellent sections representative of much of the Kinderscoutian succession. The basal marine band has, however, not been found within this area.

Type sections

Crimsworth Dean, north of Hebden Bridge [SD 9899 3079 to 9926 3141]: shows the upper boundary with the Marsden Formation, as a transition from the underlying turbiditic facies to the overlying fluvial sheet sandstone facies (Stephens et al., 1953; Davies and McLean, 1996).

Blackden Brook, Kinder Scout, Derbyshire [SK 1223 8842 to 1171 8833]: provides an excellent stream section of 150 m thickness of the Shale Grit, Grindslow Shales and the base of the Kinderscout Grit (Stevenson and Gaunt, 1971; Davies and McLean, 1996).

Lithology

Fine- to very coarse-grained and pebbly, feldspathic sandstone interbedded with grey siltstone and mudstone, with subordinate marine black shales, thin coals and seatearths. The lower part of the formation is dominated by a turbiditic facies of thinly interbedded siltstone and fine-grained sandstone with laterally impersistent and locally thick, massive, coarse to very coarse-grained sandstones. The upper part of the formation is dominated by sheet-like laterally persistent, cross-bedded sandstones, interbedded with siltstone and mudstone; coal and seatearth are largely restricted to the upper part of the formation.

A distinctive feature of the lower part of the formation within the Askrigg Block succession is the presence of brachiopod-bearing sandstones, the Cayton Gill Shell Bed and Ure Shell Bed (Wilson and Thompson, 1965; Wilson, 1977).

Lower and upper boundaries

The base of the formation is taken at the base of the dark grey, shaly mudstone Hodsonites magistrorum Marine Band with eponymous fauna, where the formation overlies the mudstone-dominated Samlesbury Formation. Elsewhere, where this marine band has not been found, the base of the formation equates with the base of the Cayton Gill Shale in the south of the Askrigg Block (Wilson, 1977) and the base of the Mousegill Marine Beds in the Stainmore Trough (Owens and Burgess, 1965). In the south of the Central Pennine Basin the base is taken at the base of the first thick quartz-feldspathic sandstone of Kinderscoutian age, present above the Bowland Shale Formation.

The top is taken at the sharp conformable base of the dark grey, shaly mudstone of the *Bilinguites gracilis* Marine Band with eponymous fauna, typically overlain by mudstone of the Marsden Formation. The marine band is underlain by sandstone including the Upper Kinderscout Grit of the Hebden Formation. Elsewhere, where the marine band is absent, in the Askrigg Block the base of the formation is taken at the base of the Wandley Gill Shale, described by Wilson and Thompson (1965) as 3 m of shale with a *Lingula* band at the base, overlying a seatearth at the top of the Upper Brimham Grit. In the Stainmore Trough the base of the formation is taken at the base of a 6 m thick shale with *Productus carbonarius*, which overlies a 0.15 m-thick shaly coal (Owens and Burgess, 1965).

Thickness

Preston 335 m; Bradford 275 m; Derbyshire 600 m thick; southern part of the Askrigg Block about 100 m; Stainmore Trough 40 m.

Distribution

North Lancashire and north Yorkshire, between Lancaster [SD 47 61] and Harrogate [SE 30 55], extending southward to north Derbyshire [SK18] and on the Askrigg Block and Stainmore Trough.

Regional correlation

The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Genetic interpretation

During the early Kinderscoutian there is a return to deposition in deep-water deltaic successions in the northern part of the basin. In Wharfedale this is dominated by 125 m of mostly delta slope siltstones with possible turbidite feeder channels, the Addlethorpe Grit. This marks the initiation of a major deltaic advance with the distributary channel sandstones of the Addingham Edge Grit, 15 to 55 m thick prograding over the delta slope deposits. The delta system appears to be thickest in the Pennines, thinning westwards into Lancashire. In the south of the basin, where hemipelagic shales had continued to be deposited until Kinderscoutian times, the greater accommodation space resulted in a marked southward thickening of the deltaic succession to about 600 m in north Derbyshire. Here, onset of deltaic sedimentation is marked by the thin-bedded distal turbidites of the Mam Tor Sandstone (Allen, 1960). This passes up into the very thick-bedded, more erosional turbidites of the Shale Grit (Walker, 1966a). The overlying Grindslow Shales represent the delta-slope deposits and the Lower Kinderscout Grit represents fluvial distributary channels (Collinson, 1969; McCabe, 1978; Hampson, 1997). The general southward progradation of deltas resulted in the youngest Kinderscoutian sandstone, the Upper Kinderscout Grit, extending furthest south. In the Goyt Trough the Longnor Sandstone, a turbiditic sandstone equivalent to the Upper Kinderscout Grit, marks the base of the Millstone Grit Group. Heavy mineral studies have demonstrated the northerly provenance of the Addingham Edge Grit (Cliff et al., 1991) and Kinderscout Grit (Chisholm and Hallsworth, 2005).

Sporadic marine environments are evidenced by the presence of subordinate marine black mudstones, and in the Askrigg Block the presence of the brachiopod-bearing sandstones, the Cayton Gill Shell Bed and Ure Shell Bed.

Biostratigraphical characterisation

Entirely of Kinderscoutian age, with the base taken at the base of the *Hodsonites magistrorum* Marine Band and the top at the base of the *Bilinguites gracilis* Marine Band.

Age

Kinderscoutian (R₁)

4.8.5 Marsden Formation (MARSD)

Name

The new name Marsden Formation is proposed to identify all Millstone Grit Group strata of Marsdenian age. The Marsden Formation is equivalent to the former Middle Grit Group of Bradford (Stephens et al., 1953), a term considered unsuitable. The new name was chosen from Marsden [SD030 124], which provides excellent sections representative of much of the lower part of the Marsdenian succession, and is also the location of the basal stage stratotype (Ramsbottom, 1981).

Type section

Stream section at Park Clough, Hey Green near Marsden, West Yorkshire [SE 0299 1246]: 20 m of dark grey mudstone from lower part of the Marsden Formation including the *Bilinguites gracilis* Marine Band, above 15 m of cross-bedded sandstone of the Hebden Formation (Ramsbottom, 1981).

Lithology

Fine- to very coarse-grained and pebbly feldspathic sandstone, interbedded with grey siltstone and mudstone, and subordinate marine black shales, thin coals and seatearths.

Lower and upper boundaries

The sharp conformable base of the formation is taken at the base of the dark grey fissile mudstone of the *Bilinguites gracilis* Marine Band, with eponymous fauna where the formation overlies the Hebden Formation. In the southern part of the Askrigg Block, where the marine band is absent, the base of the formation is taken at the base of the Wandley Gill Shale, described by Wilson and Thompson (1965) as 3 m of shale with a *Lingula* Band at the base, overlying a seatearth at the top of the Upper Brimham Grit. In the Stainmore Trough the base of the formation is taken at the base of a 6 m-thick shale with *Productus carbonarius*, which overlies a 0.15 m-thick shaly coal (Owens and Burgess, 1965). In the southern part of the Central Pennine Basin the base of the formation is taken at the base the first thick quartz-feldspathic sandstone of Marsdenian age present above the Bowland Shale Formation.

The top is taken at the sharp conformable base of the dark grey, fissile mudstone of the *Cancelloceras cancellatum* Marine Band with eponymous fauna, overlain by a dark grey mudstone-dominated succession in the lower part of the Rossendale Formation. In the Stainmore Trough, the equivalent of this marine band, but lacking the diagnostic ammonoid fauna, was referred to as the Swinstone Bottom Marine Band (Owens and Burgess, 1965).

Thickness

Up to 600 m thick between Preston and Macclesfield; Bradford 275 m; north Derbyshire 450 m; 15 m thick in the Kirkby Malzeard area of the Askrigg Block; 40 m thick in the Stainmore Trough.

Distribution

Lancashire and West Yorkshire between Lancaster [SD 47 61] and Harrogate [SE 30 55], extending southward to north Staffordshire [SK06], and the Askrigg Block and Stainmore Trough.

Genetic interpretation

During the Marsdenian, shallow-water deltas dominated, extending by late Mardenian times across the entire Pennine Basin. Early Marsdenian deltas, including that associated with the East Carlton Grit in Yorkshire and Alum Crag Grit in Lancashire, infilled the basin following the major transgression associated with the *Bilinguites gracilis* Marine Band. These deltas are relatively elongate in the flow direction, generally towards the south and show evidence of gravity-flow sedimentation in the delta-fronts (Wignall and Maynard, 1996). Subsequent deltas are laterally persistent sheet sand bodies. In the Goyt and Widmerpool troughs the turbidite-fronted deep-water deltaic successions of the Roaches and Ashover grits show a palaeocurrent towards the north-west, but have typical northerly-sourced petrography (Jones and Chisholm, 1997). These systems appear to infill the Widmerpool Trough, flowing along the axis of the trough. Up to 600 m of Marsdenian strata are recorded between Preston and Macclesfield (Collinson et al., 1977) infilling the accommodation space to the south and west of the thick Kinderscoutian succession. Heavy mineral studies have demonstrated the northerly provenance of the Ashover Grit and Chatsworth Grit (Chisholm and Hallsworth, 2005).

Biostratigraphical characterisation

Entirely of Mardenian age, the base taken at the base of the *Bilinguites gracilis* Marine Band and the top at the base of the *Cancelloceras cancellatum* Marine Band.

Age

Marsdenian (R₂)

4.8.6 Rossendale Formation (ROSSE)

Name

The new name Rossendale Formation is proposed to identify all Millstone Grit Group strata of Yeadonian age. The Rossendale Formation is equivalent to the former Rough Rock Grit Group of Bradford (Stephens et al., 1953), a term considered unsuitable as there is also a Rough Rock and Rough Rock Flags for individual sandstones within the formation. The new name was chosen from the Forest of Rossendale [SD80 20].

Type area

The Forest of Rossendale [SD 80 20] provides excellent sections, representative of much of the succession including the sandstone of the western (Haslingden Flags) and northern provenance (Rough Rock), as well as a good exposure of the basal marine band (Wright et al., 1927).

Reference sections

Orchard Farm stream section, south-west of Buxton [SK 0226 6903] is the stage stratotype for the Yeadonian, with both the *Cancelloceras cancellatum* and *Cancelloceras cumbriense* marine bands present within a c.17 m section (Ramsbottom, 1981).

Elland Bypass (A629) roadcut, near Halifax [SE 103 215] 500 m long and up to 30 m high section in the Rough Rock and Rough Rock Flags (Bristow and Myers, 1989).

BGS Winksley Borehole (SE 27 SE/9), in the southern part of the Askrigg Block [SE 2507 7150] includes the Rossendale Formation from approximately 29.7 m to 55.89 m depth (Cooper and Burgess, 1993).

Ballavaarkish (Shellag North) Borehole, north Isle of Man [NX 4625 0070] includes the Rossendale Formation from 138.4 m to 164.55 m depth, including a 7 m-thick, fine- to coarse-grained, cross-bedded, feldspathic sandstone contemporaneous with (though mineralogically and apparently provincially distinct from) the Rough Rock of the Pennine Basin. Also occurring are palaeosols and listricated claystones, one of which, near the base of the formation, may include the upper part of the *Cancelloceras cumbriense* Marine Band (Chadwick et al., 2001).

Lithology

A fine- to very coarse-grained and pebbly, feldspathic sandstone, interbedded with grey siltstone and mudstone, and subordinate marine black shales, thin coals and seatearths. Typically, the formation comprises a lower mudstone-dominated succession including two prominent marine shales, the *Cancelloceras cancellatum* and *Cancelloceras cumbriense* marine bands, and an upper sandstone-dominated succession, including the Rough Rock and Rough Rock Flags.

Lower and upper boundaries

The sharp conformable base of the formation is taken at the base of the dark grey, fissile mudstone of the *Cancelloceras cancellatum* Marine Band with eponymous fauna, where the formation overlies the Marsden Formation. It typically overlies quartz-feldspathic sandstone of the Huddersfield White

Rock (Yorkshire), Holcombe Brook Grit (Lancashire), Chatsworth Grit (Derbyshire).

The top is taken at the sharp conformable base of the dark grey, fissile mudstone of the Subcrenatum Marine Band with eponymous fauna present at the base of the Pennine Coal Measures Group. Typically, the marine band rests upon coarse or very coarse-grained and pebbly sandstone of the Rough Rock.

Thickness

Rochdale (Rossendale) 130 m thick; Bradford and north Derbyshire 75 m; Stainmore Trough and Askrigg Block 45 m; north Isle of Man 26 m.

Distribution

The formation occurs in the Central Pennine Basin from Lancashire and West Yorkshire, between Lancaster [SD 47 61] and Harrogate [SE 30 55], extending southward to north Staffordshire [SK06], the Askrigg Block [SE 10 80] and Stainmore Trough [SD 85 15] and locally on the north of the Isle of Man [NX 46 00].

Genetic interpretation

During the early Yeadonian there is a thick succession of dark mudstones associated with two widespread marine transgressions, evident as the *Cancelloceras cancellatum* and *Cancelloceras cumbriense* marine bands. Small contributions of sediment from the west are recognised in Yeadonian times with the Upper and Lower Haslingden Flags of Lancashire. These are interpreted as deposits within a birdsfoot delta (Collinson and Banks, 1975). This westerly source of sediment, shown by McLean and Chisholm (1996) became more important and extensive during the Westphalian. The upper part of the succession is dominated by the sheet sandstone of the Rough Rock. The sandstone is typically very coarse-grained and up to 45 m thick. It was deposited from braided river channels generally flowing towards the south-west (Bristow, 1988). Heavy mineral studies have demonstrated the northerly provenance of the Rough Rock (Cliff et al., 1991), but with intermixing with a southerly source in the proximity of the Wales–Brabant High (Chisholm and Hallsworth, 2005).

Biostratigraphical characterisation

Entirely of Yeadonian age, with the base taken at the base of the *Cancelloceras cancellatum* Marine Band and the top at the base of the Subcrenatum Marine Band.

Age

Yeadonian (G₁)

The **Gwespyr Sandstone** represents the first major incursion of Millstone Grit-type quartz-feldspathic deltaic sediments into North Wales, at a time of waning detrital input from the southerly sourced Cefn y fedw Sandstone delta system. The Gwespyr Sandstone is in part equivalent with the Rossendale Formation from elsewhere in the Pennine Basin. It differs in that the top of the Gwespyr Sandstone occurs above the base of the Subcrenatum Marine Band. The Gwespyr Sandstone comprises a succession of brown and buff, fine-grained, variably feldspathic and micaceous sandstones up to 5 m thick (Davies et al., 2004). Small-scale cross-lamination directed towards the south is common. Low-angle and hummocky cross-stratification occurs locally, and some units are characterised by large-scale tabular and trough cross-bedding. Subordinate thinly interbedded sequences of sandstone and mudstone and locally thick units of grey, shaly, silty, finely micaceous mudstone, are also present. Thin coals and

seatearths are intermittently developed. The sandstone is of late Namurian (Yeadonian) to early Westphalian (early Langsettian) age. The sandstone ranges from 55 m in the south up to 260 m in the north. Intertonguing mudstones (included in either the Bowland Shale Formation or Pennine Lower Coal Measures Formation) represent the associated delta plain overbank, lagoonal and interdistributary bay muds, as well as prodelta deposits.

STAFFORDSHIRE

The **Morrige Formation** is restricted to the Goyt and Widmerpool Gulf. In the Widmerpool Gulf the distinction between sandstones of southern and northern provenance is obscured by intermixing e.g. the Chatsworth Grit and Rough Rock.

4.8.7 Morrige Formation (MORRI)

Name

The Morrige Formation is a new name, derived from a gritstone edge at Morrige [SK 03 60]. The formation was previously referred to as the Millstone Grit Series, a chronostratigraphic unit equating with the Namurian Series. Despite the similarity in bedforms and lithofacies associations, the Morrige Formation can be readily distinguished by the presence of protoquartzitic sandstones from the Millstone Grit Group, which contains feldspathic sandstones. This reflects the opposing directions of the sources of the two fluviodeltaic successions, the Morrige Formation from the south and the Millstone Grit Group from the north.

Type area

Morrige, a gritstone edge 2 km east of Leek, Staffordshire in Minn Sandstone with composite sections of Minn Sandstone near Hurdlow [SK 0314 6081 to 0274 6084], overlying mudstone dominated succession at Hurdlow Farm [SK 0242 6059 to 0219 6019].

Type section

Blake Brook, Staffordshire from Lower Fleetgreen to Fernyford, parts of full thickness. Base is taken at base of lower leaf of the Minn Sandstone [SK 055 610], and top at base of Longnor Sandstone [SK 0611 611] (Aitkenhead et al., 1985).

Lithology

Interbedded dark grey, shaly mudstones and pale grey protoquartzitic siltstones and sandstones.

Lower and upper boundaries

The base is taken at the conformable base of the first thick quartzitic sandstone of the Morrige Formation above the dark grey mudstone and siltstone of the Craven Group.

The top is taken at the conformable base of the lowermost thick quartz-feldspathic sandstone of the Millstone Grit Group above the quartzitic sandstone and siltstone or dark grey, shaly mudstone of the Morrige Formation.

Thickness

Up to 600 m thick, thins northward.

Distribution

Goyt Trough of North Staffordshire and the Widmerpool half-graben of the East Midlands, located along the northern margin of the Wales–Brabant High.

Regional correlation

The formation passes northward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Genetic interpretation

The formation ranges from turbiditic sand-bodies, particularly to the north, and shallow-water fluvio-deltaic facies especially in the southern margins of the Central Pennine Basin between Arnsbergian and early Marsdenian. The clastic component is derived from the Wales–Brabant High to the south (Trewin and Holdsworth, 1973).

Biostratigraphical characterisation

The oldest quartzitic sandstone, the Minn Sandstones range from Pendleian to Arnsbergian age, E_{1b} to E_{2a} ammonoid subzones (Aitkenhead et al., 1985; Chisholm et al., 1988). The youngest quartzitic sandstone, the Brockholes Sandstones, is of mid-Marsdenian (R_{2b}) age and interdigitates with the basal feldspathic sandstone of the Millstone Grit Group (Chisholm et al., 1988).

Age

Pendleian to Marsdenian (E_1 – R_2).

SHROPSHIRE

4.8.8 Cornbrook Sandstone Formation (COS)

Name

The name Cornbrook Sandstone was first used by Dixon (1917) for a sandstone-dominated succession he considered to be Lower Carboniferous and hence older than the strata of the Millstone Grit Group.

Type section

Stream section at Cornbrook Dingle [SO 602 758 to SO 604 755], south of the Ludlow–Cleobury Mortimer road (A4117): c.215 m thick succession, base faulted, top not seen (Jones and Owen, 1961).

Reference section

Benson's Brook [SO 593 772 to 596 773], southern slopes of Titterstone Clee: complete thickness of 55 m, showing base and top (Jones and Owen, 1961).

Lithology

The formation comprises conglomerate and pebbly quartzitic sandstones, coarse to fine-grained. The sandstones are orange or brown, locally stained red, and thick-bedded. Thin mudstone beds, bluish grey or green, locally red, with seatearths and thin coals have been described by Jones and Owen (1961). The base of the formation at Benson's Brook comprises a massive conglomerate with clasts up to 25 cm of quartz and quartzite and subordinate slate, sandstone from the Old Red Sandstone Group, and limestone from the Carboniferous Limestone Supergroup (Jones and Owen, 1961).

Lower and upper boundaries

At the type locality the lower boundary is faulted (Jones and Owen, 1961). However, the pebbly sandstones of the Cornbrook Sandstone Formation are considered to rest unconformably upon limestones of the Oretton Limestone Formation at the type locality of Cornbrook Dingle and upon the Devonian St Maughans Formation (Lower Old Red Sandstone Group) at the reference section in Benson's Brook.

At Benson's Brook the boundary has been considered to occur where thick seatearths and sandstones of the Pennine Coal Measures Group rest unconformably upon thick sandstones and conglomerates of the Cornbrook Sandstone Formation (Dixon, 1917). In contrast the boundary has been argued to be faulted at this locality (Jones and Owen, 1961).

Thickness

About 55 to 215 m

Distribution

Clee Hills area of Shropshire [SO 60 75]

Regional correlation

Of comparable age to the Cen-y-fedw Sandstone and Morridge formations and may represent the southern extensions of these formations into an embayment of the Wales–Brabant High.

Genetic interpretation

The formation records fluviodeltaic deposition, with palaeocurrents indicating a sediment-source derived from the west-north-west (Cleal and Thomas, 1996).

Biostratigraphical characterisation

Macrofloral identification by Jones and Owen (1961) indicated a Duckmantian age for the formation (Cleal and Thomas, 1996). Palynological evidence, however, has been used to indicate a Pendleian and Arnsbergian age (Turner and Owens, 1993). The latter interpretation is preferred. At Benson's Brook the formation is overlain by Pennine Coal Measures Group, which have been determined palynologically to be of Langsettian or early Duckmantian age (Turner and Spinner, 1990).

Age

Pendleian and Arnsbergian

NORTH WALES

The **Cefn-y-fedw Sandstone Formation** is thickest north of the Bala Lineament. This fault zone appears to have controlled the course of the major fluvial systems. In its thickest development the formation occurs as three separate sandstone sequences, interbedded with the Bowland Shale Formation, such as within the Blacon East Borehole (Figure 9). The three sandstone sequences merge into a single, thick sandstone succession to the south. The lower sandstone is largely Pendleian, the middle sandstone mainly of Chokierian and Alportian age and the upper sandstone ranges from early Kinderscoutian to late Marsdenian in age.

4.8.9 Cefn-y-fedw Sandstone Formation (CFS)

Name

The formation has commonly been referred to as the Millstone Grit or Millstone Grit Series despite the distinction of the Cefn-y-fedw Sandstone Formation being quartzitic and derived from the south, whereas the Millstone Grit is quartz-feldspathic and derived from the north. The name Cefn-y-fedw Sandstone was first used by Morton (1886) and defined as a formation by Davies et al. (2004).

Type area

Crags and stream sections on Ruabon Mountain, west of Wrexham [SJ 25 45] (Wedd et al., 1927).

Lithology

White and pale grey, fine- to medium-grained, planar- and cross-bedded, quartzose sandstones, pebbly sandstones and thin beds of quartz conglomerate; with units of calcareous sandstone, sandy limestone, chert and siliceous mudstones in lower part; locally thick beds of siltstone and mudstone, and thin, impersistent coal seams. Lithologies are commonly arranged in coarsening upwards cycles.

Lower and upper boundaries

The base is drawn at the base of sandstone and conglomerate of Cefn-y-fedw Sandstone Formation where it rests conformably on limestone of the Minera Formation to the south or Cefn Mawr Limestone Formation in the north (north of the Bala Fault).

The top is highly diachronous, but taken at conformable contacts between sandstones of the Cefn-y-fedw Sandstone Formation and mudstones of the Bowland Shale Formation. However, the two formations exhibit complex intertonguing.

Thickness

Up to 585 m

Distribution

North-east Wales between Halkyn Mountain [SJ 22 70] and Oswestry [SJ 28 26]. Three sandstone leaves, interpreted to belong to the Cefn-y-fedw Formation, are proved in the Blacon East No.1 Borehole (SJ36NE/23) (Figure 9).

Regional correlation

The formation intertongues on Halkyn Mountain with the Pentre Chert Formation.

Genetic interpretation

The formation records fluviodeltaic deposition across the former North Wales Visean platform. The cyclic arrangement of lithologies represent progradational sequences formed in response to contemporary movements in marine base level. The sandstones and conglomerates record the advance of delta distributary channels and mouth bars across finer prodelta and interdistributary mud and silt facies (Davies et al., 2004).

Age

?Brigantian to Marsdenian

4.9 PENNINE COAL MEASURES GROUP (PCM)

The Pennine Coal Measures Group was deposited in a broad depositional Pennine Basin, though subsequent tectonism has isolated the succession into small coalfields at outcrop, and areas present at depth beneath the subcrop of the Permo-Triassic (Figure 12). The thickest development is up to 1900 m near Manchester, located in the depocentre of the Pennine Basin (Figure 13). Over much of the basin the group rests conformably upon the Millstone Grit Group, the base of the Pennine Coal Measures Group is taken at the base of the Subcrenatum Marine Band. Along the southern margin of the basin, the Pennine Coal Measures Group oversteps the Millstone Grit Group and lies unconformably upon pre-Carboniferous strata of the Wales–Brabant High.

The Coal Measures have historically had a chronostratigraphical name synonymous with Westphalian plus Stephanian strata. However, the name has recently been defined lithostratigraphically, to describe the main body of coal-bearing strata in the Westphalian succession (Powell et al., 2000a). The base of the group is taken as the base of the Subcrenatum Marine Band or at the base of the coal-bearing sequence if this marker band cannot be identified, as defined by Stubblefield and Trotter (1957). The top of the group has recently been defined as the base of lowest conformably overlying major red-bed formation — Etruria Formation or lateral equivalent (Powell et al., 2000a), in the south of the Pennine Basin, or the Permo-Triassic Unconformity, elsewhere.

The group comprises cyclothems of alternating sandstone, grey siltstone and grey mudstone, with frequent coal seams and seatearth (palaeosol) horizons. The base of the cycle is marked by mudstones, typically grey and well bedded. Dark grey, carbonaceous and fissile mudstones are commonly recognised as non-marine bands, or less commonly as marine bands. Both are of importance in correlation of the strata. Ironstones, comprising nodules of thin layers of siderite are common in the mudstones. The mudstones typically grade up into grey laminated and bioturbated siltstones. These in turn may grade up into sandstones, typically pale grey, very fine- to fine-graded, locally up to coarse-grained with common ripple lamination, cross-bedding and low-angle planar lamination. These range from subgreywackes to grainstones. The sandstones are commonly overlain by palaeosols, either as leached sandstone ganisters or seatearths, including kaolinitic fireclays. There is a general upwards decrease in the number and thickness of marine bands and contrasting increase in the importance of coals and seatearths from the Millstone Grit Group into the overlying Pennine Coal Measures Group. Cyclic sequences in the Pennine Coal Measures Group are thinner, tens of metres, and more numerous than in the underlying Millstone Grit Group.

The group is divided into three formations (Figure 4): **Pennine Lower Coal Measures, Pennine Middle Coal Measures and Pennine Upper Coal Measures formations**. Several members are recognised in the latter formation. In the North Staffordshire Coalfield three members are recognised, in ascending order: the **Clayband Ironstone, Great Row and Black Band Ironstone members**. In the East Pennines Coalfield four members are identified, in ascending order: **Ackworth, Brierley, Hemsworth and Badsworth members**.

Locally, at the margins of the Pennine Basin the grey Coal Measures facies occur interbedded with primary and secondary red beds similar in appearance to those present within the younger Warwickshire Group. These interbedded red and grey measures are considered to represent part of the Pennine Coal Measures Group. In the Wyre Forest Coalfield this succession was formerly identified as the now obsolete Kinlet Group (Whitehead and Pocock, 1947). During the current resurvey of the coalfield it has been possible to use the Pennine Basin formational nomenclature described above. In an isolated onshore outcrop in the Llandrillio-yn-Rhos area [SH 820 810], North Wales has been mapped as the **Gloddaeth Purple Sandstone Formation**. The formation is provisionally included within the Pennine Coal Measures Group. Further investigation may allow the rank and parentage of the formation to be revised. The possibility that it represents an early and local facies of the Warwickshire Group cannot be discounted.

Examples of generalised sections from Lancashire to South Staffordshire coalfields (Figure 13) and East Pennines to Warwickshire coalfields (Figure 14) summarise the main marine bands, coals and sandstones of the Coal Measures Group

4.9.1 Pennine Lower Coal Measures Formation (PLCM)

Name

The formation has historically been referred to as the Lower Coal Measures, as defined by Stubblefield and Trotter (1957). The name was applied across the UK, despite different boundary definitions existing between England and Scotland (Browne et al., 1999). To distinguish the succes-

sion present within the Pennine Basin from that present within the Midland Valley of Scotland and the South Wales Basin, the formation has been renamed the Pennine Lower Coal Measures Formation.

Type area

Numerous borehole and shaft section, but few exposures across the North Staffordshire (Potteries) Coalfield, Stoke-on-Trent [SJ 90 50] (Figure 13).

Reference sections

Top boundary: mudstone in the Vanderbeckei Marine Band, Miry Wood, Apedale [SJ 8118 4940]. To be designated a RIGS site (Rees and Wilson, 1998).

Top part: from 640 m to 318.5 m in constructed stratigraphical section (V5 British Coal, G7 British Geological Survey), Hesketh Back Cut (Crosscut), Chatterley Whitfield Colliery, Stoke-on-Trent [SJ 884 533] (Rees and Wilson, 1998).

Base and lower part: from surface down to 550.7 m depth, Ridgeway Borehole (SJ85SE14) [SJ 8923 5381] (Rees and Wilson, 1998).

Base: natural section in the River Little Don, Langsett [SE 2215 0041] basal Stratotype for the Langsettian Stage with up to 2 m section including the Subcrenatum Marine Band (Owens et al., 1985).

Ballavaarkish (Shellag North) Borehole [NX 4625 0070], north Isle of Man includes the Pennine Lower Coal Measures Formation from 120.75 m (the top of the cored section) to the base of the Subcrenatum Marine Band at about 136.8 m depth (see Chadwick et al. 2001).

Lithology

Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with mudstones containing marine fossils in the lower part, and more numerous and thicker coal seams in the upper part.

In the Lancashire and East Pennines coalfields the formation can be broadly divided into three unnamed members (Chisholm, 1990; Aitkenhead et al., 2002). From the base of the Subcrenatum Marine Band to the 80 Yard Coal (Figure 13) or Pasture Coal (Figure 14), the cyclothems usually have a marine band at the base and a palaeosol at the top, and include micaceous sandstones. Between the 80 Yard or Pasture coals and the basin-wide Arley Coal (Figure 13) or Kilburn (Better Bed) Coal (Figure 14), coal seams are thin and rare, only the palaeosol beneath the Kilburn–Arley coals is notably leached and marine band faunas are very restricted. The sandstones include both micaceous and green weakly micaceous sandstones. Between the Kilburn–Arley coals and the base of the Vanderbeckei Marine Band (Figures 13 and 14) there is a thick succession of laterally impersistent cyclothems that lack true marine bands and have thick coals. In the subsurface of the East Midlands, coal and oil exploration has revealed an abundance of alkali basalt lavas and tuffs, limited to the Pennine Lower Coal Measures Formation.

In the Northumberland and Durham Coalfield, sheet-like, coarse-grained sandstones, common marine bands and thin coals, are present in the Pennine Lower Coal Measures.

Lower and upper boundaries

The base of the formation, as defined by Stubblefield and Trotter (1957), is taken at the base of the dark grey fissile mudstone of the Subcrenatum Marine Band with eponymous fossils, or at the base of the lowest coal of the coal-bearing sequence if this marker cannot be recognised. Typically, the formation rests conformably

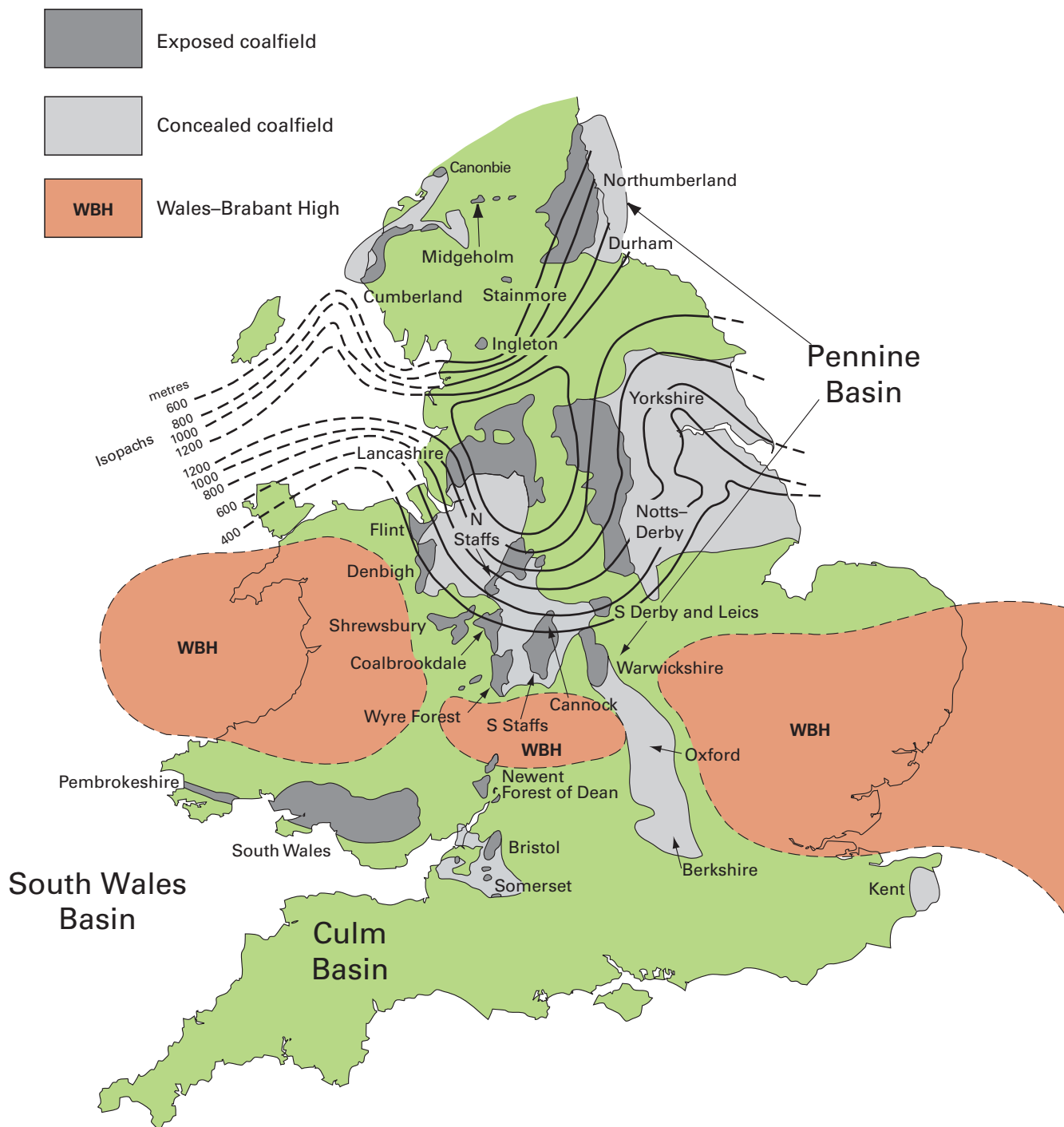


Figure 12 Coalfields of England and Wales (Powell et al., 2000b). Restored and generalised isopachs of the Lower and Middle Coal Measures within the Pennine Basin, modified from Calver (1968) and Kirby et al. (2000).

upon the Rossendale Formation (Millstone Grit Group). However, in north, west and east Cumbria, the Solway Basin (except the Canonbie area), the Stainmore and Northumberland troughs, on the Alston Block and in north-east Northumberland, the formation overlies conformably the repetitive mudstones, siltstones, sandstones, thin limestones and thin coals of the Stainmore Formation (Yoredale Group). In the Canonbie Coalfield, the formation is underlain unconformably by the Alston Formation (Yoredale Group).

The top is taken at the base of the mudstone of the Vanderbeckei Marine Band with eponymous fossils.

Thickness

Up to 650 m thick in the North Staffordshire (Potteries) Coalfield, and 720 m thick in Lancashire.

Distribution

Central and northern England, North Wales and the north Isle of Man.

Regional correlation

The formation broadly equates with the Scottish Lower Coal Measures and South Wales Lower Coal Measures formations, although in the Midland Valley of Scotland the

definition of the base differs from that of the Pennine Basin. This reflects the limited recognition of the Subcrenatum Marine Band within the Midland Valley.

Genetic interpretation

The deposits accumulated in a delta-top environment with large distributary channels. The main channels, up to 20 m thick and 20 km wide, were filled by relatively thick, sharp-based sandstones (Guion et al., 1995). Between the channels were freshwater lakes and lagoons associated with deposition of mudstones. The lakes and lagoons were filled by small deltas and crevasse splays producing the upward-coarsening siltstones and sandstones. Near emergent surfaces became swamps or raised bogs, colonised by plants which following burial formed coals. Subsidence rates were low along the southern margin of the Pennine Basin resulting in a relatively few thick seams (Waters et al., 1994). Northwards, towards the basin depocentre subsidence rates are greater and seams split. The cyclothems are typically upward-coarsening lake-fills with the principal driving form being continuous subsidence.

Some of the cycles, particularly in the early Langsetian, commence with laterally widespread marine bands that probably result from sea-level rises (Aitkenhead et al., 2002). The sandstones present within the lower part of the formation are considered to have the same source from the north or north-east as the underlying Millstone Grit (Chisholm et al., 1996). The middle part of the formation includes micaceous sandstones sourced from the north and weakly micaceous sandstones sourced from the west (Chisholm, 1990; Chisholm et al., 1996; Hallsworth and Chisholm, 2000). The latter have the same source as the Haslingden Flags of the Millstone Grit of Yeadonian age. The upper part of the formation includes sandstones, which appear to be sourced from the west (Hallsworth and Chisholm, 2000; Chisholm and Hallsworth, 2005).

Biostratigraphical characterisation

The base of the formation is taken at the base of the Subcrenatum Marine Band, which marks the base of the Langsetian Stage. The top is taken at the base of the Vanderbeckei Marine Band, which marks the base of the Duckmantian Stage.

Age

Langsetian.

4.9.2 Pennine Middle Coal Measures Formation (PMCM)

Name

The formation has historically been referred to as the Middle Coal Measures, as defined by Stubblefield and Trotter (1957). The name was applied across the UK, despite different boundary definitions existing between England and Scotland (Browne et al., 1999). To distinguish the succession present within the Pennine Basin from that present within the Midland Valley of Scotland and the South Wales Basin, the formation has been renamed the Pennine Middle Coal Measures Formation.

Type area

Potteries (North Staffordshire) Coalfield, Stoke-on-Trent [SJ 90 50]: numerous borehole and shaft sections, many no longer exposed (Figure 13).

Reference sections

Base: Vanderbeckei Marine Band at Miry Wood, Apedale [SJ 8118 4940]. To be designated a RIGS site (Rees and Wilson, 1998).

Upper part: below the Rowhurst Coal to the top of the Cambriense Marine Band in No.4 underground borehole (SJ84NW/30), from 325.5 m to 200.3 m depth, Holditch Colliery, Stoke-on-Trent [SJ 8392 4850] (Rees and Wilson, 1998).

Top part: from 161.2 m depth, at top of Cambriense Marine Band to base of borehole at 183.3 m depth, in No.1 underground borehole (SJ85SW19) at Parkhouse Colliery, Stoke-on-Trent [SJ 8396 5029] (Rees and Wilson, 1998).

Base and lower part: Hesketh Back Cut, Chatterley Whitfield Colliery from 1045 ft (318.5 m) to top of constructed stratigraphical section (V5 British Coal, G7 BGS log) [SJ 884 533] (Rees and Wilson, 1998).

Base and lower part: Duckmanton, north Derbyshire [SK 4237 7040], basal Stratotype section for the Duckmantian, includes 50 m thickness of Pennine Middle Coal Measures above 75 m of Pennine Lower Coal Measures (Owens et al., 1985).

Lithology

Interbedded grey mudstone, siltstone, pale grey sandstone and commonly coal seams, with a bed of mudstone containing marine fossils at the base, and several such marine fossil-bearing mudstones in the upper half of the unit.

The formation can be broadly divided into two unnamed members (Aitkenhead et al., 2002). From the base of the Vanderbeckei Marine Band to the base of the Maltby Marine Band (Figures 13 and 14) is similar to the upper member of the Lower Coal Measures. Between the Maltby Marine Band and the top of the Cambriense Marine Band marine bands are common at the bases of cyclothems and coals are thin. In Yorkshire, sandstones are generally thicker and coarser than is typical of the Coal Measures.

Lower and upper boundaries

The base of the formation, as defined by Stubblefield and Trotter (1957), is taken at the base of the dark grey, fissile mudstone of the Vanderbeckei Marine Band, with eponymous fauna and/or other marine fossils.

The top of the formation, as defined by Stubblefield and Trotter (1957), is taken at the top of the dark grey, fissile mudstone of the Cambriense Marine Band, with eponymous fauna and/or other marine fossils. This definition is extended to the Scottish Solway area, which formerly used the top of the Aegiranum (Skelton) Marine Band to define the top of the formation.

Thickness

Up to 600 m thick across the North Staffordshire Coalfield; about 650 m thick in Lancashire; 200 m thick in north-west England and in the north-west of the Canonbie Coalfield.

Distribution

Central and northern England, North Wales.

Regional correlation

The formation broadly equates with the Scottish Middle Coal Measures and South Wales Middle Coal Measures formations, although in the Midland Valley of Scotland the definition of the top differs from that of the Pennine Basin. This reflects the absence of the Cambriense Marine Band within the Midland Valley.

Genetic interpretation

The deposits accumulated in a delta-top environment

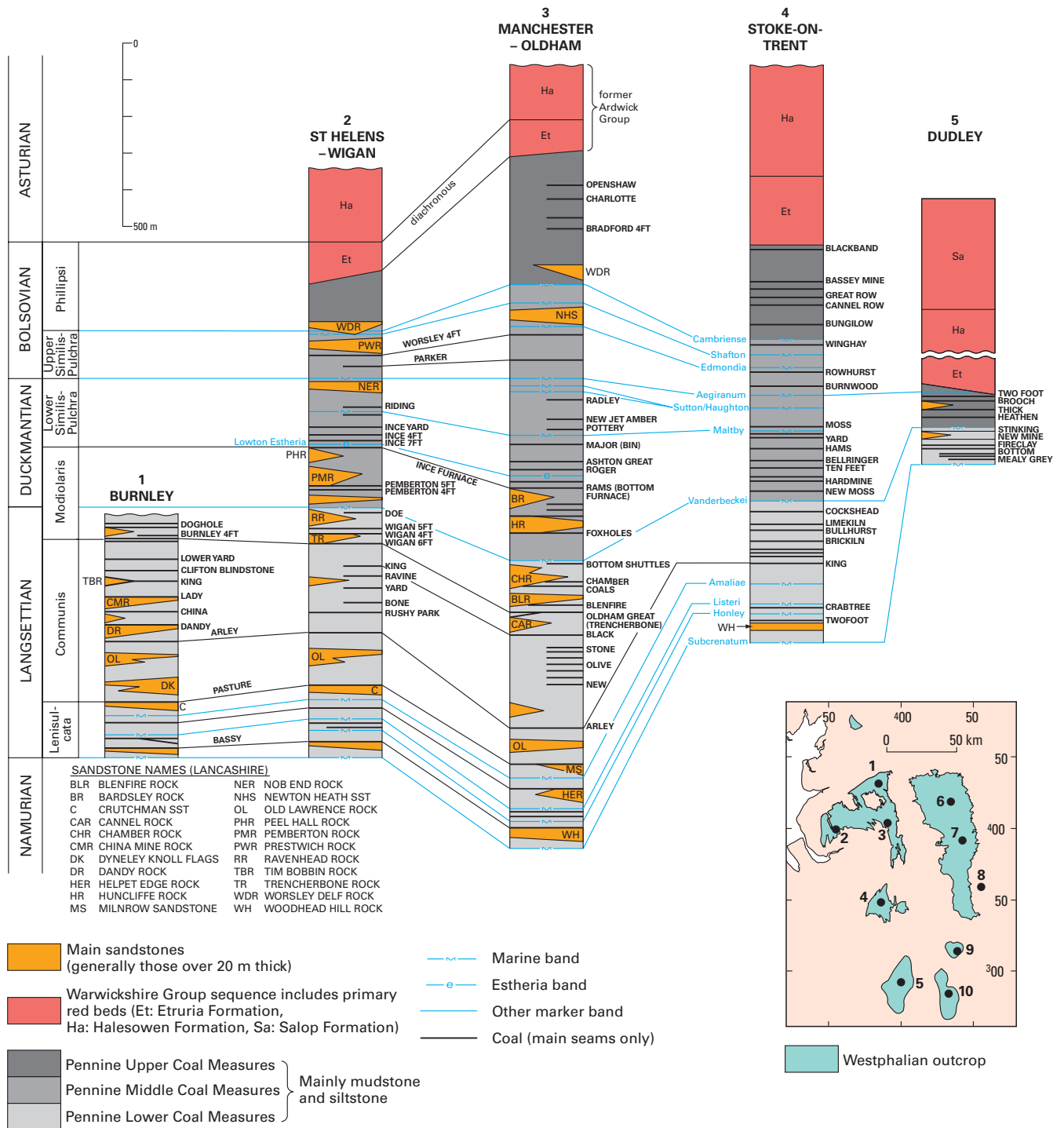


Figure 13 Generalised sections of the Pennine Coal Measures Group from the Lancashire to South Staffordshire coalfields (in part derived from Aitkenhead et al., 2002)

with large distributary channels, similar to that described for the Pennine Lower Coal Measures Formation (see Section 4.9.1). Some of the cycles commence with laterally widespread marine bands that probably result from sea-level rises. The lower part of the formation includes sandstones with a provenance from the west, representing a continuation from the upper part of the Pennine Lower Coal Measures (Hallsworth and Chisholm, 2000; Chisholm and Hallsworth, 2005). The upper part of the formation displays a return to derivation from the north as well as the start of a new influx, this time from the east and south-east (Hallsworth and Chisholm, 2000; Chisholm and Hallsworth, 2005).

Biostratigraphical characterisation

The base of the formation is taken at the base of the Vanderbeckei Marine Band, which marks the base of the Duckmantian Stage. The top is taken at the base of the Cambriense Marine Band, which occurs within the Bolsovian Stage.

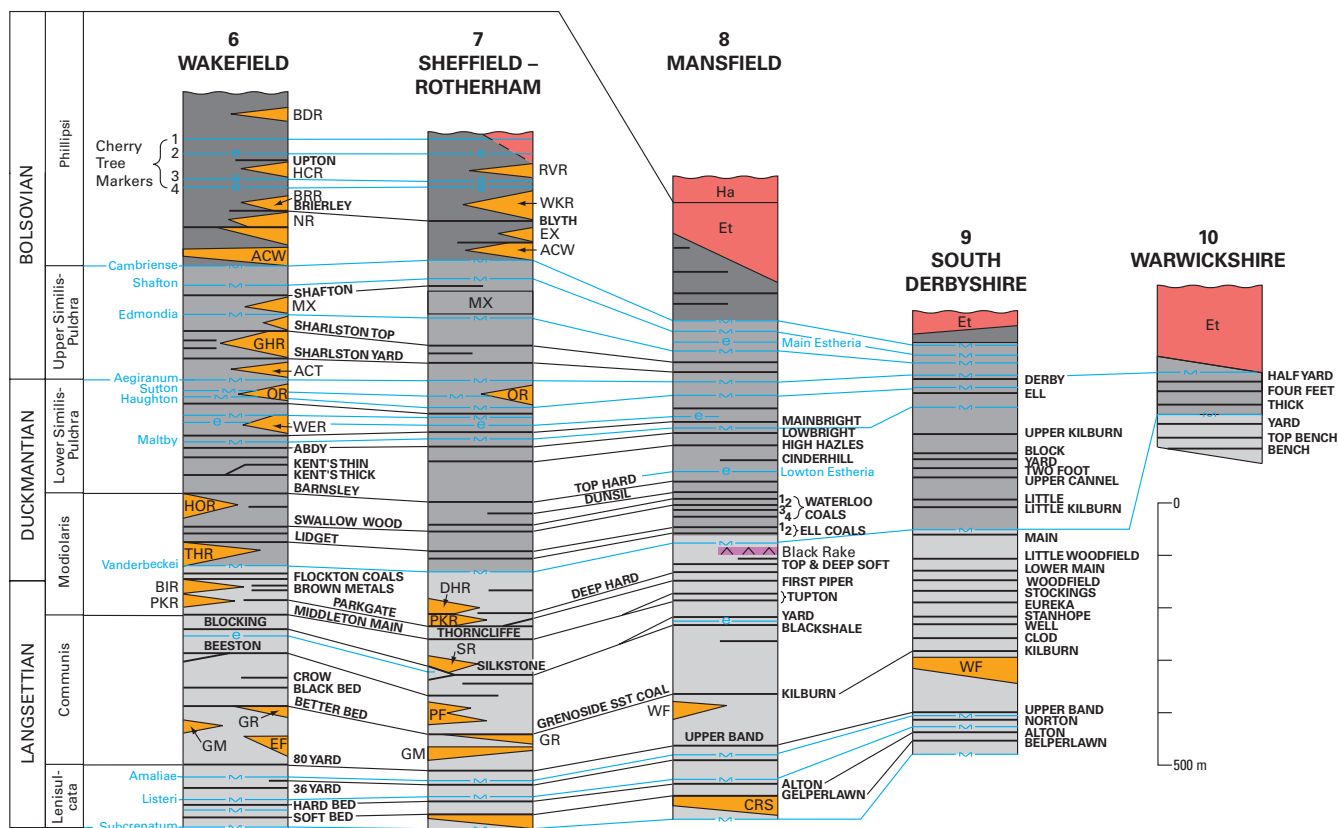
Age

Duckmantian to Bolsovian

4.9.3 Pennine Upper Coal Measures Formation (PUCM)

Name

The formation has historically been referred to as the Upper



SANDSTONE NAMES (EAST PENNINES)

ACT	ACKTON ROCK	HCR	HOUGHTON COMMON ROCK
ACW	ACKWORTH ROCK	HOR	HORBURY ROCK
BDR	BADSWORTH ROCK	MX	MEXBOROUGH ROCK
BIR	BIRSTALL ROCK	NR	NEWSTEAD (PONTEFRACT) ROCK
BRR	BRIERLEY ROCK	OR	OAKS ROCK
CRS	CRAWSHAW SANDSTONE	PF	PENISTONE FLAGS
DHR	DEEP HARD ROCK	PKR	PARKGATE ROCK
EF	ELLAND FLAGS	RVR	RAVENFIELD ROCK
EX	'EXTRA' ROCK	SR	SILKSTONE ROCK
GHR	GLASS HOUGHTON ROCK	THR	THORNHILL ROCK
GM	GREENMOOR ROCK	WER	WOOLLEY EDGE ROCK
GR	GRENSIDE SANDSTONE	WF	WINGFIELD FLAGS
		WKR	WICKERSLEY ROCK

Key as Fig 13

▲▲▲ Volcanic bed

Figure 14 Generalised sections of the Pennine Coal Measures Group from East Pennines to Warwickshire coalfields (in part derived from Aitkenhead et al., 2002).

Coal Measures, as defined by Stubblefield and Trotter (1957). The name was applied across the UK, despite different boundary definitions existing between England and Scotland (Browne et al., 1999). To distinguish the succession present within the Pennine Basin from that present within the Midland Valley of Scotland and the South Wales Basin, the formation has been renamed the Pennine Upper Coal Measures Formation.

Type area

Potteries Coalfield, Stoke-on-Trent, North Staffordshire [SJ 90 50], numerous borehole and shaft sections, few exposures (Figure 13).

Reference sections

Base and lower part: Holditch Quarry No.4 underground borehole, Stoke-on-Trent (SJ84NW30) [SJ 8392 4850], from 200.25 m depth to top of borehole, interpreted as the top of the Cambriense Marine Band to above the Great Row Coal (Rees and Wilson, 1998).

Base: Parkhouse Colliery No.1 underground borehole, Stoke-on-Trent (SJ85SW/19) [SJ 8396 5029], from rockhead in the borehole at 5.3 m depth to 161.2 m depth at the top of the Cambriense Marine Band (Rees and Wilson, 1998).

Top and upper part: Wolstanton Colliery No.3 shaft, Stoke-on-Trent [SJ 8606 4800], from 348.2 m depth to base of shaft (Rees and Wilson, 1998).

Formal subdivisions

In the North Staffordshire Coalfield three members, previously defined as formations (Ramsbottom et al., 1978) are recognised, in ascending order: the Clayband Ironstone, Great Row and Black Band Ironstone members. In the East Pennines Coalfield four members are identified, in ascending order: Ackworth, Brierley, Hemsworth and Badsworth members (Lake, 1999).

Lithology

Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with coal seams, but no mudstones containing marine fossils are present. Beds with estheriids are common (Figures 13 and 14). Coal seams are thin. In Yorkshire sandstones are common and mainly medium-grained.

Lower and upper boundaries

The base, as defined by Stubblefield and Trotter (1957),

is taken at the top of the dark grey fissile mudstone with marine fossils of the Cambriense Marine Band. In the Scottish Solway area the base of the Upper Coal Measures was formerly taken at the base of the Aegiranum (Skelton) Marine Band but is now proposed to be taken at the top of the Cumbriense Marine Band to confirm with the position elsewhere in the Pennine Basin.

The top is taken at the point in the conformable sequence where red or brown mudstones of primary origin, typically assigned to the Warwickshire Group, become predominant over the grey beds, or at base of the sub-Permian unconformity.

Thickness

Up to 350 m thick in the North Staffordshire (Potteries) Coalfield; 800 m thick in the Canonbie Coalfield.

Distribution

Central and northern England and North Wales.

Regional correlation

The formation broadly equates with the Scottish Upper Coal Measures and South Wales Upper Coal Measures formations, although in the Midland Valley of Scotland the definition of the base differs from that of the Pennine Basin. This reflects the absence of the Cambriense Marine Band within the Midland Valley.

Genetic interpretation

The deposits accumulated in a delta-top environment with large distributary channels, similar to that described for the Pennine Lower Coal Measures Formation (see Section 4.9.1). The sandstones are mainly derived from the south-east (Hallsworth and Chisholm, 2000; Chisholm and Hallsworth, 2005). The absence of marine bands indicates that marine incursions did not extend across the delta top.

Biostratigraphical characterisation

The formation is characterised by the presence on non-marine bivalves of the *Anthraconauta phillipsi* and *Anthraconauta tenuis* zones, of late Bolsovian and Asturian age, respectively.

Age

Bolsovian to Asturian

NORTH STAFFORDSHIRE COALFIELD

4.9.3.1 CLAYBAND IRONSTONE MEMBER (CBIF)

Name

Originally named the Clayband Ironstone Measures after the presence of distinctive clayband ironstones (Earp and Calver, 1961) the term was used informally by Rees and Wilson (1998). The unit is here formally redefined as the Clayband Ironstone Member.

Reference section

Holts Barn Borehole (SJ93NW2) [SJ 9005 3640]: entire thickness from 511.71 m to 423.75 m depth (Rees and Wilson, 1998).

Lithology

Grey mudstones and siltstones with thick seatearths, numerous ironstones and coals and brittle dark grey mudstones rich in fish debris. Channel sandstones are locally important.

Lower and upper boundaries

The base is taken at the top of the dark grey fissile mudstone with marine fossils of the Cambriense Marine Band.

The top of the member is taken at the base of the Cannel Row Coal.

Thickness

Up to 161 m in Parkhouse Colliery.

Distribution

North Staffordshire Coalfield

Regional correlation

The member passes laterally southward into the Etruria Formation (Warwickshire Group).

Genetic interpretation

The succession was largely deposited within delta-top lakes, with the ironstones probably formed as diagenetic segregations during burial (Rees and Wilson, 1998).

Biostratigraphical characterisation

The member is characterised by the presence on non-marine bivalves of the *Anthraconauta phillipsi* Zone.

Age

Bolsovian

4.9.3.2 GREAT ROW MEMBER (GTR)

Name

Originally named the Great Row Measures for the succession transitional between the clayband ironstones and blackband ironstones (Earp and Calver, 1961). The unit is here formally redefined as the Great Row Member.

Reference section

Holts Barn Borehole (SJ93NW2) [SJ 9005 3640]: full thickness from 423.75 m to 376.0 m depth (Rees and Wilson, 1998).

Lithology

Grey mudstones and siltstones with seatearths, numerous ironstones and thick coals. Channel sandstones are locally important.

Lower and upper boundaries

The base of the member is taken at the base of the Cannel Row Coal.

The top of the member is drawn at the base of the Bassey Mine Coal.

Thickness

Up to 92 m in Parkhouse Colliery

Distribution

North Staffordshire Coalfield

Regional correlation

The member passes laterally southward into the Etruria Formation (Warwickshire Group).

Genetic interpretation

Delta-top environment as for Pennine Upper Coal Measures Formation.

Age

Bolsovian

4.9.3.3 BLACK BAND IRONSTONE MEMBER (BBG)

Name

Originally named the Blackband Group after the presence

of distinctive blackband ironstones (Earp and Calver, 1961) the term was used informally by Rees and Wilson (1998). The unit is here formally redefined as the Black Band Ironstone Member.

Reference section

Holts Barn Borehole (SJ93NW2) [SJ 9005 3640]: entire thickness from 376.0 m to base of Etruria Formation at 257.56 m depth (Rees and Wilson, 1998).

Lithology

Grey mudstone, siltstone and sandstone with six named coals, thick seatearths and four blackband ironstones. Ironstones pass laterally into limestone or calcareous mudstone to the south. Reddened mudstones increase in number and thickness to the south and west.

Lower and upper boundaries

The base of the member is drawn at the base of the Bassey Mine Coal.

The top is marked by a passage by alternation from grey strata of the Black Band Ironstone Member to red strata of the Etruria Formation. Top of member taken at top of uppermost grey measures in succession.

Thickness

Up to 135 m in the Wolstanton Colliery No.3 Shaft (SJ84NE29) [SJ 8606 4800]. Thins toward the south and west as it passes laterally into the Etruria Formation.

Distribution

North Staffordshire Coalfield.

Regional correlation

The member passes laterally southward into the Etruria Formation (Warwickshire Group).

Genetic interpretation

Red measures are associated with primary reddening and palaeosol development associated with localised improved drainage. The ironstones represent fossil bog iron ores (Boardman, 1989).

Biostratigraphical characterisation

The member is characterised by the presence of non-marine bivalves of the *Anthraconauta phillipsi* Zone.

Age

Bolsovian

EAST PENNINES COALFIELD

4.9.3.4 ACKWORTH MEMBER (ACKW)

Name

The Upper Coal Measures was informally subdivided into four divisions (Goossens and Smith, 1973, which subsequently became formalised as members (Lake, 1999).

Type section

Cherry Tree Borehole (near South Elmsall, Yorkshire) (SE41SE/9) [SE 4915 1173]: depths of member 154.91–241.25 m. (Samples RG 4241–4455 from 50' to 1946') (Goossens and Smith, 1973).

Lithology

Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with up to eight thin coal seams. There

are five mappable sandstones including the Ackworth Rock near the base and the Newstead Rock towards the top.

Lower and upper boundaries

The base of the member is drawn at the top of the dark grey fissils mudstone with marine fossils of the Cambriense Marine Band (Stubblefield and Trotter, 1957). Where the marine band is absent through washout, it is taken at the sharp, erosive base of the Ackworth Rock.

The top is taken at the top of the seatearth present immediately below the base of the Brierley Coal.

Thickness

Maximum of 110 m at Fitzwilliam [SE 41 15], thinning to the south-east to a minimum of 85 m east of South Elmsall [SE 47 11].

Distribution

At outcrop between Ryhill [SE 38 14] and Wentbridge [SE 49 17]; it also occurs in the Pontefract Trough [SE 44 20] and faulted outliers at Sharlston [SE 39 18] and Ackworth Park [SE 44 19].

Biostratigraphical characterisation

Non-marine bivalves of the *Anthraconauta phillipsi* Zone are present throughout the member (Goossens and Smith, 1973).

Age

Bolsovian

4.9.3.5 BRIERLEY MEMBER (BRIE)

Name

The Upper Coal Measures was informally subdivided into four divisions (Goossens and Smith, 1973) which subsequently became formalised as members (Lake, 1999).

Type section

Cherry Tree Borehole (near South Elmsall, Yorkshire) SE41SE/9 [SE 4915 1173]: depths of member 105.38–154.91 m (samples RG 4241–4455 from 50' to 1946') (Goossens and Smith, 1973).

Lithology

Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with thin coal seams. Of the several mappable sandstones the Brierley Rock is the most notable.

Lower and upper boundaries

The base of the member is taken at the top of the seatearth present immediately below the base of the Brierley Coal.

The top is taken at the base of the Fourth Cherry Tree Marker, a mussel band that commonly contains euestheriids.

Thickness

Typically 50 m, thickening to around 60 m in the Hemsworth area [SE 41 13].

Distribution

Outcrops around Brierley [SE 41 11], South Kirkby [SE 45 11], north-west of Hemsworth [SE 41 13] and south-east of Thorpe Audlin [SE 48 16].

Biostratigraphical characterisation

There are up to eight non-marine bivalve bands dominated by the presence of *Anthraconauta phillipsi* and *A. cf. wrighti*, indicative of the *A. phillipsi* Zone.

Age
Bolsovian

4.9.3.6 HEMSWORTH MEMBER (HEMS)

Name

The Upper Coal Measures was informally subdivided into four divisions (Goossens and Smith, 1973) which subsequently became formalised as members (Lake, 1999).

Type sections

Cherry Tree Borehole (near South Elmsall, Yorkshire) (SE41SE/9) [SE 4915 1173]: depths of member 16.61–105.38 m (samples RG 4241–4455 from 50' to 1946') (Goossens and Smith, 1973).

Lithology

Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with thin coal seams. Of the seven mappable sandstones none are distinctive.

Lower and upper boundaries

The base of the member is taken at the base of the Fourth Cherry Tree Marker (mudstones with bivalves and euestheriids).

The top is taken at the base of the First Cherry Tree Marker (mudstones with bivalves).

Thickness

Some 93.35 m thick in the Badsworth No. 3 Borehole.

Distribution

Outcrop of the full thickness of the member is restricted to the Badsworth Trough [SE 44 12 to 47 16] and around South Elmsall [SE 47 12].

Biostratigraphical characterisation

There are three prominent mussel bands dominated by the presence of *Anthraconauta phillipsi*, indicative of the *A. phillipsi* Zone.

Age
Bolsovian

4.9.3.7 BADSWORTH MEMBER (BADS)

Name

The Upper Coal Measures was informally subdivided into four divisions (Goossens and Smith, 1973) which subsequently became formalised as members (Lake, 1999).

Type sections

Badsworth No. 4 Borehole, Badsworth, Yorkshire. (SE41SE/1) [SE 4671 1493]: depths of member 0–76.96 m (samples RG 4566–4595 from 138' to 620') (Goossens and Smith, 1973).

Cherry Tree Borehole (near South Elmsall, Yorkshire) (SE41SE/9) [SE 4915 1173]: depths of member 0–16.61 m (samples RG 4241–4455 from 50' to 1946') (Goossens and Smith, 1973).

Lithology

In the lower part comprises interbedded grey mudstone, siltstone and pale grey sandstone, with two thin coal seams. Red beds in the upper 50 m. Up to seven mappable sandstones, the thickest being the Badsworth Rock.

Lower and upper boundaries

The base of the member is drawn at the base of the First Cherry Tree Marker (mudstones with bivalves).

The top is not defined. It is represented by the highest preserved bed of Coal Measures beneath the sub-Permian Unconformity.

Thickness

Up to 90 m

Distribution

Restricted to the Badsworth Trough [SE 44 12 to 47 16] and below Permian strata at Upton Beacon [SE 47 14] and north and east of South Elmsall [SE 47 12].

Biostratigraphical characterisation

Mussel bands are dominated by the presence of *Anthraconauta phillipsi*, indicative of the *A. phillipsi* Zone.

Age
Bolsovian

4.9.4 Gloddaeth Purple Sandstone Formation (GPS)

Name

The formation, named after Gloddaeth-isaf [SH 81 81], near Penrhyn Bay, is defined by Warren et al., (1984).

Reference sections

Old quarry 300 m north of Bodysgallen [SH 7986 7958] exposing 8.5 m of purple and grey sandstone with scattered pebbles (Warren et al., 1984).

Exposure 100 m north of Bodysgallen [SH 7990 7940] in purple sandstone resting on brown dolomite of the Loggerheads Limestone Formation (Warren et al., 1984).

Lithology

Purple and red sandstone, cross-bedded with pebbly horizons.

Lower and upper boundaries

Purple and red sandstone of the formation rest unconformably upon massive to pseudobrecciated and locally dolomitised limestones of the underlying Loggerheads Limestone Formation (Clwyd Limestone Group).

The top is not seen; presumed to be unconformable contact with Permo-Triassic red sandstones of the Sherwood Sandstone Group.

Thickness

Over 23 m

Distribution

Llandrillio-yn-Rhos area [SH 820 810], North Wales.

Genetic interpretation

Possibly fluvial sandstones.

Biostratigraphical characterisation

Warren et al. (1984) cite the Gloddaeth Purple Sandstone Formation as of Dinantian age, however, unpublished palynomorph assemblages obtained from a road cutting in the late 1980s by the Robertson Group, and which include the taxa *Dictyotriletes bireticulatus* and *Endosporites globiformis*, indicate an age no older than upper Westphalian A. The well preserved nature of the assemblage suggested by the Robertson's palynology indicates that it had not been reworked.

Age
Westphalian

4.10 WARWICKSHIRE GROUP (WAWK)

The predominantly red-bed strata of alluvial facies have, in the past, been referred to collectively by terms such as the 'Barren (Coal) Measures' and 'Red Measures', although a new group name, the Warwickshire Group, has been introduced to replace them (Powell et al., 2000a). The group includes the red-bed formations and the relatively coal-poor, grey formations that overlie the Pennine Coal Measures Group, especially along the southern margin of the Pennine Basin (Figure 15). The group ranges in age from Westphalian (Duckmantian) to Early Permian (Autunian).

The name derives from the Warwickshire Coalfield where the succession is thickest (1225 m). The group is also present in the West Midlands (e.g. Sidway Mill Borehole, Figure 9), North Wales, Lancashire, South Yorkshire, Nottinghamshire and Lincolnshire. The lower boundary is taken generally at the base of the lowest red-bed formation (generally Etruria Formation) of late Carboniferous age. The upper boundary is taken at the base of unconformable (post-Variscan) Permian, or younger strata.

The Warwickshire Group succession consists of mudstone, siltstone and sandstone, mainly red, brown or purple-grey in colour. Pebbly sandstone, conglomerate and breccia are locally developed. Minor components comprise grey mudstone, thin coals, lacustrine limestone ('*Spirorbis* limestone') and pedogenic limestone (caliche; calcrete). The red beds have undergone oxidation at, or close to, the time of deposition, as opposed to those that have been reddened by later weathering, such as the sub-Permian weathering of Carboniferous strata in Lancashire (Trotter, 1954).

The succession is divided into formations, many of which can be correlated between coalfields; others are geographically restricted (Figure 15). In ascending order, the succession is the **Etruria Formation**, **Halesowen Formation** (including the **Dark Slade Member**) and **Salop Formation**. In the type area and South Staffordshire the Salop Formation includes the **Alveley Member** in its lower part, and **Enville Member** in its upper part. In Warwickshire the formation is subdivided into the **Whitacre**, **Keresley** and **Allesley members**, in ascending order, representing three upward-coarsening cycles (Bridge et al., 1998). The **Clent Formation** of South Staffordshire and the **Tile Hill Mudstone Formation** of Warwickshire are commonly attributed a Permian age, but a Stephanian age cannot be discounted. For completeness, formal definitions of these two formations are included in this report. The Kenilworth Sandstone and Ashow formations (Figure 15) are both of Permian age and are excluded from this report. Definitions of these two formations are provided by Powell et al. (2000a).

An unconformity, below the Halesowen Formation (Asturian), is traceable throughout most of the southern part the Pennine Basin, but has not been widely recognised in the northern basinal successions of South Yorkshire and Lancashire (Waters et al., 1994). In the south-east part of the Coalbrookdale Coalfield, the stratigraphically older 'Symon Unconformity' occurs between the Coal Measures and the Etruria Formation (Hamblin and Coppack, 1995).

4.10.1 Etruria Formation (ETM)

Name

The name is derived from the Etruria area of the North Staffordshire Coalfield (Gibson, 1901). It was formerly referred to as the Etruria Marl, but the lithological epithet was dropped (Besly, 1988) because the rocks are mostly mudstone with subordinate sandstone and conglomerate. This formation replaces the redundant Old Hill Marl, Kinlet

Formation, Hadley Formation, Ruabon Marl and Ardwick Marls (Powell et al., 2000a).

Type area

Potteries Syncline (North Staffordshire Coalfield) [SJ 70 30 to SK 00 60]: borehole sections and some quarries, including the original type locality at Etruria (Rees and Wilson, 1998).

Reference sections

Whole formation: Sidway Mill Borehole (SJ73NE/3) [SJ 7603 3934], from the base at 1210.84 m depth, to the top at 779.07 m depth (Figure 9) (Besly and Cleal, 1997).

Barker's Wood Borehole (SJ84NW/68) [SJ 8221 4516], from 151.79 to 461.93 m depth (Rees and Wilson, 1998).

Base: Wolstanton Colliery No.3 Shaft (SJ84NE/29) [SJ 8606 4800], at 348.26 m depth (Rees and Wilson, 1998).

Lithology

Red, purple, brown, ochreous, green, grey and commonly mottled mudstone, with lenticular greenish-grey, referred to as 'espleys', common pedogenic horizons, but coal seams are rare. Subordinate, lenticular sandstones and conglomerates commonly consist mostly of volcanic and lithic clasts. Intrusions of dolerite sills and dykes and extrusion of a small volume of volcanoclastic rocks are present in south Staffordshire and south Nottinghamshire.

Lower and upper boundaries

The lower boundary is a passage by alternation from grey mudstones of the underlying Pennine Coal Measures Group to red, purple mudstone of the Etruria Formation. Locally, in Shropshire, Warwickshire and Lincolnshire, the lower boundary is an unconformity (Symon Unconformity).

The formation is overlain conformably by predominantly grey sandstone and mudstone strata of the Halesowen Formation, although locally, in south Staffordshire the upper boundary is an unconformity.

Thickness

The formation is up to 300 m thick in the type area, but typically 50 to 100 m in the southern part of the Pennine Basin.

Distribution

English Midlands, Lancashire, Yorkshire and North Wales.

Regional correlation

The lower part of the formation passes northward into grey coal-bearing strata of the Pennine Upper Coal Measures Formation.

Genetic interpretation

The formation comprises a well-drained, alluvial floodplain facies association with brunified palaeosols and sandstones representing single channel fill or multilateral or multistorey channel fills (Glover et al., 1993). There is a localised development of a volcanic facies.

Biostratigraphical characterisation

The formation is generally Bolsovian, but ranges from late Duckmantian to early Asturian. The lower boundary is highly diachronous, with primary red-beds forming earlier in the Pennine Basin margins (Besly, 1988), most notably in south Staffordshire. Where primary reddening is less intense, non-marine bivalve faunas of the *Anthraconauta phillipsi* and *A. tenuis* Biozone have been recorded from the formation in Lancashire (Trotter, 1954), suggesting a Bolsovian to Asturian age for the onset of primary red-bed deposition.

Age
Westphalian

4.10.2 Halesowen Formation (HA)

Name

The name derives from the town of Halesowen, located in the southern part of the South Staffordshire Coalfield. The unit has been previously referred in the type area as the Halesowen Beds (Whitehead and Eastwood, 1927) and Halesowen Group (Eastwood et al., 1925). The formation replaces the redundant Highley Formation, Coalport Formation, Coed-yr-Allt Formation, Newcastle Formation, Keele Formation and Ardwick Limestones (Powell et al., 2000a).

Type sections

Composite stratotype, base: The Rumbow (R. Stour), Halesowen Town [SO 967 836].

Base: Oldnall, disused tramway track [SO 9318 8401].

Composite sections: Illey Brook, Halesowen [SO 975 816 to 977 813].

Top: Uffmoor Wood, stream section [SO 956 811 to 951 811].

Reference sections

Sidway Mill Borehole (SJ73NE/3) [SJ 7603 3934], north Staffordshire, where the succession includes the former Newcastle and Keele units (red beds, in part), with the base at 779.1 m, and the top at 472.8 m depth (Figure 9) (Besly and Cleal, 1997).

Allotment No.1 Borehole, Stafford (SJ92NW/35) [SJ 9461 2679], base at 352.0 m, top at 176.0 m depth.

Whittington Heath Borehole (SK10NW/3) [SK 1478 0800], which displays an entirely red-bed sandstone lithofacies.

Middle and upper part of formation: BGS Daleswood Farm Borehole (SO97NE/452) [SO 9512 7913], from 147.4 m depth to bottom of borehole (Glover and Powell, 1996).

Formal subdivisions

A single member, the Dark Slade Member, has been defined for the upper, mudstone-dominated part of the succession in the type area (Besly and Cleal, 1997).

Lithology

Grey-green, micaceous sandstone (litharenite), and grey-green mudstone, with thin coals and limestone beds known as the *Spirorbis* limestone, with local intraformational conglomerate, strata may be reddened locally.

Lower and upper boundaries

The base is a sharp unconformable junction between the red mudstone of the Etruria Formation and overlying grey-green, locally pebbly sandstone of the Halesowen Formation, in the Halesowen type area; may be conformable elsewhere. If the Halesowen Formation is red, the base is drawn at the base of the first litharenite above the Etruria mudstones.

The top is taken at the base of the overlying Salop Formation. At outcrop an upward change from grey to orange-red locates the boundary, except where the Halesowen Formation is itself red; in this case the boundary is drawn arbitrarily, above the top of the highest litharenite sandstone. Although in boreholes, the gamma ray log character is used.

Thickness

About 110 m thick in the type area; 76–152 m thick in South Staffordshire; 70–127 m thick in Warwickshire; about 200 m thick in the Wyre Forest; 350 m thick in north

Staffordshire; remaining thickness about 125 m in the East Midlands and about 200 m in Lancashire.

Distribution

Mostly the southern part of the Pennine Basin, central England from Oxfordshire to Lancashire and Nottinghamshire, and North Wales.

Regional correlation

The formation is interpreted as the northward equivalent of the Grovesend Formation of South Wales and southern England (see Sections 5.5.3, 5.5.6, 5.5.9 and 5.5.12).

Genetic interpretation

In the type area three upward-fining cycles are interpreted as representing the sequential transition from fluvial to floodplain-dominated sedimentation. The presence of thin coals and *Spirorbis* limestones indicate relatively high water tables with development of rheotrophic swamps and lacustrine carbonates (Glover and Powell, 1996).

Biostratigraphical characterisation

Non-marine bivalve faunas of the *A. tenuis* Biozone (Edwards, 1951), miospores (Smith and Butterworth, 1967; Butterworth and Smith, 1976) and plant macrofossils (Clayton et al., 1977; Cleal, 1984; Besly and Cleal, 1997) indicate an Asturian age for the formation. A late Asturian to Cantabrian age for the Halesowen Formation in the West Midlands and for the upper part of the formation in Warwickshire has been proposed. However, the basal Main Sulphur Coal at Coalbrookdale has been assigned a late Bolsovian age on the basis of its miospore content (Hamblin and Coppack, 1995).

Age

Asturian (Westphalian D)

4.10.2.1 DARK SLADE MEMBER (DAR)

Name

The member is named after the borehole from the Cannock Chase Coalfield, which is taken as the type locality. Previously known as the Palustrine Unit it was redefined as the Dark Slade Member by Besly and Cleal (1997) and Powell et al. (2000a).

Type section

Dark Slade Borehole (SJ91NE/16) [SJ 97644 16495]; base at 241.8 m., top at 181.3 m. (Besly and Cleal, 1997, fig. 10).

Reference section

Radwood Borehole (SJ74SE28) [SJ 7753 4176]; base at 284.9 m., top at 204.3 m (Besly and Cleal, 1997, fig. 6).

Lithology

Mudstone with subordinate sublitharenite sandstones and thin beds of *Spirorbis* limestone. Colour grey with mottled grey/brown palaeosols (but may be reddened). Distinctive geophysical log character, with gamma ray peaks.

Lower and upper boundaries

The base of the member is drawn at the base of mudstone-dominated succession resting on litharenites of lower Halesowen Formation; or at change of gamma log character.

The top is taken at the base of the overlying Salop Formation. In places where the member is grey there is a change to orange-red colours. The boundary is also marked by a change of gamma ray log character.

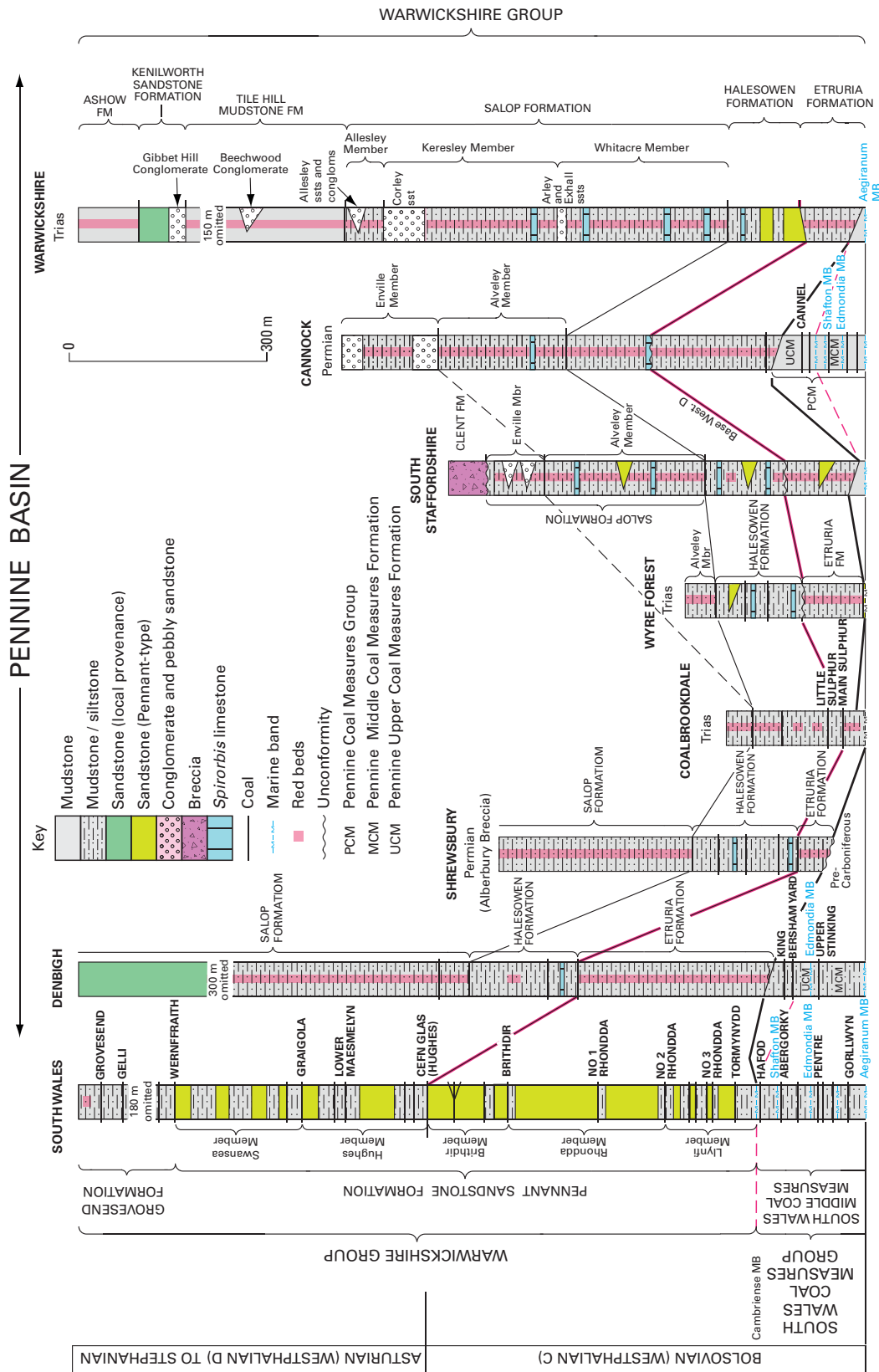


Figure 15 Generalised sections of the Warwickshire Group from the southern parts of the Pennine Basin and South Wales (from Powell et al., 2000).

Thickness

From 40 to 90 m; 60.5 m in type section

Distribution

Staffordshire, Shropshire, Warwickshire

Biostratigraphical characterisation

A coal from Alveley, Shropshire contains a miospore assemblage indicative of late Bolsovian or Asturian age (Owens, 1990).

Age

Asturian

4.10.3 Salop Formation (SAL)

Name

The name is taken from a colloquial regional term used for the Shropshire/Staffordshire area (Powell et al., 2000a). The geographical name is distinguished from the term 'Salopian', which was formerly used as a chronostratigraphical stage

name for part of the Silurian in the Welsh Borderlands. The Salop Formation includes the former Keele Formation of some areas (now Alveley Member) and former Enville Formation (now Enville Member). The Alveley and Enville units are reduced to member status since it is difficult to distinguish a mappable boundary between them over much of the area. The Radwood Formation of North Staffordshire, the Erbistock Formation (or Group) of Shropshire and Meriden Formation of Warwickshire are assigned to the Salop Formation.

Type area

The type area is Alveley [SO 76 84], Bowhills [SO 77 84] and Enville Sheepwalks [SO 82 86], in the Staffordshire/Shropshire area (Besly and Cleal, 1997).

Reference sections

Alveley No.1 Borehole (SO78NE/2) [SO 7817 8608], from surface to 76.8 m depth (Besly and Cleal, 1997).

Penn No.5 Borehole (NCB) (SO89NE/6) [SO 8925 9654] from 562.4 m (base) to 202.6 m depth (top) (Powell, 1991).

Romsley Borehole No.31 (SO97NE/216) [SO 9501 7893], from 8.85 m at the upper boundary, down to 67.35 m depth, comprising the upper part of the formation (Glover and Powell, 1996).

BGS Daleswood Farm Borehole (SO97NE/452) [SO 95117 79132], from 3.7 m close to the top of the unit, down to 147.4 m at the base of the unit (Glover and Powell, 1996).

Rough Close Borehole (SP27NE/9) [SP 26481 78509], base defined at about 718 m depth, and the top at 109 m depth, uncored, but has a full suite of geophysical logs available (Bridge et al., 1998).

Birch Tree Farm Borehole (SP38SW/161) [SP 31016 82882] in the lower part of the formation, cored from base at 558 m to 300 m (Bridge et al., 1998).

Formal subdivisions

The formation in the type area and south Staffordshire includes the Alveley Member (former Keele Formation) in its lower part, and Enville Member (former Enville Formation) in its upper part (Powell et al., 2000a) (Figure 15). In Warwickshire the formation is subdivided into the Whitacre, Keresley and Allesley members, in ascending order, representing three upward-coarsening cycles (Bridge et al., 1998).

Lithology

Red and red-brown mudstone, and red-brown (mostly sublitharenite) sandstone containing beds of pebbly sandstone and conglomerate itself containing Carboniferous limestone and chert clasts, and thin 'Spirorbis' limestone beds and caliche in the lower part of the unit.

Lower and upper boundaries

The lower conformable, transitional-gradational boundary is taken at the base of the first, at least 1 m thick, red-bed stratum, overlying the grey mudstone-dominated Dark Slade Member of the underlying Halesowen Formation. Where this is also red, the boundary is drawn arbitrarily, above the top of the highest litharenite sandstone.

In the type area at the upper boundary occurs at the base of the Clent Formation. The boundary is an unconformable or disconformable sharp junction, in the Clent Hills where the Clent Formation is a red-brown breccia; or is a gradational boundary where there is red mudstone-dominated Clent Formation; but is taken at the base of red sandstone with Uriconian volcanic clasts in the Gospel End area of the

West Midlands. In Warwickshire, the boundary is conformable below the red-brown mudstone-dominated succession of the Tile Hill Mudstone Formation.

Thickness

From 200 m to 360 m thick in Shropshire, and 625 m thick in Warwickshire.

Distribution

Staffordshire, Shropshire and Warwickshire.

Genetic interpretation

Deposition in both proximal and distal alluvial plain settings, in a semi-arid climate (Besly, 1988; Glover and Powell, 1996). Red mudstones and associated brunified alluvial and ferruginous palaeosols were deposited on a well-drained interfluvies. *Spirorbis* limestones were deposited in shallow lakes. The sediments appear to be derived from a mixed source areas located to the southern, south-eastern and south-western margins of the Pennine Basin.

Biostratigraphical characterisation

The formation is Asturian to Stephanian or early Permian (Waters et al., 1995; Besly and Cleal, 1997). Poorly preserved plant material from the Wyre Coalfield suggests the inclusion of early Stephanian (Cantabrian) beds in the Salop Formation (Besly and Cleal, 1997).

Age

Asturian to Permian

4.10.3.1 ALVELEY MEMBER (ALY)

Name

The name is derived from the village of Alveley [SO 76 84], north-west of Kidderminster. The name was introduced (Besly and Cleal, 1997) to replace the name Keele Formation (or beds), because the Keele Beds outcropping near Keele (north Staffordshire) have been shown to be red-bed equivalents of the Halesowen Formation. The member was formally defined by Powell et al. (2000a)

Type area

Quarries and stream sections around Alveley [SO 76 84], from River Severn north-east to the Bobbington area [SO 79 89].

Reference sections

Alveley No.1 Borehole (SO 78 NE/2) [SO 7817 8608]: from surface to 76.8 m (Besly and Cleal, 1997).

BGS Daleswood Farm Borehole (SO97NE/452) [SO 95117 79132], from 97.7 m (top) to 147.4 m depth (base) (Glover and Powell, 1996).

Lithology

Red mudstone and sandstone, fine- to medium-grained with thin 'Spirorbis' limestone beds and pedogenic limestone (caliche). Sandstones are mostly sublitharenites.

Lower and upper boundaries

The lower conformable, transitional-gradational boundary is arbitrarily taken at the base of the first major red-bed stratum, overlying the grey mudstone-dominated Dark Slade Member of the Halesowen Formation.

The top is poorly defined, but arbitrarily taken at the base of a sandstone-dominated succession (Enville Member), characterised by conglomerates and pebbly sandstones with extrabasinal clasts, commonly of Carboniferous limestone and chert.

Thickness

From 152 to 274 m in Alveley area; 50 to 140 m in south Staffordshire.

Distribution

West Midlands and Shropshire

Genetic interpretation

Deposition in a distal alluvial plain setting, in a semi-arid climate (Besly, 1988; Glover and Powell, 1996). Red mudstones and associated brunified alluvial and ferruginous palaeosols and caliches were deposited on a well-drained interfluvial. *Spirorbis* limestones were deposited in shallow lakes.

Age

Asturian

4.10.3.2 ENVILLE MEMBER (EN)

Name

The name is derived from the village of Enville (Whitehead and Eastwood, 1927) and the unit status has been reduced to member (Besly and Cleal, 1997). The unit was formerly known as the Enville Beds (Whitehead and Eastwood, 1927), Calcareous Conglomerate Group (Eastwood et al., 1925), Bowhills Formation (Ramsbottom et al., 1978) and Enville Formation (Besly, 1988). The member is formally defined by Powell et al. (2000a).

Type area

Bowhills [SO 77 84] and Enville Sheepwalks [SO 82 86], between Alveley and Enville villages, (Salop and West Midlands respectively).

Reference sections

Romsley Borehole (SO97NE/216) [SO 9501 7893]: upper boundary at 8.85 m, to 67.35 m depth (upper part of the member) (Glover and Powell, 1996).

BGS Daleswood Farm Borehole (SO97NE/452) [SO 95117 79132]: from 97.7 m (base) to 3.7 m depth (close to top of the member) (Glover and Powell, 1996).

Lithology

Red mudstone and red-brown, fine- to coarse-grained sandstone, locally pebbly, and lenticular beds of conglomerate. Sandstone mostly sublitharenite; conglomerate clasts mostly Carboniferous limestone and chert.

Lower and upper boundaries

The base is poorly defined; taken arbitrarily at base of sandstone dominated succession that overlies the Alveley Member and is characterised by conglomerates and pebbly sandstones with extra-basinal clasts, commonly of Carboniferous limestone and chert.

The upper boundary is unconformable/disconformable; sharp junctions with the overlying Clent Formation (breccia) in the Clent Hills; gradational boundary with mudstone dominated Clent Formation; or taken at the base of red mudstone/sandstone with Uriconian volcanic clasts in Gospel End area (West Midlands).

Thickness

From 100 to 275 m in West Midlands

Distribution

Shropshire and West Midlands

Genetic interpretation

Deposition in a proximal alluvial plain setting, in a semi-arid climate (Besly, 1988; Glover and Powell, 1996).

Biostratigraphical characterisation

The age of the member is uncertain, based on the limited presence of vertebrate fossils and plant macroflora. Crookall (in Mitchell, 1942) stated that there was no firm evidence to indicate that the Enville Member is younger than Asturian in age, whereas, Wagner (1983) concluded an Autunian age.

Age

Asturian to early Permian

4.10.3.3 WHITACRE MEMBER (WIT)

Name

The name derives from the village of Whitacre, Warwickshire and was introduced for the first upward coarsening red-bed succession overlying the grey Halesowen Formation (Bridge et al., 1998). It is equivalent to the former Keele Formation and the lowermost part of the Coventry Sandstone (Old et al., 1987). The member is formally defined by Powell et al. (2000a).

Type area

Warwickshire Coalfield between Over Whitacre and Baxterley (poor exposures) [SP 25 91 to SP 27 97].

Reference sections

Birch Tree Farm Borehole (SP38SW/161) [SP 31016 82882]: top of member (uncored) taken at 238 m below surface, base at 519.5 m below surface (Bridge et al., 1998).

Old quarry at Tipper's Hill Lane [SP 2815 8893]: exposes granule to pebble grade breccio-conglomerates composed primarily of mudstone clasts. Typifies lower part of member.

Lithology

Red and red-brown mudstone and red-brown sandstone. Mudstone-dominated in lower part, with characteristic caliches and breccias. Increasingly arenaceous towards top with impersistent conglomerates present in the uppermost part. Conglomerate clasts include chert, sandstone and limestone, mostly of Lower Carboniferous age, and caliche. Thin *Spirorbis* limestones are present at some levels.

Lower and upper boundaries

The base is transitional. It is defined in the field at the upward change from grey measures of the Halesowen Formation to red beds. Defined on geophysical logs (in uncored boreholes) above a narrow zone of high gamma radiation.

The top is drawn at the top of the highest mappable sandstone unit (Arley and Exhall sandstones) beneath the basal argillaceous beds of the overlying Keresley Member.

Thickness

Range 280–357 m; mean 334 m; based on geophysical well log data.

Distribution

Warwickshire Coalfield (northern part) Sheet 169. Also likely to extend in the subcrop across the southern part of the Warwickshire Coalfield (Sheet 184).

Genetic interpretation

Broadly upward-coarsening trend from distal (mudstone) to proximal (sandstone and conglomerate) alluvial fans (Besly, 1988; Bridge et al., 1998). A northward to north-eastward palaeoflow is indicated (Bridge et al., 1998).

Biostratigraphical characterisation

An Asturian age is indicated by the presence of non-marine bivalves (Old et al., 1987).

Age

Asturian to Stephanian

4.10.3.4 KERESLEY MEMBER (KRS)

Name

The name derives from the village of Keresley, Warwickshire and was introduced for the middle, upward-coarsening red-bed succession of the Meriden (now Salop) Formation. The member is equivalent to the middle part of the former Coventry Sandstone (Old et al., 1987). The member is formally defined by Powell et al. (2000a).

Type area

Warwickshire Coalfield; centred on the village of Corley [SP 30 85], extending from the coalfield Western Boundary Fault into north-west Coventry (poorly exposed throughout).

Reference sections

Staircase Lane Borehole (SP38SW97) [SP 3036 8129]: uncored but with good geophysical signature. Base 363 m below surface; top 78 m below surface.

Cliff section, roadside exposure 200 m north-east of Corley village [SP 3040 8520] exposes sandstones in the upper part of the Member (Corley Sandstone).

Lithology

Red and red-brown mudstone and red-brown sandstone. Mudstone-dominated in lower part, with characteristic caliches and breccias. Increasingly arenaceous towards top with impersistent conglomerates present in the uppermost part. Conglomerate clasts include chert, sandstone and limestone, mostly of Lower Carboniferous age. Thin *Spirorbis* limestones are present at some levels.

Lower and upper boundaries

The base is taken immediately above the sandstone unit named informally as the Arley and Exhall sandstones at the top of the Whitacre Member.

The top is taken at the highest mappable sandstone (Corley Sandstone) beneath the basal argillaceous sequence of the overlying Allesley Member.

Thickness

Range 197 m to 306 m; mean 258 m.

Distribution

Warwickshire Coalfield (northern part) Sheet 169. Also likely to extend in the subcrop across the southern part of the Warwickshire Coalfield (Sheet 184).

Genetic interpretation

Broadly upward-coarsening trend from distal (mudstone) to proximal (sandstone and conglomerate) alluvial fans (Besly, 1988; Bridge et al., 1998).

Age

Asturian to Stephanian

4.10.3.5 ALLESLEY MEMBER (ASY)

Name

The name derives from the village of Allesley, Warwickshire and was introduced for the uppermost, upward-coarsening red-bed succession of the Meriden (now Salop) Formation. The member is equivalent to the upper part of the former

Coventry Sandstone (Old et al., 1987). The member is formally defined by Powell et al. (2000a).

Type area

Warwickshire Coalfield; outcrops centred on the village of Allesley and extending from the Western Boundary Fault to the western suburbs of Coventry (poor exposure) [SP 24 81 to SP 33 78].

Reference section

Mount Nod Well No.2, Coventry (SP27NE46) [SP 2922 7927]: top proved at 38.3 m below surface and base proved at 170.5 m below surface.

Lithology

Red and red-brown mudstone and red-brown sandstone. Mudstone-dominated in lower part, with characteristic caliches and breccias. Increasingly arenaceous towards top with impersistent conglomerates present in the uppermost part. Conglomerate clasts include chert, sandstone and limestone, mostly of Lower Carboniferous age. Thin *Spirorbis* limestones are present at some levels.

Lower and upper boundaries

The base is taken at the junction between the highest sandstone package in the Keresley Member (Corley Sandstone) and the overlying mudstone unit.

The top is defined at the incoming of mudstones of the essentially argillaceous Tile Hill Mudstone Formation.

Thickness

About 140 m

Distribution

Warwickshire Coalfield (Sheet 169). Also likely to extend in the subcrop across the southern part of the coalfield (Sheet 184).

Genetic interpretation

Broadly upward-coarsening trend from distal (mudstone) to proximal (sandstone and conglomerate) alluvial fans (Besly, 1988; Bridge et al., 1998).

Age

Asturian to Stephanian

4.10.4 Clent Formation (CLT)

Name

The name is derived from the type area, Clent Hills, West Midlands. Previous names include: Clent Hills Breccia, Trappoid Breccia, Breccia Group, Clent Group, Clent Breccias, Northfield Breccia, Nechells Breccia and Quartzite Breccia (Powell et al., 2000a).

Type area

Clent Hills, near Hagley; from Park Visitors Car Park [SO 935 807] to summit of Clent Hills.

Reference sections

Breccia lithofacies; Romsley Borehole No.31 (SO97NE216) [SO 9501 7893]; lower boundary at 8.85 m depth (Glover and Powell, 1996).

Mudstone/sandstone lithofacies; Penn No.5 Borehole (SO89NE6) [SO 8925 9654]; from 83 m depth (base) to 20 m depth (top) (Glover and Powell, 1996).

(Mudstone dominated strata), Penn Common, Penn Brook (stream section) SO 913 955 to SO 893 940].

Lithology

Breccia, sub-angular, with red-brown mudstone matrix, clasts predominantly 'Precambrian-Uriconian' volcanic rocks and subordinate Lower Palaeozoic rocks. Red pebbly mudstone and sandstone in Wolverhampton area.

Lower and upper boundaries

The base is an unconformable/disconformable boundary between underlying mudstone/sandstone of Salop Formation (Enville Member) and coarse breccia above (in type area); gradational boundary in Wolverhampton area.

The top of the member is generally the modern erosion surface in type area, but is locally overlain unconformably by Kidderminster Formation (Triassic).

Thickness

About 138 m in the Clent Hills, about 240 m in the Wolverhampton/Baggeridge area to north.

Distribution

West Midlands; south Staffordshire and Birmingham areas.

Regional correlation

The Clent Formation has not been recognised in the Warwickshire Coalfield. It may be equivalent, in part, to the Tile Hill Mudstone Formation, and/or to the overlying Kenilworth Sandstone and Ashow formations (Powell et al., 2000a).

Genetic interpretation

Interpreted as proximal alluvial fan deposits with pebble clasts derived locally from uplifted hinterland blocks associated with the Wales–Brabant High to the south. The northward passage to a mudstone-dominated succession reflects a transition toward a distal alluvial fan. The breccias mark a major change in provenance and lithofacies from the underlying Salop Formation.

Biostratigraphical characterisation

The formation is probably early Permian, possibly late Stephanian in age (Waters et al., 1995), although there is no fossil evidence for this.

Age

Early Permian

4.10.5 Tile Hill Mudstone Formation (TLM)

Name

The name is taken from Tile Hill, west of Coventry. It was previously known as the Tile Hill Marl Group (Shotton,

1929; Old et al., 1987). The formation is formally defined by Powell et al. (2000a).

Type area

Tile Hill, Warwickshire [SP 28 78]. Poor exposures, but see reference sections.

Reference sections

Tile Hill Railway Station Borehole (SP27NE1) [SP 2781 7755]. Mudstones with subordinate sandstones recorded to 211.3 m depth (Bridge et al., 1998).

Stream section north of Broad Lane, Tile Hill [SP 2789 7975 to SP 2800 7975]: in flaggy red-brown sandstone and interbedded mudstone (Bridge et al., 1998).

Mount Nod No.2 Borehole (SP27NE46) [SP 2922 7927]: Basal 38.3 m of formation recorded as 'hard red marl' with 'sandy beds' (Bridge et al., 1998).

Lithology

Red-brown mudstones with subordinate thin red-brown and green, flaggy, fine- to coarse-grained sandstones with rare thin conglomeratic lenses.

Lower and upper boundaries

The base is taken at the first red-brown mudstone, above the highest mappable persistent red-brown sandstone of the Salop Formation.

The top is taken at the change from red-brown mudstone, to the predominantly red-brown sandstone of the Kenilworth Sandstone Formation.

Thickness

Some 280 m thick

Distribution

Extensive outcrops in the southern part of the Warwickshire Coalfield.

Genetic interpretation

Alluvial plain environment associated with fine-grained siliciclastic sedimentation within a distal floodplain setting.

Biostratigraphical characterisation

The formation has been regarded as Autunian (earliest Permian) on the basis of vertebrate fauna and ichnofauna (Vernon, 1912; Dix, 1935; Haubold and Sarjeant, 1973). However, the base of the Permian in Warwickshire is usually drawn higher up, at the base of the Kenilworth Sandstone Formation. This age is based on the occurrence of the pelycosaurs *Sphenacodon britannicus* and *Haptodus grandis* (Paton, 1974) and the amphibian *Dascyiceps bucklandi* (Paton, 1975).

Age

Asturian to Stephanian

5 South Wales–Bristol

The area south of the Wales–Brabant High developed a succession similar to that seen north of the high. The earliest Carboniferous strata are the Avon Group, a shale-dominated shelf succession. This is overlain by a carbonate succession, the Pembroke Limestone Group, which shows an evolution from ramp to shelf facies during the Tournaisian to Viséan. The platform carbonates are overlain by late Viséan to early Namurian dominantly basinal shales and cherts. The Marros Group, of Namurian age, represents incursions of dominantly quartzose siliciclastics derived from the Wales–Brabant High to the north. The overlying South Wales Coal Measures Group is of Langsettian to Bolsovian age and comprises fluvio-deltaic facies comparable to Pennine Coal Measures present to the north of the Wales–Brabant High. The Coal Measures are overlain by alluvial deposits of the Warwickshire Group. The lithostratigraphical succession is summarised in Figure 16.

5.1 AVON GROUP (AVO)

The Avon Group is a new name proposed to replace the obsolete terms Lower Limestone Shale Group (Kellaway and Welch, 1955) and Cefn Bryn Shales (George, 1939). The Avon Group comprises up to 150 m of interbedded grey mudstones and thin- to medium-bedded skeletal packstones with one to several thick units of ooidal and skeletal grainstones. Thin units of calcite mudstone and mudstone and sparse thin ironstones are locally present. The group represents Tournaisian mid to inner shelf/ramp deposits with coeval barrier, back barrier and coastal plain sediments, deposited during a major phase of northward-directed marine transgression. As such, it is considered to be sufficiently distinct from the overlying shelf and ramp carbonates of the Pembroke Limestone Group to be recognised as a separate group. The Avon Group is present across South Wales, Monmouth and Chepstow, Bristol, the Mendips and Clee Hills and Little Wenlock areas of Shropshire. The group is proved in a borehole at Cannington Park, Somerset, representing the southern limit of the group; it passes southward into the Pilton Mudstone Formation of the North Devon Basin.

SOUTH WALES

Existing mapping allows only an undifferentiated group to be identified over large areas of South Wales, e.g. Pembroke, Gower, Forest of Dean. However, recent mapping has allowed the group to be subdivided in South Wales into the **Tongwynlais, Castell Coch Limestone** and **Cwmyniscoy Mudstone formations** (Figure 17) (Waters and Lawrence, 1987; Wilson et al., 1990). The group ranges from 140 m thick in the southern Vale of Glamorgan, thinning northward to 10 m on the north-west crop (Ammanford area) of the South Wales Coalfield.

5.1.1 Tongwynlais Formation (TGW)

Name

The formation was named and defined by Waters and Lawrence (1987).

Type section

Road section (Merthyr Road), 1.5 km, west-south-west of Rhiwbina Farm, Tongwynlais, Cardiff [ST 1301 8245 to 1303 8244]: semi-continuous exposure through the entire formation (38 m thick), with both lower and upper boundaries seen (Gayer et al., 1973; Burchette, 1987).

Lithology

Lower part comprises thin- to thick-bedded skeletal, peloidal, ooidal and sandy grainstones and packstones with subordinate grey mudstones, calcite mudstones, calcretes and ironstones. Upper part comprises thin- to medium-bedded skeletal packstones and grey mudstones.

Lower and upper boundaries

A thin unit (3 to 4 m) of red, sparsely shelly, calcareous sandstones, sandy limestones, and mudstones with calcrete caps the red fluvial sandstones of the underlying Quartz Conglomerate Group. The sharp base of the Tongwynlais Formation is taken at the top of this thin unit at the incoming of restricted marine or peritidal, green or grey mudstones, micrites, calcisiltites and skeletal packstones/grainstones.

Interbedded thin- to medium-bedded grey skeletal packstones and mudstones forming the upper part of the Tongwynlais Formation thicken upwards and pass up quickly, but gradationally, into the medium- to thick-bedded ooidal and skeletal grainstones of the Castell Coch Limestone Formation. The top of the Tongwynlais Formation is taken at the top of the last mudstone bed.

Thickness

Up to 50 m in the south of the Vale of Glamorgan, thinning northwards to a feather edge in the Risca area.

Distribution

Vale of Glamorgan [ST 00 74]. The formation is overstepped northwards by the Castell Coch Limestone Formation. The formation is present but not mapped in the south-east crop of the South Wales Coalfield [ST 17 85], Gower [SS 50 90], Pembrokeshire [SM 99 01] and Chepstow [ST 53 93] areas.

Genetic interpretation

The formation was deposited during a marine transgression. The lower part represents deposition in an ooidal shoal, embayment and peritidal environments. The upper part represents deposition on a storm influenced, open marine, nearshore shelf

Age

Courseyan

5.1.2 Castell Coch Limestone Formation (CCL)

Name

Previously referred to as the Bastard Limestone (Strahan and Cantrill, 1912), defined as a formation by Waters and Lawrence (1987).

Type section

Castell Coch Quarry, 50 m west of Castell Coch, Tongwynlais,

Cardiff [ST 1300 8261]: entire formation seen, including upper boundary (Waters and Lawrence, 1987).

Lithology

Grey, locally reddened, medium- to thick-bedded, cross-bedded, ooidal and skeletal grainstones. Thin units of grey mudstone, calcite mudstone and calcisiltite are locally present in the uppermost part of the formation. North of Risca, conglomerates, calcareous sandstones and sandy limestones are present in the lowermost part. In the Abergavenny area of the North Crop, the formation comprises a lag conglomerate, generally less than 1 m thick, overlain by calcareous sandstone, sandy limestone and cross-bedded, shelly, ooidal and crinoidal calcarenites (Barclay, 1989). This in turn passes gradationally into a thin-bedded succession of shale, micrite and ooidal, peloidal, fine-grained limestone with common stromatolitic lamination. The upper part of the formation comprises a wedge of bimodally cross-bedded ooidal calcarenite.

Lower and upper boundaries

Interbedded thin- to medium-bedded grey skeletal packstones and mudstones forming the upper part of the Tongwynlais Formation thicken upwards and pass up quickly, but gradationally, into the medium- to thick-bedded ooidal and skeletal grainstones of the Castell Coch Limestone Formation. The base of the Castell Coch Limestone Formation is taken at the incoming of a mudstone-free sequence. North of Risca, the formation overlaps the Tongwynlais Formation to overlie the component formations of the Quartz Conglomerate Group. The base is taken at the sharp erosive contact between the green grey sandstones, quartz conglomerates and red and green mudstones of the Quartz Conglomerate Group and the overlying calcareous sandstones, sandy limestones, and skeletal and ooidal grainstones of the Castell Coch Limestone Formation. A persistent phosphatic, conglomeratic lag up to 0.7 m thick is present at the base.

Where back barrier mudstones, calcite mudstones and calcisiltites occupy the uppermost part of the formation, the top is taken at the sharp base of the overlying marine interbedded grey mudstones and packstones of the Cwmyniscoy Mudstone Formation. The contact is commonly erosional and overlain by a packstone or grainstone bed rich in intraclasts of the underlying back barrier mudstones. Where the uppermost part of the formation comprises barrier grainstones, the top is taken at the sharp incoming of the overlying interbedded grey mudstones and packstones of the Cwmyniscoy Mudstone Formation.

Thickness

Some 30 m on the north crop of the South Wales Coalfield (Abergavenny), thinning southwards to 9 m in the south of the Vale of Glamorgan.

Distribution

Vale of Glamorgan [ST 00 74] and South Wales Coalfield [SO 09 02], east of Swansea. Present but unmapped in the east crop of the South Wales Coalfield [ST 25 90], Pembrokeshire [SM 99 01], Gower [SS 50 90] and Monmouth and Chepstow areas [ST 53 93].

Genetic interpretation

The formation represents the first regional shallowing event to affect the Tournaisian shelf. The ooidal and skeletal grainstones were deposited as part of a barrier complex. The mudstone, calcite mudstone and calcisiltite represent back barrier peritidal deposits. The basal phosphatic lag

conglomerate represents deposition in the littoral zone during initial transgression (Barclay, 1989).

Biostratigraphical characterisation

Spores from the base of the formation indicate an early Tournaisian (Tn_{2a}) age, with the base becoming younger towards the north (Lovell, 1978).

Age

Courceyan

5.1.3 Cwmyniscoy Mudstone Formation (CCM)

Name

The formation was formally defined by Waters and Lawrence (1987).

Type section

Quarry 300 m south of Cwmyniscoy, Pontypool [ST 2834 9934]: complete section exposed, 29 m thick, with lower and upper boundaries seen (Squirrell and Downing, 1969).

Lithology

Interbedded grey mudstones and thin- to medium-bedded skeletal packstones.

Lower and upper boundaries

Where back-barrier mudstones, calcite mudstones and calcisiltites occupy the uppermost part of the underlying Castell Coch Limestone Formation, the base of the Cwmyniscoy Mudstone Formation is taken at the sharp incoming of marine, interbedded grey mudstones and packstones. The contact is commonly erosional and overlain by a packstone or grainstone bed rich in intraclasts of the underlying back barrier mudstones. Where the uppermost part of the Castell Coch Limestone Formation comprises barrier grainstones, the base of the Cwmyniscoy Mudstone Formation is taken at the sharp incoming of interbedded grey mudstones and packstones.

The contact of the Cwmyniscoy Mudstone Formation with the overlying Barry Harbour Limestone Formation is gradational. In the uppermost part of the Cwmyniscoy Mudstone Formation, the proportion of packstone beds increases to exceed that of mudstone. The top of the Cwmyniscoy Mudstone Formation is taken at the top of the last significant mudstone bed above which the succession becomes dominated by stacked fine and coarse skeletal packstones with scattered thin beds and partings of calcareous mudstone. In the north crop of the South Wales Coalfield, the Cwmyniscoy Mudstone Formation is overlain by the Sychnant Dolomite Formation or the Pwll-y-cwm Oolite Formation. The junction with the Sychnant Dolomite Formation is gradational. Thin beds of calcite mudstone and dolomitic limestone appear in the uppermost part of the Cwmyniscoy Mudstone Formation mudstone/packstone sequence. The top of the formation is taken at the entrance of abundant, thin-bedded, fine-grained, dolomitised skeletal packstones of the Sychnant Dolomite Formation. The contact with the Pwll-y-cwm Oolite Formation is sharp and taken at the entrance of thick bedded pale grey ooidal grainstone above the interbedded mudstones and packstones of the Cwmyniscoy Mudstone Formation.

Thickness

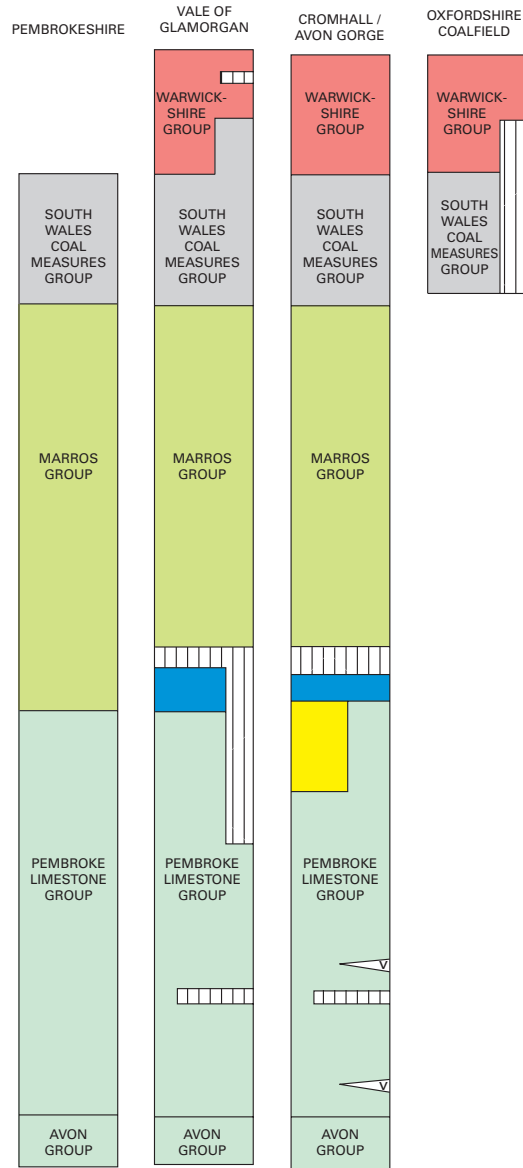
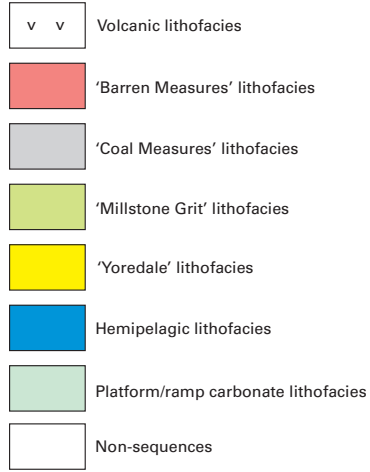
About 60 m in the south of the Vale of Glamorgan, thinning northwards to 10 m on the north crop of the South Wales Coalfield (Abergavenny).

Distribution

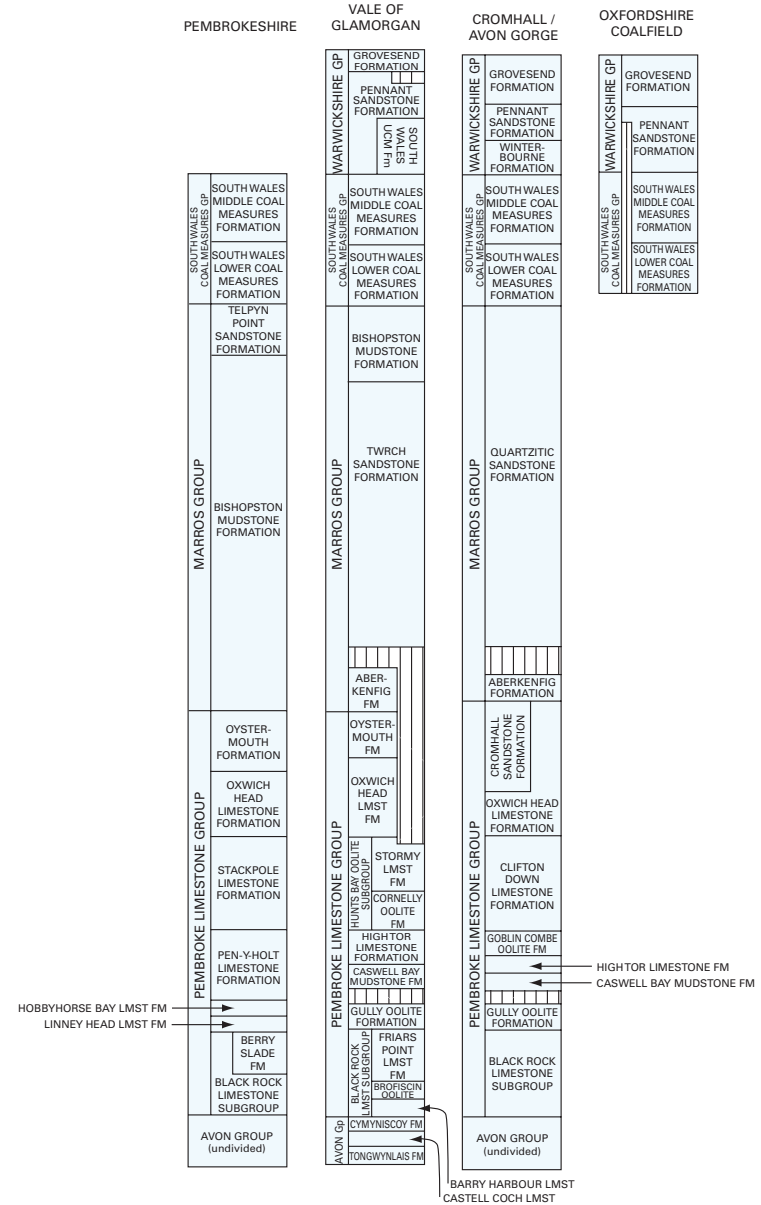
Vale of Glamorgan [ST 00 74] and South Wales Coalfield

Group and main lithofacies

Facies



Group and formation nomenclature



Chrono-stratigraphy

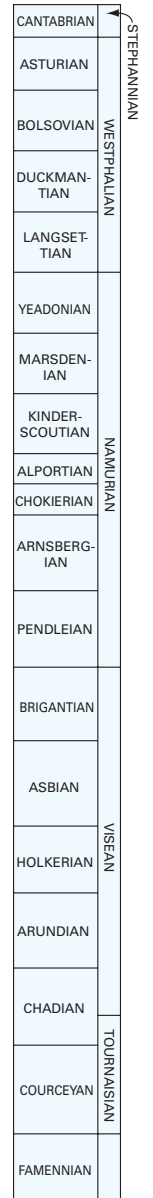
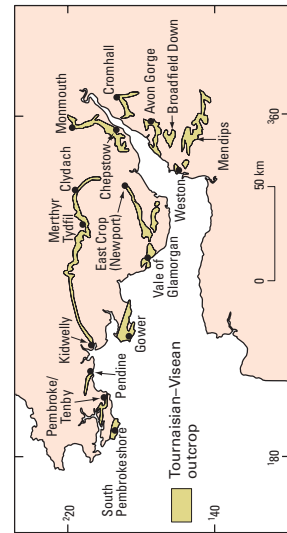
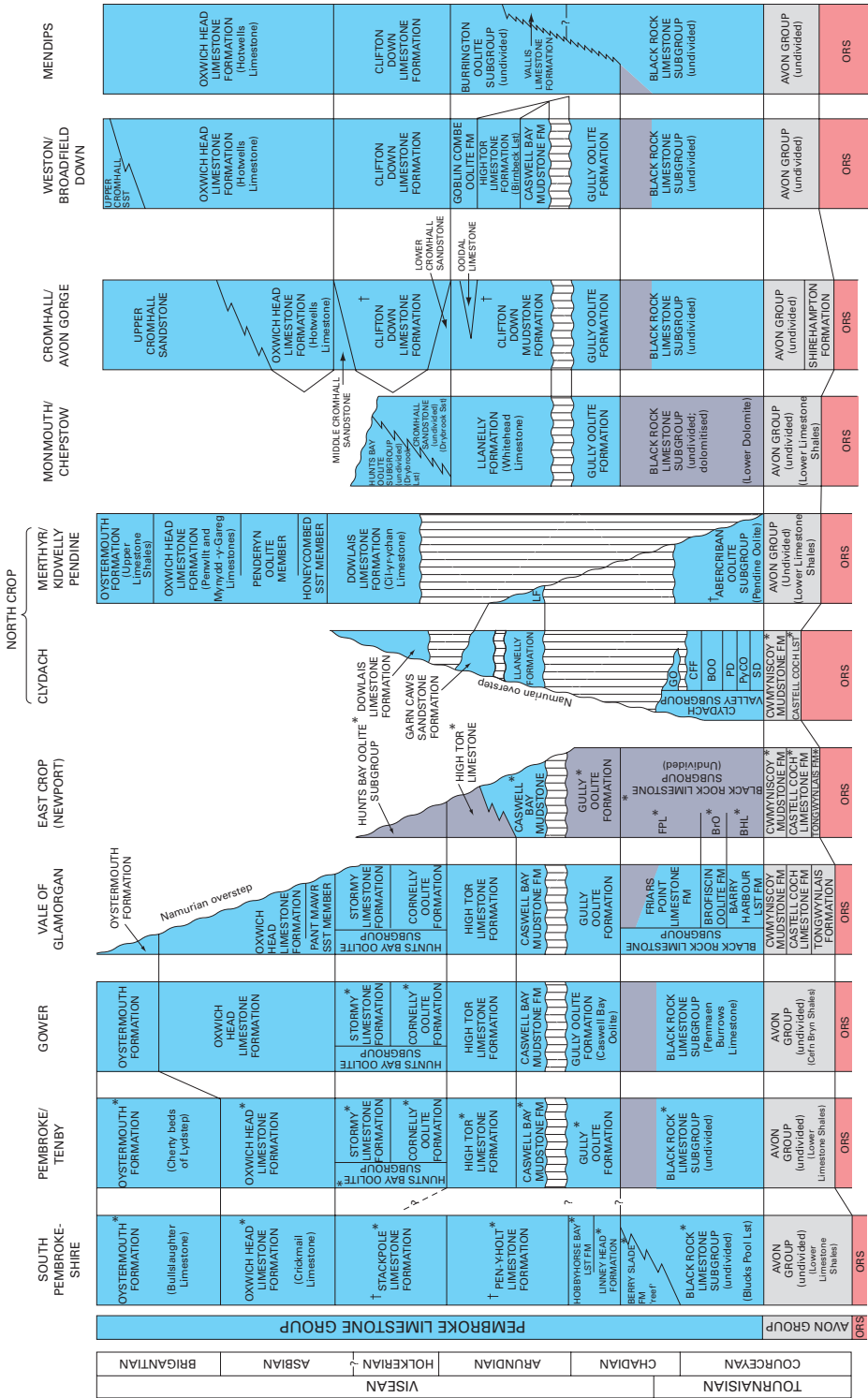


Figure 16 South Wales and southern England lithostratigraphical nomenclature.



Divisions of Clydach Valley Group :

- GO Gwern Oolite Formation
- CFF Coed Fryddwln Formation
- BOO Blaen Onnen Oolite Formation
- PD Pantyddarren Formation
- PycO Pwll-y-Cwm Oolite Formation
- SD Sychman Dolomite Formation

* Division/network not shown of current published maps
 † In need of revision following assessment in field
 Superseded local nomenclature shown in lower case in brackets ()

Figure 17 South Wales and Bristol Tournaisian and Visean lithostratigraphical nomenclature.

[ST 06 81], east of Swansea. Present but unmapped in east crop of South Wales Coalfield [ST 25 90], Pembrokeshire [SM 99 01], Gower [SS 50 90] and Monmouth and Chepstow [ST 53 93] areas.

Genetic interpretation

The formation represents a deepening marine environment with deposition on a storm-dominated muddy carbonate mid shelf (Waters and Lawrence, 1987; Wilson et al., 1990). The limestone beds may represent tempestites deposited during storm surges (Barclay, 1989).

Age
 Courceyan

BRISTOL

The Avon Group ranges from 156 m in the south Mendips, thinning north to about 96 m thick in the Bristol area. The group is also recorded in the Cannington Park inlier, Somerset, by the Knap Farm Borehole (ST24SW/1) [ST 2479 4011], which records 139.6 m of dark grey shale and mudstone with subordinate beds of crinoidal limestone. The group is typically entirely Tournaisian in age (Figure 17). Within the Knap Farm Borehole a Hastarian age has been recorded for all but the lowermost 1.9 m, for which a Devonian age has been assigned (Mitchell et al., 1982).

Though generally unsubdivided, the Shirehampton Formation has been recognised in the Bristol district (Barton

et al., 2002). The undivided Avon Group strata above the **Shirehampton Formation** was previously referred to as the Maesbury Mudstone Formation (Barton et al., 2002). It consists of greenish grey mudstone with interbedded dark grey crinoidal limestone, about 60 to 80 m thick in the Avon Gorge and around Portishead. The limestone beds have a rich shelly fauna, although are poor in corals. The base of the formation is marked by a non-sequence, with a thin, grey, pebbly and phosphatic limestone, resting upon an irregular surface above the 'Bryozoa Bed' (Kellaway and Welch, 1993).

5.1.4 Shirehampton Formation (SHB)

Name

Formerly the Shirehampton Beds (Kellaway and Welch, 1955), the unit was defined as a formation by Barton et al. (2002).

Type section

Portway road cutting, 1 km east of Shirehampton church, Bristol [ST 5408 7685 to 5415 7684]: only lowermost part of unit seen, including lower boundary, though it is likely that this cutting has become considerably degraded since it was erected as a type section in 1955 (Kellaway and Welch, 1993).

Lithology

Interbedded, thin- to medium-bedded red, green and grey mudstone, limestone, sandstone and siltstone with a thick red crinoidal limestone, known as the Bryozoa Bed, developed at the top.

Lower and upper boundaries

The base is gradational, but is taken for convenience at the top of the Sneyd Park Fish Bed, a conglomeratic fish-bearing sandstone at the top of the red sandstones, mudstones, siltstones and conglomerates of the underlying Portishead Formation. Above the Sneyd Park Fish Bed, grey mudstones and limestones of the formation appear interbedded with red sandstones and mudstones. This boundary is in need of work.

The top is taken at the irregular erosive contact between the red crinoidal limestone (Bryozoa Bed) of the formation and the overlying pebbly phosphatic limestone (Palate Bed), the basal bed of the interbedded limestones and mudstones of the undivided Avon Group.

Thickness

The formation is about 30 to 50 m thick in the Bristol area, but less than 20 m in the Chepstow area.

Distribution

Bristol area [ST 60 74]: there is considerable confusion over the exact extent. Locally mistakenly included in the Portishead Formation on BGS maps.

Regional correlation

It is thought to pass south into Avon Group undivided.

Genetic interpretation

Mainly deposited in a marine influenced lagoonal environment.

Age

Courseyan

SHROPSHIRE

Strata correlated with the Avon Group have been interpreted to occur at Cleehills and Little Wenlock in Shropshire (Mitchell and Reynolds, 1981). The former area comprises undifferentiated

Avon Group, whereas the latter is identified as a single formation, the **Jackie Parr Limestone Formation**.

The southern part of the Cleehills Outlier, in the vicinity of Cleehill [SO 571 750], includes an approximately 40 m thick succession dominated by calcareous mudstones and limestones (Turner and Spinner, 1988). The lower part of the succession, about 20 m thick, was considered by George (1956a) to equate with the Lower Limestone Shales (now the Avon Group) and the upper part was referred to as the Main Limestone. The Main Limestone became the Oretton Limestone of George et al. (1976), now considered part of the Pembroke Limestone Group.

The basal part of the succession comprises dark reddish brown, coarse-grained conglomeratic sandstone up to 11 m thick, with subangular to rounded pebbles of quartz and quartzite and subordinate jasper (Greig et al., 1968). The group rests unconformably upon the Devonian Farlow Sandstone Formation. The conglomeratic sandstone passes upwards into calcareous mudstones and impure buff limestones.

The group is of Tournaisian age. From miospore assemblages the succession is considered to belong to the younger part of the PC Zone (Turner and Spinner, 1988).

5.1.5 Jackie Parr Limestone Formation (JPLS)

Name

The formation was described by (Whitehead et al., 1928) and referred to as Carboniferous Limestone; the term Jackie Parr Limestone Formation first used by (Bridge and Hough, 2002).

Type section

Lilleshall Borehole L6 (SJ71NW/33) [SJ 7358 1572], 8.5–39.0 m depth below ground level (Riley, 1998).

Lithology

Interbedded limestone and sandstone sequence with subordinate dolomite, pebbly sandstone and claystone. Heavily pedogenic. Sandstone variable composition; limestone typically packstone or grainstone.

Lower and upper boundaries

The base of the formation is proved in boreholes only. The boundary is thought to be possibly unconformable or transitional. The boundary is taken at the top of the lowermost limestone above a sandstone-dominated sequence of the Village Farm Formation.

The top of the formation is proved in boreholes only. The boundary is thought to be possibly unconformable. The boundary is taken at the top of the uppermost limestone below a sandstone-dominated sequence of the Lydbrook Sandstone Formation.

Thickness

Some 30.5 m maximum proved (from Lilleshall L6 borehole).

Distribution

Lilleshall (North Shropshire) [SJ73 15].

Genetic interpretation

The formation was deposited in environments ranging from turbulent shallow marine to high intertidal/supratidal conditions (Bridge and Hough, 2002).

Biostratigraphical characterisation

Conodonts indicate an assemblage of the *Siphonodella* Biozone and the macrofauna lie within the *Vaughnia vetus*

Zone, indicative of an early Tournaisian age (Mitchell and Reynolds, 1981).

Age
Tournaisian

BERKSHIRE COALFIELD

The Avon Group has been proved in the concealed Berkshire Coalfield (Figure 3) in a single borehole, the Aston Tirrold Borehole (SU58NE 42) [SU 5810 8720]. The full succession of the undivided group is 1.85 m, comprising grey, argillaceous, thin-bedded bioclastic limestone, interbedded with grey mudstone (Foster et al., 1989). Miospore assemblages confirm a Courceyan age for the group.

KENT COALFIELD

The Avon Group has been proved in the concealed Kent Coalfield (Figure 3) in two boreholes (Smart et al., 1966; Mitchell, 1981). The Harmansole Borehole (TR15SW 1) [TR 141 528] proved 7.92 m of limestone of early Tournaisian age, resting upon strata of Old Red Sandstone facies, believed to be of Devonian age. The Trapham Borehole (TR25NW 2) [TR 234 571] proved a 4.11 m thick succession with late Tournaisian fauna. The successions comprise dark grey crinoidal or ooidal limestone interbedded with dark grey shale.

5.2 PEMBROKE LIMESTONE GROUP (PEMB)

The Pembroke Limestone Group is a new name proposed for the platform and ramp carbonates of South Wales and Bristol/Mendip areas. In the Pembroke area, the group is well exposed and shows a wide range of lithological facies. The group ranges from Courceyan to Brigantian age and is up to 1025 m thick.

The lower ramp part of the group is distinguished as the Black Rock Limestone Subgroup, formerly referred to as a group. Formations have been identified in areas of recent mapping in the Vale of Glamorgan (Waters and Lawrence, 1987; Wilson et al., 1990) areas of South Wales (Figures 16 and 17). Elsewhere, an absence of recent mapping in the Pembroke and Gower areas of South Wales and the Bristol area, makes it difficult to constrain the component formations. In the North Crop, coeval strata comprise the Clydach Valley Subgroup and Abercriban Oolite Formation (Barclay, 1989).

Above the Black Rock Limestone Subgroup, seven formations are recognised over most of South Wales and a subgroup and three formations are found in the Bristol area (Figures 16 and 17).

SOUTH WALES: SOUTH AND EAST CROP

The **Black Rock Limestone Subgroup** of South Wales comprises skeletal, dominantly crinoidal limestone of Tournaisian to Chadian age. Here, three formations have been formally defined: the **Barry Harbour Limestone**, **Brofiscin Oolite** and **Friars Point Limestone formations**. In the East Crop, at Newport these formations are entirely dolomitised.

In Pembrokeshire, the Black Rock Limestone Subgroup was formerly referred to as the Blucks Pool Limestone (George et al., 1976). Here, the subgroup is overlain by the laterally impersistent **Berry Slade Formation** of 'reef' facies.

The Chadian to Arundian succession of **Gully Oolite**, **Caswell Bay Mudstone** and **High Tor Limestone forma-**

tions is widespread across the South Crop. The equivalent succession in South Pembrokeshire includes the **Linney Head**, **Hobbyhorse Bay Limestone** and **Pen-y-holt Limestone formations**, as shown by George et al. (1976). The base of the Pen-y-holt Limestone provides the stratotype for the base of the Arundian Stage. The relationship between the Pen-y-holt Limestone and High Tor Limestone is uncertain and is in need of further investigation.

The **Hunts Bay Oolite Subgroup** (formerly group) of South Wales comprises two formations in the Vale of Glamorgan; the **Cornelly Oolite** (with component **Cefnyrhendy Oolite** and **Argoed Limestone members**) and **Stormy Limestone formations**. Subdivision of the subgroup is complicated by extensive dolomitisation in the East Crop, around Newport (Figure 17). The **Stackpole Limestone Formation** of South Pembrokeshire is of broadly equivalent age to the Hunts Bay Oolite Subgroup (George et al., 1976). Further research is necessary to determine if this limestone can be integrated within the formation nomenclature of the Vale of Glamorgan.

The Asbian to Brigantian part of the Pembroke Limestone Group comprises a relatively simple succession of the **Oxwich Head Limestone Formation** (including a **Pant Mawr Sandstone Member**), overlain by the **Oystermouth Formation**.

5.2A Black Rock Limestone Subgroup (BRL)

Name

Previously referred to as the Black Rock Limestone (Kellaway and Welch, 1955) and in Pembrokeshire as the Blucks Pool Limestone (George et al., 1976), the unit is here formally redefined as a subgroup. In the Gower, the subgroup replaces the obsolete Penmaen Burrows Limestone Group, which comprised a lower Shipway Limestone, Tears Point Limestone and upper Langland Dolomite (George et al., 1976). Both the Gower and Pembrokeshire lack recent mapping, and hence the relationship of the stratigraphy with that defined for the Black Rock Limestone Subgroup of the Vale of Glamorgan is in need of further research.

Type section

Black Rocks quarry and crags, immediately west of Durdham Down, on the north side of Avon Gorge, Bristol [ST 5591 7475 to ST 5620 7445]: Incomplete section 158 m thick, with upper boundary seen (Kellaway and Welch, 1993).

Formal subdivisions

Three formations have been formally defined in the Vale of Glamorgan: the Barry Harbour Limestone, Brofiscin Oolite and Friars Point Limestone formations.

Lithology

Thin- to thick-bedded, dark grey to black, foetid, fine to coarse-grained skeletal (mainly crinoid) packstones with subordinate thin beds of shaly argillaceous skeletal packstone and mudstone. Widespread burrowing, tractional structures and silicified limestones characterise the lowermost part of the subgroup. A unit of ooidal limestone (Brofiscin Oolite Formation) is developed in the lower part in Gower, Vale of Glamorgan and east crop of the South Wales Coalfield. The upper part of the formation is dolomitised in the south, while along the southern and eastern crop of the South Wales Coalfield and in the Monmouth and Chepstow area, the entire formation is dolomitised. Tuffs and basalt are present in the lower part of the subgroup in the Weston-super-Mare area (Middle Hope Volcanic Member).

Lower and upper boundaries

The base is conformable and taken at the gradational incoming of dark grey fine to coarse skeletal packstones with scattered mudstone partings of the subgroup above the interbedded mudstones and skeletal packstones (Cwmyniscoy Mudstone Formation) of the Avon Group.

The top of the subgroup is taken at the sharp contact between the dolomitised packstones of the subgroup and the overlying ooidal grainstones or dolomitised ooid-limestone of the Gully Oolite Formation. In the south the junction appears conformable, but in the north a thin red clay overlying a palaeokarstic surface is locally present; in such cases the top is taken at the top of the red clay. In the eastern Mendips the upper boundary is taken at the incoming of pale grey coarse crinoidal limestones of the Vallis Limestone Formation, above the dolomitised packstones of the underlying Black Rock Limestone Subgroup. Little is known about this contact which needs further investigation. In the Bristol area the top is taken at the junction of the sparsely crinoidal dolomites of the Black Rock Subgroup and the crinoidal limestones of the overlying Sub-Oolite Bed of the Gully Oolite Formation. Little is known about this contact, which needs further investigation.

Thickness

About 500 m in the southern Vale of Glamorgan, thinning northwards to 70 m in the Monmouth area. Some 188 m in the Cannington inlier, Somerset, 365 m in the eastern Mendips, thinning northwards to 158 m at Bristol and 104 m to the north of Bristol at Cromhall.

Distribution

South Pembrokeshire [SM 99 01], Gower [SS 50 90], south and south-east crop of South Wales Coalfield [ST 17 85], Vale of Glamorgan [ST 00 74], Monmouth and Chepstow [ST 53 93], Bristol [ST 60 74] and the Mendips [ST 50 53] areas. The subgroup is also recorded in the subsurface in the Cannington inlier.

Regional correlation

In South Wales the subgroup passes northwards into the Clydach Valley Subgroup (Figure 17).

Genetic interpretation

The subgroup represents deposition in an inner to mid ramp setting with local ooid shoal development.

Age

Courseyan to Chadian

5.2A.1 Barry Harbour Limestone Formation (BHL)

Name

The formation was previously identified as part of the following: Black Rock Limestone and Lower Dolomite (Kellaway and Welch, 1955); the Penmaen Burrows Limestone on the Swansea (247) Sheet; Shipway Limestone and Rudry Formation (George et al., 1976). The formation was named and defined by Waters and Lawrence (1987).

Type section

The low cliffs and reefs on the western side of the old Barry Harbour [ST 1004 6646 to 1043 6630]: the entire formation, 80 m thick, is exposed, including lower and upper boundaries (Waters and Lawrence, 1987).

Formal subdivisions

Yorke Rock Bed present at the top of the formation in the Barry area.

Lithology

Thin- to medium-bedded, dark grey, coarse to fine-grained, commonly graded, skeletal (predominantly crinoidal, with subordinate brachiopods) packstones, either stacked or separated by thin beds and partings of calcareous mudstone. Planar, low-angle and hummocky cross-stratification, and cross-lamination are common, with scattered bioturbation. Silicification of fossils and replacive elongate chert nodules are common. In the Barry area, a unit (3–5 m) of cross-bedded crinoidal grainstone, the Yorke Rock Bed, occurs at the top of the formation. In the north west of the Vale of Glamorgan, thin beds of ooid grainstone are present in the uppermost part of the formation. Along the south-east and east crop of the South Wales Coalfield, the formation is predominantly dolomitised; the upper part comprising very fine- to fine-grained, pale to dark grey, partly laminated and cross-laminated dolomitised packstones with sparse fossiliferous lenses that are locally silicified.

Lower and upper boundaries

The contact of the Cwmyniscoy Mudstone Formation with the overlying Barry Harbour Limestone Formation is gradational. In the uppermost part of the Cwmyniscoy Mudstone Formation, the proportion of packstone beds increases to exceed that of mudstone. The base of the Barry Harbour Limestone Formation is taken at the top of the last significant mudstone bed in the Cwmyniscoy Mudstone Formation, above which the succession becomes dominated by stacked, fine to coarse-grained skeletal packstones with scattered thin beds and partings of calcareous mudstone.

In the Barry area, the top of the formation is taken at the sharp contact between the crinoidal grainstones of the Yorke Rock Bed, and the thin to medium bedded, fine to coarse-grained, skeletal packstones with scattered thin beds and partings of mudstone of the overlying Friars Point Limestone Formation. To the north of Barry, the top of the formation is taken at the sharp contact between the thin to medium bedded packstones of the Barry Harbour Limestone Formation and the thick-bedded ooidal grainstones of the Brofiscin Oolite Formation. Along the south-east and east crop of the South Wales Coalfield the top is taken at the sharp junction between the dolomitised packstones of the Barry Harbour Limestone Formation and the overlying dolomitised ooid limestone of the Brofiscin Oolite Formation.

Thickness

About 80 m in the south of the Vale of Glamorgan, thinning north to 32 m on the south crop of the South Wales Coalfield.

Distribution

Mapped in the Vale of Glamorgan [ST 00 74]. Also present in the Gower [SS 50 90], Pembrokeshire [SM 99 01], east crop of the South Wales Coalfield [ST 25 90], Monmouth/Chepstow [ST 53 93] and Bristol/Mendip [ST 50 65] areas, but not mapped.

Regional correlation

The formation passes northwards into the Clydach Valley Subgroup.

Genetic interpretation

The formation was deposited in a shallow inner ramp setting and represents high-energy storm deposits.

Biostratigraphical characterisation

At Barry, the formation falls entirely within the *Zaphrentites delanouei* Coral Zone (Waters and Lawrence, 1987).

Age
Courseyan

5.2A.2 Brofiscin Oolite Formation (BFO)

Name

Formerly referred to as the Candleston Oolite (George, 1933), the unit was formally defined as a formation by Waters and Lawrence (1987).

Type section

Brofiscin Quarry, 300 m south-south-east of Brofiscin Farm, Groesfaen, Vale of Glamorgan [ST 0685 8122]: entire formation exposed, including upper and lower boundaries (Waters and Lawrence, 1987).

Lithology

Pale to purplish grey, thick-bedded to massive, cross-bedded, ooidal grainstone. On the south-east and east crop of the South Wales Coalfield the formation is dolomitised.

Lower and upper boundaries

The base of the formation is taken at the sharp contact between the thin to medium bedded packstones of the underlying Barry Harbour Limestone Formation and the thick-bedded ooidal grainstones of the Brofiscin Oolite Formation. Along the south-east and east crop of the South Wales Coalfield, the base is taken at the sharp junction between the dolomitised packstones of the Barry Harbour Limestone Formation and the overlying dolomitised ooidal limestone of the Brofiscin Oolite Formation.

The top of the formation is taken at the sharp junction of the ooidal grainstones of the Brofiscin Oolite Formation and the overlying thin to medium bedded skeletal packstones of the Friars Point Limestone Formation. Along the south-east and east crop of the South Wales Coalfield the top is taken at the sharp junction between the dolomitised ooid-limestone of the formation and the very fine to fine-grained dolomitised packstones of the Friars Point Limestone Formation.

Thickness

Some 17 m in the north of the Vale of Glamorgan; thinning southwards and is thin or absent in the south of the Vale of Glamorgan.

Distribution

Vale of Glamorgan [ST 00 74] and the south and east crops [ST 25 90] of the South Wales Coalfield, east of Swansea. Present in Gower [SS 50 90], but not mapped.

Regional correlation

The formation passes into the Clydach Valley Subgroup to the north.

Genetic interpretation

The formation was deposited as an ooid shoal.

Biostratigraphical characterisation

At Barry, the formation falls entirely within the coral *Zaphrentites delanouei* Coral Zone (Waters and Lawrence, 1987). At Brofiscin Quarry the base of the *Pseudopolygnathus multistriatus* Conodont Zone occurs 5–6 m below the top of the formation (Waters and Lawrence, 1987).

Age
Courseyan

5.2A.3 Friars Point Limestone Formation (FPL)

Name

The formation has been previously referred to as: the Laminosa Dolomite (Vaughan, 1905); part of the Black Rock Limestone, the Black Rock Dolomite and part of the Lower Dolomite (Kellaway and Welch, 1955); part of the Penmaen Burrows Limestone on the Swansea (247) Sheet; the Tears Point Limestone, Langland Dolomite and part of the Rudry Formation (George et al., 1976). The unit was formally defined as a formation by Waters and Lawrence (1987).

Type section

Coast section at Friars Point, Barry Island, Vale of Glamorgan [ST 1070 6641 to 1115 6586]: lower three quarters of the formation (300 m) exposed, with lower boundary seen (Waters and Lawrence, 1987).

Lithology

Thin- to thick-bedded, dark grey to black, foetid, fine- to coarse-grained skeletal (mainly crinoid) packstones with subordinate thin beds of shaly argillaceous skeletal packstone and mudstone. Widespread burrowing and a lack of tractional structures characterises all but the lowermost part of the formation. The upper part of the formation is dolomitised in the south, while along the southern and eastern crop of the South Wales Coalfield, the entire formation is dolomitised.

Lower and upper boundaries

In the Barry area, the base of the formation is taken at the sharp contact between the crinoidal grainstones of the Yorke Rock Bed that caps the Barry Harbour Limestone Formation, and the overlying thin to medium bedded, fine to coarse-grained, skeletal packstones with scattered thin beds and partings of mudstone of the Friars Point Limestone Formation. North of Barry, the base of the formation is taken at the sharp junction of the ooidal grainstones of the Brofiscin Oolite Formation and the overlying thin- to medium-bedded skeletal packstones of the Friars Point Limestone Formation. Along the south-east and east crop of the South Wales Coalfield the base is taken at the sharp junction between the dolomitised ooid-limestone of the Brofiscin Oolite Formation and the very fine to fine-grained dolomitised packstones of the Friars Point Limestone Formation.

The top of the formation is taken at the sharp contact between the dolomitised packstones of the formation and the overlying ooidal grainstones or dolomitised ooid-limestone of the Gully Oolite Formation. In the south the junction appears conformable, but in the north a thin red clay overlying a palaeokarstic surface is locally present; in such cases the top is taken at the top of the red clay.

Thickness

In excess of 410 m in the south of the Vale of Glamorgan, thinning north to 76 m on the south crop of the South Wales Coalfield.

Distribution

Mapped in the Vale of Glamorgan [ST 00 74]. Also present in Gower [SS 50 90], Pembrokeshire [SM 99 01], east crop of the South Wales Coalfield [ST 25 90], Monmouth/Chepstow [ST 53 93] and Bristol/Mendip areas [ST 50 65] but not mapped.

Regional correlation

Passes northwards in Wales into the Clydach Valley Subgroup.

Genetic interpretation

The formation records renewed transgression and re-establishment of deeper-water conditions with deposition in a mid-ramp environment.

Biostratigraphical characterisation

At Barry, the top of the coral *Zaphrentites delanouei* Coral Zone occurs 45 m above the base of the formation, with the *Caninophyllum patulum* and *Siphonophyllia cylindrica* coral zones also present higher within the formation (Waters and Lawrence, 1987). At Brofiscin Quarry the base of the *Pseudopolygnathus mehli* Conodont Zone occurs 6.5 m above the base of the formation, whereas at Barry it occurs between 50 and 73 m above the base of the formation (Waters and Lawrence, 1987).

Age

Courseyan to Chadian

5.2.4 Berry Slade Formation (BRYS)

Name

The name was used by George et al. (1976) and is here formally defined.

Type section

Variably accessible cliffs and foreshore at Berry Slade, Castlemartin, south Pembrokeshire [SR 888 972 to 882 967]: entire formation seen, including lower and upper boundaries, and comprises reef and flank facies (Dixon, 1921).

Lithology

Massive, grey Waulsortian 'reefs', comprising dolomitised carbonate mudstone with locally abundant spar filled fenestrae (stromatactoid structure) and sparse crinoid debris. Reefs are locally overlain by and pass into a flank facies comprising thin-bedded dark-limestones and dolomites with cherts and thin mudstones. The stratigraphical position of the flank facies is uncertain and requires further work.

Lower and upper boundaries

The base is taken at gradational boundary between medium- to thick-bedded crinoidal argillaceous packstones with cherts nodules and shaly partings of the underlying Black Rock Limestone Subgroup, and the dolomitised reef limestones of the formation.

The top is taken at the junction of massive dolomitised reef limestones of the formation and the overlying dark limestones with thin mudstones and cherts of the Linney Head Formation. Where the top of the formation is in flank facies, the boundary is imprecise but taken at the increase in chert content at the base of the Linney Head Formation.

Thickness

Some 80 m in type section in south Pembrokeshire.

Distribution

Castlemartin area, south-west Pembrokeshire [SR 95 98].

Regional correlation

The formation passes northwards into the Black Rock Limestone Subgroup.

Genetic interpretation

Waulsortian reef

Age

Chadian

5.2.5 Gully Oolite Formation (GUO)

Name

The formation name, first used in the Bristol area (Kellaway and Welch, 1955), replaces the term Caninia Oolite (Vaughan, 1905), Crease Limestone (Kellaway and Welch, 1955) and Caswell Bay Oolite used on the Swansea (247) Sheet and by George et al. (1976).

Type section

Gully Quarry and adjacent road section, eastern side of Avon Gorge, Bristol [ST 5620 7446 to 5621 7436]: incomplete section (26 m thick) in lowermost part of formation, with lower boundary seen in the quarry and upper boundary in the road section (Kellaway and Welch, 1993).

Lithology

Medium- to thick-bedded, pale grey, ooidal grainstone with subordinate beds of fine-grained skeletal packstone. Cross-laminated and cross-bedded, some burrowing. Locally dolomitised, especially on the south-east and east crop of the South Wales Coalfield and in the Chepstow area. A palaeokarstic surface is overlain by a green/red mudstone/clay palaeosol, which caps the formation. In the Bristol area, 6 to 21 m of grey crinoidal limestone, the Sub-Oolite Bed, locally occurs at the base of the formation.

Lower and upper boundaries

The base is taken at the gradational to sharp contact between the dolomitised, sparsely crinoidal packstones of the Friars Point Limestone Formation or its parent the Black Rock Limestone Subgroup and the overlying ooidal grainstones or dolomitised ooid-limestone of the formation. In the south the junction appears conformable, but in the north a thin red clay overlying a palaeokarstic surface is locally present; in such cases the top is taken at the top of the red clay. The base of the formation in the Bristol area is locally taken at the junction of the sparsely crinoidal dolomites of the Black Rock Limestone Subgroup and the crinoidal limestones of the overlying Sub-Oolite Bed.

The top of the formation is taken at the sharp erosional contact, sometimes referred to as the mid-Avonian unconformity, between the mudstone/clay palaeosol at the top of the formation and the overlying thin bedded calcite mudstones and mudstones of the overlying Caswell Bay Mudstone Formation (South Wales) or the Clifton Down Mudstone Formation (Bristol and Broadfield Down areas). A conglomeratic lag is locally present at the base of the Caswell Bay Mudstone Formation. In the southern parts of the outcrop, the formation is overlain by the High Tor Limestone Formation, the capping palaeosol being absent. Here the top is taken at the irregular erosional contact between the ooidal grainstones of the formation and the overlying coarse skeletal packstone/grainstones of the High Tor Limestone Formation.

Thickness

Some 83 m in the southern Vale of Glamorgan, thinning to 19 m in the south-east crop of the South Wales Coalfield.

Distribution

Gower [SS 50 90], Vale of Glamorgan [ST 00 74], south-east crop of the South Wales Coalfield [ST 17 85], Monmouth/Chepstow [ST 53 93], Bristol [ST 60 74], Weston-super-Mare [ST 30 60] and Broadfield Down [ST 50 65] areas. Present but not mapped in the Tenby [SN 13 01] and Pembroke [SM 97 03] areas.

Regional correlation

Passes east in the Mendips into the Burrington Oolite Subgroup (Figure 17). The lateral continuation of this formation to Pembroke and Tenby is known, but is in need of modern mapping. In South Pembrokeshire coeval Chadian strata comprise the Linney Head Limestone and Hobbyhorse Bay Limestone formations (George et al., 1976).

Genetic interpretation

The formation was deposited during a Chadian regression that culminated in the non-sequence at the top of the formation (Figure 14).

Biostratigraphical characterisation

Foraminifera and dasycladacean algae from the Cardiff district, including the single-walled *Koninckopora*, indicate a Chadian age (Waters and Lawrence, 1987). At Middle Hope, near Weston-super-Mare, the presence of the brachiopod *Levitusia humerosa* at the base of the formation indicates a Chadian age (Whittaker and Green, 1983).

Age

Chadian

5.2.6 Linney Head Formation (LHD)

Name

Previously referred to as the Linney Head Beds (Dixon, 1921; Simpson and Kalvoda, 1987), it is here formally defined as a formation.

Type section

Sea cliffs at Linney Head, Castlemartin, south-west Pembrokeshire [SR 883 957]: entire unit exposed (30 m thick), with lower and upper boundaries seen (Dixon, 1921).

Lithology

Thin- to thick-bedded, dark grey, crinoidal wackestones with abundant chert beds interbedded with mudstones and nodular limestones. Packstones are present in the uppermost part.

Lower and upper boundaries

The base is taken at the junction of massive dolomitised reef limestones of the Berry Slade Formation and the overlying dark limestones with thin mudstones and cherts of the formation. Where the top of the Berry Slade Formation is in flank facies, the boundary is imprecise but taken at the increase in chert content at the base of the Linney Head Formation.

The top is taken at the sharp junction between the dark limestones, cherts and mudstones of the formation and the overlying thick bedded coarsely crinoidal limestones of the Hobbyhorse Bay Limestone Formation (Simpson and Kalvoda, 1987).

Thickness

Some 30 m at type section.

Distribution

Castlemartin area, south-west Pembrokeshire [SR 95 98].

Regional correlation

Relationship to coeval Gully Oolite Formation to north is unknown.

Genetic interpretation

Deposited in a distal ramp setting. Crinoid debris accumulated more or less in situ; the orientation of crinoid stems

suggesting a palaeocurrent from north-west to south-east (Simpson and Kalvoda, 1987).

Biostratigraphical characterisation

The foraminiferal assemblage corresponds to the *Tetrataxis-Eotextularia diversa* Foraminifera Zone of late Courceyan to Chadian (Simpson and Kalvoda, 1987).

Age

Courceyan to Chadian

5.2.7 Hobbyhorse Bay Limestone Formation (HBL)

Name

The name was used by George et al. (1976) and formally defined by Simpson and Kalvoda (1987).

Type section

East side of Hobbyhorse Bay, 500 m east of Linney Head, Castlemartin area, South Pembrokeshire [SR 8880 9560]: entire unit seen, with lower and upper boundaries exposed (Simpson and Kalvoda, 1987).

Lithology

Grey, thick-bedded, coarsely crinoidal packstones; locally dolomitised.

Lower and upper boundaries

The base is taken at the sharp junction between the dark limestones, cherts and mudstones of the Linney Head Formation and the overlying thick-bedded, coarsely crinoidal limestones of the formation.

The top is taken at the sharp junction between dolomitised crinoidal packstones at the top of the formation and the crinoidal packstones with mudstone partings of the overlying Pen-y-holt Limestone Formation. This boundary is unsatisfactory but has not been changed as it defines the base of the Arundian Stage and needs further work.

Thickness

Some 17 m at the type locality.

Distribution

Castlemartin area [SR 95 98], south-west Pembrokeshire.

Regional correlation

The relationship to coeval Gully Oolite Formation to the north is unknown.

Genetic interpretation

The formation was deposited in a distal ramp setting. Crinoid debris accumulated more or less in situ.

Age

Chadian

5.2.8 Pen-y-holt Limestone Formation (PYHL)

Name

The formation was named and described by George et al. (1976).

Type section

Variably accessible sea cliffs between Hobbyhorse Bay and The Wash, south of Castlemartin, south-west Pembrokeshire [SR 8880 9570 to 9200 9430]: entire unit seen, with lower and upper boundaries exposed (Dixon, 1921; Simpson and Kalvoda, 1987).

Lithology

Dark grey, thin- to medium-bedded crinoidal wackestones and calcareous mudstones. Scattered chert nodules and bands, together with silicified fossils. Local dolomitisation. Crinoidal packstones with regular stylolitic partings comprise the basal 5 m.

Lower and upper boundaries

The base is taken at the sharp junction between dolomitised crinoidal packstones at the top of the underlying Hobbyhorse Bay Limestone Formation and the crinoidal packstones with mudstone partings of the Pen-y-holt Limestone Formation. This boundary is unsatisfactory (Simpson and Kalvoda, 1987), but has not been changed as it defines the base of the Arundian Stage and needs further work.

The top is taken at the gradational boundary between the dark grey interbedded wackestones and mudstones of the formation and the pale grey, thick-bedded, skeletal and ooidal limestones of the overlying Stackpole Limestone Formation. Top taken at base of first ooidal limestone in Stackpole Limestone Formation.

Thickness

Up to 280 m

Distribution

Castlemartin area [SR 95 98], south-west Pembrokeshire.

Regional correlation

Relationship with coeval High Tor Limestone Formation to the north-east uncertain and needs further investigation.

Genetic interpretation

Wackestones represent storm generated deposits on a muddy distal carbonate ramp. Crinoid debris accumulated more or less in situ; the orientation of crinoid stems in the basal part of the formation suggesting a bimodal palaeocurrent from north-west and south-east (Simpson and Kalvoda, 1987).

Biostratigraphical characterisation

The type section was taken as the basal stratotype for the Arundian Stage (George et al., 1976), defined as the first lithological change occurring below the entry of Archaeiscidae foraminifera. However, the first archaeiscids occur about 16 m above the base of the formation (Ramsbottom, 1981; Simpson and Kalvoda, 1987), indicating that the formation is Chadian in age at the base. The remainder of the succession is Arundian in age.

Age

Chadian to Arundian

5.2.9 Caswell Bay Mudstone Formation (CBM)

Name

The name was used on the Swansea (247) Sheet and by George et al. (1976) and is here formally defined.

Type section

Cliffs and foreshore reefs on west and east side of Caswell Bay, Gower [SS 5897 8753 to SS 5908 8720]: mainly completely exposed, including lower and upper boundary, with the section repeated three times by folding (Ramsay, 1987).

Lithology

Thinly interbedded grey and green grey peloidal and bioclastic micrites, wackestones and packstones, and cryp-

talgal laminites. Dolomitisation is locally common; on the south-east and east crop of the South Wales Coalfield and in the Chepstow area, the formation is predominantly dolomitised.

Lower and upper boundaries

The base of the formation is taken at the sharp erosional contact between the mudstone/clay palaeosol at the top of the Gully Oolite Formation and the overlying thin-bedded calcite mudstones and mudstones of the formation. A conglomeratic lag is locally present at the base of the Caswell Bay Mudstone Formation.

The top of the formation is taken at the sharp erosional contact between the thin-bedded calcite mudstones and mudstones of the formation and the overlying coarse peloidal and skeletal packstone/grainstones forming the lower part of the overlying High Tor Limestone Formation.

Thickness

Some 15 m on the south crop of the South Wales Coalfield, thinning southwards to a feather-edge in the central Vale of Glamorgan, south-west Gower and south-west Pembrokeshire.

Distribution

Gower [SS 50 90], Vale of Glamorgan [ST 00 74], south-east crop of the South Wales Coalfield [ST 17 85] and Weston-super-Mare areas [ST 32 60]. Present in Pembroke [SM 97 03] and Tenby [SN 13 01] areas but not mapped.

Regional correlation

The formation passes northwards into the Llanelly Formation in Wales and Clifton Down Mudstone Formation in the Bristol area (Figure 17).

Genetic interpretation

The formation was deposited within a lagoonal/peritidal setting (Waters and Lawrence, 1987).

Biostratigraphical characterisation

Although considered Chadian in age by George et al. (1976), deposition of the formation is interpreted to have occurred in response to an Arundian sea-level rise (Riding and Wright, 1981). There is no faunal evidence to support an Arundian age.

Age

Arundian?

5.2.10 High Tor Limestone Formation (HTL)

Name

The formation was first named on the Swansea (247) Sheet and subsequently used by George et al. (1976). In the Bristol area it was formerly referred to as the Birnbeck Limestone Formation (Whittaker and Green, 1983).

Type section

Sea cliffs and foreshore reefs below High Tor, Southgate, Gower [SS 5535 8707 to 5603 8676]: the formation is completely exposed apart from a few minor gaps (about 115 m thick), with lower and upper boundaries seen (Ramsay, 1987).

Formal subdivisions

Flat Holm Limestone Member and Spring Cove Lava Member (see Section 5.2.30).

Lithology

Medium grey, predominantly thick-bedded, fine- to coarse-grained, burrowed, skeletal packstones, with thin beds and partings of shaly dolomite mudstone and siltstone. Some thin-bedded, dark grey, bituminous, skeletal packstones are interbedded with thin argillaceous wackestones and mudstones. Coarse, locally cross-bedded, peloidal/skeletal/ooidal packstone /grainstones developed in lower and upper parts in northern sections. On the south-east crop of the South Wales Coalfield the formation is predominantly dolomitised.

Lower and upper boundaries

The base is taken at the sharp erosional contact between the thin bedded calcite mudstones and mudstones of the underlying Caswell Bay Mudstone Formation and the overlying coarse peloidal/skeletal/ooidal packstone/grainstones forming the lower part of the formation in South Wales and the Weston-super-Mare area. A basaltic lava is present in the the lower part of the sequence in the Weston-super-Mare area (Whittaker and Green, 1983). In the southern parts of the Welsh outcrop, the base is taken at the sharp erosional contact between the ooidal grainstones of the Gully Oolite Formation and the overlying coarse skeletal packstone/grainstones of the formation.

The top of the formation is gradational and taken at the incoming of a predominantly ooidal grainstone sequence (Hunts Bay Oolite Subgroup) above the skeletal packstones or skeletal/peloidal/oolitic packstone/grainstones of the formation.

Thickness

About 55 m on the south crop of the South Wales Coalfield, thickening southwards to 133 m in the west/central Vale of Glamorgan (Waters and Lawrence, 1987; Wilson et al., 1990). The thickest development occurs where the underlying Caswell Bay Mudstone Formation is absent.

Distribution

Mapped in the Gower [SS 50 90], Vale of Glamorgan [ST 00 74] and the Weston-super-Mare [ST 32 60] areas. Present but not mapped in the Tenby [SN 13 01] and Pembroke [SM 97 03] areas.

Regional correlation

Passes northwards into the Llanelly Formation in Wales and into the Clifton Down Mudstone Formation in the Bristol/Broadfield Down area (Figure 17). Passes eastwards into the Burrington Oolite Subgroup in the Mendips.

Genetic interpretation

The High Tor Limestone formed a barrier complex during early Arundian times, limiting the peritidal deposits of the Caswell Bay Mudstone to the north. During continued transgression the barrier complex migrated northwards over the peritidal facies (Wilson et al., 1990). The upper part of the formation records regression and subsequent return of high-energy shoreface deposits.

Biostratigraphical characterisation

In the Cardiff area, the formation contains typical Arundian assemblages, including rich suites of algae and foraminifera (Waters and Lawrence, 1987; Wilson et al., 1990). A coral bed located 11.4 m above the base of the formation at Spring Cove, Weston-super-Mare and 10.5 m above the base at Flat Holm (within the Flat Holm Limestone Member) contains typical Arundian fauna (Whittaker and Green, 1983). In both the Cardiff and Weston-super-Mare areas, the upper part of

the formation includes fauna typical of a mid Arundian age (Waters and Lawrence, 1987; Wilson et al., 1990).

Age

Arundian

5.2B Hunts Bay Oolite Subgroup (HBO)

Name

In the Forest of Dean the subgroup was formerly known as the Drybrook Limestone (Kellaway and Welch, 1955) and in the Vale of Glamorgan was named and defined as the Hunts Bay Group by Wilson et al. (1990).

Type section

Cliffs and foreshore reefs between Bacon Hole and Pwll ddu Head, Southgate, Gower, South Wales [SS 5604 8674 5728 8632]: unit entirely present, apart from a few minor gaps in exposure, with lower and upper boundaries seen

Formal subdivisions

In the Vale of Glamorgan: the Cornelly Oolite and Stormy Limestone formations (Figure 17).

Lithology

Mainly ooidal limestones, with subordinate skeletal, peloidal and oncolitic limestones and calcite mudstones. Mainly dolomitised on the south-east and east crop of the South Wales Coalfield.

Lower and upper boundaries

The base of the subgroup is gradational and taken at the incoming of a predominantly ooidal grainstone sequence, locally with units of calcite mudstone, above the skeletal packstones or skeletal/peloidal/ooidal packstone/grainstones of the underlying High Tor Limestone Formation.

In the Vale of Glamorgan the top is taken at the sharp contact, defined by a palaeokarstic surface, between the heterolithic lithologies of the subgroup and the overlying partially dolomitised sandy skeletal packstones and calcareous sandstones of the Pant Mawr Sandstone Member (Oxwich Head Limestone Formation). In the Gower and Pembrokeshire it is taken at the palaeokarstic surface separating the heterolithic lithologies of the subgroup from the mottled and pseudobrecciated skeletal packstones of the overlying Oxwich Head Limestone Formation.

Thickness

Some 245 m in central Vale of Glamorgan, thinning to the east and north and removed in the East Crop by the Namurian overstep and to a feather-edge in the Forest of Dean.

Distribution

Pembroke [SM 97 03], Tenby [SN 13 01], Gower [SS 50 90], Vale of Glamorgan [ST 00 74], east crop of the South Wales Coalfield [ST 17 85] and Monmouth and Chepstow areas [ST 53 93].

Regional correlation

Passes eastwards into the Clifton Down Limestone Formation of the Bristol/Mendip area, southwards into the Stackpole Limestone Formation of south Pembrokeshire and northwards in South Wales into the Dowlais Limestone Formation (Figure 17).

Genetic interpretation

The subgroup was deposited during the Arundian within a

complex of ooidal barrier shoal (Cornelly Oolite Formation: Cefnyrhendy Oolite Member) and lagoonal/peritidal back-barrier environment (Stormy Limestone Formation). Early Holkerian transgression resulted in deposition of carbonates in an offshore platform setting (Cornelly Oolite Formation: Argoed Limestone Member).

Age
Arundian to Holkerian

5.2B.11 Cornelly Oolite Formation (CNLL)

Name
Previously referred to as the Seminula Oolite (George, 1933), the formation was named and defined by Wilson et al. (1990).

Type section
South face of Cornelly Quarry, 250 m north of Mount Pleasant Farm, South Cornelly, Vale of Glamorgan [SS 835 800]: top third of unit and upper boundary seen.

Formal subdivisions
In the northern Vale of Glamorgan the Cefnyrhendy Oolite Member is present at the base of the formation and is overlain by the Argoed Limestone Member.

Lithology
Thick-bedded, cross-bedded, pale grey ooid grainstones with scattered beds of medium grey, fine-grained skeletal packstone. Compound ooids of pisolitic proportions are common. Thin mudstone, associated with the palaeokarstic surface at the top of the Cefnyrhendy Oolite Member, is present in the north-east of the Vale of Glamorgan.

Lower and upper boundaries
The base of the formation is gradational and taken at the incoming of a predominantly ooidal grainstone sequence above the skeletal packstones or skeletal/peloidal/ooidal packstone/grainstones of the underlying High Tor Limestone Formation.

The top of the formation is taken at the base of the first bed of calcite mudstone of the overlying Stormy Limestone Formation occurring above the ooid grainstones and subordinate skeletal packstones of the formation.

Thickness
Some 135 m in the west of the Vale of Glamorgan, thickening to 180 m in the eastern part of the Vale of Glamorgan.

Distribution
Central and western Vale of Glamorgan [ST 00 74]. Present in Gower [SS 50 90] and Pembrokeshire [SM 99 01] areas, but not mapped.

Regional correlation
Passes eastwards into undivided Hunts Bay Oolite Subgroup (Figure 17).

Genetic interpretation
The Cefnyrhendy Oolite Member records continued late Arundian shoaling, which locally resulted in emergence and palaeokarst development. The succeeding strata record a basal Holkerian marine transgression and re-establishment of ooid-limestone shoals.

Age
Arundian to Holkerian

5.2B.11.1 CEFNYRHENDY OOLITE MEMBER (CEO)

Name
The member was first named and defined by Waters and Lawrence (1987).

Type section
Hendy Quarry, 400 m north of Miskin church, Vale of Glamorgan [ST 0480 8130]: entire formation seen, 13 m thick, including lower and upper boundaries (Waters and Lawrence, 1987).

Lithology
Massive to thick-bedded, locally cross-bedded ooid grainstone. A palaeokarstic surface at the top is locally overlain by a thin clay palaeosol. The formation is dolomitised along the south-east crop of the South Wales Coalfield.

Lower and upper boundaries
The lower gradational junction with the underlying skeletal, peloidal and ooidal packstone/grainstones of the underlying High Tor Limestone Formation. The base is taken at the incoming of a predominantly ooidal grainstone sequence.

The top is taken at the top of the clay palaeosol capping the formation, or the top of the underlying palaeokarstic surface if the clay is absent. The palaeosol/palaeokarst is sharply overlain by a bed of grey calcareous mudstone, overlain by thin- to medium-bedded, fine- to coarse-grained crinoidal skeletal packstones of the Argoed Limestone Member of the Cornelly Oolite Formation.

Thickness
Some 13 m in the northern Vale of Glamorgan, thickening southwards to 40 m in the central part of the Vale of Glamorgan.

Distribution
Northern part of Vale of Glamorgan

Regional correlation
The member passes southwards into upper part of High Tor Limestone Formation. The relationship to the coeval Goblin Combe Oolite Formation in the Bristol Mendip area is unknown.

Genetic interpretation
The formation was deposited in a barrier environment.

Biostratigraphical characterisation
Foraminifera and algae from the type section include an assemblage characteristic of late Arundian age (Waters and Lawrence, 1987).

Age
Arundian

5.2B.11.2 ARGOED LIMESTONE MEMBER (ARL)

Name
The member was first named and defined by Wilson et al. (1990).

Type section
Argoed Isha Quarry, 150 m south of Argoed, Llanharry, Vale of Glamorgan [SS 993 790]: entire formation seen, including base and top (Wilson et al., 1990).

Lithology
Thin- to medium-bedded, fine- to coarse-grained crinoidal skeletal packstones with a bed of grey calcareous mudstone

at the base. Dolomitised along the south-east crop of the South Wales Coalfield.

Lower and upper boundaries

The base is taken at the base of a bed of grey calcareous mudstone, overlain by thin- to medium-bedded, fine- to coarse-grained crinoidal skeletal packstones that overlies the clay palaeosol capping the underlying Cefnyrhendy Oolite Member, or the top of the underlying palaeokarstic surface if the clay palaeosol is absent.

The top is a gradational boundary, taken at the first bed of ooidal grainstone of the Cornelly Oolite Formation above the crinoidal skeletal packstones of the member.

Thickness

Some 10 m

Distribution

Northern Vale of Glamorgan [ST 00 74]

Regional correlation

The member passes south into the High Tor Limestone Formation.

Genetic interpretation

Deposited in an offshore platform setting and representing the basal Holkerian transgression.

Biostratigraphical characterisation

The member includes foraminifera characteristic of Holkerian age (Waters and Lawrence, 1987).

Age

Holkerian

5.2B.12 Stormy Limestone Formation (STYL)

Name

The formation was named and defined by Wilson et al. (1990), corresponding to the previously termed 'Modiola' or 'Lagoon' phase at the top of the S₂ subzone.

Type section

Stormy Down Quarry, 500 m south-east of Ballas Farm, South Cornelly, Vale of Glamorgan [SS 842 804]: lower third of unit and lower boundary exposed.

Lithology

Interbedded cryptalgal and fenestral, calcite mudstones, coquinaid limestones, skeletal, peloid, intaclast, ooid packstone/grainstones, ooid grainstones and the characteristic oncolitic grainstones. Scattered algal bioherms are locally present.

Lower and upper boundaries

The base is taken at the base of the first bed of calcite mudstone occurring above the ooid grainstones and subordinate skeletal packstones of the underlying Cornelly Oolite Formation.

In the Vale of Glamorgan the top is taken at the sharp contact, defined by a palaeokarstic surface, between the heterolithic lithologies of the formation and the overlying partially dolomitised sandy skeletal packstones and calcareous sandstones of the Pant Mawr Sandstone Member (Oxwich Head Limestone Formation). In Gower and Pembrokeshire it is taken at the palaeokarstic surface separating the heterolithic lithologies of the formation from the mottled and pseudobrecciated skeletal packstones of the Oxwich Head Limestone Formation.

Thickness

Between 55 and 65 m in the central and western Vale of Glamorgan.

Distribution

Mapped in the west and central Vale of Glamorgan [ST 00 74]. Present also in Gower [SS 50 90] and the Pembroke/Tenby area [SM 99 01] but has not been mapped.

Regional correlation

Passes laterally eastwards into Hunts Bay Oolite Subgroup undivided (Figure 17), that cannot be subdivided into Cornelly Oolite and Stormy Limestone formations.

Genetic interpretation

The formation was deposited in a lagoonal/peritidal back-barrier environment, which developed behind the Cornelly Oolite shoal (Wilson et al., 1990).

Age

Holkerian to ?Asbian

5.2.13 Stackpole Limestone Formation (STPL)

Name

Referred to as the Stackpole Limestone (George et al., 1976), it is here formally defined as a formation.

Type section

Sea cliffs between Stackpole Quay and Barafundle Bay, Castlemartin, south-west Pembrokeshire [SR 9950 9540 to 9928 9520]: entire unit seen (250 m thick), with lower and upper boundaries exposed (Dixon, 1921).

Lithology

Pale grey, thick-bedded skeletal and ooidal limestones; scattered cherts and silicified fossils; local dolomitisation. Dark grey, thinner-bedded limestones are common in lower part. Pale grey oncolitic limestones and calcite mudstones are common in uppermost part.

Lower and upper boundaries

The base is taken at the gradational boundary between the dark grey interbedded wackestones and mudstones of the underlying Pen-y-holt Limestone Formation and the pale grey, thick-bedded skeletal and ooidal limestones of the formation. Boundary taken at base of first ooidal limestone.

The top is taken at the outgoing of pale grey calcite mudstones of the formation and the incoming of mottled (pseudobrecciated) skeletal packstones and palaeokarstic surfaces of the overlying Oxwich Head Limestone Formation.

Thickness

Some 260 m at type locality

Distribution

Castlemartin area [SR 95 98], south-west Pembrokeshire

Regional correlation

The relationship with the coeval Hunts Bay Oolite Subgroup to the north and east is uncertain and needs further investigation.

Genetic interpretation

Deposited in a front barrier, barrier and back barrier setting.

Age

?Arundian to Holkerian

5.2.14 Oxwich Head Limestone Formation (OHL)

Name

The formation was first named on the Swansea (247) Sheet and the term here replaces the Hotwells Limestone Formation of the Bristol/Mendips area (Kellaway and Welch, 1955), Crickmail Limestone, Penwylt Limestone and Mynydd-y-Garreg Limestone (George et al., 1976) and Llandyfan Limestone Beds on the Carmarthen (230) Sheet.

Type section

Cliff and foreshore section on eastern and southern side of Oxwich Head, Gower [SN 5030 8625 to 5045 8435]: most of the formation is exposed, apart from the uppermost part, with the lower boundary seen.

Formal subdivisions

The Pant Mawr Sandstone Member of the Vale of Glamorgan and the Honeycombed Sandstone and Penderyn Oolite members in the North Crop of the South Wales Coalfield (see Sections 5.2.25.1 and 5.2.25.2).

Lithology

Thick-bedded, fine- to coarse-grained, recrystallised, bioturbated skeletal packstones with distinctive light to dark grey mottling and pseudobrecciation and ooidal limestones. Units of dark grey, irregularly bedded skeletal packstones with shaly partings are developed at intervals. Thin unit of calcareous sandstone and sandy skeletal packstone (Pant Mawr Sandstone and Honeycombed Sandstone members) at base in the Vale of Glamorgan and north-west crop of South Wales Coalfield respectively. Unit of ooidal limestone in lower part (Penderyn Oolite Member) on north-west crop of the South Wales Coalfield. Palaeokarstic surfaces, overlain by red and grey clay palaeosols, punctuate the formation; thin coals developed in palaeosols in Gower.

Lower and upper boundaries

In the Vale of Glamorgan the base is taken at the sharp contact, defined by a palaeokarstic surface, between the heterolithic lithologies of the underlying Stormy Limestone Formation and the overlying partially dolomitised sandy skeletal packstones and calcareous sandstones of the Pant Mawr Sandstone Member. On the north-western crop of the South Wales Coalfield, it is taken at the sharp junction of the calcareous sandstone of the basal Honeycombed Sandstone Member and the underlying dark bituminous skeletal/peloidal grainstone/packstone/wackestone of the Dowlais Limestone Formation. In Gower and Pembrokeshire it is taken at the palaeokarstic surface separating the heterolithic lithologies of the underlying Hunts Bay Oolite Subgroup from the mottled and pseudobrecciated skeletal packstones of the formation. In the Bristol/Mendip area the formation overlies the Clifton Down Limestone Formation. The base here needs further work but is generally taken at the gradational change from calcite mudstones and ooidal limestones of the Clifton Down Limestone Formation to ooidal and skeletal limestones of the formation. In the north of the Bristol area the formation overlies the middle tongue of the Cromhall Sandstone Formation, the base being taken at the incoming of ooidal and skeletal limestones above the sandstones of the Cromhall Sandstone Formation.

The top is taken at the palaeokarstic surface separating the thick-bedded mottled and pseudobrecciated skeletal packstones of the formation and the overlying thin to medium bedded argillaceous limestones, cherts and mudstones of the Oystermouth Formation.

Thickness

About 125 m in the central Vale of Glamorgan, thickening southwards to 183 m in the Mendips. To the east of Bridgend, the formation thins and is removed by the overstep at the base of the Marros Group.

Distribution

Mapped in the western and central Vale of Glamorgan [ST 00 74], Gower [SS 50 90], north-west crop of the South Wales Coalfield [SN 90 13] and Bristol/Mendips area [ST 50 65]. Present but unmapped in south Pembrokeshire [SM 99 01].

Regional correlation

Interfingers with and passes northwards into the Cromhall Sandstone Formation in the Bristol area (Figure 17).

Genetic interpretation

The basal sandstones probably represent terrigenous sands, introduced onto an emergent carbonate shelf during marine regression at the end of the Holkerian, and subsequently marine-reworked during base Asbian transgression (Wilson et al., 1990). The overlying limestone accumulated on a mature carbonate platform in which periodic sea-level falls resulted in emergence.

Biostratigraphical characterisation

The basal bed of the formation at Pant Mawr Quarry, near Bridgend, includes the foraminifera *Bibradya inflata*, a diagnostic Asbian form (Wilson et al., 1990). In the Mendips, the base of the formation includes the brachiopod *Davidsonina septosa*, indicative of a late Asbian age (Green and Welch, 1965).

Age

Asbian to Brigantian

5.2.14.1 PANT MAWR SANDSTONE MEMBER (PMSA)

Name

The member was named and defined by Wilson et al. (1990).

Type section

Pant Mawr Quarry, 1 km north-west of Mount Pleasant Farm, South Cornelly, Vale of Glamorgan [SS 828 802]: entire unit present, with lower and upper boundaries seen.

Lithology

Partially dolomitised, sandy, skeletal packstone in lower part, and thin-bedded, cross-bedded, fine-grained calcareous sandstone in upper part.

Lower and upper boundaries

The base is taken at the sharp contact, defined by a palaeokarstic surface, between the calcite mudstones and skeletal/peloidal/ooid packstone/grainstones of the underlying Stormy Limestone Formation and the overlying partially dolomitised, sandy skeletal packstones and calcareous sandstones of the member.

The top is taken at the sharp junction at the top of the calcareous sandstones of the member and the overlying thick bedded, fine to coarse-grained, mottled and pseudobrecciated skeletal packstones of the remainder of the Oxwich Head Limestone Formation.

Thickness

From 1.5 to 4 m

Distribution

Western Vale of Glamorgan [ST 00 74].

Regional correlation

May pass north into coeval Honeycombed Sandstone Member on north crop of the South Wales Coalfield.

Genetic interpretation

Represents transgressive shoreface deposits.

Biostratigraphical characterisation

The basal bed of the member at the type section includes the foraminifera *Bibradya inflata*, a diagnostic Asbian form (Wilson et al. (1990).

Age

Asbian

5.2.15 Oystermouth Formation (OB)

Name

Formerly known as the Upper Limestone Shales (Strahan, 1907), the Rottenstone Beds and the Oystermouth Beds on the Swansea (247) Sheet, the unit is here defined as a formation.

Type section

Oystermouth Quarry, immediately east of Oystermouth Castle, Oystermouth, Swansea [SS 6150 8835]: partial section (25 m thick) with lower and upper boundaries not exposed (Dixon and Vaughan, 1912).

Lithology

Thin- to medium-bedded, dark grey argillaceous limestones and mudstones. Chert nodules and beds, and silicified limestones are common. Interbedded argillaceous limestones and mudstones, commonly deeply weathered to decalcified rottenstone and pale grey, white and yellow clay. In western Gower and south Pembrokeshire, units of medium- to thick-bedded skeletal packstone and ooidal limestone with cherts occur in the lower part of the formation.

Lower and upper boundaries

The base is taken at the palaeokarstic surface separating the thick-bedded, mottled and pseudobrecciated skeletal packstones of the Oxwich Head Limestone Formation and the overlying thin- to medium-bedded argillaceous limestones, cherts and mudstones of the formation.

The top is taken at the top of the last limestone in the gradational junction between the interbedded limestones and mudstones of the formation and the overlying thin-bedded, banded cherts and mudstones and siliceous mudstones of the Aberkenfig Formation.

Thickness

Some 61 m on the Gower, thinning northwards to a feather-edge on the north-western crop of the South Wales Coalfield.

Distribution

South Pembrokeshire [SM 99 01], Gower [SS 50 90], north-western crop of the South Wales Coalfield [SN 63 17] and western Vale of Glamorgan [SS 80 80].

Genetic interpretation

The formation represents a significant increase in terrigenous mud supplied to the carbonate shelf.

Biostratigraphical characterisation

In the Kenfig Borehole [SS 8055 8167] the formation includes the ammonoids *Neoglyphioceras* sp. and *Sudeticeras* sp., indicative of a late Brigantian age (George et al., 1976).

Age

Brigantian

SOUTH WALES: NORTH CROP

The **Clydach Valley Subgroup** of the North Crop of the South Wales Coalfield is of equivalent age to the Black Rock Limestone Subgroup of the South Crop (Figure 17), but is of distinctive lithofacies and is recognised as a distinct subgroup. The transition between the two subgroups, present within the East Crop of South Wales, is obscured by extensive dolomitisation and the Namurian overstep. The interdigitating ooid-limestones and dolostones of the Clydach Valley Subgroup have been identified as formations, described by Barclay (1989). In upward succession, these are (Figure 17): The **Sychnant Dolomite, Pwll-y-Cwm Oolite, Pantydarren, Blaen Onnen Oolite, Coed Ffyddlwn and Gilwern Oolite formations**. Towards the east of Abergavenny the succession becomes entirely dolomitic. To the west, in the Merthyr Tydfil district, the succession is entirely ooidal, forming the **Abercriban Oolite Subgroup** (Barclay et al., 1988). The Abercriban Oolite and Clydach Valley subgroups are laterally equivalent and the former is retained as a local informal term for the ooidal limestone-dominated succession synonymous with the more heterogeneous Clydach Valley Subgroup.

The **Llanelly Formation** of the North Crop comprises mainly four members (Wright, 1981; Barclay, 1989), in ascending order: **Clydach Halt, Cheltenham Limestone, Penllwyn Oolite and Gilwern Clay members**.

The **Dowlais Limestone Formation** of the North Crop is broadly of equivalent age to the Hunts Bay Oolite Subgroup (George et al., 1976). Further research is necessary to determine if this limestone can be integrated within the formation nomenclature of the Vale of Glamorgan.

The **Oxwich Head Limestone and Oystermouth formations** are equivalent to those described in the South Crop, although the lower part of the Oxwich Head Limestone Formation includes the **Honeycombed Sandstone and Penderyn Oolite members**.

5.2C Abercriban Oolite Subgroup (ABO)

Name

Previously considered part of the Oolite Group (George, 1954), the unit was defined as the Abercriban Oolite Group (Barclay et al., 1988), here redefined as an informal subgroup.

Type section

Abercriban Quarry, Powys [SO 0667 1244]: 13.4 m of pale grey ooidal grainstones with thin dolostone interbeds are exposed (Barclay et al., 1988).

Reference section

Baltic Quarry, Powys [SO 0652 1170], 1 km south of Abercriban Quarry: complete section of the subgroup, with about 28 m of beds exposed in the main quarry face, with the overlying Llanelly Formation exposed on an upper step (Dickson and Wright, 1993).

Lithology

Massive, pale grey, ooidal grainstone with some fine-grained micritic and dolomitic interbeds.

Lower and upper boundaries

The base is placed at the sharp junction between a thin dolostone underlying the lowermost ooidal grainstone of

the Abercriban Oolite Subgroup and the top of the grey mudstones forming the uppermost part of the Cwmyrniscoy Mudstone Formation.

The top is placed at a palaeokarstic surface, below which the ooidal grainstone at the top of the Abercriban Oolite Subgroup becomes increasingly disordered upwards and irregular ooidal limestone masses become separated by grey-green mudstone films. The palaeokarstic surface marks a regionally developed unconformity, overlain by micritic to grainstone limestones of the Llanelly Formation.

Thickness

Up to 30 m in the Chwar Pant-y-rhiw area [c. SO 200 157].

Distribution

North-east crop of South Wales Coalfield, from about 500 m east of Carn-yr-onen [SN 888 165] to Waun Watcyn [SO 210 150].

Regional correlation

Passes laterally to the east into, and may be considered synonymous with, the Clydach Valley Subgroup.

Genetic interpretation

Ooid-limestone shoal deposits

Age

Courseyan to Chadian

5.2D Clydach Valley Subgroup (CLD)

Name

Formerly referred to as the Oolite Group (George, 1954), Clydach Beds (George, 1956b, 1958), the Clydach Valley Group (Barclay, 1989) and is here redefined as a subgroup.

Type area

Clydach Valley, near Brynmawr, Monmouthshire, South Wales [SO 225 125], in which the subgroup is exposed in numerous quarries on both sides of the valley and in the river gorge (Barclay, 1989).

Type section

Roadside outcrops at Blackrock on the north side of the Clydach valley [SO 2178 1274] provide an easily accessible, well exposed section through the lower part of the subgroup (Barclay, 1989). The Pwll-y-Cwm Oolite, Pantydarren and Blaen Onnen Oolite formations are exposed.

Formal subdivisions

In upward succession, the subgroup comprises the Sychnant Dolomite, Pwll-y-Cwm Oolite, Pantydarren, Blaen Onnen Oolite, Coed Ffyddlwn and Gilwern Oolite formations.

Lithology

Cyclic sequence of massive ooidal grainstones with interbedded fine-grained, thinly bedded crinoidal dolostones.

Lower and upper boundaries

The base is placed at the base of the lowest bed of fine-grained dolostone, the Sychnant Dolomite Formation, where there is a conformable, interdigitating gradation from the grey calcareous mudstone of the underlying Cwmyrniscoy Mudstone Formation of the Avon Group.

The top is a major, regionally developed palaeokarstic surface, which truncates the massive, pale grey ooidal

grainstone of the Gilwern Oolite Formation. It is unconformably overlain by the grey, micritic limestones and green clays (Clydach Halt Member) at the base of the Llanelly Formation, which comprises mainly well-bedded, cyclical micrite to grainstone limestones with green clay interbeds.

Thickness

From 20 m in the type area of the Clydach Valley [SO 225 125] to 60 m near Pontypool [SO 289 015].

Distribution

In a narrow outcrop around the north-east and east crops of the South Wales Coalfield, extending from about 2.5 km north-west of the Clydach valley [SO 210 150] south to the Pontypool area [c.ST 280 985].

Regional correlation

Equivalent age to the Black Rock Limestone Subgroup of the South Crop of the South Wales Coalfield.

Genetic interpretation

The subgroup was deposited within peritidal and ooidal shoal environments with numerous palaeosols (Barclay, 1989).

Age

Courseyan to Chadian

5.2D.16 Sychnant Dolomite Formation (SYCN)

Name

Previously unnamed and referred to as Bed 1 of the Oolite Group (George, 1954), and included within the overlying Pwll -y-Cwm Oolite (George et al., 1976), the formation was named and defined by Barclay (1989).

Type section

Nant Sychnant stream section, a tributary of the Clydach south-west of the village of Danycoed [SO 2256 1251] in the Clydach Valley: 3 m of buff dolostone are sharply overlain by dolomitised ooidal grainstones of the Blaen Onnen Oolite Formation. The base is not exposed (Barclay, 1989).

Reference section

Roadside section on the Heads of the Valleys road (A465) [SO 2165 1265]: 3 m of fine-grained dolostones are present (Barclay, 1989). The basal contact with the underlying Cwmyrniscoy Mudstone Formation and a palaeokarst surface at its top are exposed.

Lithology

Buff, fine-grained, bedded dolostones (dolomitised skeletal packstones).

Lower and upper boundaries

The lower boundary is gradational, with thinly bedded grey mudstones and skeletal packstones of the underlying Cwmyrniscoy Mudstone Formation, interbedded with thin, fine-grained dolostones of the Sychnant Dolomite Formation. The base of the latter is placed at the base of the dolostone overlying the highest grey mudstone bed.

The top is placed at an irregular palaeokarstic surface cut in buff dolostone of the formation, overlain by pale grey ooidal grainstones of the Pwll-y-Cwm Oolite Formation.

Thickness

About 5 m

Distribution

North-east crop of the South Wales Coalfield, from north-west of the Clydach Valley [SO 210 150] south-eastwards to the Blorengue [c.SO 268 110]. The correlation of similar dolostones further west, near Pontsticill in the Taff Fechan valley [SO 06 11] remains uncertain and are currently ascribed to the Pembroke Limestone Group.

Genetic interpretation

Shallow marine conditions affected by bottom currents, with early dolomitisation probably related to a regressive phase which produced the palaeokarstic surface at the top of the formation (Barclay, 1989).

Age

Courseyan

5.2D.17 Pwll-y-Cwm Oolite Formation (PWCO)

Name

First defined by George et al (1954) and subsequently by Barclay (1989).

Type section

River gorge section at Pwll-y-Cwm in the Clydach River near Brynmawr, South Wales [SO 2176 1270]: entire thickness of 7.6 m forms a waterfall (Barclay, 1989). It is sharply overlain by fine-grained dolostone of the Pantydarren Formation.

Reference section

Roadside section on Heads of the Valleys road (A456) in the Clydach Valley, 2 km east of Brynmawr, South Wales [SO 2180 1272]; more accessible section than the type section, with the palaeokarstic surface forming the base of the formation exposed (Barclay, 1989).

Lithology

Pale grey ooidal grainstone

Lower and upper boundaries

The base is placed at an irregular, palaeokarstic surface cut in underlying dolostones of the Sychnant Dolomite Formation, which is overlain by ooidal grainstones of the Pwll-y-Cwm Oolite Formation.

The top is a sharp, planar boundary at which the topmost ooidal limestones of the Pwll-y-Cwm Oolite Formation are overlain by dolostones of the Pantydarren Formation.

Thickness

About 7 m

Distribution

North-east crop of the South Wales Coalfield; correlation at Cwar -yr-Hendre [SO 090 146] is uncertain, but if the basal 2–4 m of ooidal grainstone of the sequence there is the Pwll-y-Cwm Oolite, it extends eastwards from there to Craig-yr-Hafod [SO 2720 1001], where it is dolomitised.

Genetic interpretation

Ooid-limestone shoal deposits

Age

Courseyan

5.2D.18 Pantydarren Formation (PYDN)

Name

First defined as Bed 3 (George, 1954, p.288), it was renamed the Pantydarren Beds and defined by Barclay (1989).

Type area

Disused quarries at Coed Pantydarren, 1 km north of the Clydach gorge, near Brynmawr, South Wales [SO 2200 1380]: exposure of 5 m of fine-grained, thin-bedded dolomites of the Pantydarren Formation sharply overlying massive pale grey ooidal grainstones of the Pwll-y-Cwm Oolite Formation (Barclay, 1989).

Reference section

Roadside section on the old Brynmawr road at Blackrock [SO 2178 1274]: the entire formation, including the lower boundary (with the Pwll-y-Cwm Oolite Formation) and upper boundary (with the Blaen Onnen Oolite Formation) are exposed (Barclay, 1989).

Lithology

Fine-grained, thinly bedded dolostones with minor mudstone layers.

Lower and upper boundaries

The base is a sharp, planar boundary upon which the basal dolostones of the Pantydarren Formation overlie ooidal grainstone of the underlying Pwll-y-Cwm Formation.

The top is a sharp junction where dolostones of the Pantydarren Formation are overlain by ooidal grainstone of the Blaen Onnen Oolite Formation.

Thickness

About 5 m

Distribution

North-east crop of the South Wales Coalfield, from Darren Disgwlfaf [SO 217 145], south-east to around Craig yr Hafod [SO 2720 1001].

Genetic interpretation

The presence of ostracods, algal remains and spore-rich mudstones suggests deposition within a lagoonal or peritidal environment (Barclay, 1989).

Age

Courseyan

5.2D.19 Blaen Onnen Oolite Formation (BLO)

Name

The formation was previously referred to as Bed 4 of the Oolite Group (George, 1954) and the Middle Oolite (Owen et al., 1965). The unit was named the Blaen Onnen Oolite by George et al. (1976), maintaining a misspelling that originated during the original geological survey (Robertson, 1927). Ordnance Survey maps show the locality as Blaen Onneu. To avoid further confusion the name Blaen Onnen was retained and formally defined as a formation by Barclay (1989).

Type section

Blaen Onneu Quarry [SO 1542 1686], 2 km south of Llangyndr, Powys: the formation is at its maximum of 14 m thick; it rests sharply on a 0.3–0.5 m-thick bed of calcite nodules and has a spectacular pinnacled palaeokarstic top blanketed by a 5 m-thick rubbly palaeosol (Barclay, 1989; Dickson and Wright, 1993).

Lithology

Massive, medium-grained, ooidal grainstone to crinoidal dolostone.

Lower and upper boundaries

In the Clydach Valley, the base is a sharp, palaeokarstic surface cut in dolomites of the Pantyddarren Formation, overlain by basal ooidal grainstones of the Blaen Onnen Oolite Formation. At the type locality, the base is placed at the base of massive ooidal grainstones that overlie a prominent 0.3 to 0.5 m-thick rubbly bed of radiating fibrous calcite nodules.

The top is a sharp junction in the Clydach Valley, where fine-grained dolostones of the Coed Ffyddlwn Formation overlie the topmost ooidal grainstones of the Blaen Onnen Oolite Formation.

Thickness

Up to 14 m

Distribution

North-east crop of the South Wales Coalfield; its correlation with parts of the Abercriban Oolite Subgroup in the Merthyr Tydfil district is unclear, and thus its known limits extend from Cwar yr Hendre [SO 090 146] east to Craig-y-Gaer [SO 2290 1263]. To the south of the Clydach Valley it becomes dolomitised, but is present at Craig Quarry [SO 2723 0738] and may be a crinoidal dolostone at Gallowsgreen Quarry, Varteg Hill [SO 2662 0677].

Genetic interpretation

Ooid-limestone shoal deposits

Biostratigraphical characterisation

The Blaen Onnen Oolite contains a conodont assemblage indicative of the *Pseudopolygnathus multistriatus* Conodont Zone, of Tournaisian age (Barclay, 1989).

Age

Courseyan

5.2D.20 Coed Ffyddlwn Formation (COFYD)

Name

Formerly Beds 5 and 6 of George (1954), defined as a formation by Barclay (1989).

Type section

Clydach gorge, 2 km east of Brynmawr, South Wales; named from Coed Ffyddlwn [SO 2215 1126]: here, the formation has a sharp base, rests on the Blaen Onnen Oolite Formation and is 14 m thick (Barclay, 1989). It comprises mainly fine-grained, homogeneous dolostones and, in the topmost 2 m, micritic limestones (the Darren Ddu Limestone Member).

Formal subdivisions

The upper part of the formation is recognised as the Darren Ddu Limestone Member.

Lithology

The lower part comprises fine-grained dolostones, the upper part (the Darren Ddu Limestone Member) comprises thinly bedded micritic limestones, fine grainstones and mudstones.

Lower and upper boundaries

The base is a sharp junction between the topmost ooidal

grainstone of the Blaen Onnen Oolite Formation and the basal dolostones of the Coed Ffyddlwn Formation.

The top is a sharp erosion surface overlain by the basal, coarse ooidal grainstone bed (Craig-y-Gaer Coral Bed) of the overlying Gilwern Oolite Formation.

Thickness

Up to 18 m

Distribution

North-east crop of the South Wales Coalfield, from Chwar Pant-y-rhiw [SO 2020 1560] south-east to about the area of Gallowsgreen Quarry, Varteg Hill [SO 2662 0677].

Genetic interpretation

Evidence of peritidal deposition, particularly in the Darren Ddu Limestone Member, includes siliciclastic influxes, calcretes, micritic crusts, desiccation cracks and cryptalgal lamination (Barclay, 1989). Concretions of shell and crinoid debris indicate the local presence of tractional currents in the intertidal zone.

Age

Courseyan

5.2D.20.1 DARREN DDU LIMESTONE MEMBER (DDL M)

Name

Formerly Bed 6 (part of the Marker Beds) of George (1954), and part of the Clydach Beds (George et al., 1976), it was recognised as a member by Barclay (1989).

Type section

A small disused quarry [SO 2194 1290] on Darren Ddu, Clydach Valley, 2 km east of Brynmawr, Blaenau-Gwent, South Wales: exposes 2.36 m of thinly bedded lime mudstones, grey-green mudstones and dolomitic mudstones resting with sharp planar contact on fine-grained dolostones.

Lithology

Thinly bedded, pale grey micritic limestones (lime mudstones), locally peloidal, with green-grey mudstones, cream laminated dolomitic mudstones; algal laminite locally at top.

Lower and upper boundaries

The base is placed at the sharp, planar junction between pale grey lime mudstone at the base of the member and the underlying fine-grained dolostone of the lower part of the Coed Ffyddlwn Formation.

The upper boundary is placed at an irregular, stylolitic surface cut in the topmost pale grey lime mudstone of the member, which is overlain by coarse bioclastic grainstone (the Craig-y-Gaer Coral Bed) at the base of the Gilwern Oolite Formation.

Thickness

From 2 to 3 m

Distribution

Clydach valley, on the north-east crop of the South Wales Coalfield [SO 215 125]

Genetic interpretation

Evidence of peritidal deposition includes siliciclastic influxes, calcretes, micritic crusts, desiccation cracks and cryptalgal lamination (Barclay, 1989).

Age

Courseyan

5.2D.21 Gilwern Oolite Formation (GWO)

Name

Originally referred to as the Gilwern Oolite (George, 1954) and redefined as a formation by Barclay (1989). Named from Gilwern Hill, near Clydach Gorge, Brynmawr, South Wales.

Type area

Named from Gilwern Hill, near Clydach Gorge, Brynmawr, South Wales [SO 22 13]. Extensively exposed in disused quarries (for example at Craig-y-Gaer in the Clydach Gorge [e.g. SO 22381330], 2 km east of Brynmawr, South Wales (Barclay, 1989).

Reference section

Llanelly Quarry, Clydach Gorge [SO 2235 1240]: the formation is up to 10m thick and well exposed at the base of the quarry face (Barclay, 1989). The basal beds are not exposed at the base of the face, but can be examined nearby at the entrance to the quarry.

Lithology

Massive ooidal grainstone, shelly, crinoidal bed at base; becomes dolomitised on east crop of coalfield.

Lower and upper boundaries

The base is placed at an erosion surface. In the type area, this is cut in micritic limestones of the underlying Coed Ffyddlwn Formation (Darren Ddu Member), which is overlain by coarse shelly, crinoidal grainstone (Craig-y-Gaer Coral Bed) at the base of the Gilwern Oolite Formation.

The top is a major palaeokarstic surface, with extensive dissolution and palaeosol formation of the ooidal grainstone at the top of the formation. This is overlain by micritic limestones and green clay (Clydach Halt Member) forming the basal part of the overlying Llanelly Formation.

Thickness

From 10 m in the Clydach gorge to 20 m on the east crop.

Distribution

North-east crop of South Wales Coalfield, from between Blean Onnen Quarry and Chwar Pant-y-rhiw [c.SO 185165] east to the Clydach gorge and south down the east crop of the coalfield, where it is dolomitised, but perhaps correlatable with 1.4 m of massive, cross-bedded dolomites at Gallowsgreen Quarry [SO 2662 0677], Varteg Hill.

Genetic interpretation

Ooid-limestone shoal deposits

Biostratigraphical characterisation

The Gilwern Oolite Formation has in the past been attributed to Chadian and Arundian age, though a solely Chadian age is now generally accepted (Barclay, 1989). Conodont faunas are typical of the *Polygnathus mehli* Zone.

Age

Chadian

5.2.22 Llanelly Formation (LLY)

Name

Previously referred to as the Calcite Mudstone Group (George, 1954), it was called the Llanelly Formation by George et al. (1976).

Type section

Llanelly Quarry, Clydach Gorge, near Brynmawr, South Wales [SO 2235 1240]: the formation is 20 m thick, rests disconformably on the Gilwern Oolite Formation and is unconformably overlain by the Dowlais Limestone Formation. (Barclay, 1989).

Formal subdivisions

The formation is subdivided, in ascending order, into the Clydach Halt, Cheltenham Limestone, Penllwyn Oolite and Gilwern Clay members.

Lithology

Well-bedded peritidal, cyclic micritic to grainstone limestones with green clay interbeds at base, overlain by ooidal grainstone and capped by green and red-mottled clay palaeosol.

Lower and upper boundaries

The base is placed at a major palaeokarstic surface truncating the underlying ooidal grainstones of the Gilwern Oolite Formation and overlain by the micritic limestones (Clydach Halt Member) of the Llanelly Formation.

The top is a sharp unconformity at which the topmost green-red mottled clay (the Gilwern Clay) of the Llanelly Formation is overlain by dark grey limestones of the Dowlais Limestone Formation.

Thickness

Maximum thickness of 20 m at type locality. Toward the west the formation thins and is completely removed by overstep of the overlying Dowlais Limestone. In the East Crop, the formation is absent due to overstep by the Marros Group.

Distribution

North-east crop of South Wales Coalfield, from the Hepste Valley [SN 971 129] east to the Clydach gorge [SO 214 125] and southwards down the east crop on the west side of the Afon Lwyd valley to about 1 km south of Blaenavon [SO 261 077].

Regional correlation

The formation is the northward equivalent of the Caswell Bay Mudstone and High Tor Limestone (Figure 17).

Genetic interpretation

The lowermost and uppermost parts of the formation are fluvial deposits, with the intervening succession dominated by peritidal deposits and ooid-limestone shoals (Wright, 1981).

Biostratigraphical characterisation

Foraminifera including archaediscids were recorded by George (1954), indicating an Arundian age.

Age

Arundian

5.2.22.1 CLYDACH HALT MEMBER (CLDH)

Name

The member was named and defined by Wright (1981).

Type section

Quarry face of the abandoned Clydach Lime Works (Cwm) Quarry [SO 235 127]: entire thickness of 4 m, including lower boundary proved and comprises two calccrete palaeosols separated by conglomerate (Wright, 1981).

Lithology

A heterolithic, lenticular unit of conglomerates, limestone layers and micritic nodules, green clays and sandstones with some dolostones.

Lower and upper boundaries

The base is placed at the base of green claystone and rubbly limestones (calcretes), where they overlie and infill an irregular palaeokarstic surface at the top of the underlying Gilwern Oolite Formation.

The top is placed at the incoming of well-bedded, thinly bedded, cyclic limestones (the Cheltenham Limestone Member), where the basal bed of limestone sharply overlies the topmost green clay or rubbly limestone of the Clydach Halt Member.

Thickness

Generally 1 to 2 m, 6 m locally; 4 m at the type locality.

Distribution

North-east crop of the South Wales Coalfield, with sporadic development or preservation from Pontsticill, as seen in Baltic Quarry [SO 0659 1184] and Odynau Tyler Bont Quarry [SO 0635 1125], east to the Gilwern Hill area [c.SO 250 117].

Genetic interpretation

The member is interpreted as fluvial deposits, with shallow channel fills, sheet-flood deposits and palaeosols within interdistributary area (Barclay, 1989).

Age

Arundian

5.2.22.2 CHELTENHAM LIMESTONE MEMBER (CHLM)

Name

The member was named and defined by Wright (1981).

Reference section

Llanelly Quarry [SO 224 125], on the south side of the Clydach Gorge, 2 km east of Brynmawr, South Wales: provides a complete section of the member, where it is at its thickest. It is 8 m thick and comprises a succession of mainly thin-bedded limestones (Wright, 1981).

Lithology

Thin- to medium-bedded, mainly fine-grained limestones with pale green clay interbeds; the limestones are commonly arranged in fining-upwards cycles and comprise grainstone, wackestone and lime mudstone (including algal laminites). The presence of quartz silt, sand and pebbles increases toward the north.

Lower and upper boundaries

The base is placed at the base of the lowest bedded limestone, where it sharply overlies the topmost rubbly limestone or clay with limestone nodules that forms the topmost bed of the underlying Clydach Halt Member.

The top is placed at the sharp junction between the topmost fine-grained limestone of the Cheltenham Limestone Member and the base of the ooidal grainstone at the base of the overlying Penllwyn Oolite Member. A palaeosol horizon is commonly present at the top of the member, its top marking the junction.

Thickness

From 1.7 m at Cwar yr Hendre [SO 099 149] to 8 m in the Clydach gorge [SO 224 125].

Distribution

North-east crop of the South Wales Coalfield; the Cheltenham Limestone Member is most widespread of the members of the Llanelly Formation, with the same geographical limits — from the Hepste Valley [SN 971 129] east to the Clydach gorge [SO 214 125] and southwards down the east crop on the west side of the Afon Lwyd valley to about 1 km south of Blaenavon [SO 261 077].

Genetic interpretation

The member developed in response to marine transgression and formation of a shallow marine peritidal complex with emergence at the tops of cycles marked by the green clays.

Age

Arundian

5.2.22.3 PENLLWYN OOLITE MEMBER (PENO)

Name

Initially referred to as the *Linoproductus* Oolite (George, 1954), the unit was named and defined by Wright (1981) and is here defined as a member.

Reference sections

Llanelly Quarry [SO 224 125] on the south side of the Clydach gorge, 2 km east of Brynmawr, South Wales: provides a complete section of the member, where it is 3 m thick (Wright, 1982).

Clydach Halt Lime Works (Cwm) Quarry [SO 235 127] provides a good section of the member where it is at its thickest (4 m) and has a thin algal laminite in its middle.

Lithology

Ooidal limestone and bioclastic limestone, bioturbated, locally ripple-marked and cross-bedded; oncoids are present at the base and stromatolites are present at the top. The limestone is a grainstone, with some local fining up to packstone and wackestone.

Lower and upper boundaries

The base is placed where bioclastic grainstone, forming the base of the member, lies sharply on and truncates the underlying limestone or calcrete forming the topmost bed of the Cheltenham Limestone Member.

The top is placed at a palaeokarstic surface, which truncates the member and is overlain by the green clay forming the lowermost part of the overlying Gilwern Clay Member.

Thickness

From 3 to 5 m thick

Distribution

North-east crop of the South Wales Coalfield, from Cwar yr Ystrad [SO 081 142] to Gilwern Hill area [SO 247120].

Genetic interpretation

The member formed as an ooid-limestone shoal.

Age

Arundian

5.2.22.4 GILWERN CLAY MEMBER (GWCL)

Name

The unit was named the Llanelly Pedocomplex (Wright, 1982), and renamed the Gilwern Clay by Barclay (1989).

Type section

Llanelly Quarry [SO 224 125]: the member is completely

exposed at its thickest development, although largely inaccessible. It comprises 7.4 m of mottled clay containing platy calcrete at its base, and calcrete nodules for 5.3 m above, where pyrite and carbonised rootlets appear, culminating in a grey seatearth capped by a thin coal.

Lithology

Green and red-brown and purple mottled clay with limestone (calcrete) nodules and, locally, a grey rootlet bed (seatearth) and thin coal at top.

Lower and upper boundaries

The base is placed at the karstified top of the underlying Penllwyn Oolite Member, where the basal green clay of the Gilwern Clay Member drapes the irregular surface of the Penllwyn Oolite Member.

The top is placed at the sharp, disconformable junction between the topmost clay (a seatearth at Llanelly Quarry) and the overlying sandy limestone forming the base of the Dowlais Limestone Formation. Where the Garn Caws Sandstone Formation is present, the top is placed at the irregular scoured surface where the topmost clays of the member are erosively overlain by the Garn Caws Sandstone Formation. Note that Wright (1981) included this sandstone in the Gilwern Clay, but it was subsequently given separate formation status by Barclay (1989).

Thickness

From 5 m (Cwar yr Hendre) to 7.4 m (Llanelly Quarry).

Distribution

North-east crop of the South Wales Coalfield, from Cwar yr Ystrad [SO 081 142] to Gilwern Hill area [SO 247 120].

Genetic interpretation

Interpreted as a palaeosol developed in response to a major marine regression and re-establishment of fluvial floodplain deposition.

Age

Arundian

5.2.23 Garn Caws Sandstone Formation (GACA)

Name

The unit was formerly included in the Dowlais Limestone (George, 1954) and in the Gilwern Clay Member of the Llanelly Formation (Wright, 1981) and was subsequently redefined as a formation (Barclay and Jackson, 1982).

Type area

Extensive outcrops on the hill of Garn Caws, Powys [SO 1295 1680] (Barclay, 1989).

Reference section

Excellent exposures at Blaen Onneu Quarry, Powys [SO 151 169] show 12 m of quartzitic sandstone with some thin green-grey, plant-bearing mudstone beds (Wright, 1981; Barclay, 1989).

Lithology

White, quartzitic sandstones and conglomerates with some thin intercalated plant-bearing green-grey mudstones and seatearth.

Lower and upper boundaries

The base is placed at the base of quartzitic sandstone or conglomerate where it rests with sharp base on an erosion

surface cut in the underlying Gilwern Clay Member of the Llanelly Formation.

The top is placed at the top of the quartzitic sandstone, where it is sharply and unconformably overlain by the basal limestone of the Dowlais Limestone Formation.

Thickness

Up to 12 m (maximum at Blaen Onneu Quarry).

Distribution

North-east crop of the South Wales Coalfield, from the area of Cwar yr Hendre [SO 099 149] eastwards to the type area of Garn Caws [SO 120 164], and further eastwards to the Clydach Valley [c.SO 215127].

Genetic interpretation

The sandstones and conglomerates were deposited within distributary channels of a deltaic complex that prograded southwards onto the carbonate shelf during a major regression (Barclay, 1989). The plant-bearing clay layers are probably interdistributary lake deposits.

Age

Arundian

5.2.24 Dowlais Limestone Formation (DWL)

Name

Previously referred to as the Upper Seminula Zone (S2) Limestone (Robertson, 1927) and the Cil-yr-ychen Limestone on the BGS Merthyr Tydfil (Sheet 231) and Ammanford (Sheet 230) 1:50 000-scale maps. The unit was referred to as the Dowlais Limestone by George et al. (1976) and formally defined by Barclay et al. (1988).

Type area

Extensive quarries around Morlais Castle, Dowlais, near Merthyr Tydfil, Glamorgan, South Wales [SO 054 698] (Barclay et al., 1988).

Lithology

Tabular, thick-bedded, medium to dark grey, fetid, bituminous, fossiliferous, peloidal grainstone, packstone and wackestone limestones with dark grey shale interbeds; minor dark grey, micritic limestones and pale grey ooidal limestones and some local basal sandstones.

Lower and upper boundaries

The base is placed at a regional unconformity, the basal limestone of the Dowlais Formation overstepping the underlying formations westwards on the north crop of the South Wales Coalfield, from the Llanelly Formation (green and red-mottled clay) in the east to the Avon Group (thinly bedded fissile mudstones and limestones) in the west.

The top is placed at the conformable junction of the dark grey limestones of the Dowlais Formation with the overlying pale grey ooidal limestones of the Penderyn Oolite Member of the Oxwich Head Limestone Formation. From the type area eastwards, the formation is truncated by a pre-Namurian unconformity.

Thickness

Up to about 120 m

Distribution

North crop of South Wales Coalfield, from Kidwelly [SN 415 077] to Gilwern Hill [SO 2450 1280].

Regional correlation

Same age as, and may be considered components of, the Hunts Bay Oolite Subgroup.

Genetic interpretation

Subtidal, shelf lagoonal and peritidal deposits (Barclay et al., 1988; Barclay, 1989).

Age

Holkerian

5.2.25 Oxwich Head Limestone Formation (OHL)

See Section 5.2.14 for detailed description of the formation. The Honeycombed Sandstone and Penderyn Oolite members of the North Crop of the South Wales Coalfield are described below.

5.2.25.1 HONEYCOMBED SANDSTONE MEMBER (HNCS)

The unit was first named by Robertson (1932), continued to be used by Barclay et al. (1988) and is here formally defined as a member.

Type section

Penderyn Quarry (Cwar Aberamman), 250 m east of Penderyn Church, Penderyn, Powys [SN 9460 0864]: entire unit seen, with lower and upper boundaries seen (Robertson, 1932).

Lithology

Calcareous, locally conglomeratic, sandstone, with distinctive honeycomb weathering. Locally in two tongues, separated by pale grey ooidal grainstone.

Lower and upper boundaries

The base is taken at the sharp junction of the calcareous sandstone of the member and the underlying dark bituminous skeletal/peloidal grainstone/packstone/wackestone of the Dowlais Limestone Formation.

The upper boundary is taken at top of the upper tongue of calcareous sandstone of the Member, above which the pale grey ooid grainstones of the Penderyn Oolite Member enter.

Thickness

From 4 to 12 m

Distribution

North crop of the South Wales Coalfield [SN 94 14].

Genetic interpretation

The member was deposited as a transgressive shoreface sand/ooidal limestone.

Age

Asbian

5.2.25.2 PENDERYN OOLITE MEMBER (PDO)

Name

Referred to as the Light Oolite (Robertson, 1932), the member was shown as the lower, ooidal part of Llandyfan Limestone on the BGS Merthyr Tydfil 1:50 000 Sheet 231). The unit was referred to as the Penderyn Oolite by George et al. (1976).

Type section

Penderyn Quarry, near the village of Penderyn, Powys [SN 9575 0880]: entire thickness of 13 m recorded here (Barclay et al., 1988).

Lithology

Pale grey, massive ooid-limestone with lenticular sandstone, rubbly limestone and shelly mudstone, locally with coal streaks and seatearth, at the top.

Lower and upper boundaries

The base is taken at the junction of pale grey massive ooid-limestone of the Penderyn Oolite Member with calcareous sandstone of the underlying Honeycombed Sandstone Member or dark grey skeletal or peloidal grainstones, packstones and wackestones of the Dowlais Limestone Formation.

The top is taken at the top of the ooid-limestone or lenticular sandstone and mudstone of the Penderyn Oolite Member above which dark grey cyclic shelly and crinoidal grainstones of the undivided part of the Oxwich Head Limestone Formation enter.

Thickness

From 13 m at type locality to 21 m elsewhere.

Distribution

North crop of South Wales Coalfield, extending eastwards from near Crwbin [SN 467 125] to near Ponsticill [SO 072 112].

Genetic interpretation

Ooid-limestone shoal deposits.

Age

Asbian

5.2.26 Oystermouth Formation (OB)

See Section 5.2(B).15 for detailed description of the formation.

BRISTOL

The lowermost part of the Pembroke Limestone Group in the Bristol region is identified as the **Black Rock Limestone Subgroup**. In the Bristol region the subgroup is undivided, other than the presence of the **Middle Hope Volcanic Member**.

In the central and eastern parts of the Mendips, the Black Rock Limestone Subgroup is overlain by a distinctively crinoidal, non-ooidal facies, mapped as the **Vallis Limestone Formation** (Figure 17). This formation passes laterally within the Mendips into the **Burrington Oolite Subgroup**, where poor exposure of a limestone-dominated succession prevented subdivision of a succession into component formations. In the Weston area the subgroup passes laterally into the **Gully Oolite, Caswell Bay Mudstone, High Tor Limestone** and **Goblin Combe Oolite formations** (Whittaker and Green, 1983). The High Tor Limestone Formation includes a single member, the **Spring Cove Lava Member**. In the Avon Gorge area the succession above the unconformity at the top of the Gully Oolite Formation is represented by a single formation, the **Clifton Down Mudstone Formation**. Further to the north, in the Monmouth/Chepstow area, there is a passage to the **Llanely Formation**, of equivalent age.

The Holkerian succession of the Monmouth/Chepstow region includes the **Hunts Bay Oolite Subgroup** and the **Cromhall Sandstone Formation** (Figure 17). Towards the south the Cromhall Sandstone Formation splits into three leaves, which in the Cromhall/Avon Gorge area interdigitates with the **Clifton Down Limestone** (with component

Cheddar Limestone and **Cheddar Oolite members** in the Cheddar Gorge area) and **Oxwich Head Limestone formations**, with only the upper leaf extending into the Weston/Broadfield area.

The Cannington Park inlier [ST 245 405] represents the southernmost outcrop of the Pembroke Limestone Group. The published map for Taunton and the Quantock Hills (Sheet 295) identifies the unit at outcrop as Carboniferous Limestone (undifferentiated). The Knap Farm Borehole (ST24SW/1) [ST 2479 4011] provides a detailed record of the succession (Edmonds and Williams, 1985). The lowermost part of the Pembroke Limestone Group in the borehole is recognised as a 187.9 m thickness of the Black Rock Limestone Subgroup. The overlying succession has been provided with local names (Edmonds and Williams, 1985), although these names have not been applied outside of this borehole record and only limited attempt has been made to correlate with strata present further to the north. The succession above the Black Rock Limestone Subgroup is as follows (with uppermost unit at top):

Cannington Park Limestone: pale grey limestone with ooidal texture, possibly equivalent to the Goblin Combe Oolite Formation, 93.2 m thick

Knap Limestone: pale grey limestone, porcellaneous near the top, coarser grained with ooid-limestone-like beds, dolomitic bands and crinoidal limestones, 156.35 m

Cynwir Castle Limestone: dark grey, fine-grained limestone with common stylolites, 101.66 m thick

Cynwir Cherty Limestone: dark grey, fine-grained limestone with chert bands and nodules, thin beds of calcareous sandstone and silty shale are present locally, 206.47 m thick

Cannington Reef Limestone: grey, fine-grained or porcellaneous limestone with Waulsortian reefs, bands of dolomitised limestone, locally common crinoidal debris and stylolites, 220.73 m thick.

Further work is required to determine if these units should be formalised as formations or whether regionally applicable names could be used.

5.2E Black Rock Limestone Subgroup

Black Rock Limestone Subgroup is defined fully in Section 5.2A.

In the Bristol region the subgroup consists of dark grey to black, well-bedded, fine-grained, poorly sorted crinoidal limestone, locally with chert bands and nodules. The thickness of the subgroup decreases toward the north; a maximum of more than 250 m is recorded in the Mendips; 150 m at Bristol, including about 30 m of secondary dolomite at the top; at Chepstow and the Forest of Dean the subgroup is 90 to 120 m thick. The base of the subgroup is gradational and is marked by upward increase in the proportion of limestone. The subgroup contains a rich fauna of conodonts, corals and foraminifera and ranges from Tournaisian to Chadian age.

The subgroup was formerly subdivided into Black Rock Limestone and Black Rock Dolomite formations. The dolostone generally occurs within the upper part of the subgroup over the Bristol–Mendips areas, but occurs throughout the succession at Chepstow and the Forest of Dean. These formation names are now considered obsolete as they represent non-dolomitised and dolomitised limestone, respectively, rather than distinguished by primary lithological variations. Further studies are necessary to determine if

component formations of the subgroup can be identified in the Bristol region.

5.2E.26.1 MIDDLE HOPE VOLCANIC MEMBER (MHVO)

Name

The member was referred to by numerous authors (Geikie and Strahan, 1899; Morgan and Reynolds, 1904; Reynolds, 1917; Matthews et al., 1973), formerly known as the Woodspring Lava and Tuff. The Middle Hope Volcanic Member was defined by Whittaker et al. (1983), occurring within undivided Black Rock Limestone Subgroup.

Type section

Swallow Cliff [ST 3245 6605], Middle Hope, north Somerset: complete thickness seen (Speedyman, 1977; Jeffreys, 1979; Whittaker and Green, 1983; Waters, 2003).

Lithology

The lower part of the member comprises upward-coarsening multicoloured, mainly red-brown and green, tuffs, with bioclastic material. Lapilli-rich beds, 3 to 5 cm thick, within this unit also increase in grain size upwards. Associated with the tuffs are thin-bedded limestones, some planar stratified or showing symmetrical ripples. The multicoloured tuffs are overlain by green, graded and ungraded lapilli-tuffs, with clasts of devitrified amygdaloidal basalt and bioclastic material. Calcite vein networks are prominent locally. Within the ungraded lapilli-tuffs there are matrix- and clast-supported conglomerates, with clasts of chert nodules and limestones. Also associated with the lapilli-tuffs are beds of bioclastic limestones and both cross-stratified and laminated sandstones. Within the lapilli-tuffs is a prominent, laterally impersistent basaltic pillow lava (3.5 to 4.3 m thick), very weathered with abundant calcite-filled amygdales up to 10 cm across. The upper surface of the basalt is very irregular and highly amygdaloidal.

Lower and upper boundaries

The base is taken at a sharp conformable boundary where bioturbated wackestones and packstones of the Black Rock Limestone Subgroup are overlain by multicoloured tuffs.

The upper boundary is taken at a sharp, erosive boundary where red nodular limestones with green tuff laminae and beds are overlain by cross-bedded, bioclastic grainstones of the Black Rock Limestone Subgroup.

Thickness

From 37 m at Swallow Cliff in the west, to 4 m in the east of the site [ST 348 669].

Distribution

Restricted to Middle Hope [ST 322 659], north Somerset.

Genetic interpretation

The coarsening-up trend in the lower tuff unit records increased intensity of volcanic activity with time, with the lapilli-rich layers indicating periods of more energetic eruptions. Associated limestones were probably deposited by storm currents (Faulkner, 1989). The overlying lapilli-tuffs were also deposited in marine waters, and were emplaced either by sediment-gravity flows related to the eruptions, or by marine currents. The pillow basalts indicate subaqueous igneous activity, and show that the site was close to the volcanic centre. The lapilli-tuffs were deposited in relatively shallow water as the volcanic cone built up to its maximum height. Progressive eastward thinning of the volcanic beds, suggests that the source of this volcanic material lay to the west of the site.

Age
Tournaisian

5.2.27 Vallis Limestone Formation (VL)

Name

The unit was named and described by Green and Welch (1965) and is here defined as a formation.

Type section

Crags on eastern side of Vallis Vale gorge, west of Frome, Somerset [ST 7543 4930 to 7483 4921]: entire unit seen, with exposure of upper boundary; lower boundary is not seen.

Lithology

Pale grey coarse-grained crinoidal limestones.

Lower and upper boundaries

The base is taken at the incoming of pale grey, coarse, crinoidal limestones of the formation above the dolomitised packstones of the underlying Black Rock Limestone Subgroup. Little known about this contact which needs further investigation.

The top is taken at the incoming of ooidal limestones and crinoidal/ooidal limestones of the overlying Burrington Oolite Subgroup above the coarse crinoidal limestone of the formation. Little known about this contact which needs further investigation. At the type locality it is taken at the incoming of calcite mudstones and ooidal/crinoidal limestones of the Clifton Down Limestone Formation.

Thickness

Some 152 m in the eastern Mendips, thinning west to a feather-edge in the central Mendips.

Distribution

Eastern Mendips [ST 70 45].

Regional correlation

Passes westwards into the Burrington Oolite Subgroup. The geometry of this formation is problematical and needs further investigation.

Genetic interpretation

Deposited in a shallow shelf/ramp environment.

Age

Arundian

5.2F Burrington Oolite Subgroup (BO)

Name

The subgroup was introduced and defined by Green and Welch (1965).

Type section

Burrington Combe, Burrington, Somerset [ST 4713 5810 to 4714 5815]: 210 m thick incomplete section, with lower boundary seen (Green and Welch, 1965).

Lithology

Massive pale grey ooidal limestones and ooidal/peloidal/crinoidal limestones. There are beds of coarse crinoidal limestone in the lower part and calcite mudstones in the uppermost part. The subgroup is locally dolomitised in the lowermost part.

Lower and upper boundaries

The base is taken at the gradational junction of sparsely crinoidal dolomite of the underlying Black Rock Limestone Subgroup and the ooidal limestone (locally dolomitised) of the subgroup. In the eastern Mendips, taken at the incoming of ooidal limestones above the coarse crinoidal limestones of the Vallis Limestone Formation. Both contacts need further investigation.

The top is taken at the incoming of calcite mudstones and dark splintery limestones of the Clifton Down Limestone Formation above the ooidal and ooidal/crinoidal limestones of the subgroup.

Thickness

From 210 m at Burrington Combe to 230 m at Wells, thinning to a feather-edge in the eastern Mendips.

Distribution

Mendips [ST 50 55] and Weston-super-Mare area [ST 30 60].

Regional correlation

Passes north into the Gully Oolite, Clifton Down Mudstone and Goblin Combe Oolite formations. Passes east into Gully Oolite, Caswell Bay Mudstone, High Tor Limestone and Goblin Combe Oolite formations. Passes east into Vallis Limestone Formation and supposedly the Black Rock Limestone Subgroup but this needs further investigation.

Genetic interpretation

Ooid-limestone shoal deposits

Age

Chadian to Arundian

5.2.28 Gully Oolite Formation (GUO)

The formation is fully described from South Wales (South Crop) (See Section 5.2A.5 for details).

In the Bristol region the Gully Oolite Formation is a distinctive pale grey, medium- to fine-grained, cross-bedded ooid-limestone in which macrofossils are rare. The ooid-limestone weathers white and is massive with conspicuous vertical joints. The formation is 35 to 40 m thick on Broadfield Down (Kellaway and Welch, 1993) and within the Weston area (Whittaker and Green, 1983), including 1 to 7 m of pale grey, well-sorted crinoidal limestone at the base ('Sub-Oolite Bed'). The maximum thickness of 64 m is recorded north-east of Bristol (Kellaway and Welch, 1993). The base of the formation is sharp and flat. The formation can be correlated across the Bristol region and South Wales. In the Forest of Dean this formation, 10 to 30 m thick, replaces the obsolete term Crease Limestone. A Chadian age for the formation has been demonstrated in the Weston area (Whittaker and Green, 1983).

5.2.29 Caswell Bay Mudstone Formation (CBM)

The Caswell Bay Mudstone Formation is defined fully in the type area, located in the South Crop of South Wales (see Section 5.2A.9).

In the Bristol region, the formation comprises pale grey, calcareous mudstone, interbedded with dark grey and brown shale. The calcareous mudstones weather whitish grey or buff, and are poorly fossiliferous. The formation overlies a prominent erosion surface at the top of the Gully Oolite. On the south side of Broadfield Down, about 12 m

of basaltic lava and tuff occur in the lower part of the formation. The formation is about 5 m thick in the Weston area (Whittaker and Green, 1983), but is absent from the Mendips. Deposition during early Arundian marine transgression has been postulated for this formation in South Wales (see Section 5.2.9), although it is taken to be of Chadian age by George et al. (1976).

5.2.30 High Tor Limestone Formation (HTL)

See Section 5.2A.10 for detailed description. In the Bristol/Mendips region the formation was formerly referred to as the Birnbeck Limestone Formation. It comprises grey to dark grey, bioclastic limestone. The lower part consists of 20 to 30 m of grey, very thickly bedded, massive or cross-bedded, relatively unfossiliferous, commonly ooidal limestone the **Flat Holm Limestone Member** (Whittaker and Green, 1983). The upper part consists of 37 to 45 m of grey to dark grey, bioturbated and fossiliferous, thick-bedded limestone. The 15 m-thick **Spring Cove Lava Member** is present in the Weston area. The formation is entirely Arundian in age, and the base of the Arundian Stage is assumed to occur at the base of this formation (Whittaker and Green, 1983). These authors have assumed that the formation accumulated in response to basal Arundian marine transgression. This formation is not present in the Bristol area, where it has passed laterally into the Clifton Down Mudstone, or within the Mendips, where it is included within the undivided Burrington Oolite Subgroup.

5.2.30.1 FLAT HOLM LIMESTONE MEMBER (FHL)

Name

The member was first named and defined by Whittaker and Green (1983).

Type section

Cliffs and foreshore reefs on the east coast of Flat Holm island between Dripping Cove and Lighthouse Point [ST 2230 6476 to 2227 6467]: entire section seen, 31 m thick, with both lower and upper boundaries exposed (Whittaker and Green, 1983).

Lithology

Dark grey, medium-bedded, skeletal limestones with thick bedded, locally cross-bedded, commonly ooidal limestones at the base. Units of interbedded dolomite mudstone, dolomite siltstone and mudstone punctuate the succession.

Lower and upper boundaries

The base is taken at the sharp erosive contact of the massive to thick-bedded, pale grey, skeletal and ooidal limestones of the member and the thin- to medium-bedded dolomite and calcite mudstones and mudstones of the underlying Caswell Bay Mudstone Formation.

The top is taken at the top of the uppermost unit of interbedded dolomite mudstone and dolomite siltstone, and mudstone of the member, which is overlain by massive to thick bedded, pale grey, skeletal and ooidal limestones of the remaining part of the High Tor Limestone Formation.

Thickness

Some 31 m at the type section.

Distribution

Flat Holm Island [ST 22 64], South Wales.

Genetic interpretation

Deposited as a transgressive barrier and offshore shelf sequence.

Biostratigraphical characterisation

A coral bed located 10.5 m above the base of the member at Flat Holm contains typical Arundian fauna (Whittaker and Green, 1983).

Age

Arundian

5.2.30.2 SPRING COVE LAVA MEMBER (SCLA)

Name

The unit was described as the Spring Cove Lava (Boulton, 1904; Reynolds, 1917; Speedyman, 1977; Jeffreys, 1979) named after the type locality. The unit was described fully by Whittaker and Green (1983) and is here defined as a member.

Type section

Composite section in a coastal cliff at Spring Cove [ST 310 625]: complete thickness seen (Whittaker and Green, 1983; Waters, 2003).

Lithology

Olivine basalt, typically fine grained, chocolate-brown, massive and highly amygdaloidal with imperfect pillow structures and red ooidal limestone fragments in all stages of alteration and assimilation, which in places appear to occupy spaces between pillows. In the centre of the member, cindery lava is mixed with broken limestone fragments. Calcite veins are common throughout.

Lower and upper boundaries

The base is irregular and channelled up to 1.2 m into the underlying limestone of the High Tor Limestone Formation.

The top is a sharp boundary with overlying reddish-fawn, dolomitised limestone of the High Tor Limestone Formation; tuffaceous debris in lower 1.5 m, increasing towards the base.

Thickness

Up to 15 m

Distribution

Restricted to Spring Cove [ST 310 625], north Somerset.

Regional correlation

The member is approximately contemporaneous with lavas and tuffs from the Bristol District at Goblin Combe, Broadfield Down, Cadbury Camp and Tickenham.

Genetic interpretation

The internal structure of lenticular sheets of lava, tuff and agglomerate, sloping to the south, as described by Boulton (1904) was used by him to suggest the presence of a vent to the north. The pillow structures are indicative of subaqueous eruption. The irregular shape of limestone fragments present within the lava in various stages of alteration and assimilation (Boulton, 1904) and the slightly undulating and cross-cutting relationship of the lava with underlying limestones (Whittaker and Green, 1983) led these authors to suggest that the lava was extruded onto sediments which were not fully consolidated. The 'tuffs and agglomerates' were interpreted as an autobreccia, possibly formed as a result of a submarine slide of pillow lavas with included clasts of limestone (Speedyman,

1977). These deposits were subsequently overridden by further pillow lavas.

Age
Arundian

5.2.31 Goblin Combe Oolite Formation (GCO)

Name

The formation was named and defined by Kellaway and Welch (1955).

Type section

North side of Goblin Combe, north-east of Congresbury, Broadfield Down, Somerset [ST 4667 6541 to ST 4735 6537]: entire unit exposed (38 m thick), with both lower and upper boundaries seen (Kellaway and Welch, 1993).

Lithology

Pale grey to grey, thick-bedded to massive, medium to coarse-grained ooid-limestone, and ooidal limestone with lenses of crinoidal limestone.

Lower and upper boundaries

In the Bristol area and Broadfield Down the base is taken at the incoming of ooidal limestones of the formation above the dolomite and calcite mudstones and mudstones of the underlying Clifton Down Mudstone Formation (Kellaway and Welch, 1993). In the Weston-super-Mare area and Steepholme it is taken at the incoming of massive, coarse crinoidal and ooidal limestones of the formation above the grey to dark grey, medium bedded skeletal limestones of the High Tor Limestone Formation (Whittaker and Green, 1983).

In the Weston -super-Mare area the top is taken at the incoming of calcite mudstones of the Clifton Down Limestone Formation above the ooidal limestones of the formation (Whittaker and Green, 1983). In the Bristol area it is taken at the incoming of calcite mudstones and skeletal limestones of the Clifton Down Limestone Formation above the ooidal limestones of the formation (Kellaway and Welch, 1993).

Thickness

From 15 m in the Bristol area (Avon Gorge) to 70 m at Weston-super-Mare.

Distribution

Bristol [ST 60 74], Broadfield Down [ST 50 65] and Weston-super-Mare [ST 30 60] areas

Regional correlation

Passes northwards into the Clifton Down Mudstone Formation and south into the Burrington Oolite Subgroup (Figure 17).

Genetic interpretation

Deposited in a barrier environment.

Age
Arundian

5.2.32 Clifton Down Mudstone Formation (CDM)

Name

The formation has been previously referred to as the Middle Limestone Shales (Morgan, 1885), the Caninia Shales and Dolomite (Vaughan, 1905) and the Lower Clifton Down Mudstone and Upper Clifton Down Mudstone (Ramsbottom,

1973). The formation was named and defined by Kellaway and Welch (1955).

Type section

Portway road section, east bank of Avon Gorge, Clifton, Bristol [ST 5621 7435 to 5623 7422]: entire unit is exposed, 59 m thick, with both the lower and upper boundaries seen (Kellaway and Welch, 1993).

Lithology

Thin to medium-bedded, poorly fossiliferous, calcite mudstones, dolomite mudstones and mudstones. A unit of crinoidal and ooidal limestone occurs in the middle of the formation. A 15 m thick unit of ooidal and crinoidal limestone occurs in upper part of formation (said to correlate with the Goblin Combe Oolite Formation of Broadfield Down, but this is not proven). Basalt, tuff and ashy limestone are present in the middle of the formation on Broadfield Down.

Lower and upper boundaries

The base is taken at an irregular erosive contact of dolomite and calcite mudstones and mudstones of the formation above the clay palaeosol of the underlying Gully Oolite Formation.

In the Bristol area the upper boundary is taken at the sharp contact between the interbedded dolomite and calcite mudstones and mudstones of the formation and the basal sandy limestone of the overlying Clifton Down Limestone Formation. The boundary needs further investigation. In Broadfield Down, the upper boundary is taken at the incoming of ooidal limestones of the Goblin Combe Oolite Formation above the interbedded dolomite and calcite mudstones and mudstones of the formation.

Thickness

Some 60 m at Bristol and northern Broadfield Down, thinning to a feather-edge on the southern side of Broadfield Down.

Distribution

Bristol area [ST 60 74] and Broadfield Down [ST 50 65].

Regional correlation

Passes north-westwards into the Llanelly Formation and southwards into the Burrington Oolite Subgroup.

Genetic interpretation

Formation deposited mainly in a back-barrier setting.

Age
Arundian

5.2.33 Cromhall Sandstone Formation (CHSA)

Name

The formation was previously identified as the Lower Cromhall Sandstone, Middle Cromhall Sandstone and Upper Cromhall Sandstone (Kellaway and Welch, 1955) in the Bristol region and the Lower Drybrook Sandstone and Upper Drybrook Sandstone (Trotter, 1942) in the Monmouth and Chepstow areas. The hierarchy of the Lower, Middle and Upper Cromhall sandstones is uncertain. Undoubtedly, at the time of deposition, these three tongues merged together in proximity to the southern flank of the Wales–Brabant High. This suggests the unit be considered a single Cromhall Sandstone Formation, with the distinct tongues given member status.

Type area

Cromhall area, north of Bristol [ST 697 906]: where the three tongues are mapped (Kellaway and Welch, 1993).

Lithology

The formation comprises up to three tongues. The lower tongue comprises brown and red, fine to coarse-grained quartzitic sandstone with subordinate mudstones and sparse thin limestones. The base is locally conglomeratic. The middle tongue is similar but contains units of dolomitised limestone. The upper tongue comprises grey and red coarse-grained, quartzitic sandstones, sandy crinoidal and ooidal limestones, mudstones, siltstones and grey seatearths arranged in 'Yoredale'-type cyclic sequences. Units of crinoidal and ooidal limestone are locally developed. Pyrite is common, the oxidation of which is responsible for the strong red colours, which characterise the formation at outcrop.

Lower and upper boundaries

The lower boundary of the Cromhall Sandstone Formation is taken at the base of the lower tongue, the base of the first sandstone overlying the calcite and dolomite mudstones and limestones of the underlying Clifton Down Mudstone Formation in the Bristol area and the Llanelly Formation in the Monmouth and Chepstow area. The base of the middle tongue is taken at the base of the first sandstone in the upper part of the Clifton Down Limestone Formation. The base of the upper tongue is taken at the base of first sandstone or mudstone above the skeletal and ooidal limestones of the Oxwich Head Limestone Formation.

The top of the lower tongue is taken at the incoming of calcite mudstones and ooidal and skeletal limestones of the Clifton Down Limestone Formation in the Bristol area and the Hunts Bay Oolite Subgroup in the Monmouth and Chepstow area, above the sandstones and mudstones of the lower tongue. The top of the middle tongue is taken at the base of the entrance of skeletal limestones of the Oxwich Head Limestone Formation above the sandstones and mudstones of the middle tongue. The top of the upper tongue is taken at the entrance of cherts and cherty marine mudstones of the overlying undivided Marros Group above the sandstones and mudstones of the upper tongue.

Thickness

The lower tongue is 6 m thick at Chipping Sodbury to 43 m at Cromhall. The middle tongue is 27 m at Chipping Sodbury to 30 m at Tytherington. The upper tongue is 18 m thick on Broadfield Down, thickening north to 240 m at Cromhall.

Distribution

Bristol, Monmouth and Chepstow area. In the Cromhall area the lower and middle tongues merge. North of Bristol the middle and upper tongues unite. The upper tongue is absent from the west of the Bristol region, removed by erosion at the base of the overlying (Namurian) sequence.

Regional correlation

Passes laterally southwards into formations of the Pembroke Limestone Group (Llanelly, Clifton Down Mudstone, Clifton Down Limestone and Oxwich Head Limestone formations) (Figure 17).

Genetic interpretation

The formation was deposited mainly in a fluvial environment on a marine influenced coastal plain.

Age

Arundian to Brigantian

5.2.34 Clifton Down Limestone Formation (CDL)

Name

The formation was named and defined by Kellaway and Welch (1955). The *Seminula Oolite* (Reynolds, 1921) is an obsolete term commonly used for the ooid-limestones in the middle of the formation in the Bristol area.

Type section

Great Quarry and the Portway road section, east side of Avon Gorge, Bristol [ST 5623 7422 to 5633 7380]: most of unit (266 m) seen, apart from a gap in the lower part, with both lower and upper boundaries exposed (Kellaway and Welch, 1955).

Formal subdivisions

In the Cheddar Gorge area a lower Cheddar Limestone Member and overlying Cheddar Oolite Member are recognised.

Lithology

Splintery dark grey calcite and dolomite mudstones, pale grey ooidal, dark grey bioclastic and oncolitic limestones and some mudstones. Scattered cherts and silicified fossils are present in the lower half. Sandy limestone is present at the base in Bristol area (Kellaway and Welch, 1993).

Lower and upper boundaries

In the Bristol area, the base is taken at the sharp contact between the interbedded dolomite and calcite mudstones and mudstones of the underlying Clifton Down Mudstone Formation and the basal sandy limestone of the Clifton Down Limestone Formation. This boundary needs further investigation. In Broadfield Down and the Mendips it is taken at the incoming of calcite mudstones of the Clifton Down Mudstone Formation above the ooidal and ooidal/bioclastic limestones of the Goblin Combe Oolite Formation and undivided Burrington Oolite Subgroup, respectively.

The top is taken at the top of the last calcite mudstones of the formation, above which occur the dark grey crinoidal and bioclastic limestones and paler ooid-limestone of the Oxwich Head Limestone Formation.

Thickness

Some 266 m in the Avon Gorge at Bristol, thinning north to 137 m north of Bristol and thinning south to 150 to 200 m in the Mendips.

Distribution

Bristol area [ST 60 74] and Mendips [ST 50 53]

Regional correlation

The formation passes laterally into the Hunts Bay Oolite Subgroup in the Monmouth and Chepstow area (Figure 17).

Genetic interpretation

Deposited in a barrier/back barrier/shelf lagoon setting. The ooidal beds are interpreted as tidal channel or bar deposits.

Biostratigraphical characterisation

The base of the Holkerian Stage taken at the sharp base of the 'Seminula Oolite' (George et al., 1976).

Age

Arundian to Holkerian

5.2.34.1 CHEDDAR LIMESTONE MEMBER (CDRL)

Name

The name was first used and described by Green and Welch (1965).

Type section

North side of Cheddar Gorge, Mendips, Somerset [ST 4806 5461 to 4800 5450]: entire unit seen, 35 m thick, with lower and upper boundaries exposed (Green and Welch, 1965).

Lithology

Dark grey crinoidal and splintery limestones with chert in the upper part.

Lower and upper boundaries

The base is taken at the appearance of dark limestones of the Cheddar Limestone Member above the ooidal and ooidal/crinoidal limestones of the Burrington Oolite Subgroup. This equates with the local base of the Clifton Down Limestone Formation.

The top is taken at the incoming of pale grey ooid-limestone of the Cheddar Oolite Member above the dark limestones of the member.

Thickness

From 30 to 37 m in the Cheddar area

Distribution

Cheddar area [ST 48 54], central Mendips

Regional correlation

The member passes laterally into the Clifton Down Limestone Formation in all directions.

Genetic interpretation

Poor lithological description does not allow for an environmental interpretation.

Age

Holkerian

5.2.34.2 CHEDDAR OOLITE MEMBER (CDRO)

Name

The name was first used and described by Green and Welch (1965).

Type section

Cheddar Gorge, Mendips, Somerset [ST 4761 5452 to 4738 5439]: the unit is 55 m thick, mostly exposed apart from a gap in the upper part, with both lower and upper boundaries seen (Green and Welch, 1965).

Lithology

Pale grey ooid-limestone.

Lower and upper boundaries

The base is taken at the incoming of pale grey ooid-limestones of the Cheddar Oolite Member above the dark limestones of the Cheddar Limestone Member.

The top is taken at the incoming of dark grey fine-grained limestones, rich in corals, of the undivided Clifton Down Limestone Formation, above the pale ooid-limestone of the member.

Thickness

From 36 to 60 m in the Cheddar area, southern Mendips

Distribution

Cheddar area [ST 48 54], central Mendips

Regional correlation

The member passes laterally into Clifton Down Limestone Formation in all directions.

Genetic interpretation

The ooidal beds are interpreted as tidal channel or bar deposits.

Age

Holkerian

5.2.35 Oxwich Head Limestone Formation (OHL)

See Section 5.2.14 for description of the Oxwich Head Limestone Formation. In the Bristol/Mendips area the formation was formerly referred to as the Hotwells Limestone Formation. The formation here comprises hard, massive, grey to dark grey, ooidal and crinoidal limestone with an abundant coral and brachiopod fauna. The formation is about 225 m thick on Broadfield Down, but less than 100 m thick in the Avon Gorge and absent north of Bristol. The upper part of the formation passes laterally northward into the sandy facies of the Upper Cromhall Sandstone. The formation is considered Asbian in age; a possible non-sequence at the sharp base of the formation may be indicated by the absence of diagnostic early Asbian fauna (Kellaway and Welch, 1993). The formation represents high-energy marine deposits characteristic of an open shelf environment.

SHROPSHIRE

Platform carbonates are present in Shropshire at an outlier of Carboniferous strata between Cleehill [SO 571 750] to Oreton [SO 665 806]. This outcrop comprises a single **Oreton Limestone Formation**, which in the southern part of the outcrop overlies strata of the Avon Group. Because of comparisons with the succession in South Wales, the Oreton Limestone Formation is here considered to be a component of the Pembroke Limestone Group.

5.2.36 Oreton Limestone Formation (ORTL)

Name

The unit was referred to as the Main Limestone by George (1956a) and the Oreton Limestone by George et al. (1976) and is here formally defined as a formation.

Type section

Two quarries at Oreton, approximately 250 m north-east of the New Inn. The western quarry [SO 6519 8068] comprises 11.5 m of limestone, ooidal in the lower 8 m (Greig et al., 1968); the eastern quarry [SO 6518 8062] comprises 10 to 11 m of ooidal limestone (Greig et al., 1968).

Lithology

The formation comprises hard grey crystalline limestones, crinoidal limestones and ooidal limestones. The uppermost part of the succession, about 25 m thick, comprises mudstone with thin nodular limestones.

Lower and upper boundaries

The base is taken at the base of the lowermost ooidal or crinoidal limestone in a limestone-dominated sequence of the Oreton Limestone Formation, underlain conformably by calcareous mudstone and impure limestone of the Avon Group in the southern crop near Cleehill [SO 571 750]. This boundary has not been mapped on the Ludlow (181) Sheet. In the north crop near Oreton [SO 665 806] the Oreton Limestone Formation is shown resting directly upon conglomeratic sandstone, interpreted to be the basal unit of the Avon Group.

Mudstone and nodular limestones of the Oreton Limestone Formation are overlain with an angular uncon-

formity by quartzitic sandstone of the Cornbrook Sandstone Formation.

Thickness

Estimated to be about 45 m in the northern outcrop between Oreton and Farlow [SO 646 803] (Greig et al., 1968) and 20 m in the south crop at Cleehill [SO 571 750].

Distribution

Clee Hills Outlier, between Cleehill [SO 571 750] and Oreton [SO 665 806].

Regional correlation

Has been proposed to be a northern equivalent of the Pwll-y-Cwm Oolite of the North Crop of the South Wales Coalfield (George et al., 1976).

Genetic interpretation

Ooid shoals

Biostratigraphical characterisation

The formation is of Tournaisian age. The succession was considered to belong to part of the coral-brachiopod K and Z zones (Greig et al., 1968). From miospore assemblages the succession is considered to belong to the younger part of the PC Zone (Turner and Spinner, 1988).

Age

Tournaisian

BERKSHIRE

The Pembroke Limestone Group has been proved in the concealed Berkshire Coalfield in a single borehole, the Foudry Bridge Borehole (SU76NW 58) [SU 7063 6602]. The unbottomed succession of the undivided group is 15.15 m thick, comprising grey to dark grey, bioclastic limestone, interbedded with thin calcareous mudstone considered Holkerian in age (Foster et al., 1989).

KENT COALFIELD

The Pembroke Limestone Group has been proved in the concealed Kent Coalfield in 14 boreholes (Smart et al., 1966; Mitchell, 1981). Up to 131 m thickness of pale grey ooidal or dark grey bituminous limestone, interbedded with black shale have been recorded, attributed to the Holkerian Stage (Mitchell, 1981)

5.3 MARROS GROUP (MARR)

The Namurian succession of South Wales and Bristol, of Millstone Grit Facies, has traditionally been named Millstone Grit Series (Woodland and Evans, 1964). The term is considered unsuitable, firstly as it is used as chronostratigraphical term, but also because the unit comprises predominantly quartzose sandstones, locally derived from the Wales–Brabant High and as such is readily distinguishable from the Millstone Grit Group of the Pennine Basin. The Namurian succession of South Wales is comparable to that developed in North Wales. However, the two successions evolved in isolation, so separate group and formation nomenclature are proposed. The South Wales and Bristol successions are similar and warrant use of a single group name. Uncertainties in correlation between the two areas suggest that separate formation nomenclatures be established.

Although the Namurian succession is thickest and most complete in the basal succession of the Gower, it is

poorly exposed, not representative of the group elsewhere, and the Gower is more associated with the Tournaisian to Viséan rocks. Marros Group is therefore suggested, there being good coastal cliff sections between Marros Sands and Telpyn Point, Carmarthenshire (Cleal and Thomas, 1996).

The component formations of the Marros Group in South Wales and Bristol have traditional names that are considered unsuitable and hence a new nomenclature is proposed (Figure 18).

SOUTH WALES

Delta plain to marine mudstones dominate in the Tenby area and in thicker successions in Gower, with fluvial and littoral quartzitic sandstones and quartz conglomerates occupying the basal half of the group towards the north-east and east crops of the South Wales Coalfield. The Marros Group (undifferentiated) succession at the Gower comprises about 700 m of dominantly shales, with numerous marine bands. Sandstones only occur in strata of Chokierian and Marsdenian age. The Namurian succession thins and shows several depositional breaks both northwards, approaching the southern flank of the Wales–Brabant High, and eastward, approaching the Usk Anticline (George, 1970, figure 25). A new formational nomenclature is proposed here: in ascending order the **Aberkenfig, Twrch Sandstone, Bishopston Mudstone and Telpyn Point Sandstone formations**.

5.3.1 Aberkenfig Formation (ABKH)

Name

Formerly referred to as the Plastic Clays (Strahan et al., 1907; Ware, 1939; Ramsbottom et al., 1978), renamed after Aberkenfig, the location of the Kenfig Borehole type locality. The Aberkenfig Formation is included within the Marros Group for practical reasons, on the basis of existing mapping information. It may ideally be considered a stand-alone formation between the Pembroke Limestone and Marros groups, but would require future fieldwork to allow it to be isolated from the Marros Group.

Type section

Kenfig No.2B Borehole (SS88SW/81) [SS 8055 8167], near North Cornelly, Porthcawl, South Wales: proves the formation from 13.46 to 48.46 m depth (Wilson et al., 1990).

Reference section

Sarn Park M4 Motorway cutting [SS 918 827], where the formation comprises about 15 m thickness of black fissile mudstones and cherts. The lowermost beds contain a pebbly lag, with a non-sequence at the base, resting upon the Oystermouth Formation.

Lithology

Dark grey fissile mudstones with thin-bedded radiolarian cherts and siliceous mudstones.

Lower and upper boundaries

The base is a gradational boundary with white-weathering, black, fine-grained limestones and interbedded black mudstones of the underlying Oystermouth Formation passes upwards into the thin-bedded radiolarian cherts and mudstones of the Aberkenfig Formation. In the type section of the Kenfig Borehole, the base is at 48.46 m depth.

The top is taken at the top of the highest chert or siliceous mudstone of the formation, where it is overlain by the lowest quartzite of the overlying Twrch Sandstone Formation. In

the type section of the Kenfig Borehole, the top is not seen, the formation being unconformably overlain by marl and red clay of the Mercia Mudstone Group at 12.8 m depth.

Thickness

Some 35 m at the type locality. To the east the formation is removed by the unconformity at the base of the Twrch Sandstone Formation.

Distribution

Parts of northern and southern peripheries of the South Wales Coalfield: on the north crop in the Ammanford district, from Garn [c.SN 540 139] east to Llandybie [c.SN 645 173]; on the south crop, from west Gower [c.SS 430 945] (not exposed) east to Swansea Bay, and east of Swansea Bay to the Sarn Park area [approximately SS 920 830].

Genetic interpretation

The formation accumulated predominantly from suspension in moderately deep water, below the storm wave-base, in a setting isolated from coarser grade siliciclastic contamination, but in which radiolaria were abundant.

Biostratigraphical characterisation

In the Gower a possible Brigantian age for the formation is proposed by Ramsbottom et al. (1978), but they indicate that the evidence is inconclusive. In the North Crop the formation is considered to be Pendleian in age. In the Sarn Park reference section, mid to late Arnsbergian fauna have been proved in the basal lag of the formation, with the Pendleian part of the succession absent (Wilson et al., 1990).

Age

Pendleian to Arnsbergian

5.3.2 Twrch Sandstone Formation (TWR)

Name

The unit was formerly called the Basal Grit(s) (Robertson, 1927) or Basal Grit Group (George, 2000). The new name is from the Twrch Valley (Ammanford sheet), where the formation is thickest and well exposed.

Type area

Type area is the Twrch Valley, where the formation is thickest (about 190 m) and is well exposed in the Afon Twrch from the top of the formation [SN 7719 1508] to a fault [SN 7844 1846], where it is faulted against the Avon Group. It is also well exposed on the precipitous slopes (Tyle-Garw) on the east side of the Twrch Valley (Ware, 1939) (Figure 18).

Lithology

The formation is dominated by quartzose sandstone with thin mudstone/siltstone interbeds. The sandstone is commonly pebbly and conglomeratic and may occur in upward-coarsening cycles or with channelled bases and upward-fining cycles.

Lower and upper boundaries

The base is placed at the base of a major development of quartz arenite and quartz pebble conglomerate; generally an unconformity, the Twrch Sandstone Formation resting with discordance on the limestones of the underlying Pembroke Limestone Group. In the south of the type area, it rests unconformably on the Oystermouth Formation, in the north on the Oxwich Head Limestone Formation.

The top is placed at a sharp junction, generally a disconformity, where the lowermost grey mudstones of the

Bishopston Mudstone Formation overlies the highest quartz arenites of the Twrch Sandstone Formation.

Thickness

About 190 m at the type locality. Further to the east, the formation thins dramatically eastward from 150 m to less than 20 m. This reflects a successive overstep in the formation. Toward the west of the type area, in Pembrokeshire the formation also thins as it passes laterally into the Bishopston Mudstone Formation.

Distribution

On the northern limb of the Pembrokeshire Coalfield westwards from Ragwen Point [SN 220 071] to just east of Druidston [SM 877 170] and eastwards along the north crop of the main South Wales Coalfield to near Blaenavon [SO 270 110], south-east to Machen [ST 225 895].

Regional correlation

Passes laterally to the west into the Bishopston Mudstone Formation (Figure 18).

Genetic interpretation

Deposition in deltas (upward-coarsening) and fluvial channels (upward-fining) environments. Some mudstone beds contain *Lingula* and probably represent marine transgressions.

Biostratigraphical characterisation

In the type area the strata are Pendleian to Marsdenian in age; the base of the formation is Arnsbergian in age in the west of the Merthyr Tydfil district (Barclay et al., 1988) and Yeadonian in the east of the Abergavenny district (Barclay, 1989).

Age

Pendleian to Yeadonian

5.3.3 Bishopston Mudstone Formation (BISHM)

Name

Formerly called the Middle Shale Group in Pembrokeshire (Archer, 1965) or Shale Group in the North Crop (Robertson, 1927). The name proposed by Cleal and Thomas (Cleal and Thomas, 1996) and defined formally here is from the area of the thickest development in South Wales.

Type section

Type area is Bishopston, Gower, where the formation is at its thickest and of most basal facies. A section through the lower half of the succession along the mill-race and stream at Barland Common, Bishopston [SS 5766 8965 to 5788 9003], comprises 490 m of strata, was first recorded by De La Beche (1846). At least 20 goniatite-bearing marine bands were recorded during the 1945–54 survey by J V Stephens (Barclay and Stephens, in prep.). The strata dip steeply to the north (about 75 degrees).

Reference section

Sea shore sections near Marros Sands, from Telpyn Point eastwards, Carmarthenshire [SN 193 075 to 198 076]: where 107.9 m (345 feet) of the formation are exposed, the lowermost 15 to 18 m are unexposed (Archer, 1965; George and Kelling, 1982).

Lithology

Medium to dark grey mudstones, commonly fossiliferous, with some beds of medium grey siltstones and beds of interbedded siltstone and mudstone. Sporadic, minor pale grey quartzitic sandstones and rare thin coals.

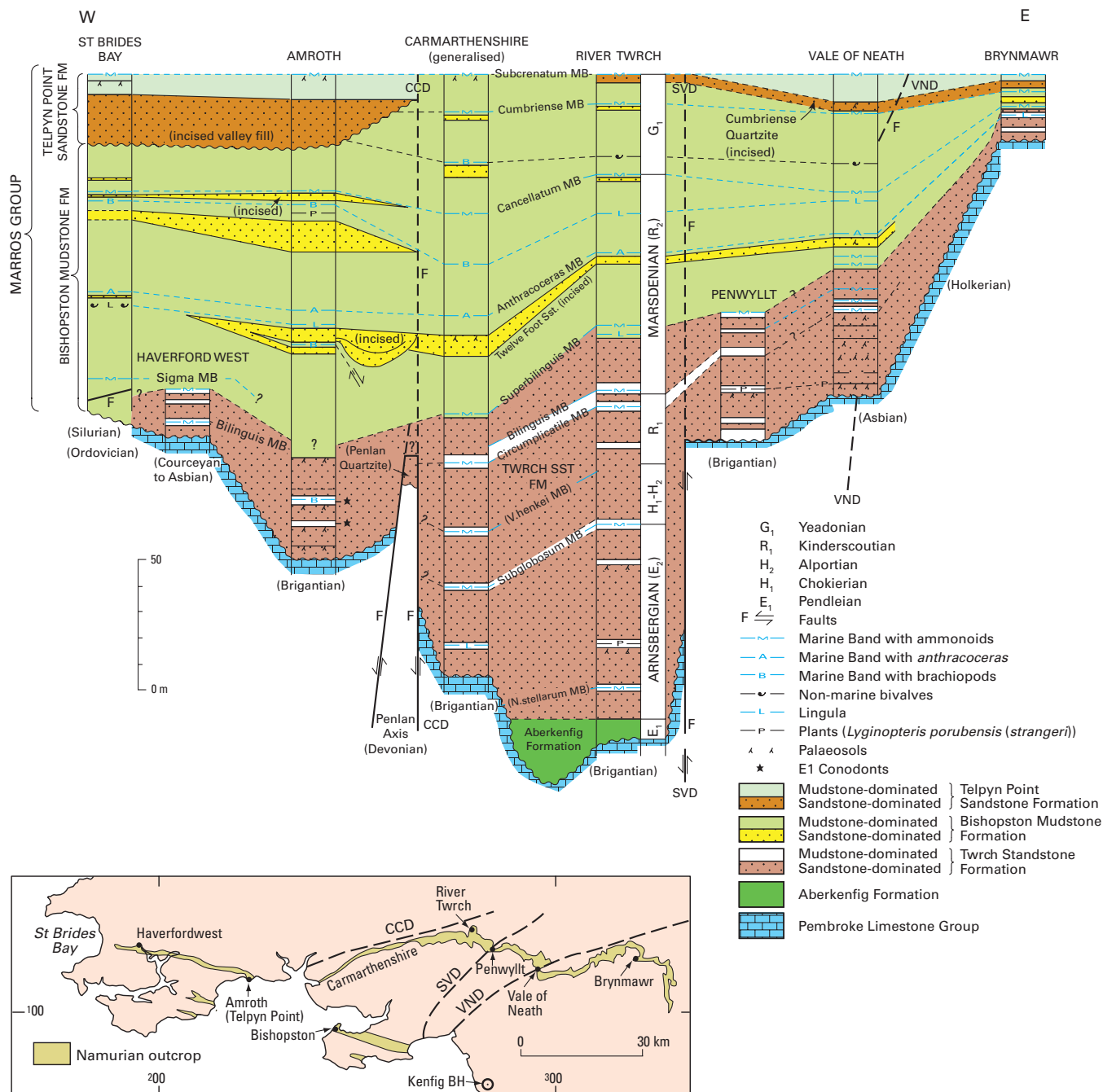


Figure 18 Namurian stratigraphy of the Marros Group in South Wales (after George, 2000).

Lower and upper boundaries

The base is taken at the base of thick, dark grey fossiliferous mudstones, where they conformably overlie cherts and dark grey fissile mudstones of the underlying Aberkenfig Formation in the type area. Elsewhere, the base is placed at the base of thick grey, sporadically fossiliferous mudstones which disconformably overlie quartzites of the Twrch Sandstone Formation.

The top is placed at the top of the highest dark grey mudstone, where it is disconformably overlain by pale grey quartzitic sandstones of the Telpyn Sandstone Formation.

Thickness

Up to about 750 m in the type area of Barland Common, Bishopston.

Distribution

The formation crops out in a narrow belt around the periphery of the South Wales Coalfield and its extension in Pembrokeshire. The outcrop around the main coalfield extends from near Kidwelly [SN 360 050] on the north crop east/north-east to near Brynmawr [SO 20 11] and south to near Caerphilly [ST 20 86] and west to Swansea Bay [SS 79 84]; in Gower from Bishopston to Mumbles; and in the Pembroke Peninsula from Druidston [SM 860 169] to Marros [SN 198 076]; and on the southern limb of the syncline from Tenby [SN 135 010] north-west to near the Cleddau River [c.SN 012 085].

Genetic interpretation

Mudstones of delta plain and pro-delta marine origin with sporadic, minor sandstones.

Biostratigraphical characterisation

The base can be taken at the base of the Bilinguites super-bilinguis Marine Band over most of the area between Pembrokeshire and Merthyr Tydfil district (George, 1970, figure 24; Barclay et al., 1988). To the north-east, the base of the formation occurs at the base of the Cancelloceras cumbriense Marine Band over most of the Abergavenny district (Barclay, 1989). An older age for the formation is estimated from the Gower, where the Twrch Sandstone Formation is absent.

Age

Pendleian to Yeadonian

5.3.4 Telpyn Point Sandstone Formation (TELPP)

Name

The unit has been referred to as the Farewell Rock (Ware, 1939; Archer, 1965; Hampson, 1998) and Upper Sandstone Group (George, 1982, 2001). Because of the confusion of several different 'Farewell Rocks' (two above the Subcrenatum Marine Band in the east of the coalfield, and this one below it), the term has been discarded. The Telpyn Point Sandstone Formation is a new term, defined here for the first time.

Type section

Foreshore and cliff section at Telpyn Point, Pembrokeshire [SN 186 074]: all but the very topmost beds immediately below the Subcrenatum Marine Band are exposed and comprise 8.7 m of silty mudstones and striped beds above 19.0 m of fine-grained quartzitic sandstone (Archer, 1965; George, 1982, 2000).

Reference section

Foreshore exposures at Settling Nose, Pembrokeshire [SM 858 157], where 7.62 m of mudstones overlie 21.33 m of quartzitic sandstone (Archer, 1965).

Lithology

Fluvial, fine- to coarse-grained, locally pebbly and conglomeratic, pale grey, quartzitic sandstones with thin argillaceous mudstone/siltstone and seatearth interbeds; sporadic impersistent, thin coals in the argillaceous beds.

Lower and upper boundaries

The base is placed at the base of the lowermost quartzite of the formation, where it overlies a sharp surface or erosion surface cut in the underlying mudstones of the Bishopston Mudstone Formation. At the type section at Telpyn Point, the boundary is placed at the base of a fine-grained quartzitic sandstone at 27.66 m (90 feet 9 inches) below the top of the section measured by Archer (1965).

The top is placed at the top of the highest quartzitic sandstone of the formation, immediately or close below the base of the dark grey fossiliferous mudstones of the Subcrenatum Marine Band. Note that, for practical mapping purposes, any development of thin non-marine beds between the top of the highest quartzite and the base of the Subcrenatum Marine band are included in the Telpyn Point Sandstone Formation. There are 8.7 m of these at Telpyn Point and 7.62 m at Settling Nose.

Thickness

Some 18.97 m at type section to 21.3 m at Settling Nose.

Distribution

Around the margins of the Pembrokeshire Coalfield, and on

the east crop of the main South Wales Coalfield, from the Clydach Valley south to Blaenserchan.

Genetic interpretation

Fluvial sandstones

Biostratigraphical characterisation

The Subcrenatum Marine Band, which marks the base of the Langsettian Stage, occurs immediately above the top of the formation.

Age

Kinderscoutian to Yeadonian

BRISTOL

The Marros Group (undifferentiated) in the Bristol area equates with 'Quartzitic Sandstone Formation' of Kellaway and Welch (1993). The oldest strata comprise 15 m of cherty mudstone and a marine fauna that includes fish fragments. This probable Pendleian succession is equivalent to the Aberkenfig Formation of South Wales. Although recognisable, this cherty mudstone was mapped as part of the Quartzitic Sandstone Formation (Kellaway and Welch 1993), despite the overlying quartzitic sandstones resting upon a marked unconformity that locally removes the chert- and limestone-bearing unit. It is recommended that future resurveys should distinguish a separate Aberkenfig Formation.

The pragmatic approach at present is to have an undifferentiated Marros Group in the Bristol region, retaining usage of the **Quartzitic Sandstone Formation**. A new name is required for the predominantly quartzitic sandstone succession, though it was felt that no members of the SFC Committee had sufficient experience to propose a new name. If and when new mapping provides sufficient information, the chert- and limestone-bearing unit may be isolated as a formation, possibly as the Aberkenfig Formation or a locally named equivalent.

5.3.5 Quartzitic Sandstone Formation (QSG)

Name

The formation was defined by Kellaway and Welch (1955, 1993) in the Bristol district.

Type sections

The BGS Ashton Park Borehole (ST57SE/73), Ashton Court Estate next to A370 behind the Smith Arms [ST 5633 7146]; from 1315 ft 2 in (400.8 m) to 708 ft 6 in (215.9 m) (Kellaway, 1967).

Lithology

The formation comprises grey mudstones and seatearths with thin carbonaceous or coaly beds and a preponderance of hard, pale grey quartzitic sandstone, sometimes pebbly, within the middle of the sequence. The sandstones have erosive bases and are commonly conglomeratic with pebbles of white quartz, chert and ironstone. The mudstones include marine bands with *Lingula*.

Lower and upper boundaries

The base is defined as the incoming of mudstones and sandstones above the carbonates of the Oxwich Head Limestone Formation.

The top is taken at the base of the *Gastrioceras* subcrenatum (Ashton Vale) Marine Band.

Thickness

The formation thins southward; in the northern part of the Bristol coalfield the formation may be 300 m thick, whereas in the southern part of the Mendips it is only about 53 m thick. The formation is 185 m thick at the type locality.

Distribution

Bristol area (Wells–Bath–Bristol–Wickwar).

Genetic interpretation

The succession is dominantly fluviodeltaic comprising mainly lacustrine muds, with brackish influence indicated by rare *Lingula*, distributary sand bodies, and emergence indicated by the development of seatearths and coals in poorly drained mires.

Biostratigraphical characterisation

The Subcrenatum Marine Band, which marks the base of the Langsettian Stage, occurs immediately above the top of the formation.

Age

Pendleian to Yeadonian

CANNINGTON PARK, SOMERSET

Three small inliers of Namurian strata occur to the north-west of Cannington [ST 23 39; ST 25 40 and 24 41] (Figure 3). The succession is referred to as the **Rodway Siltstone Formation**. This succession was deposited above the southerly margin of the South Wales–Bristol carbonate platform. Typical turbidite-dominated strata of Namurian age deposited within the Culm Basin outcrop some 30 km to the south-west of the Cannington Park inliers.

5.3.6 Rodway Siltstone Formation (RSI)

Name

The term Rodway Beds (Whittaker, 1975) and Rodway Siltstones (Edmonds and Williams, 1985) is here formally redefined as a formation.

Type section

The Withiel Farm No.1 Borehole (ST23NW/6), near Cannington, Bridgwater [ST 2435 3981] proves the thickest development of the formation from ground surface to 138.2 m depth and records the base.

Lithology

Dark grey, locally red, purple and green stained, micaceous siltstone with subordinate thin beds of pale grey or purple-stained, fine- to medium-grained, locally bioturbated sandstone. Near the base, there are small-scale rhythmic cycles of sandstone, siltstone and black shale.

Lower and upper boundaries

At the type locality the base of the formation is faulted against medium to pale grey ooidal limestone of the Pembroke Limestone Group. A non-tectonised base of the formation has not been recorded at crop or in boreholes, suggesting that the formation was displaced to its current location above a low-angle lag fault (Whittaker, 1975).

The grey siltstone of the Rodway Siltstone Formation is unconformably overlain by red, yellow and buff mottled, fine- to medium-grained sandstone of the Otter Sandstone Formation (Sherwood Sandstone Group).

Thickness

More than 138 m at the type locality.

Distribution

The outcrop is restricted to the Rodway inlier [ST 244 398] and Swang Farm inlier [ST 231 392], located north-west of Cannington, Somerset. The formation is also proved in boreholes to occur beneath the Sherwood Sandstone and Mercia Mudstone groups within the vicinity of the inliers.

Regional correlation

The formation occurs within an intermediate location between Yeadonian mudstones and sandstones of the Quartzitic Sandstone Formation (Bristol region) and the turbiditic sandstones of the Crackington Formation (Culm Basin).

Genetic interpretation

Shallow marine siliciclastic deposits lacking turbidites typical of the Culm Supergroup present to the south (Edmonds and Williams, 1985).

Biostratigraphical characterisation

The *Cancelloceras cancellatum* Marine Band was recorded in the Withiel Farm No.1 Borehole 5.75 m above the base of the formation (Whittaker, 1975).

Age

Marsdenian to Yeadonian

5.4 SOUTH WALES COAL MEASURES GROUP (SWCM)

Coal Measures Group is applied to the grey (productive) measures, in accordance with its use in the Pennine Basin (Powell et al., 2000a). The epithet of ‘South Wales’ is used to distinguish these Coal Measures from those present in the Pennine Basin and Midland Valley. Three component formations are recognised with the same name and bounding marine bands as for the Pennine Coal Measures Group. The main lithologies present within the succession south of the Wales–Brabant High are equivalent to those described fully for the Pennine Coal Measures Group. The Lower, Middle and Upper Coal Measures formations may also have the epithet of ‘South Wales’ if it is helpful to distinguish these formations from those developed within the Pennine Basin. These formations are discussed for South Wales, the Bristol region and the sub-surface Berkshire and Kent coalfields (Figures 19 and 20). The South Wales Coal Measures Group is absent in the Forest of Dean and Oxfordshire coalfields.

SOUTH WALES

The South Wales Coal Measures Group is thickest in the west and south-west of the coalfield (about 900 m in the Swansea area) and attenuated in the East Crop (about 240 m), adjacent to the active Usk Anticline (Figure 19). The succession is predominantly argillaceous, with widespread sandstones being rare. The group is mainly Langsettian to Bolsovian in age, locally extending into Asturian age in the eastern part of the coalfield. The Pembrokeshire Coalfield is an attenuated westward extension of the main South Wales Coalfield (Thomas, 1974).

5.4.1 South Wales Lower Coal Measures Formation (SWLCM)

Name

Previously referred to as the Lower Coal Measures

(Stubblefield and Trotter, 1957), the unit is here formally redefined as a formation and given the epithet ‘South Wales’ to distinguish it from similar strata within the Pennine Basin of central and northern England and North Wales.

Type area

Type area is the South Wales Coalfield and its western extension in Pembrokeshire [SM 86 15], from where it extends eastwards to Abersychan, Monmouthshire [SO 29 02]. It extends from the Black Mountain [SN 670 215] in the north, southwards to the Swansea–Port Talbot area [SS8085] and crops out in a peripheral belt around the coalfield.

Type section

Stream exposures in the Cwm Gwrelych–Nant Llyn Fach area [SN 891 064 to SN 9010 0533]. The section extends south from near Pont Walby, 1 km east of Glyn Neath, West Glamorgan (Robertson, 1932; Cleal and Thomas, 1996; Evans et al., 2003.). The entire thickness of the formation (253 m), including base and top, is proved in the section.

Lithology

Grey coal-bearing mudstones/siltstones, with seatearths and minor sandstones. It shows two distinct lithological variations. Between the Subcrenatum Marine Band and Garw Coal (Figure 19), in a succession that equates with the *Lenisulcata* Biozone, coal seams are thin and impersistent, marine bands relatively common and there are several thick quartzitic sandstone beds collectively known as the Farewell Rock (Woodland et al., 1957b). There are some lenticular, coarse and pebbly sandstones on the East and South Crops. Between the Garw Coal and the Vanderbeckei Marine Band, the succession is dominated by thick coals and there are relatively few marine bands.

Lower and upper boundaries

Typically, the base is taken at the base of the Subcrenatum Marine Band (Stubblefield and Trotter, 1957); a conformable surface where topmost mudstones or sandstones of the Marros Group are overlain by fossiliferous grey mudstones of the Subcrenatum Marine Band. The formation rests unconformably upon Tournaisian Avon Group, Viséan Pembroke Limestone Group or Devonian strata in the Berkshire and Kent coalfields.

The top is taken at the base of Vanderbeckei (Amman) Marine Band (Stubblefield and Trotter, 1957), where basal fossiliferous marine mudstone of the marine band overlies the sharp top of the Amman Rider Coal (and its equivalents).

Thickness

From 80 m to about 300 m in the South Wales Coalfield, thickest in the Swansea area; from about 160 m in the Bristol district to 200 m thick in the Somerset Coalfield.

Distribution

South Wales Coalfield, Bristol and Somerset coalfields at outcrop and Berkshire and Kent coalfields in subcrop. The formation is absent in the Forest of Dean and Newent coalfields.

Genetic interpretation

Sandstones mainly present in the lower part of the formation represent mainly southward-prograding delta lobes, or fluvial sands with channelled bases. Some lenticular, coarse and pebbly sandstones on the East and South Crops formed as littoral or sub-littoral sandbodies (Kelling and Collinson, 1992).

Biostratigraphical characterisation

The presence of the Subcrenatum Marine Band at the base and the Vanderbeckei Marine Band immediately overlying the formation, constrains the succession to a Langsettian age.

Age

Langsettian

5.4.2 South Wales Middle Coal Measures Formation (SWMCM)

Name

Previously referred to as the Middle Coal Measures (Stubblefield and Trotter, 1957), the unit is here formally redefined as a formation and given the epithet ‘South Wales’ to distinguish it from similar strata within the Pennine Basin of central and northern England and North Wales.

Type area

The type area is the South Wales Coalfield. The formation crops out in a peripheral belt around the coalfield, extending from south of Little Haven, Pembrokeshire in the west to near Pontypool in the east; and from near Llandybie [SN 610 149] in the north to the Swansea–Port Talbot area [approx. SS780 840] in the south.

Reference section

Stream exposures in the Cwm Gwrelych–Nant Llyn Fach area [SN 9010 0533 to SN 9023 0502], about 1 km east of Glyn Neath, West Glamorgan; from the base of the Vanderbeckei Marine Band [SN 9010 0533] for about 300 m upstream, exposing the basal part of the formation (Cleal and Thomas, 1996; Evans et al., 2003.).

Lithology

Grey coal-bearing mudstones/siltstones with seatearths and minor sandstones. Thick, extensive coal seams, seatearths and numerous ironstone bands are common (Woodland et al., 1957b). A minor component of sandstone is present in the north-east of the main South Wales Coalfield. The formation maintains broad lithological similarities with the upper part of the South Wales Lower Coal Measures Formation. In the Bristol Coalfields the formation includes a number of worked coal seams that mainly occur below the Aegiranum Marine Band (Figure 20).

Lower and upper boundaries

The base is taken at the base of the Vanderbeckei (Amman) Marine Band (Stubblefield and Trotter, 1957), where grey marine fossiliferous mudstone of the marine band conformably overlies the Amman Rider Coal (or the local equivalent where the Amman Rider amalgamates with the underlying coals). In the stream exposures in the Cwm Gwrelych–Nant Llyn Fach area, the boundary [SN 9010 0533] lies at the top of a 0.18 m-thick coal, at the base of 0.10 m of grey mudstone with lingulids and fish fragments (the Vanderbeckei Marine Band).

The top is taken at the top of the Cambriense (Upper Cwmgorse) Marine Band (Stubblefield and Trotter, 1957), where grey marine fossiliferous mudstone at the top of the marine band is conformably overlain by non-marine mudstone marking the base of the South Wales Upper Coal Measures or by Pennant sandstones marking the base of the Pennant Sandstone Formation.

Thickness

In the South Wales Coalfield the formation ranges from about 120 m in the East Crop [SO 20] to 240 m in the

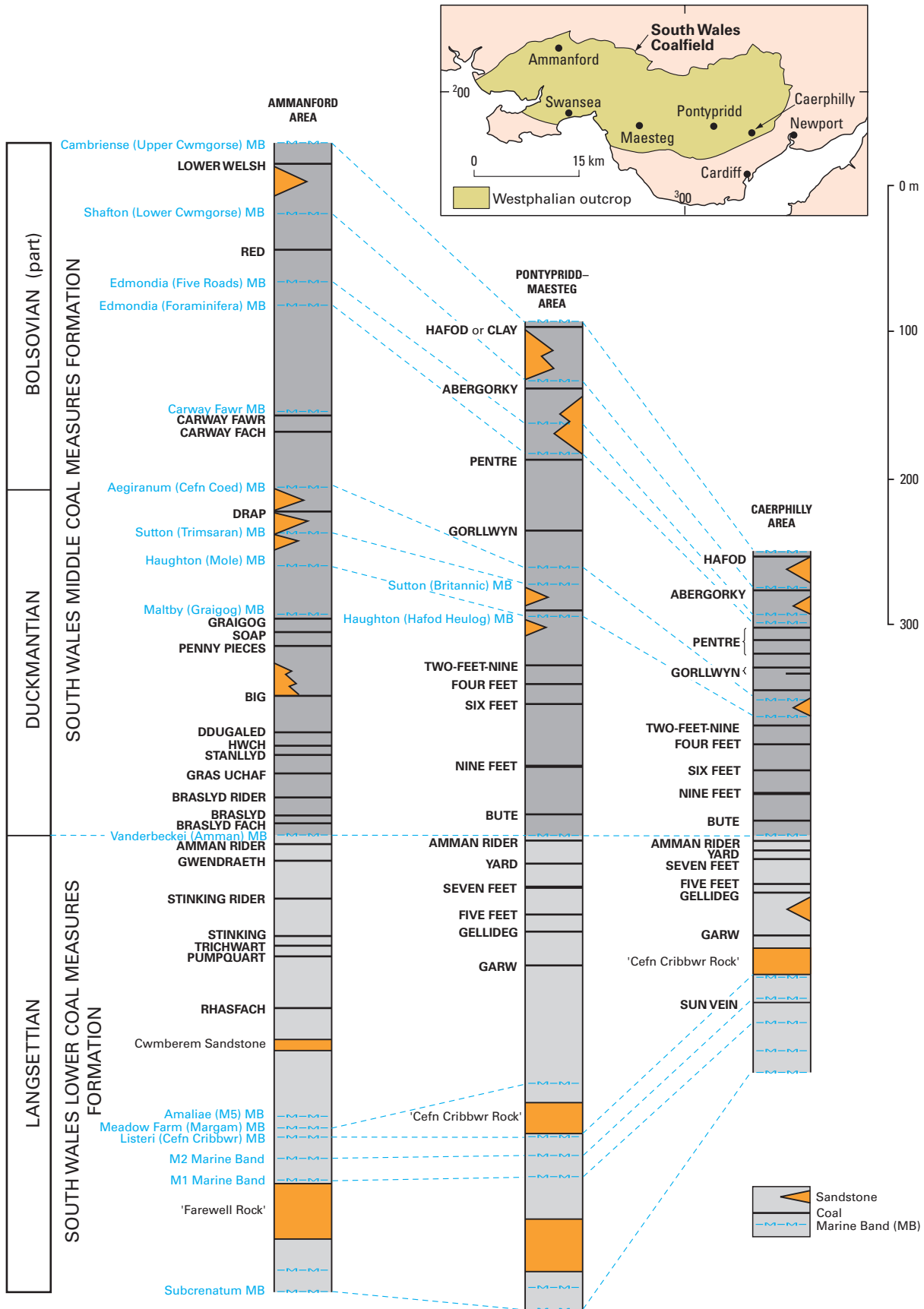


Figure 19 Generalised sections of the South Wales Coal Measures Group in the South Wales Coalfield (Thomas, 1974).

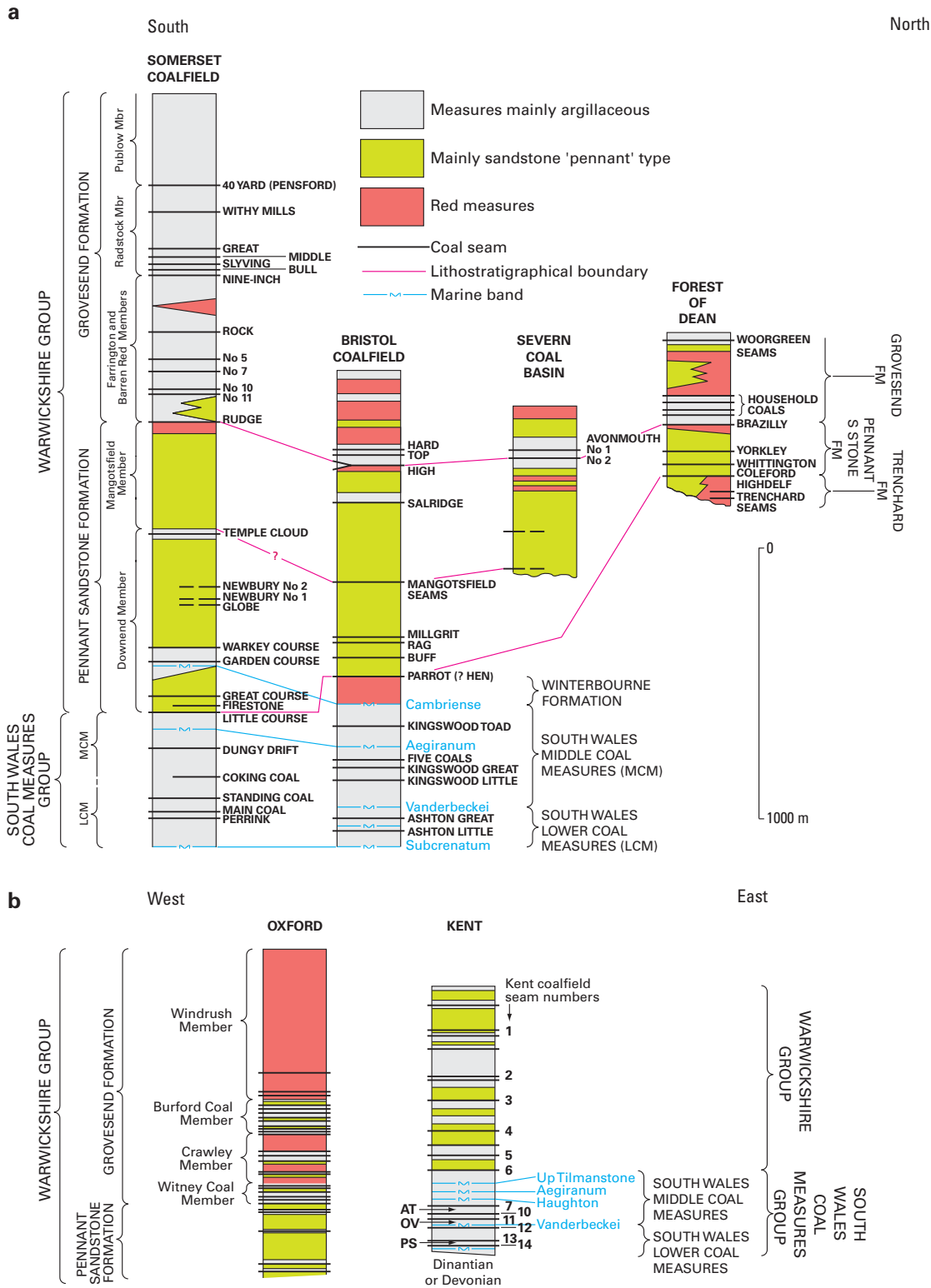


Figure 20 Generalised sections of the Warwickshire Group from the Somerset, Bristol, Severn and Forest of Dean coalfields (Green, 1992).

Swansea area; 375 m in the Somerset Coalfield and up to 419 m in the Bristol Coalfield.

Distribution

South Wales Coalfield, Bristol and Somerset coalfields at outcrop and Berkshire and Kent coalfields in subcrop. The formation is absent in the Forest of Dean and Newent coalfields.

Genetic interpretation

Sandstone present in the north-east of the main coalfield developed as southward-prograding delta lobes. However, in the west and notably in the Pembrokeshire Coalfield, fluvio-deltaic sandbodies appear to be northward prograding (Kelling and Collinson, 1992).

Biostratigraphical characterisation

The presence of the Vanderbeckei Marine Band at the base

and the Cambriense Marine Band immediately overlying the formation, constrains the succession to a Duckmantian to Bolsovian age.

Age
Duckmantian to Bolsovian

5.4.3 South Wales Upper Coal Measures Formation (SWUCM)

Name

Historically, the Upper Coal Measures of South Wales has been used synonymously with Pennant Measures. The Pennant Sandstone Formation is now considered to be distinct from the South Wales Coal Measures Group. The South Wales Upper Coal Measures Formation no longer equates with Pennant Measures, but is restricted to the grey measures above the Cambriense (Upper Cwmgorse) Marine Band. The grey facies formerly ascribed to the Llynfi Beds and Rhondda Beds in the east of the South Wales Coalfield (Woodland et al., 1957b) should be reclassified as South Wales Upper Coal Measures Formation.

Reference section

Margam Park No.3 Borehole (SS88NW/13) [SS 8162 8730], near Margam, Port Talbot, South Wales, provides a reference section in which the top of the formation is at 619 ft 4 in (188.77 m) and the base at 706 ft 3 in (215.26 m) depth (Woodland and Evans, 1964).

Lithology

Grey (productive) coal-bearing mudstones/siltstones with seatearths and minor grey, quartz-rich sandstones, coals and ironstones.

Lower and upper boundaries

The base of the formation is placed at the top of the Cambriense (Upper Cwmgorse) Marine Band. Medium-grey mudstones or siltstones conformably overlie darker grey, fossiliferous mudstones of the Cambriense Marine Band, which mark the top of the underlying South Wales Middle Coal Measures (Stubblefield and Trotter, 1957).

The top of the formation is placed at the incoming of the first thick (over about 3 m) lithic arenite ('Pennant Sandstone'), where the arenite rests conformably but diachronously on grey mudstones/siltstones at the top of the South Wales Upper Coal Measures Formation. On the east crop of the coalfield, the top is placed at the diachronous incoming of red/green mottled mudstones which mark the base of the Deri Formation, of Bolsovian to Asturian age (see Section 5.5.1).

Thickness

Up to a maximum of 184 m south-west of Ammanford [SN 58 09].

Distribution

Widespread throughout the South Wales Coalfield, from the Twyi estuary [SN 38 01] west of Pembrey east to the Rhymney area [SO 120 058] on the north crop of the coalfield and to Risca [ST 24 92] on the south crop.

Regional correlation

The formation passes laterally into the Llynfi Member of the Pennant Sandstone Formation in South Wales.

Genetic interpretation

Fluvio-lacustrine deposits

Biostratigraphical characterisation

The base of the formation is placed at the top of the Cambriense Marine Band of Bolsovian age.

Age
Bolsovian

BRISTOL

Variscan (late Carboniferous–early Permian) deformation has isolated previously contiguous Coal Measures strata into a number of distinct areas or 'basins' in the Bristol–Somerset area. The Bristol Coalfield includes the Kingswood Anticline and Coalpit Heath Syncline to the east and north-east of Bristol, while the Somerset Coalfield comprises the Pensford and Radstock synclines to the south-east. The Avonmouth and Nailsea synclines contain coal basins that are structurally distinct, although linked to the major coalfields in the subsurface. In the Bristol and Somerset areas about 73 per cent of the coalfields are concealed beneath Mesozoic strata. In the Bristol region the South Wales Coal Measures Group is subdivided into **South Wales Lower and Middle Coal Measures formations** of Langsetian to Bolsovian age (Figure 20) and detailed in sections 5.4.1.1 and 5.4.1.2.

The Cambriense Marine Band and overlying Upper Coal Measures Formation have not been recognised in the Bristol region, and the mapped base of the Pennant Sandstone Group is taken as the approximate top of the South Wales Middle Coal Measures Formation.

BERKSHIRE COALFIELD

In the Berkshire Coalfield the Foudry Bridge Borehole (SU76NW58) [SU 7063 6602] shows a succession, from 813.69 to 675.5 m depth, of siltstone and mudstone with coals, seatearths and thin sandstones and a marine band that yielded a fauna including *Lingula mytilloides* and foraminifera including *Ammodiscus*, considered to indicate a late Langsetian age (Foster et al., 1989). Higher in the succession, the miospores *Dictyotriletes bireticulatus*, *Densosporites* spp. and *Laevigatosporites* spp. suggest the strata range from the base of the *Communis* Biozone to the top of the Duckmantian Stage (Foster et al., 1989). The absence of the marine band with the definitive ammonoid *Anthracoceratites vanderbeckei* precludes subdivision of the South Wales Coal Measures Group into the South Wales Lower and Middle Coal Measures formations.

The Aston Tirrold Borehole (SU58NE42) [SU 5579 8722] includes a succession of basic volcanic rocks (olivine basalts and dolerites) intruded by dolerite sills. This unnamed volcanic succession includes sedimentary intercalations and a coal seam near the base, which include palynomorphs indicative of the SS Miospore Zone (early Langsetian) (Foster et al., 1989). This volcanic unit is probably a local equivalent of the South Wales Lower and Middle Coal Measures formations.

KENT

The **South Wales Coal Measures Group** is up to 285 m thick in the concealed Kent Coalfield. Both The **South Wales Lower, Middle and Upper Coal Measures formations** are predominantly argillaceous, with rare and generally thin sandstone, several marine bands and coal seams, which show markedly variable thicknesses and seam splitting.

The Subcrenatum Marine Band is not recognised in the Kent Coalfield, nor have non-marine bivalves of the *Carbonicola lenisulcata* Zone been recorded (Stubblefield and Trueman, 1946). The South Wales Lower Coal Measures Formation is associated with non-marine bivalves of the *C. communis* Zone. The lowermost proven marine band is the Vanderbeckei (Ripple) Marine Band the Ripple Marine Band (Bisson et al., 1967). Above the marine band, non-marine bivalves of the *Anthraconaia modiolaris* Zone are recorded within the basal part of the South Wales Middle Coal Measures Formation, with the base of the Lower *similis-pulchra* Zone taken at the base of the Kent No.11 Seam (Bisson et al., 1967). The Houghton (Snowdown) Marine Band includes *Lingula mytilloides*, recorded about 14 m below the Aegiranum (Lower Tilmanstone) Marine Band (Stubblefield and Trueman, 1946; Bisson et al., 1967). Two marine bands with *Lingula mytilloides*, separated by about 30 m of strata, occur below the Kent No.6 Seam. Referred to as the Upper Tilmanstone Marine Bands, they are interpreted as the local representatives of the Cambriense Marine Band (Bisson et al., 1967). The South Wales Upper Coal Measures Formation, the base of which is taken at the top of the Cambriense Marine Band, is devoid of marine bands and includes strata of the *Anthraconauta phillipsii* Zone, with the top of the formation taken at the top of the Kent No.6 Seam.

5.5 WARWICKSHIRE GROUP (WAWK)

The **Warwickshire Group** was introduced in the Pennine Basin to replace terms such as the 'Barren (Coal) Measures' and 'Red Measures' for strata that overlie the Pennine Coal Measures Group (Powell et al., 2000a). In the Pennine Basin the group includes predominantly red-bed formations and a coal-bearing grey formation with Pennant-type sandstones, the Halesowen Formation (see section 4.10.2). South of the Wales–Brabant High similar red and grey measures are found, though grey, coal-bearing strata with Pennant-type sandstones predominate.

A geographically restricted barren red measures succession of late Bolsovian to possibly early Asturian (Westphalian D) age, is present above the Cambriense Marine Band in both the East Crop of the South Wales Coalfield (**Deri Formation**) and the Bristol Coalfield (**Winterbourne Formation**). A younger barren red measures succession, the **Trenchard Formation**, in the Forest of Dean, resting unconformably upon Viséan and older strata (Figure 20).

The red-bed succession, where present, is overlain conformably by the laterally extensive **Pennant Sandstone Formation**, in turn overlain by the **Grovesend Formation**.

SOUTH WALES

The succession comprises, in ascending order: the **Deri Formation** (limited to the East Crop), the **Pennant Sandstone Formation** and **Grovesend Formation**. The Pennant Sandstone Formation is subdivided into five members in South Wales, the **Llynfi**, **Rhondda**, **Brithdir**, **Hughes** and **Swansea members** (Figure 15), which replace the 'beds' of the same name. The members are bound by coal seams that are correlateable across the South Wales Coalfield. The bases of the former 'beds' have traditionally been taken at the bases of the correlateable coal seams. However, in order to ensure that the bases of group and formations are consistently defined, the base of each newly defined formation should be taken at the base of the sandstone (top of the coal seam).

It is important to note that the obsolete term of Lower and Upper Pennant Measures (Woodland et al., 1957b) was defined in South Wales as a chronostratigraphical term to distinguish Bolsovian and Asturian strata. These terms do not equate with the formations defined above as the base of the Asturian stage is approximately at the base of the Hughes Member of the Pennant Sandstone Formation.

5.5.1 Deri Formation (DER)

Name

Formerly known as the Deri Beds of Howell and Cox (1924), named after the village of Deri in the Bargoed Rhymney Valley, south Wales [SO 13 02] (Howell and Cox, 1924), the formation has little natural exposure. The formation was traditionally considered part of the 'Upper Coal Measures' and the 'Llynfi and Rhondda beds' were forced through the red-bed succession, despite the local absence of correlateable coal seams (Downing and Squirrell, 1965; Squirrell and Downing, 1969; Barclay, 1989).

Reference section

Former Ogilvie Colliery South Pit, Deri (SO10SW/9) [SO 1207 0294]: lower part of formation recorded from ground surface to 121.08 m depth (Barclay, 1989).

Lithology

Red, purple, green and orange mottled mudstones and mudstone palaeosols, pale green siltstones and pale grey quartz arenites and conglomerates. Thin coals progressively fail eastwards towards the Usk Anticline.

Lower and upper boundaries

The base is taken at the base of the first substantial development of red, green or purple mudstone, where it overlies grey mudstones of the South Wales Coal Measures Group. The base of the formation is diachronous, prograding westwards above the South Wales Upper Coal Measures Formation.

The top of the formation is diachronous and gradational, and placed where the topmost development of red, green or purple mudstone, or white quartz arenite, is overlain by either grey mudstones of the South Wales Coal Measures Group or, on the east crop of the South Wales Coalfield, where it is overlain by the Brithdir Coal, marking the local base of the Pennant Sandstone Formation.

Thickness

The formation thickens eastward towards the Usk Anticline with maximum thickness of 180 m.

Distribution

Confined to the eastern part of the South Wales Coalfield, extending from the Cynon Valley near Penrhiwceiber [ST 0597] eastwards (Downing and Squirrell, 1965, Figure 1).

Regional correlation

The formation passes westward into the Llynfi and Rhondda members of the Pennant Sandstone Formation. It is comparable to the Winterbourne Formation of the Bristol district (see Section 5.5.4).

Genetic interpretation

The raised topography associated with the active Usk Anticline enhancing drainage, resulting in a primary red-dened alluvial plain succession, and providing a local source for the conglomerate.

Age

Bolsovian to Asturian

5.5.2 Pennant Sandstone Formation (PES)

Name

The unit was named after the predominant Pennant sandstone facies of the South Wales Coalfield, previously referred to as Pennant Measures (Woodland et al., 1957a), Pennant Sandstone or Pennant Group in earlier schemes.

Type area

The formation crops out widely in the South Wales Coalfield, from near Llanelli [SN 40 00] in the west to near Pontypool [ST 25 03] in the east (Woodland et al., 1957b).

Reference section

The Earlswood road cutting [SS 730 944 to SS 730 946] and nearby Ferryboat Inn Quarry [SS 731 940] provide a well documented reference section of the Pennant Sandstone Formation, with more recent cuttings at the adjacent M4 interchange adding to the exposures [SS 728 942 to SS 728 948]: records about 170 m thickness of the Rhondda Member (Kelling, 1971; Cleal and Thomas, 1996).

Formal subdivisions

In South Wales the Pennant Sandstone Formation is subdivided into five members: the Llynfi, Rhondda, Brithdir, Hughes and Swansea members (Figure 15), which replace the 'beds' of the same name. In the Bristol and Somerset coalfields the formation is subdivided into two members, the Downend and Mangotsfield members, maintaining the use of existing names (Figure 20).

Lithology

Green-grey and blue-grey, feldspathic, micaceous, lithic arenites (Pennant-type sandstones) of southerly provenance and minor conglomerates, with thin mudstone/siltstone and seatearth interbeds and mainly thin coals. The lithologies are commonly arranged in fining-upwards channel-fill sequences.

Lower and upper boundaries

The base of the formation is markedly diachronous, placed at the base of the first thick (over approximately 3 m) sandstone of Pennant type (lithic arenite), occurring at younger levels towards the north. Generally sharp and non-gradational, the base overlies grey mudstones/siltstones of the South Wales Coal Measures Group. In the Swansea area of the south-west of the coalfield, in practice the base can be taken at, or just above, the top of the Cambriense Marine Band. In the eastern part of the South Wales Coalfield the base of the formation rises to the level of the Brithdir Coal (base of Brithdir Member). The base of the formation ranges from up to 180 m below the Cambriense Marine Band in the Somerset Coalfield, to 180 m above the same marine band in the Bristol Coalfield (Figure 20).

The top is taken at the base of the grey mudstone-dominated succession of the Grovesend Formation. This is taken at the base of Swansea Four-Foot/Mynyddislwyn seam above the massive 'Pennant' sandstones of the underlying Swansea Member. In the eastern part of the coalfield, the coal appears to lie at an unconformity, with the Swansea Member apparently absent and the coal resting on 'Pennant' sandstones of the Hughes Member.

Thickness

The formation is thickest, up to 1335 m, in the Swansea area [SS 73 94] of the south-west of the South Wales Coalfield, thinning both to the north and east. In the east of the South Wales Coalfield [SO 25 03] the formation is c.275 m thick. In the Somerset Coalfield the formation is in

excess of 1000 m, thinning northwards to about 700 m in the Bristol Coalfield.

Distribution

The formation extends across the South Wales, Bristol and Forest of Dean coalfields at outcrop and the subsurface Oxfordshire-Berkshire Coalfield. A distinct sandstone-dominated formation cannot be recognised within the subsurface Kent Coalfield.

Genetic interpretation

The sandstones formed in channels and floodplains within a broad alluvial tract, with low- to moderate-sinuosity rivers flowing northward from a rising Hercynian mountain belt to the south (Kelling and Collinson, 1992).

Age

Late Bolsovian to early Asturian age

5.5.2.1 LLYNFI MEMBER (LLFB)

Name

Previously defined as the Llynfi Beds (Woodland et al., 1957a), it is here redefined as a member.

Type area

Llynfi Valley area, near Tondu, South Wales [SS 896 850] (Woodland et al., 1957a).

Lithology

Green-grey and blue-grey, feldspathic, micaceous lithic arenites ('Pennant sandstones') with thin mudstone/siltstone and seatearth interbeds and mainly thin coals.

Lower and upper boundaries

The base is placed at the base of the lowermost thick (over about 3 m) bed of lithic arenite ('Pennant sandstone'), overlying the mudstone-dominated succession of the South Wales Coal Measures Group. The base lies immediately above the Cambriense (Upper Cwmgorse) Marine Band in south-west of the South Wales Coalfield basin. North-eastwards, the Pennant sandstone facies commences at a progressively higher level.

The top is taken at the base of the No.2 Rhondda Coal (Woodland et al., 1957b), overlain by lithic arenite and thin mudstones and siltstones which make up most of the Rhondda Member. The base of the coal rests on a mainly thin development of seatearth and mudstone at the top of the member, which overlie thick lithic arenites.

Thickness

Up to 420 m in the Swansea district.

Distribution

South Wales Coalfield

Age

Bolsovian

5.5.2.2 RHONDDA MEMBER (RA)

Name

Previously defined as the Rhondda Beds (Woodland et al., 1957a), it is here redefined as a member.

Type area

Type area Rhondda valleys, South Wales [SS 98 95] (Woodland et al., 1957a).

Reference section

Ty'n-y-bedw Quarry [SS 9690 9700], Treorchy, Rhondda

Valley, south Wales: exposes 44 m of massive and cross-bedded sandstones with several beds of siltstone and silty mudstone up to 3 m thick (Woodland and Evans, 1964). The base of the section lies 3–6 m above the No.2 Rhondda Coal.

Lithology

Green-grey lithic arenites ('Pennant sandstones') with thin mudstone/siltstone and seatearth interbeds and mainly thin coals.

Lower and upper boundaries

The base of the member is placed at the base of No.2 Rhondda Coal in the type area of the Rhondda valleys; the seam is named the Llwydcoed Seam in the Ammanford district and the Wernddu in the Swansea district. The coal rests conformably on lithic ('Pennant') sandstones and thin mudstone/siltstones of the underlying Llynfi Member.

The top is placed at the base of the Brithdir Coal, where the coal overlies thin mudstone/seatearth at the top of the member and is overlain by lithic ('Pennant') sandstone and thin siltstone/mudstone of the Brithdir Member.

Thickness

Up to 320 m in the Swansea–Port Talbot district [c.SS 775 940]

Distribution

South Wales Coalfield; on north crop from Burry Port [SN 42 02] to the Bargoed Taff Valley [SO 115 054] and on south crop from the Loughor estuary [SS 535 957] to Risca [ST 24 92].

Age

Bolsovian to Asturian

5.5.2.3 BRITHDIR MEMBER (BD)

Name

Previously defined as the Brithdir Beds (Woodland et al., 1957a), it is here redefined as a member.

Type area

No designated type area; named after the basal coal; extensive throughout the South Wales Coalfield [SS 545 960 to 268 990] (Woodland et al., 1957a).

Reference section

Craig-yr-Hesg Quarries, north of Pontypridd in the Taff Valley [ST 0790 9180]: quarry faces 40 m high expose massive, lithic ('Pennant') sandstones, with individual units over 4 m thick (Woodland and Evans, 1964).

Lithology

Green-grey lithic arenites ('Pennant sandstones') with thin mudstone/siltstone and seatearth interbeds and mainly thin coals.

Lower and upper boundaries

The base is placed at the base of the Brithdir Coal above 'Pennant' sandstones and thin mudstones/siltstones of the Rhondda Member or above red/green mudstones of the Deri Formation on the east crop of the coalfield.

The top is taken at the base of the Hughes (Cefn Glas) Coal, where the coal rests on the topmost 'Pennant' sandstones and thin mudstones/siltstones and is overlain by 'Pennant' sandstones of thin mudstones/siltstones of the Hughes Member.

Thickness

From 45 m in the Pontypool area [ST 268 990] to 200 m in the Swansea area [SS 660 945].

Distribution

Extensive throughout the South Wales Coalfield, from Pembrey [SN 42 02] east to Blaenavon [SO 230 085] and, on the south crop, from Gower [SS 545 960] to Pontypool [ST 268 990].

Age

Asturian

5.5.2.4 HUGHES MEMBER (H)

Name

Previously defined as the Hughes Beds (Woodland et al., 1957a), it is here redefined as a member.

Reference section

There is no designated type area, the member being named after the basal coal, the Hughes Seam of the Swansea–Gower area of the South Wales Coalfield (Woodland et al., 1957a). A reference section is provided by exposures in a disused mineral railway cutting at Tir-Evan-Llwyd [SS 765 951], south-east of Neath in which 7.6 m of 'Pennant' sandstone contains lenticular mudstone beds (Barclay and Stephens, in prep.).

Lithology

Green-grey lithic arenites ('Pennant sandstones') with thin mudstone/siltstone and seatearth interbeds and mainly thin coals.

Lower and upper boundaries

The base is placed at the base of the Hughes (Cefn Glas, Wenallt, Bettws Four-Feet, Ty-du etc) Coal, in a predominantly arenaceous sequence of the Pennant Sandstone Formation, underlain conformably by mudstone, siltstone and seatearth at the top of the Brithdir Member.

The top is taken at the base of the Golden (Swansea Three-Feet, Graigola) Coal, overlain conformably by sandstone and thin mudstone and siltstone of the Swansea Member. In the east of the coalfield, the top is placed at the base of the Mynyddislwyn Coal.

Thickness

From 45 m near Pontypool [SO 250 150] thickening westwards to 270 m near Swansea [SS 570 960].

Distribution

Widespread outcrop throughout the South Wales Coalfield, from Llanelli [SN 49 02] to near Pontypool [ST 268 980].

Age

Asturian

5.5.2.5 SWANSEA MEMBER (SW)

Name

Previously defined as the Swansea Beds (Woodland et al., 1957a), it is here redefined as a member.

Reference section

There is no designated stratotype, the member named from the Swansea district (Woodland et al., 1957a). Allt-y-fran Quarry [SN 5136 0143], Tyrfran, Llanelli, South Wales, provides a reference section in which 9.9 m of mudstones

and siltstones overlies 'Pennant' sandstones (Barclay and Stephens, in prep.).

Lithology

Green-grey lithic arenites ('Pennant sandstones') with thin mudstone/siltstone and seatearth interbeds and mainly thin coals.

Lower and upper boundaries

The base is placed at the base of the Golden (Swansea Three-Foot or Graigola) Coal (Woodland et al., 1957b), underlain conformably by sandstone and thin mudstone and siltstone of the Hughes Member.

The top is placed at the base of the Wernffraith Seam (correlated with the Mynyddislwyn Seam of the eastern part of the South Wales Coalfield) (Woodland et al., 1957b), overlain conformably by the mudstone-dominated succession of the Grovesend Formation.

Thickness

From 274 to 290 m

Distribution

Western part of the South Wales Coalfield, from Llanelli [SN 49 01] to the Neath area [around SS 75 97].

Age

Asturian

5.5.3 Grovesend Formation (GDB)

Name

Previously referred to as the Grovesend Beds in South Wales (Woodland et al., 1957a), the unit is here redefined as a formation. The formation is used to replace the term 'Supra-Pennant Measures' of the Somerset, Bristol (Kellaway and Welch, 1993) and Forest of Dean coalfields (Welch and Trotter, 1961).

Type area

Village of Grovesend [SN 593 005], 10 km north-west of Swansea, south Wales (Woodland et al., 1957a).

Reference section

Railway cutting at Penllergaer [SS 619 999 to SS 624 997]: exposes 22 m of mainly grey mudstones and siltstones with two coals (Loughor Seam, 0.5 m and Penyscallen Seam, 0.4 m). Fossiliferous mudstones with non-marine bivalves and estheriids lie in the roofs of the coals (Owen, 1971; Cleal and Thomas, 1996).

Formal subdivisions

In the Bristol and Oxfordshire–Berkshire coalfields the succession is associated with alternating thicknesses of coal-bearing grey measures and barren red measures, here defined as separate members. There are up to four members recognised in the Somerset and Bristol coalfields, the Farrington, Barren Red, Radstock and Publow members. In the Oxfordshire Coalfield the succession is subdivided into the Witney Coal, Crawley, Burford Coal, and Windrush members.

Lithology

Predominantly argillaceous, comprising mudstones and siltstones, with well-developed coals; the coals are not as thick or historically as economic to work as the coals of the underlying Pennant Sandstone Formation. There are subordinate, though locally thick, lithic sandstones of

Pennant-type. There are locally developed red beds in the type area.

Lower and upper boundaries

The base of the formation is defined as the base of the lowest coal seam above the sandstone-dominated succession of the Pennant Sandstone Formation. This is at the base of the laterally correlateable Rudge Coal in the Radstock part of the Somerset Coalfield, the High Coal of the Bristol Coalfield and Avonmouth No. 1 Coal of the Severn Coal Basin (Figure 20). In the South Wales Coalfield the base is generally taken at the base of the Swansea Four-Foot of the Swansea district (equivalent to the Llantwit No.3 Seam in the Pontypridd district and the Mynyddislwyn Seam of east of the Taff valley), where it overlies mudstone seatearth at the top of the predominantly arenaceous Swansea Member in the Swansea district and the similar Hughes Member in the east of the coalfield. It is a conformable boundary in the west, but is assumed to be an unconformable one in the east (Woodland et al., 1957b; Squirrell and Downing, 1964; Barclay, 1989).

The Grovesend Formation is the youngest unit found in the South Wales and Forest of Dean coalfields. The formation is overlain unconformably by Triassic strata, including sandstones of the Sherwood Sandstone Group in the Newent Coalfield, by mudstones of the Mercia Mudstone Group in the Oxfordshire Coalfield and either the Sherwood Sandstone or Mercia Mudstone groups in the Bristol/Somerset coalfields.

Thickness

The thickest development of the formation is within Oxfordshire–Berkshire coalfields, where there is up to 700 m. In the South Wales Coalfield the formation is up to 426 m thick.

Distribution

Small areas in the South Wales Coalfield, the formation being preserved in the cores of synclines and fault troughs from Llanelli [SN 50 00] to Llanhilleth [SO 25 05], also Somerset, Bristol, Forest of Dean and Oxfordshire coalfields. A distinct mudstone-dominated formation cannot be recognised within the subsurface Kent Coalfield.

Genetic interpretation

The formation was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment. Periods of improved drainage are associated with oxidation and development of primary red beds.

Biostratigraphical characterisation

The formation ranges from Asturian to possibly Cantabrian (early Stephanian) in age (Ramsbottom et al., 1978).

Age

Asturian

BRISTOL

In the Bristol Coalfield, the succession between the Cambriense Marine Band and the base of the Pennant Sandstone Formation (Figure 18) is defined here as the **Winterbourne Formation**.

The **Pennant Sandstone Formation** is described in detail in Section 5.5.1.2. Red measures, which include red sandstone and conglomerate associated with nearby uplift and erosion of the Usk Anticline also occurs. The formation is subdivided into two members, the **Downend** and

Mangotsfield members, maintaining the use of existing names (Figure 20).

The **Grovesend Formation**, described in detail in Section 5.5.1.8., is present in the Somerset, Bristol and Severn coalfields and comprises grey and red mudstone-dominated successions of Asturian age. Four members are recognised, the **Farrington, Barren Red, Radstock and Publow members** (Figure 20).

5.5.4 Winterbourne Formation (WINT)

Name

In the Bristol Coalfield, the succession between the Cambriense Marine Band and the base of the Pennant Sandstone Formation (Figure 20), formerly described as the lower part of the Downend Formation (Kellaway and Welch, 1993), is here defined here as the Winterbourne Formation. The new name is proposed because of the revision of the definition of the Pennant Sandstone Formation from a chronostratigraphical unit, with a base taken at the top of the Cambriense Marine Band, to a lithostratigraphical unit with the base defined at the base of the lowermost mapped sandstone of 'Pennant' type. As a consequence the base of the Pennant Sandstone Formation (and the redefined Downend Member) occurs some distance above the Cambriense Marine Band.

Type section

Harry Stoke C (Downend) Borehole (ST67NE/1): entire thickness of formation from 485.0 m to 317.1 m (Kellaway and Welch, 1993).

Lithology

Grey and red mudstone with common thin and lenticular beds of quartz-conglomerate and pebbly sandstone.

Lower and upper boundaries

The base of the formation is taken at the top of the dark grey to black fissile mudstone of the Cambriense Marine Band, overlain by grey and red mudstone, locally conglomerate and pebbly sandstone, of the Winterbourne Formation.

The grey and red mudstone, locally conglomerate and pebbly sandstone, of the Winterbourne Formation is overlain with a sharp, slightly erosive base, by the first lithic sandstone of 'Pennant' type of the Downend Member.

Thickness

Up to 180 m

Distribution

Northern limb of Kingswood Anticline and Coalpit Heath Basin of Bristol Coalfield [ST 70 80].

Regional correlation

Interpreted as an equivalent of the Deri Formation.

Genetic interpretation

The formation developed to the east of the active Usk Anticline. The raised topography associated with the active Usk Anticline enhancing drainage, resulting in a primary reddened alluvial plain succession, and providing a local source for the conglomerate.

Biostratigraphical characterisation

The position of the formation immediately above the Cambriense Marine Band and the presence on the non-

marine bivalve *Anthraconauta phillipsii* indicate a late Bolsovian (*A. phillipsii* Biozone) age.

Age

Bolsovian

5.5.5 Pennant Sandstone Formation (PES)

(see Section 5.5.2 for details).

5.5.5.1 DOWNEND MEMBER (DN)

Name

Initially defined as a group (Kellaway, 1969) and subsequently defined as a formation (Kellaway and Welch, 1993), the base was originally taken at the base of the Cambriense (Winterbourne) Marine Band and included strata here redefined as the Winterbourne Formation. The unit is here redefined as a member with the base redefined to the basal of the lowermost Pennant-type sandstone.

Type area

Downend, Avon [ST 65 77]

Reference sections

The sandstone quarry at Frenchay Bridge [ST 639 771]: about 30 m of massive sandstone (Kellaway and Welch, 1993).

Harry Stoke C (Downend) borehole (ST67NE/1) [ST 6504 7677] from 317.1 m to 10.4 m (Kellaway and Welch, 1993).

Lithology

Sandstone with some conglomerate and pebbly sandstone and sporadic fissile mudstone beds. Some workable coal seams are also present. Sandstone is typically a coarse-grained lithic arenite of 'Pennant' type.

Lower and upper boundaries

Base is taken at the base of the lowest mappable lithic sandstone of 'Pennant' type above the grey and red mudstone-dominated succession of the Winterbourne Formation. The base is diachronous; in the Somerset Coalfield the base of the member occurs between the Aegiranum and Cambriense marine bands, whereas in the Bristol Coalfield it occurs above the Cambriense Marine Band.

The top of the Downend Member is defined, using the criteria described for the Pennant Sandstone Formation of South Wales, at the top of the Mangotsfield Coal and associated thin fissile mudstone. Overlain by the sandstone-dominated succession of the Mangotsfield Member (Figure 20).

Thickness

About 120 m thick in the northern part of the Bristol Coalfield [ST 78], broadly thickening southward to about 660 m in the Somerset Coalfield [ST 75]. About 275 m in the type area.

Distribution

Bristol and Somerset coalfields

Genetic interpretation

The sandstones formed in channels and floodplains within a broad alluvial tract.

Biostratigraphical characterisation

The lower part of the member is Bolsovian in age. This is constrained in the Somerset Coalfield with the base of the member occurring between the Aegiranum and Cambriense marine bands, whereas in the Bristol Coalfield

it occurs above the Cambriense Marine Band. At Bickley Wood [ST 644 703] plant fossils have been interpreted as indicating a lower or middle Asturian age (Cleal and Thomas, 1996).

Age

Bolsovian to Asturian

5.5.5.2 MANGOTSFIELD MEMBER (MGF)

Name

Initially defined as a group (Kellaway, 1969) and subsequently defined as a formation (Kellaway and Welch, 1993), the unit is here redefined as a member.

Type section

Winterbourne railway cutting, Avon [ST 651 799]: 200 m thick succession (Cleal and Thomas, 1996).

Type area

Mangotsfield, Avon [ST 65 77]: parts of the member are exposed along the River Frome and quarries between Frenchay [ST 641 772] and Hambrook [ST 645 788].

Lithology

Predominantly cross-bedded, lithic arenite, 'Pennant' sandstone in the lower part, and an upper part with thick grey shale beds interbedded with sandstone and sparse coal seams (Kellaway and Welch, 1993). The sandstone weathers to a distinctive red to purple colour.

Lower and upper boundaries

The base is taken at the base of the lowermost lithic arenite 'Pennant' sandstone of the Mangotsfield Member, resting sharply upon the Mangotsfield Coal, present at the top of the Downend Member.

The top is taken at the top of the Rudge Vein Coal in the Somerset Coalfield; top of the High Vein Coal in the Bristol Coalfield; top of the Avonmouth No.2 Coal in the Severn Coalfield. Overlain by grey mudstone of the Farrington Member.

Thickness

Up to about 580 m at Iron Acton [ST 67 84] to Engine Common [ST 70 84]; 450 m proved in the type area.

Distribution

Bristol, Somerset and Severn coalfields

Genetic interpretation

The sandstones formed in channels and floodplains within a broad alluvial tract, with palaeocurrents toward the north and north-west (Cleal and Thomas, 1996).

Biostratigraphical characterisation

A poor record of *Alethopteris serlii* Subzone macroflora is listed by Cleal (1997) suggesting a late Bolsovian age.

Age

Bolsovian

5.5.6 Grovesend Formation (GDB)

(see Section 5.5.3 for details)

The component members have been distinguished as either grey, coal-bearing successions or red successions lacking coal. For the coal-bearing members, the base and top of the members are defined, respectively, at the base of the lowermost coal and top of the uppermost coal. By definition,

for the barren members, their base occurs at the top of the uppermost coal of the underlying member.

5.5.6.1 FARRINGTON MEMBER (FRF)

Name

Initially defined as the Farrington Group (Kellaway, 1969) and subsequently defined as a formation (Kellaway and Welch, 1993), the unit is here redefined as a member.

Type area

Farrington Gurney [ST 63 55], Somerset Coalfield.

Reference section

Old Mills Colliery, underground borehole (ST65NE15) [ST 6516 5516]: from top of the Rudge Vein Coal at 261.9 m below OD to 250.5 m below OD.

Lithology

Grey mudstone with subordinate sandstone (lithic arenite) beds and numerous thin coal seams associated with comparatively thick seatearth clays.

Lower and upper boundaries

The base of the member is taken at the top of the Rudge Vein Coal in the Somerset Coalfield; top of the High Vein Coal in the Bristol Coalfield; top of the Avonmouth No.2 Coal in the Severn Coalfield. Underlain by sandstones of the Mangotsfield Member.

The top is taken at the top of the uppermost coal seam of the Farrington Member, overlain conformably by red and grey measures of the 'Barren Red Member'.

Thickness

Thickest (up to 425 m) in the Radstock part of the Somerset Coalfield and thins northward to less than 60 m in the Bristol Coalfield (Kellaway and Welch, 1993).

Distribution

Bristol, Somerset and Severn coalfields.

Regional correlation

The member is partly coeval with the Barren Red Member. This member is suggested to be equivalent to the Witney Coal Member of the Oxfordshire-Berkshire Coalfield (Poole, 1969).

Genetic interpretation

The member was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment.

Biostratigraphical characterisation

The member contains macroflora typical of the *D. plueckenetii* Subzone, indicating a late Asturian age (Cleal, 1997).

Age

Asturian

5.5.6.2 BARREN RED MEMBER (BRR)

Name

The Barren Red Member was loosely defined as barren red measures in the Radstock Syncline (Green, 1992). However, (Kellaway and Welch, 1993) gave a broader definition, preferred here, of red and grey measures lacking workable coals. It is proposed that use of the term 'Barren Red Member' should be replaced with a name conforming to standard lithostratigraphical procedure, based upon an as yet undefined type section.

Reference section

Hursley Hill Borehole (ST66NW2) [ST 6180 6565]: from base of hole at 731.5 m to top of member at 585.4 m.

Lithology

Red and grey mottled mudstone, seatearth, 'Pennant' type lithic sandstones, but no coal seams.

Lower and upper boundaries

The base of the member is defined as the top of the uppermost coal seam of the Farrington Member, dominated by grey mudstone and subordinate sandstone. This coal may change between coalfields (Figure 20), overcoming difficulties which exist in correlating seams.

The top is taken at the base of the Nine-Inch Vein Coal of the grey mudstone-dominated Radstock Member in the Somerset Coalfield. The top of the member is not seen elsewhere.

Thickness

Up to 230 m thick in the Radstock Syncline and 275 m thick in the Coalpit Heath Syncline.

Distribution

Bristol, Somerset and Severn coalfields.

Regional correlation

The member is partly coeval with the Farrington Member.

Genetic interpretation

The member was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment. Periods of improved drainage are associated with oxidation and development of primary red beds.

Age

Asturian

5.5.6.3 RADSTOCK MEMBER (RAD)

Name

Initially defined as a group (Kellaway, 1969) and subsequently defined as a formation (Kellaway and Welch, 1993), the unit is here redefined as a member.

Type area

Radstock, Somerset [ST 68 55].

Reference section

Hursley Hill Borehole (ST66NW2) [ST 6180 6565]: from base of member at 585.4 m to top of member at 306.6 m.

Lithology

Grey mudstone and numerous thin, muddy coal seams.

Lower and upper boundaries

In the Radstock Basin the base of the member is taken at the base of the Nine Inch Seam. In the Pensford Basin the base is taken at the base of the Number Eight Seam (Kellaway and Welch, 1993). Underlain by red and grey mottled mudstone of the Barren Red Member.

In the Radstock Basin the top of the member is taken at the top of the Withy Mills Seam. In the Pensford Basin the top occurs at the top of the Forty Yard Seam (Kellaway and Welch, 1993). Overlain by grey mudstone and siltstone of the Publow Member.

Thickness

Up to 315 m in the Pensford Basin; 250 m in the Radstock Basin.

Distribution

Restricted to the Somerset Coalfield.

Genetic interpretation

The member was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment.

Biostratigraphical characterisation

The member contains macroflora typical of the *D. plueckenetii* Subzone, indicating a late Asturian age (Cleal, 1997).

Age

Asturian

5.5.6.4 PUBLLOW MEMBER (PUB)

Name

Initially defined as a group (Kellaway, 1969) and subsequently defined as a formation (Kellaway and Welch, 1993), the unit is here redefined as a member.

Type area

Publow, Somerset [ST 62 64], located in the Pensford Basin.

Reference section

Hursley Hill Borehole (ST 66 NW 2) [ST 6180 6565]: from base of member at 306.6 m to the top of the borehole; top of the member not proved.

Lithology

Mainly of grey mudstone and siltstone, with subordinate sandstone and rare thin coals. The sandstones are typically of lithic arenite ('Pennant' type), but also include massive quartzose sandstones.

Lower and upper boundaries

The base of the member is taken at the top of the Withy Mills Vein Coal in the Radstock Basin; top of the Forty Yard Vein Coal in the Pensford Basin. Underlain conformably by grey mudstones of the Radstock Member.

The top of the member is truncated by the Permo-Triassic unconformity, overlain by the Mercia Mudstone Group.

Thickness

A maximum thickness of 600 m is recorded in the Pensford Basin (Kellaway and Welch, 1993).

Distribution

Somerset Coalfield [ST 66]

Genetic interpretation

The member was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment.

Biostratigraphical characterisation

The member contains non-marine bivalves indicative of the *Anthraconauta tenuis* Zone and plants assigned to an Asturian age (Kellaway and Welch, 1993). However, subsequent work has identified macroflora indicative of the *Odontopteris cantabrigica* Zone, of Stephanian age (R H Wagner, in Cleal, 1997).

Age

Asturian to Stephanian

FOREST OF DEAN

The **Trenchard Formation**, of possible Asturian (Westphalian D) age, rests unconformably upon Visean and older strata (Cleal and Thomas, 1996) (Figure 20). The Trenchard Formation comprises a red-bed and conglomeratic facies in the north of the coalfield, similar to the Deri Formation of the East Crop of South Wales and the Winterbourne Formation of Bristol. The formation is overlain by and passes laterally southward into the **Coleford Member**, the local Forest of Dean representative of the **Pennant Sandstone Formation**. The uppermost Carboniferous strata of the Forest of Dean Coalfield comprise the **Cinderford Member**, the proposed local representative of the **Grovesend Formation**.

5.5.7 Trenchard Formation (TRGP)

Name

Originally defined as the Trenchard Group (Trotter, 1942), which included all 'Coal Measures' strata below the Coleford High Delf. The unit is here redefined as a formation and is restricted to the coarsely arenaceous deposits of non-Pennant sandstone type present in the north of the coalfield.

Type section

The disused Puddlebrook Quarry [SO 646 183], 1 km north of Drybrook: Exposure of the basal conglomerate of the Trenchard Formation (Cleal and Thomas, 1996).

Lithology

Grey or pinkish grey quartzose sandstone. Quartzose conglomerate beds are common at the base of the formation, increasing in thickness and clast size toward the north (Jones, 1972).

Lower and upper boundaries

The basal conglomerate of the Trenchard Formation rests unconformably upon the quartzitic sandstone of the Cromhall Sandstone Formation.

The top is taken at the base of the lowermost thick (mappable) sandstone of 'Pennant'-type (lithic arenite) of the Pennant Sandstone Formation, resting conformably above coarse-grained sandstone of the Trenchard Formation. This is a significant change to the definition of Trotter (1942), who included all strata below the Coleford High Delf as part of his Trenchard Group.

Thickness

Up to 120 m thick in the north of the coalfield, thinning southwards as it passes into the Pennant Sandstone Formation.

Distribution

Restricted to the northern part of the Forest of Dean coalfield, approximately north of a line from Mailscott Wood, Coleford [SO 562 142] to Ruspidge, Cinderford [SO 649 119].

Regional correlation

Lithologically comparable to the Deri Formation of the East Crop of the South Wales Coalfield or the Winterbourne Formation of the Bristol region. However, the Trenchard formation appears to be younger than these equivalent formations, both of which are Bolsovian in age.

Genetic interpretation

The Trenchard Formation comprises a red-bed and con-

glomeratic facies with a northerly source of siliciclastic strata interpreted as alluvial braidplain deposits (Jones, 1972) or mature conglomerates deposited in a littoral marine environment (Stead, 1975).

Biostratigraphical characterisation

The age of the Trenchard Formation is poorly constrained and was originally considered to be Bolsovian in age (Welch and Trotter, 1961). Spore assemblages from the Trenchard Coal belong to the *Thymospora obscura* Miospore Zone (Wagner and Spinner, 1972), suggesting an Asturian age.

Age

Asturian

5.5.8 Pennant Sandstone Formation (PES)

(see Section 5.5.2 for details).

5.5.8.1 COLEFORD MEMBER (COFD)

Name

Formerly referred to as the Forest of Dean Pennant Formation (Cleal and Thomas, 1996), the unit is here defined as the Coleford Member of the Pennant Sandstone Formation.

Type section

Disused quarries and abandoned railway line at Meezy Hurst [SO 638 089 to SO 647 091] proves a 300 m thick succession of the Coleford Member from the southern part of the coalfield, and development of the basal unconformity (Cleal and Thomas, 1996).

Lithology

Mainly thick-bedded, coarse-grained sandstone of 'Pennant'-type, with subordinate interbeds of grey and green mudstone with ironstone concretions and coal. The sandstone is trough cross-bedded to planar bedded and beds commonly show erosive scours. Sandstone beds from beneath the Coleford High Delf seam are typically fine- to medium-grained. Coals seams up to 1.5 m thick are present within the succession.

Lower and upper boundaries

The base is taken at the base of the lowermost thick (mappable) sandstone of 'Pennant'-type (lithic arenite). Occurs conformably above coarse-grained sandstone of the Trenchard Formation in the north of the Forest of Dean Coalfield and unconformably upon limestone and sandstone of the Pembroke Limestone Group in the south.

The top is taken at the base of the Brazilly Coal, present at the base of a grey mudstone-dominated succession of the Cinderford Member of the Grovesend Formation. The coal rests conformably upon thick-bedded, coarse-grained sandstone of the Coleford Member.

Thickness

The formation ranges in thickness from 180 m in the north to 300 m in the south, at the type locality.

Distribution

Restricted to the Forest of Dean Coalfield [SO 60].

Genetic interpretation

Fluvial channel deposits. The northward thinning of the member results from the northward progradation of the Pennant Sandstone Formation strata onto barren red measures of the Trenchard Formation. Palaeocurrents and the

litharenite petrography of the sandstones of the Coleford Member established that they were derived from the south, as opposed to the northerly source of Trenchard Formation siliciclastic stata (Jones, 1972).

Biostratigraphical characterisation

The roof of the Coleford High Delf contains non-marine bivalves indicative of the *Anthraconauta tenuis* Zone (Calver, in Welch and Trotter, 1961) and the plant macrofossil *Lobopteris vestita* of the *Dicksonites plueckenetii* Subzone (Wagner and Spinner, 1972), indicative of a late Asturian age (Cleal and Thomas, 1996).

Age

Asturian

5.5.9 Grovesend Formation (GDB)

(see Section 5.5.3 for details)

5.5.9.1 CINDERFORD MEMBER (CIFD)

Name

Previously referred to as the Supra-Pennant Group (Trotter, 1942) or Supra-Pennant Formation (Cleal and Thomas, 1996), the unit is here defined as the Cinderford Member of the Grovesend Formation.

Type section

The disused Oakenhill railway cutting [SO 631 080], 1.5 km east of Parkend: Overgrown section in the lower, argillaceous part of the member (Cleal and Thomas, 1996).

Lithology

Mainly grey mudstone and siltstone, with some reddening, coal and sandstone. The lower part of the succession is dominantly argillaceous and includes relatively thick coals, including the Brazilly and Crow coals. The middle part of the member includes the Serridge Sandstone, which passes from exclusively sandstone in the north to interbedded sandstone and shale to the south. The upper argillaceous part of the member includes further coal seams (Woodgreen Coals).

Lower and upper boundaries

The base is taken at the base of the Brazilly Coal, which rests conformably upon thick-bedded, coarse-grained sandstone of the Pennant Sandstone Formation.

The top is taken at the top of the member is not present in the Forest of Dean outlier.

Thickness

About 340 m

Distribution

Restricted to the central part of the Forest of Dean outlier [SO 60].

Genetic interpretation

Mainly floodplain deposits with some fluvial channel sandstones (Serridge Sandstone).

Biostratigraphical characterisation

Plant macrofossils from the lower part of the member, listed by Trotter (1942) are typical of the upper part of the *Lobopteris vestita* Zone, suggesting a late Asturian age (Cleal, 1987). Higher in the succession, above the Twenty Inch Seam, plants listed by Wagner and Spinner (1972) are typical of the *Odontopteris cantabrica* Zone, of Stephanian age (Cleal, 1987).

Age

Asturian to Cantabrian

NEWENT COALFIELD

Carboniferous rocks have a narrow outcrop (about 6 km by 1 km) in the vicinity of Newent, Gloucestershire [SO 708 242]. The lower **Stallion Hill Sandstone Formation** is similar in appearance to the Trenchard Formation of the Forest of Dean. It is overlain by a mudstone-dominated succession attributed to the **Grovesend Formation** (see Section 5.5.3), previously described as Upper Coal Measures (Worssam et al., 1989). A true thickness of about 208 m was recorded in the Lower House No.1 (SO62NE4) and No. 2 (SO62NE5) boreholes [SO 6988 2629], with the base of the formation not reached. The formation is overlain unconformably by the Bridgnorth Sandstone Formation. The mudstones in the upper 84 m of core are mainly purple, locally red, and mainly grey below. *Spirorbis* limestones are present in the lower part of the purple measures. Sandstones are a subordinate component of the core (up to 12% of the total thickness). Below 173 m depth the grey succession includes upward cycles of mudstone, thin sandstone, seatearth and coal. Macrofloral assemblages belong to the *Lobopteris vestita* Biozone, indicative of a late Asturian age (Cleal, 1987).

Other smaller outcrops of Carboniferous strata extend northward between the Newent Coalfield and the Wyre Forest Coalfield. These coalfields have been used to postulate the presence of a breach in the Wales–Brabant High, with depositional connection between the South Wales and Pennine Basin, referred to as the ‘Herefordshire Straits’, which became established during Duckmantian times (Wills, 1956). These include Storridge Hill [SO 757 487] near Great Malvern, Berrow Hill [SO 744 585] and Martley [SO 755 597] near Worcester, and Woodbury [SO 750 645] in the Abberley Hills.

At Berrow Hill, strata attributed to the Halesowen Formation (formerly Highley Formation) overlies unconformably the Raglan Mudstone Formation and is in turn unconformably overlain by the Haffield Breccia Formation. The formation was originally referred to as the Martley Measures (Wills, 1956). The outcrop is truncated to the east by the East Malvern Fault (Barclay et al., 1997). There are no sections, but approximately 25 m-thick succession is seen at outcrop as greenish grey and yellow mottled clay. The succession is of probable Asturian age.

The presence of microflora of the *Thymospora obscura* Biozone suggest the succession at Woodbury is late Bolsovian to early Cantabrian in age (Spinner, 1966).

5.5.10 Stallion Hill Sandstone Formation (SLN)

Name

The name was first proposed by Worssam et al. (1989) and in this report is formally defined as a formation.

Type section

Stallion Hill [SO 7151 2405]: 5.7 m thick sandstone.

Lithology

The formation is mainly sandstone with some interbedded mudstones. The sandstone is friable, fine- to coarse-grained, grey, cross-bedded and slightly micaceous. The mudstones are buff, purple and red-brown mottled. Locally, at the base of the formation is a loosely cemented, poorly sorted conglomerate about 10 m thick. The conglomerate has a red-brown sandy matrix and subrounded clasts of igneous rocks, quartzite, sandstone and limestone up to 15 cm diameter.

Lower and upper boundaries

The grey sandstone of the Stallion Hill Sandstone Formation rests unconformably upon the red mudstones of the Raglan Mudstone Formation.

There is a conformable passage from the grey sandstone of the Stallion Hill Sandstone Formation into the overlying grey mudstone with subordinate sandstone, seatearth and coal of the Grovesend Formation.

Thickness

Up to 80 m

Distribution

Restricted to the Newent Coalfield, Gloucestershire. The formation crops out between Stallion Hill [SO 715 238] and Bouldson Lea [SO 7083 2422].

Regional correlation

The formation is considered to be a lateral equivalent of the Trenchard Formation of the Forest of Dean Coalfield (Worssam et al., 1989).

Genetic interpretation

The grey succession with presence of coals and seatearths is consistent with development on a river floodplain. The presence of *Spirorbis* limestones is indicative of intermittent development of a lacustrine environment.

Biostratigraphical characterisation

No biostratigraphical evidence for the age of the formation has been found. By comparison with the Trenchard Formation in the Forest of Dean a Bolsovian to Asturian age is proposed (Worssam et al., 1989).

Age

Westphalian (possibly Bolsovian to Asturian)

OXFORDSHIRE–BERKSHIRE COALFIELD

The succession of the **Pennant Sandstone Formation** consists of up to 335 m of greenish grey, cross-bedded, coarse-grained sandstone of 'Pennant'-type, with subordinate beds of grey mudstone, shale and seatearth and coal seams up to 1.5 m thick. The formation, formerly the Arenaceous Coal Group of Poole (1969), rests unconformably upon strata of Devonian or older age. The formation is Asturian in age in the Oxfordshire Coalfield, though an earlier Bolsovian age for the lower part of the formation is proposed for the Berkshire Coalfield to the south (Foster et al., 1989). This indicates a northward younging of the first incoming of 'Pennant'-type sandstones, analogous to that seen in the Bristol–South Wales regions. The formation may be absent in North Oxfordshire and Warwickshire to the north.

5.5.11 Pennant Sandstone Formation (PES)

(see Section 5.5.2 for details).

The Pennant Sandstone Formation of the Oxfordshire–Berkshire Coalfield is not divided into members.

5.5.12 Grovesend Formation (GDB)

(see Section 5.5.3 for details)

The Grovesend Formation can be traced northward into the exposed Warwickshire Coalfield, where it has been mapped as the Halesowen Formation. The Halesowen Formation lacks the primary red-bed successions found

in the Oxfordshire–Berkshire Coalfield. The Grovesend Formation of the Oxfordshire–Berkshire Coalfield comprises, in ascending order: the **Witney Coal**, **Crawley**, **Burford Coal** and **Windrush members**.

5.5.12.1 WITNEY COAL MEMBER (WTC)

Name

Poole (1969) was first to name the unit, which he recognised as a group, but is here redefined as a member.

Type section

Apley Barn Borehole (SP31SW3) [SP3438 1066]: complete thickness of the member from 875.4 m to 792.4 m (Poole, 1969).

Reference section

Steeple Aston Borehole (SP42NE12) [SP 4687 2586]: complete thickness of the member from 467.4 m to 424.66 m (Poole, 1977).

Lithology

Grey coal-bearing succession, with typical upward-coarsening cycles from mudstone to sandstone, capped by a seatearth and coal.

Lower and upper boundaries

In the type section, grey mudstone with basal coal of the Witney Coal Member overlies conformably pale greenish grey, rooted, fine-grained sandstone of the Pennant Sandstone Formation.

In the type section, greyish blue, brown, yellow and red mudstone of the Crawley Member, overlies conformably dark grey, carbonaceous mudstone of the Witney Coal Member.

Thickness

Maximum thickness of 83 m in the type section; 43 m in the Steeple Aston Borehole.

Distribution

Widespread in the Oxfordshire Coalfield, proved only in the subsurface. Also proved in a single borehole, Harwell No.3 (SU48NE92) [SU 46801 86441], in the Berkshire Coalfield (Foster et al., 1989).

Regional correlation

This member is equivalent to the Farrington Member of the Bristol region (Poole, 1969).

Genetic interpretation

The cycles represent deposition in prograding deltas.

Biostratigraphical characterisation

The member includes miospores of the XII Zone (Smith, 1987) and macroflora of the *Dicksonites plueckenetii* Subzone (Cleal, 1997), both indicative of an Asturian age.

Age

Asturian

5.5.12.2 CRAWLEY MEMBER (CRW)

Name

Poole (1969) was first to name the unit, which he recognised as a group, but is here redefined as a member.

Type section

Apley Barn Borehole (SP31SW3) [SP3438 1066]: complete thickness of the member from 792.4 m to 587.8 m (Poole, 1969).

Reference section

Steeple Aston Borehole (SP42NE12) [SP 4687 2586]: complete thickness of the member from 424.66 m to 322.44 m (Poole, 1977).

Lithology

Thick beds of red mudstone with common desiccation cracks, interbedded with conglomerate, grey seatearth, sandstone and mudstone and scarce thin coals.

Lower and upper boundaries

In the type section, greyish blue, brown, yellow and red mudstone of the Crawley Member, overlies conformably dark grey, carbonaceous mudstone of the Witney Coal Member.

In the type section, dark grey, carbonaceous mudstone with basal coal of the Burford Coal Member, overlies conformably grey to red mudstone-dominated succession of the Crawley Member.

Thickness

Maximum thickness of 205 m in the type section; 102 m in the Steeple Aston Borehole.

Distribution

Oxfordshire Coalfield; in the subsurface only.

Regional correlation

This member is considered equivalent to the 'Barren Red Member' of the Bristol Region (Poole, 1969).

Genetic interpretation

The member was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment. Periods of improved drainage are associated with oxidation, development of primary red beds and abundance of desiccation cracks.

Biostratigraphical characterisation

The member includes miospores indicative of Zone XII, broadly equating to the middle Asturian (Smith, 1987).

Age

Asturian

5.5.12.3 BURFORD COAL MEMBER (BRFC)

Name

Poole (1969) was first to name the unit, which he recognised as a group, but is here redefined as a member.

Type section

Apley Barn Borehole (SP31SW3) [SP3438 1066]: complete thickness of the member from 587.8 m to 449.6 m (Poole, 1969).

Reference sections

Steeple Aston Borehole (SP42NE12) [SP 4687 2586]: base of the member at 322.44 m and unconformable top at 228.98 m (Poole, 1977).

Upton Borehole (SP21SW1) [SP 2315 1313]: from 1049.88 to 928.29 m (Worssam, 1963; Poole, 1977).

Lithology

Grey mudstone, sandstone, seatearth and coal. In the upper part of the member there are several thin *Spirorbis* limestone beds and secondary reddening of the succession.

Lower and upper boundaries

In the type section, dark grey, carbonaceous mudstone with basal coal, overlies conformably grey to red mudstone-dominated succession of the Crawley Member.

In the type section, reddish brown, blue mottled mudstone with calcareous nodules of the Windrush Member, overlies conformably grey mudstone of the Burford Coal Member. In the Steeple Aston Borehole, the upper boundary is an unconformity, overlain by fine- to medium-grained sandstones of the Mercia Mudstone Group.

Thickness

Some 138 m thick in the type section; 122 m in the Upton Borehole; 93 m in the Steeple Aston Borehole.

Distribution

Oxfordshire Coalfield; in the subsurface only.

Regional correlation

This member is considered equivalent to the Radstock Member of the Bristol region (Poole, 1969).

Genetic interpretation

The succession was deposited in a fluvio-lacustrine environment, the *Spirorbis* limestones indicative of lacustrine deposition.

Biostratigraphical characterisation

The member includes miospores indicative of Zone XII, broadly equating to the middle Asturian (Smith, 1987). However, the determination of the macroflora *Odontopteris brardii* from the member indicate assignment to the *Odontopteris cantabrica* Zone (Cleal, 1997), the base of which is coincident with the base of the Cantabrian Stage.

Age

Asturian to Cantabrian

5.5.12.4 WINDRUSH MEMBER (WNR)

Name

Poole (1969) was first to name the unit, which he recognised as a group, but is here redefined as a member.

Type section

Apley Barn Borehole (SP31SW3) [SP 3438 1066]: from 449.6 m to 250.2 m (Poole, 1969).

Reference section

Upton Borehole (SP21SW1) [SP 2315 1313]: from 928.29 m to 337.49 m (Worssam, 1963).

Lithology

Consists of approximately equal proportions of red and grey strata. The red intervals are dominated by red massive mudstone with beds of red silty mudstone with common desiccation cracks. The grey intervals include upward-coarsening cycles of grey, locally reddened, mudstone to sandstone capped by seatearth and thin coal seams.

Lower and upper boundaries

In the type section, reddish brown, blue mottled mudstone with calcareous nodules of the Windrush Member, overlies conformably grey mudstone of the Burford Coal Member.

The top of the member is defined as the unconformity at the base of the overlying Permo-Triassic strata of the Mercia Mudstone Group.

Thickness

Up to 590 m in the Upton Borehole, thinning markedly eastward to 200 m in the Apley Barn Borehole (Poole, 1969).

Distribution

Oxfordshire Coalfield; in the subsurface only.

Regional correlation

The member has been correlated with the Alveley Member of the Salop Formation of Central England (see Section 4.10.3.1) and the Publow Member of the Bristol region (see Section 5.5.6.4) (Poole, 1969). However, coals present in the formation can be correlated with coals within the middle and upper part of the Halesowen Formation to the north.

Genetic interpretation

The member was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment. Periods of improved drainage are associated with oxidation, development of primary red beds

Biostratigraphical characterisation

The member includes miospores indicative of Zone XIII,

broadly equating to the late Asturian (Smith, 1987). However, the determination of *Sphenophyllum oblongifolium* from the member indicates assignment to the macrofloral *Odontopteris cantabrica* Zone (Cleal, 1997), the base of which is coincident with the base of the Cantabrian Stage.

Age

Asturian to Cantabrian

KENT COALFIELD

The **Warwickshire Group (undifferentiated)** of the concealed Kent Coalfield consists of about 600 m of 'Pennant'-type sandstone, with some thick mudstones and several economic coal seams. Red-bed facies are absent from the succession.

The group is entirely Asturian in age, resting above a non-sequence upon South Wales Upper Coal Measures Formation. The measures above the Kent No. 6 Seam include *Anthraconaia pruvosti*, of probable *Anthraconauta tenuis* Zone (Bisson et al., 1967). This suggests the absence of strata equivalent to the Upper *similis-pulchra* Zone and *Anthraconauta phillipsii* Zone (Stubblefield and Trueman, 1946).

6 South-west England

To the south of the Mississippian platform carbonate successions of the Bristol, Mendips, Somerset and South Wales, deposition was controlled by the presence of four Devonian to Carboniferous basins. From south to north these are the South Devon, Tavy, Culm and North Devon basins (Figure 21) (Leveridge, 2006). The South Devon and Tavy basins predominantly evolved during the Devonian, although the basinal architecture with local development of highs persisted into the Carboniferous. The Culm Basin was initiated in the latest Famennian. Successive extensional faulting gradually compartmentalised the Culm Basin into several sub-basins, comprising a central graben, the Central Devon Sub-basin, bounded by two half-grabens, the Bideford Sub-basin to the north and the Launceston Sub-basin to the south. Today, the Bideford Sub-basin is bounded to the north by the Brushford Fault, the Central Devon Sub-basin by the Greencliff Fault and the Launceston Sub-basin by the Rusey Fault (Figures 1 and 21). During the Devonian the North Devon Basin accumulated a very thick succession of shelfal and progradational continental facies deposited in an area of staged subsidence. From the early Tournaisian, this remnant of the northern shelf situated beyond the northern bounding structure of the Culm Basin, subsided sufficiently to allow shelf and Culm facies to be deposited in continuity with the deposits of the Culm Basin.

The term Culm Measures, entrenched in the literature (Sedgwick and Murchison, 1840), has been retained as the Culm Supergroup, which embraces the Carboniferous, predominantly deep-water pelagic and hemi-pelagic facies and 'Millstone Grit' facies, deposited in the four basins. Shallow marine and deeper water mudstones of late Devonian to early Tournaisian age, formerly included within the Culm Measures or a Transition Group, show stronger affinity in terms of facies with the underlying Devonian strata. These strata are assigned to the Exmoor Group in north Devon, the Hyner Mudstone and Trusham Mudstone formations of the eastern part of the Central Devon Sub-basin and the Tamar Group in south Devon, all excluded from the Culm Supergroup.

The Culm Supergroup is subdivided in the Culm and North Devon basins into the Teign Valley Group and the Holsworthy Group (Figure 21). These divisions broadly equate with the earlier terms, Lower and Upper Culm, initially employed by Sedgwick and Murchison (1840). In the South Devon Basin, the Culm Supergroup is represented by the Chudleigh Group, broadly equivalent in age and environments of deposition as the Teign Valley Group of the Culm Basin. As a result of basin inversion, known deposits of Carboniferous age from the Tavy Basin are restricted to thrust sheets derived from about the Laneast High, separating the Tavy and Culm basins.

6.1 EXMOOR GROUP (EXM)

The predominantly grey mudstone succession of the Exmoor Group, defined by (Waters et al., In press), comprises three shallow marine and pro-delta, mudstone-dominated sequences, each capped by fluvial /lacustrine and deltaic sandstone-dominated sequences. Uppermost part of

group comprises transgressive shallow marine mudstones. The group, which is Emsian to Tournaisian in age is up to 7000 m thick and crops out in north Devon and west Somerset [SS 80 40]. The group passes southwards beneath the Culm Basin into the Tamar Group. Only one formation, the **Pilton Mudstone Formation**, is in part of Carboniferous age.

6.1.1 Pilton Mudstone Formation (PLT)

Name

Previously referred to as the Pilton Beds (Hall, 1867) and Pilton Shales (Edmonds et al., 1979), the unit is here redefined as the Pilton Mudstone Formation.

Type section

Coastal cliff from south side of Baggy Point to south side of Saunton Down [SS 4220 4020–4450 3775], Croyde, north Devon. The section exposes the basal junction with the Baggy Sandstones Formation and the lower third of the Pilton Mudstone Formation (Edmonds et al., 1979). The sequence is folded.

Lithology

Grey mudstones and siltstones with thin- to thick-bedded, locally calcareous sandstones and beds and lenses of limestone. Sandstones are thickest and predominate in the lower half of the formation, whilst mudstones predominate in the upper half. Rich shelly neritic fauna occur in the mudstones and limestones.

Lower and upper boundaries

At the coast, the lower boundary is taken at the incoming of interbedded mudstones, siltstones and sandstones of the Pilton Mudstone Formation above a prominent slumped unit overlain by cross-bedded medium-grained sandstones of the underlying Baggy Sandstone Formation. Inland, the boundary is taken above the highest, sugary, buff-brown, fine- to medium-grained feldspathic and micaceous sandstone, typical of the Baggy Sandstone Formation.

Between Brushford and Wellington, the upper boundary is taken at the incoming of hard black finely laminated rarely fossiliferous cherty mudstones of the Doddiscombe Formation above the soft medium to dark grey mudstones with scattered very thin fossiliferous limestones, siltstones and sandstones of the underlying Pilton Mudstone Formation. West of South Molton, the upper boundary is taken at the gradational incoming of dark grey to black rarely fossiliferous, slightly siliceous, finely laminated mudstones of the overlying Doddiscombe Formation (Unit D of the Pilton Beds of Prentice (1960b)), above the fossiliferous mudstones with thin sandstones and siltstones of the underlying Pilton Mudstone Formation. The Doddiscombe Formation has not been mapped by BGS west of South Molton; instead it has been included in the Pilton Mudstone Formation and/or the Codden Hill Chert Formation. Further work is therefore needed.

Thickness

About 500 m

Distribution

Between Croyde and Wellington, North Devon [SS 70 28].

Genetic interpretation

Shallow marine

Biostratigraphical characterisation

Trilobites and goniatites show the formation to range from the late Famennian *Wocklumaria* Zone to the Tournaisian *Gattendorfia* Zone and possibly into the *Ammonellipsites* Zone s.l..

Age

Famennian to Tournaisian

6.2 THE HYNER MUDSTONE AND TRUSHAM MUDSTONE FORMATIONS

6.2.1 Hyner Mudstone Formation (HYMU)

Name

Previously referred to as the Hyner Formation (Chesher, 1968) and Hyner Shale (Selwood et al., 1984), named after Hyner Farm [SX 839 820], the unit is here redefined as the Hyner Mudstone Formation.

Type section

Road section (B3193) east of Christow [SX 8405 8482 to SX 8408 8487], middle Teign valley, south Devon. There are 44 m of locally fossiliferous mudstones in the uppermost part of the formation; the boundary with the overlying Trusham Mudstone Formation is exposed (Selwood et al., 1984).

Lithology

Hard dark blue-grey or bluish green-grey, generally mottled, silty shales and mudstones. Calcareous bands and nodules, and calcareous shales and mudstones occur near the top, together with a calcareous siltstone (locally yielding trilobite and pelagic ostracod faunas). Within the metamorphic aureole of the Dartmoor Granite, calc-flints and hornfels are developed and siliceous nodules are characteristic of the lower parts of the formation.

Lower and upper boundaries

The lower boundary is not seen. The upper boundary is taken at the gradational incoming of grey and green micaceous shales of the overlying Trusham Mudstone Formation above the dark blue or bluish-green mottled shales and calcareous beds of the Hyner Mudstone Formation. Commonly this boundary cannot be detected in the metamorphic aureole of the Dartmoor Granite.

Thickness

At least 250 m

Distribution

Middle Teign Valley [SX 84 85], eastern Dartmoor, south Devon.

Regional correlation

Probably passes north into the Pilton Mudstone Formation of North Devon within the Culm Basin.

Genetic interpretation

Distal shelf muds with locally developed sparse benthos.

Biostratigraphical characterisation

Late Famennian *Wocklumeria* Zone ostracods and trilobites

occur in the uppermost part of the formation and are overlain by horizons with early Tournaisian *Gattendorfia* Zone ostracods.

Age

Famennian to Tournaisian

6.2.2 Trusham Mudstone Formation (TMSH)

Name

Previously referred to as the Trusham Formation (Chesher, 1968) and Trusham Shale (Selwood et al., 1984), the unit is here redefined as the Trusham Mudstone Formation.

Type sections

Track section north of Leigh [SX 8426 8113], near Trusham, Devon: much of the formation is exposed (64 m), but neither upper nor lower contacts are seen (Selwood et al., 1984). The section yields early Tournaisian ostracods.

Lithology

Olive-green, soapy 'shales' exhibiting a conchoidal fracture and pale grey 'shales' with calcareous micaceous laminae. The small bivalve *Sanguinolites? ellipticus* is locally abundant in the upper part of the formation. Sparse shelly benthos and pelagic ostracods are locally present.

Lower and upper boundaries

The lower boundary is taken at the gradational incoming of pale grey and green micaceous shales of the Trusham Mudstone Formation above the dark blue-grey or bluish green-grey mottled shales and calcareous beds of the underlying Hyner Mudstone Formation. Commonly this boundary cannot be detected in the metamorphic aureole of the Dartmoor Granite.

The upper boundary is taken at the incoming of bluish black and black mudstones of the overlying Combe Mudstone Formation above the olive green and pale grey mudstones of the Trusham Mudstone Formation.

Thickness

Some 65 m

Distribution

Middle Teign Valley and Ilsington areas, eastern Dartmoor [SX 84 85], south Devon.

Regional correlation

Probably passes north into the Pilton Mudstone Formation of north Devon under the Culm synclinorium.

Genetic interpretation

Distal shelf muds with sparse benthos.

Biostratigraphical characterisation

Early Tournaisian *Gattendorfia* Zone ostracods occur at several levels.

Age

Tournaisian

6.3 TAMAR GROUP (TAMA)

The Tamar Group, as redefined by Waters et al. (2007), comprises component basinal mudstone formations characterised either by grey, purple and red or green and grey-green colourations. Intertonguing with the mud-

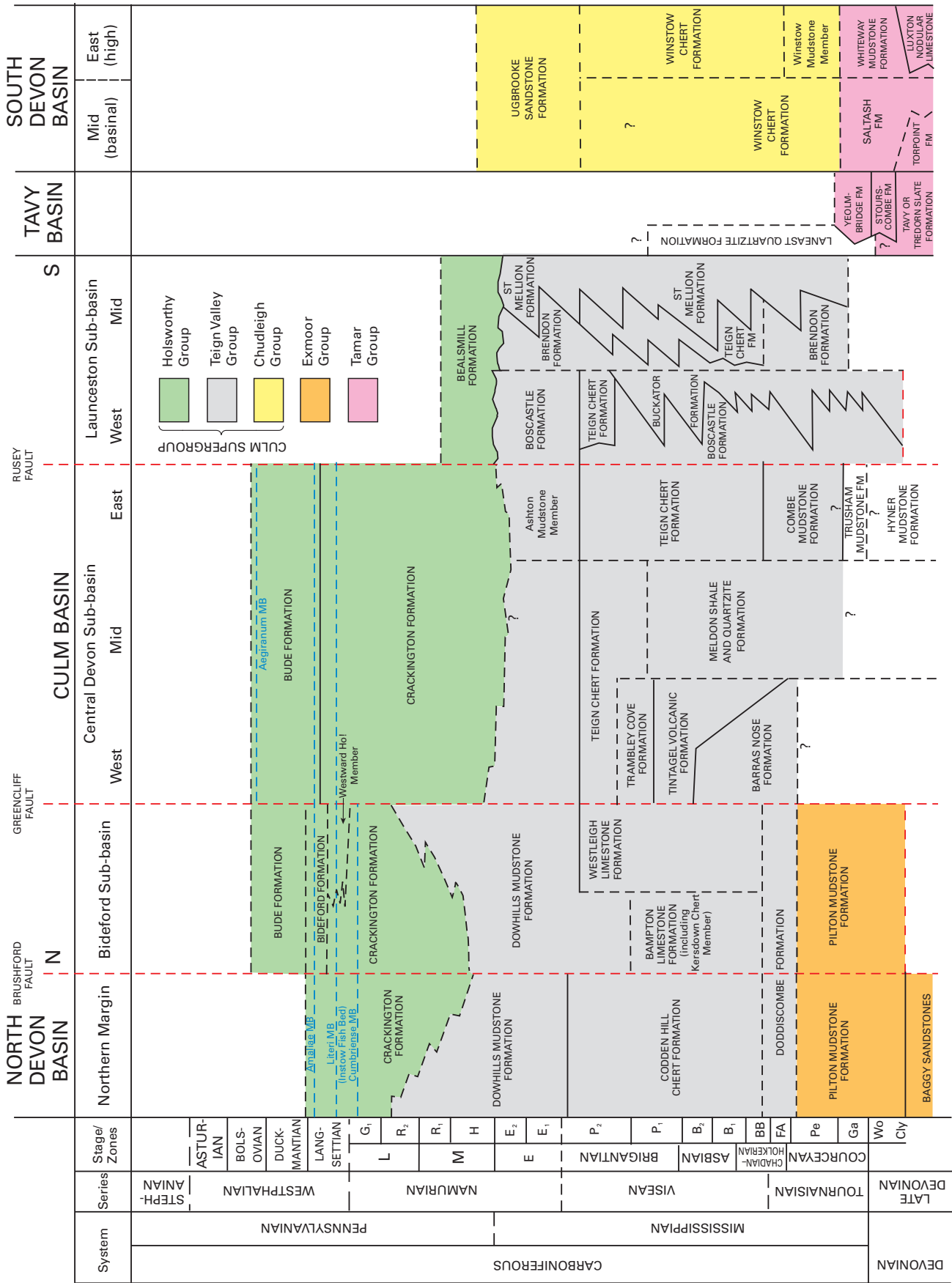


Figure 21 South-west England lithostratigraphical nomenclature.

stone-dominated formations are thick, geographically separated formations of thick to massive bedded shallow water bioclastic and reef limestone, locally capped by condensed nodular limestones and mudstones, which accumulated on and adjacent to basement highs. Thick units of basaltic lava (spilite), massive and bedded hyl-

clastite, and bedded tuff are also present in the group. The group, which is Emsian to Tournaisian in age is up to 5200 m thick.

Four mudstone-dominated formations, the **Rora Mudstone**, **Saltash**, **Whiteway Mudstone** and **Yeolmbridge formations** are in part Carboniferous in age.

6.3.1 Rora Mudstone Formation (RRAM)

Name

Previously referred to as the Liverton Slates and Ilsington Slates (Bristow, 1963) and Rora Slate (Selwood et al., 1984), the unit is here redefined as the Rora Mudstone Formation.

Type section

South Rora Down Quarry, south-west of Liverton, south Devon [SX 7957 7425]: 2 m of green and purple mudstones with a thin bed of black siliceous mudstone is exposed in the upper part of the formation (Selwood et al., 1984). Neither the base nor the top of the formation is seen.

Lithology

The formation comprises purple, green and greyish green mudstones. Scattered siliceous and calcareous nodules are developed at some levels. A prominent 10 m thick unit of buff weathering calcareous laminated siltstone, capped by 2 m of interbedded grey silty mudstones and siliceous black mudstones, is present at the top of the formation.

Lower and upper boundaries

The lower boundary is not seen. May possibly overlie the Tavy Formation but further work is needed.

The upper boundary is taken at the sharp incoming of the black mudstones of the 'Ararat Slate' (Teign Chert Formation) above the buff weathering calcareous laminated siltstones capped by 2 m of interbedded grey silty mudstones and siliceous black mudstones at the top of the underlying Rora Mudstone Formation.

Thickness

Uncertain but probably not more than 200 m exposed.

Distribution

Liverton area (SX 79 75), south Devon

Regional correlation

Similar in facies to the Torpoint Formation but outcrops further north than main crop of the Torpoint Formation in the South Devon Basin. May have been deposited in a separate basin (Tavy Basin) and/or structurally inserted into its present position. Further work needed.

Genetic interpretation

Basinal muds

Biostratigraphical characterisation

Late Famennian Upper *Clymenia* to *Wocklumeria* Zone ammonoids are present in the formation while ammonoids from near the top suggest it ranges into the *Gattendorfia* Zone. This is confirmed by the presence of a conodont no younger than the *anchoralis* Zone in the lowermost part of the Teign Chert Formation ('Ararat Slate').

Age

Famennian to Tournaisian

6.3.2 Saltash Formation (SAH)

Name

The formation has been given numerous names over recent years. It has been referred to as the Nordon Slate (Selwood et al., 1984) and Nordon Formation (Leveridge et al., 2003), the Trevoise Slate (Kirchgasser, 1970) and Trevoise Slate Formation (Selwood et al., 1998), the Jennycliff Slate

Formation (Chandler and Mccall, 1985) and Jennycliff Slates (Hobson, 1976; House et al., 1977; Pound, 1983), the Plymton Slate Formation (Chandler and Mccall, 1985), and the Tempellow Slate, Rosenum Slate and Mileport Slate formations (Burton, 1974; Burton and Tanner, 1986). The unit was defined as the Saltash Formation by Leveridge et al. (Leveridge et al., 2002).

Type section

River cliff on west bank of River Tamar [SX 4315 5852 to SX 4291 5790], 380–1000 m south of the Tamar Bridge, at Saltash, east Cornwall. The section exposes folded silt-laminated grey mudstones, locally bioturbated, with scattered thin beds of sandstone and laminae of limestone (Leveridge et al., 2002). Units of basaltic lava and hyaloclastite are present as well as high-level basaltic intrusions. Neither the lower or upper contacts of the formation are exposed.

Formal subdivisions

The following are recognised as formal members of the Saltash Formation, though as they are all Devonian age their definition is outside of the scope of this report:

- Wearde Sandstone Member
- St Germans Tuff Member
- Marble Cliff Limestone Member
- Bourton Limestone Member
- Marldon Limestone Member
- Dartington Limestone Member
- Penny's Wood Limestone Member
- Dittisham Member
- St Mary's Bay Member

Lithology

Dark grey and grey silty mudstone with variable proportions of laminae and thin beds of siltstone and sandstone. Bioturbation is locally present, especially in the lower part. There are scattered units of thin- to thick-bedded limestone (e.g. Marble Cliff Limestone Member), thin- to thick-bedded sandstone (e.g. Wearde Sandstone Member), basaltic lava (spilite), massive and bedded hyaloclastite, and bedded tuff (e.g. St Germans Tuff Member).

Lower and upper boundaries

The lower boundary is mainly thrust out in the east where it is assumed to overlie the Staddon Formation. In the west, on the north Cornish coast, it is taken at the incoming of dark and pale grey mudstones with sparse thin sandstones of the Saltash Formation above the sandstones and siltstones with subordinate mudstones of the underlying Bedruthan Formation.

The upper boundary is predominantly tectonic, except in the east in the Tamar valley, where it is taken at the incoming of dark grey cherts and siliceous mudstones of the Winstow Chert Formation above the medium grey silty mudstones of the Saltash Formation.

Thickness

About 3900 m on the north Cornwall coast. Comparable thicknesses are expected elsewhere.

Distribution

From Trevoise Head area [SW 86 76], north Cornwall to Torquay area [SX 93 65], south Devon.

Regional correlation

The formation passes laterally into and interfingers with the red and purple mudstones of the Torpoint, Saltern Cove, Harbour Cove and Polzeath Slate formations. It also passes

laterally into the numerous middle/upper Devonian carbonate formations forming 'tectonic highs' between Plymouth and Torquay. It passes laterally into the grey, green and red mudstones of the Gurrington Slate Formation and Whiteway Mudstone Formation.

Genetic interpretation

The formation is mainly basinal. Units of sandstone and limestone are mainly turbiditic. Some mudstones are shallow marine in areas adjacent to Middle Devonian carbonate build-ups and in the lowest part of the formation.

Biostratigraphical characterisation

The oldest ages come from the Plymouth area where macrofauna confirm a late early Emsian age. The stratigraphic position of these dates in relation to the base of the formation is unknown. In north Cornwall, in the Trevoise Head area, the base is within the Eifelian; the oldest date from the formation being provided by late Eifelian goniatites. The underlying Bedruthan Formation contains an Eifelian macrofauna. The top of the formation is within the early Tournaisian. In the Plymouth area, in structurally complex sections, the formation yields palynomorph floras dated as late Famennian to early Tournaisian and early Tournaisian. The overlying Winstow Chert Formation has not yielded a definitive fauna but probable Tournaisian palynomorphs have been obtained.

Age

Emsian to Tournaisian

6.3.3 Whiteway Mudstone Formation (WWYM)

Name

Formerly referred to as part of the Mount Pleasant Group (House and Butcher, 1973), the unit was defined as the Whiteway Slate by Selwood et al. (Selwood et al., 1984).

Type section

A cutting at the rear of a barn in the eastern side of Whiteway Barton farmyard [SX 8844 7525], 2 km north-north-east of Kingsteignton, south Devon. The section, 45 m thick, is in pale green and buff mudstones in the upper part of the formation and spans the Devonian–Carboniferous boundary (Selwood et al., 1984). Neither the basal or upper boundary of the formation is seen.

Lithology

Consists predominantly of red and purple mudstone with subordinate green and grey-black, locally laminated mudstone. Calcareous nodules are common where the formation is condensed and near the base, but in thicker developments calcareous, siliceous, and rarely sideritic nodules and laminae are sparsely present. The mudstones and calcareous nodules contain a rich planktonic fauna of ammonoids, ostracods and conodonts; benthic fauna include crinoid debris and brachiopods, amongst others. Thin units of basaltic (spilitic) lava are sparsely present in thicker developments.

Lower and upper boundaries

The lower boundary is taken at the gradational incoming of red, purple and green mudstones with scattered limestone nodules of the Whiteway Mudstone Formation above the red and green nodular cephalopod limestones with subordinate mudstones of the underlying Luxton Nodular Limestone.

The upper boundary is taken at the incoming of black sooty and siliceous mudstones of the Winstow Mudstone

Member (basal Winstow Chert Formation) above the purple, green and grey mudstones of the underlying Whiteway Mudstone Formation. The contact is generally sharp.

Thickness

From 26 m to ?200 m

Distribution

Between Chudleigh (SX 870 784), Bishopsteignton (SX 905 735) and East Oggwell (SX 845 695) areas, south Devon.

Regional correlation

Confined to the highs above the drowned Middle Devonian carbonate build ups, it passes basinwards into the Gurrington Slate Formation of the Newton Abbot (SX 85 72) area or its equivalent, the Torpoint and Saltash formations of south Devon and Cornwall.

Genetic interpretation

Deposited on the crest and flanks of a high.

Biostratigraphical characterisation

The base of the formation is diachronous, ranging from the *Platyclymenia* Zone to the *Clymenia* Zone based on ammonoids and conodonts. The uppermost part of the formation contains *Gattendorfia* Zone ostracods and trilobites, while conodonts in the lowermost part of the overlying Winstow Mudstone Member (basal Winstow Chert Formation) are of the upper *Siphonodella crenulata* Biozone (and probably post-*Gattendorfia*, pre-*Pericyclus* Zone s.l.) (Selwood et al., 1984).

Age

Famennian to Tournaisian

6.3.4 Yeolmbridge Formation (YF)

Name

Originally defined as the Yeolmbridge Beds (Selwood, 1960), it has also been referred to as part of the Transition Group (McKeown et al., 1973).

Type section

Yeolmbridge Quarry [SX 3206 8745], 3 km north of Launceston, east Cornwall. The quarry is partially flooded and only 15 m in the lower part of the formation is exposed around the entire rim of the quarry. The basal junction is thought to have been exposed at one time on the basis of late Famennian faunas from museum collections. The section comprises silt-laminated mudstones with sparse sandstones (Whiteley, 2004). Thin limestones and limestone nodules are locally present.

Lithology

Dark green-grey, black and green mudstones with variably abundant siltstone laminae and scattered thin- to medium-bedded sandstones, limestone nodules and units of nodular cephalopod limestone. Lavas and thin tuff beds are occasionally present.

Lower and upper boundaries

The lower boundary is taken at the gradational incoming of silt-laminated, dark green-grey and black mudstones of the Yeolmbridge Formation above the dark green-grey and black mudstones with siliceous thin beds and nodules of the underlying Stourscombe Formation. This contact is not well documented and needs further work.

The upper boundary is not seen as it is everywhere tectonic.

Thickness

Not known due to structure, but unlikely to exceed 100 m.

Distribution

Launceston area [SX 33 84]. The formation is mapped as questionably part of the Transition Group on the Holsworthy sheet (323). It may extend westwards to the north Cornwall coast, where it has been mapped as Transition Group, and eastwards to west Dartmoor, but further work is needed.

Genetic interpretation

Deposits of the crest and flanks of an intra-basinal high.

Biostratigraphical characterisation

Gattendorfia Zone ammonoids, and upper *costatus* Zone (*Wocklumeria* Zone) and *duplicata* Zone (*Gattendorfia* Zone) conodonts demonstrate that the formation ranges from the late Famennian to the early Tournaisian (Selwood, 1960).

Age

Famennian to Tournaisian

6.4 TEIGN VALLEY GROUP (TEVY)

The Teign Valley Group is a new name proposed to replace the succession commonly referred to historically as Lower Culm. The group, broadly of Mississippian age, mainly comprises strata referable to the hemipelagic facies. The group crops out in north Devon and south Somerset, extending east of Barnstaple, and north Cornwall–south Devon, including the type area of the Teign Valley (Figure 21). The northern outcrop is largely continuous, whereas the southern outcrop is commonly broken by thrusts. This tectonic disruption and presence of overfolds has resulted in difficulties in determining a lithostratigraphical succession. Different lithostratigraphical schemes evolved for distinct thrust sheets, resulting in a plethora of names (Edmonds et al., 1975).

There is some uncertainty as to which group the sandy turbidites on the southern margin of the Culm Basin belong. Those of the St Mellion outlier, situated at the southern margin of the Culm Basin, namely the St Mellion and Brendon formations, range from Tournaisian to earliest Namurian and belong to the Teign Valley Group. The status of the earliest Namurian Ugbrooke Sandstone Formation is more difficult as it has been mapped as part of the South Devon Basin succession. Further fieldwork would be needed to resolve the issue, as it might be a thrust slice, sourced from the Culm Basin to the north. Its relationship to the underlying Teign Valley Group is fairly well constrained in that its base is either Namurian E or H in age, suggesting a link with the St Mellion outlier. The formation has been placed in the Teign Valley Group pending further investigation.

The deformation of the Mississippian succession has made attempts at estimating the thickness of the group difficult. The group is estimated to be about 230 m thick in the Okehampton area of the south crop, derived from Dearman (1959).

The base of the Teign Valley Group is taken at the onset of anoxic bottom conditions in the earliest Tournaisian, generally in the latest *Gattendorfia* Zone. In most places the base is easily recognised as the black anoxic mudstones that overlie generally more oxidic, green, and purple and green, mud-dominated sequences of the Tamar or Exmoor groups. However, in the South Devon Basin, the black mudstones cannot be separated easily from the dark grey mudstones of

the underlying Saltash Formation (early Devonian to early Carboniferous) and have therefore been included within the latter, which forms part of the predominantly Devonian, Tamar Group. The top of the group is taken at the base of the Crackington Formation in the Culm and North Devon basins, with the exception of the Launceston Sub-basin, where it is taken at the base of the Bealsmill Formation.

The group comprises black mudstones, cherts and limestones with local sandy or carbonate turbidite systems. Locally in north Cornwall, north Dartmoor and south Devon, spilitic lavas, tuffs and volcanic breccias dominate, forming the **Tintagel Volcanic Formation**. Subordinate tuff beds are also locally present within the Codden Hill Chert Formation. Cherts interbedded with shales, limestones and tuffs are common within the Brigantian succession throughout the Culm Basin. The names for the basal black mudstones have been rationalised and now comprise the **Combe Mudstone Formation** in the east, the **Trambley Cove and Barras Nose formations** in the west and the **Meldon Shale and Quartzite Formation** in north Dartmoor. The plethora of names for the chert formation has been reduced to a single **Codden Hill Chert Formation** in the North Devon Basin and **Teign Chert Formation** in the Culm Basin. The mudstones in particular are affected by regional metamorphism associated with Variscan tectonism, resulting in the development of slates and phyllites.

The group was deposited within an anoxic, deep marine environment with subordinate influx of carbonate and siliciclastic turbidites. The carbonate platform of South Wales–Bristol forms a source for many of the carbonate turbidites, notably the **Bampton and Westleigh Limestone formations**, whereas uplift to the south may have sourced much of the siliciclastic turbidites, namely the **St Mellion and Brendon formations**. Radiolarian cherts were probably deposited within a low-energy, deep-water environment.

The presence of post-*Gattendorfia*/ pre-*Pericyclus* Zone conodonts (Matthews, 1969) is indicative of an early Tournaisian age for the base of the group. The Barras Nose Formation yields conodonts indicative of late Tournaisian to late Asbian age (Freshney et al., 1972). Tournaisian coral and brachiopod faunas have been recognised in the basal limestones of the Buckator Formation (Freshney et al., 1972), though conodonts range from late Tournaisian to Brigantian for the formation as a whole. The Codden Hill Chert Formation in the south crop yields late Tournaisian conodonts and ammonoids indicative of a Brigantian (P_{1a} to P_{2a} Zones).

The proposed scheme, detailed below, rationalises the abundant local names currently used in the Teign Valley Group, especially the chert formations.

NORTHERN MARGIN AND NORTHERN SUB-BASIN

6.4.1 Doddiscombe Formation (DDC)

Name

The formation was originally referred to as the Basement Beds (Ussher, 1887) and part of the Lower Culm Measures (Ussher, 1900). Subsequently, it has been termed part of the Basement Formation (Swarbrick, 1962), part of the Pilton Beds (Prentice, 1960b), part of the Pilton Shales (Edmonds et al., 1979) and the Landkey Formation (Jackson, 1991). The unit was described as the Doddiscombe Beds (Webby and Thomas, 1965), with this name retained during the current definition, but redefined as a formation.

Type section

Doddiscombe Quarry [SS 9845 2329], 3 km north-east of Bampton, north-east Devon. There are 6.9 m of mudstone,

pale to dark grey, massive to planar laminated. Upper and lower boundaries not exposed.

Lithology

Hard, black, slightly siliceous, finely laminated mudstones with sparse very thin siltstone beds. There are scattered thin lenticular chert and phosphate nodules and sparse impure limestones and local pale calcareous mudstones. The formation is rarely fossiliferous.

Lower and upper boundaries

Between Brushford and Wellington, the lower boundary is taken at the incoming of hard black finely laminated unfossiliferous slightly siliceous mudstones of the Doddiscombe Formation above the soft medium to dark grey mudstones with scattered very thin fossiliferous limestones, siltstones and sandstones of the underlying Pilton Mudstone Formation. West of South Molton, the lower boundary is taken at the incoming of dark grey to black rarely fossiliferous slightly siliceous, finely laminated mudstones (Unit D of the Pilton Beds of Prentice, 1960b), known to equate with the Doddiscombe Formation, above the fossiliferous mudstones with thin sandstones and siltstones of the underlying Pilton Mudstone Formation. The Doddiscombe Formation has not been mapped by BGS west of South Molton; instead it has been included in the Pilton Mudstone Formation and/or the Codden Hill Chert Formation. Further work is therefore needed.

Between Brushford and Wellington, the upper boundary is taken at the incoming of thin to medium bedded soft siliceous mudstones with impure limestones and cherts of the Bampton Limestone Formation above the hard, black, finely laminated unfossiliferous cherty mudstones of the underlying Doddiscombe Formation. West of South Molton, the upper boundary is taken at the incoming of dark grey interbedded siliceous mudstones and shaly mudstones of the overlying Codden Hill Chert Formation above the dark unfossiliferous slightly siliceous mudstones (Unit D of the Pilton Beds of Prentice, 1960b), known to equate with the Doddiscombe Formation. Neither this boundary, nor the Doddiscombe Formation has been mapped by BGS west of South Molton and further work is needed.

Thickness

Between 8 and 80 m; the lower thickness is likely to be tectonic.

Distribution

Between Brushford (SS 92 26) and Wellington (ST 13 20), Somerset. Known to extend west of South Molton to the Barnstaple area (SS 50 33) as the dark unfossiliferous silty mudstones, Unit D, of the Pilton Beds of Prentice (1960b). This unit has not been mapped by BGS west of South Molton and further work is needed.

Regional correlation

May extend southwards under the Culm synclinorium as the Combe Mudstone and the Barras Nose formations of the Mississippian south crop.

Genetic interpretation

Starved basinal deposit

Biostratigraphical characterisation

A single Courceyan goniatite is known from the formation. The upper part of the underlying Pilton Mudstone Formation contains trilobites and goniatites ranging from the Tournaisian *Gattendorfia* Zone possibly into the *Ammonellipsites* Zone

s.l. (Tn₂). The lower part of the overlying Codden Hill Chert Formation contains early Viséan (late Chadian) goniatites of the *Fascipericyclus-Ammonellipsites* Zone, while the overlying Bampton Limestone Formation yields conodonts and goniatites of the upper part of the *Ammonellipsites* Zone s.l.. The Doddiscombe Formation is therefore constrained as mid/late Tournaisian to possibly earliest Viséan.

Age

Tournaisian to early Viséan

6.4.2 Codden Hill Chert Formation (COH)

Name

Originally described as the Codden Hill Beds (Ussher, 1887), it has variously been referred to as the Chert Beds (Prentice, 1960b), Codden Hill Chert (Edmonds et al., 1985) and Codden Hill Group (Jackson, 1991), with component Tawstock, Hearson and Rubble Hills formations. The unit is here redefined as a formation.

Type sections

Quarry at the western end of Codden Hill, Bishop's Tawton, north Devon [SS 5696 2972]. Quarry exposes about 20 m of bedded cherts with thin siliceous shaly partings and beds in the middle of the formation (Edmonds et al., 1985). Neither the lower or upper boundary of the formation is seen.

Lithology

Lower half (Tawstock Formation of Jackson, 1991) comprises thin- to medium-bedded pale and dark grey siliceous mudstones, shaly mudstones and cherts. Upper half (Hearson and Rubble Hills formations of Jackson, 1991) comprises thin to medium bedded limestones turbidites and mudstones with streaky laminated cherts in the uppermost part. Two thin tuffs are present and pectinoid bivalves are common in upper half.

Facies variations mapped on sheet 293 (Barnstaple) by Edmonds et al (Edmonds et al., 1985) have been shown by Jackson (1991) to be illusory and due to faulting resulting in stratigraphic omissions. Similarly a facies recognised by Prentice (1960b) in the Fremington area and dominated by limestones and mudstones has been shown by Jackson (1991) to be the upper half of the formation with the lower half thrust out.

Lower and upper boundaries

The lower boundary is taken at the incoming of thin bedded dark grey siliceous mudstones and shaly mudstones of the Codden Hill Chert Formation above the dark grey slightly siliceous mudstones of the Doddiscombe Formation (Unit D of the Pilton Beds of Prentice 1960b). The Doddiscombe Formation has not been mapped on sheet 293 (Barnstaple) by Edmonds et al (1985), being included in the Pilton Mudstone Formation and/or Codden Hill Chert Formation. Further work is needed.

West of South Molton, the upper boundary is taken at the incoming of dark grey to black pyritic mudstones with thin siltstones of the overlying Dowhills Mudstone Formation above the streaky laminated cherts and mudstones of the Codden Hill Chert Formation. The boundary is taken at the top of the highest chert bed. The Dowhills Mudstone Formation (Limekiln Beds of Prentice, 1960b), was included by Edmonds et al. (1985) on Sheet 293 (Barnstaple) in the Crackington Formation. Further work is needed.

Thickness

Some 190 m

Distribution

Between Fremington and South Molton, North Devon (SS 70 28).

Regional correlation

Passes east into the Bampton Limestone Formation. Probably passes southwards beneath the Culm Synclinorium into the Teign Chert Formation.

Genetic interpretation

Starved basinal deposits with limestone turbidites.

Biostratigraphical characterisation

Late Chadian goniatites of the *Fascipericyclus-Ammonellites* Zone occur in the middle of the formation, while the occurrence of Courceyan goniatites in the underlying Doddiscombe Formation suggests that the Tournaisian/Visean boundary is contained in the lower part of the formation. Late Visean P_{1d}-P_{2b} goniatite faunas occur in the upper part of the formation. Cherts at the top of the formation are thought by Jackson (1991) to be possibly Namurian by comparison with the South Wales and the Bristol succession.

Age

Late Tournaisian to early Namurian

6.4.3 Bampton Limestone Formation (BPLM)

Name

Originally defined as part of the Lower Culm Measures (Ussher, 1900), it was considered part of the Basement Formation (Swarbrick, 1962) and referred to as the Chert Formation (Swarbrick, 1962). Subsequently, it was named the Bampton Limestone Group (Webby and Thomas, 1965) and is here redefined as a formation.

Type section

Kersdown Quarry, Bampton, Somerset [SS 964 222]. The disused quarry exposes all but the lowermost and top-most beds of the formation, all three divisions being seen (Whiteley, 2004). Here, 40 m of uniform, thin-bedded siliceous mudstone interbedded with a few thin silicified limestone beds occupies the core of a tight anticline. These are overlain by 7 m of cherts with interbedded mudstone and limestone of the Kersdown Chert Member. The upper part of the quarry shows a gradation into overlying black, faintly laminated siliceous mudstone at the base and alternations of limestone and mudstone above, up to 15 m thick.

Reference section

North-west face of Kiln Cottage Quarry, Bampton, north-east Devon [SS 950 222]: 23 m of mudstone and limestone from the uppermost part of the Bampton Limestone Formation (Whiteley, 2004). Overlain by 5–6 m exposure of dark grey mudstone and thin siltstone of the basal part of Dowhills Mudstone Formation.

Formal subdivisions

The Kersdown Chert Member, from the middle of the formation, is formally defined. The lower and upper parts of the formation, comprising silicified mudstone with limestone, have been referred to as Hayne Beech Member and Bailey's Member, respectively (Whiteley, 2004). These are mapped as Bampton Limestone Formation, undifferentiated.

Lithology

Thin- to medium-bedded limestones, cherts, siliceous radiolarian mudstones (termed cherts in some literature) and

mudstones. The limestones are locally partly silicified. The proportion of limestone, chert and mudstone varies vertically allowing a threefold division in the Bampton area; elsewhere these divisions have not been proved and there is evidence that north of Bampton the formation is dominated by mudstones and cherts. At the base, the informal Hayne Beech Beds comprise soft, pale weathering, siliceous radiolarian laminated shaly mudstones (cherts of literature) with some impure argillaceous limestones. Above, the Kersdown Chert Member comprises laminated cherts with interbedded shaly mudstones and a few limestones. The upper unit, the informal Bailey's Beds consists of black shaly mudstones with limestones and minor cherts, the top 4 m yields abundant spirally striated goniatites and pectinoid bivalves (*Posidonia* Beds).

Lower and upper boundaries

Between Brushford and Ashbrittle the lower boundary is taken at the incoming of thin- to medium-bedded soft siliceous mudstones with impure limestones and cherts of the Bampton Limestone Formation above the hard black finely laminated unfossiliferous cherty mudstones of the underlying Doddiscombe Formation.

Between Brushford and Ashbrittle the upper boundary is taken at the incoming of dark grey, predominantly unfossiliferous, finely laminated silty mudstones with scattered siltstones of the overlying Dowhills Mudstone Formation above the highest limestone bed of the Bampton Limestone Formation.

Thickness

About 80 m

Distribution

Between Brushford (SS 92 26) and Ashbrittle (ST 04 21), Somerset.

Regional correlation

Passes westwards into the Codden Hill Formation and eastwards into the Westleigh Limestone Formation. Thought to pass southwards beneath the Culm synclinorium into the Teign Chert Formation of the south crop.

Genetic interpretation

Starved basinal deposits with limestone turbidites.

Biostratigraphical characterisation

The lower part of the formation is undated but the underlying Doddiscombe Formation is Courceyan in the Barnstaple area. Conodonts and goniatites of the upper part of the *Ammonellites* Zone s.l. are found in the Kersdown Chert Member suggesting an early to mid Visean age. The upper part of the Bailey's Beds yields P_{1b} to P_{1d} goniatites. The formation therefore ranges from possibly late Tournaisian to late Visean (Brigantian).

Age

Late Tournaisian to late Visean

6.4.3.1 KERSDOWN CHERT MEMBER (KSDC)

Name

Originally defined as the Middle Bampton Cherts (Thomas, 1962), the unit was renamed the Kersdown Beds (Webby and Thomas, 1965). The unit is here redefined as the Kersdown Chert Formation.

Type section

Kersdown Quarry [SS 964 222], Bampton, Somerset. The

entire member, 7 m thick, is seen together with lower and upper boundaries (Whiteley, 2004).

Lithology

Dark grey to black laminated thin- to thick- bedded blocky cherts with interbedded shaly siliceous mudstones and a few partly silicified limestones. Scattered chert nodules occur within the limestones.

Lower and upper boundaries

The lower boundary is taken at the incoming of abundant blocky chert with few limestones of the Kersdown Chert Member above the siliceous radiolarian shaly mudstones with some silicified limestones forming the lower part (Hayne Beech Beds) of the Bampton Limestone Formation.

The upper boundary is taken at the incoming of black shaly mudstones with limestones and minor cherts (Bailey's Beds), forming the upper part of the Bampton Limestone Formation, above the blocky cherts with few limestones of the Kersdown Chert Member.

Thickness

Some 7 m at type locality.

Distribution

Between Brushford [SS 92 26] and Ashbrittle [ST 04 21], Somerset.

Genetic interpretation

Starved basinal deposits and limestone turbidites.

Biostratigraphical characterisation

The member contains goniatites and conodonts with a range from early to mid Viséan.

Age

Viséan

6.4.4 Westleigh Limestone Formation (WST)

Name

Previously referred to as the Westleigh Limestone Group (Thomas, 1962) and component Lower Westleigh Limestones and Upper Westleigh Limestones (Thomas, 1963a, b), the unit is here redefined as the Westleigh Limestone Formation.

Type section

Disused West Whipcott Quarry [ST 069 186], 1.5 km north of Westleigh, east Devon. The section exposes 25 m of folded and faulted thin- to thick-bedded limestones and mudstones of the (upper) Westleigh Limestone Formation (Whiteley, 2004).

Lithology

The lower part (informally known as the Lower Westleigh Limestone) comprises thin- bedded, platy, fine-grained (mud and silt grade), commonly partly silicified limestones. Shaly mudstone interbeds are sparsely developed. The upper part (informally known as the Upper Westleigh Limestone) comprises thin to massive beds of coarse, locally conglomeratic, bioclastic/ooidal/pelloidal calcarenite interbedded with subordinate mudstones and calcilutites. Silicification is locally present. The Lower Westleigh Limestone is only present around Westleigh; to the north it passes into the Upper Westleigh Limestone.

Lower and upper boundaries

Around Westleigh, the lower boundary is taken at the incoming of thin-bedded fine-grained limestones of the (lower) Westleigh Limestone Formation above the black, hard cherty mudstones of the underlying Doddiscombe Formation. To the north it is taken at the incoming of thin- to thick-bedded coarse calcarenites and mudstones of the (upper) Westleigh Limestone Formation above the black hard cherty mudstones of the underlying Doddiscombe Formation.

The upper boundary is taken at the incoming of dark grey unfossiliferous finely laminated silty mudstones with scattered siltstones of the overlying Dowhills Mudstone Formation above the highest limestone bed of the Westleigh Limestone Formation.

Thickness

Not known but probably about 100 m.

Distribution

Between Ashbrittle [ST 04 21], and Wellington [ST 13 20], Somerset.

Regional correlation

Sharp contact to west with coeval Bampton Limestone Formation interpreted as due to submarine sliding.

Genetic interpretation

The lower part of the formation is problematical, possibly forming as a slope deposit representing background sedimentation; the upper part comprises limestone turbidites.

Biostratigraphical characterisation

The lower Westleigh Limestone Formation is undated but probably extends into the early/mid Viséan as it rests on the late Tournaisian/early Viséan Doddiscombe Formation. The upper Westleigh Limestone Formation yields late Asbian (B₂) and Brigantian (P_{1d} to P_{2a}) goniatites.

Age

Viséan

6.4.5 Dowhills Mudstone Formation (DHLS)

Name

Originally termed the Limekiln Beds (Prentice, 1960b), the unit has been termed the Ashton Formation (Chesher, 1968) in the South crop of the Culm synclinorium and part of the Crackington Formation (Edmonds et al., 1985) in the north crop. The unit was named and defined as the Dowhills Beds by Webby and Thomas (1965), a name that is retained but redefined as a formation in this study.

Type section

Stream section 300 m to the west-south-west of Dowhills Farm, 3 km east of Bampton, north-east Devon [SS 9928 2173]: intermittent exposure of up to 15 m of dark grey fissile mudstone.

Reference section

North-west face of Kiln Cottage Quarry, Bampton, north-east Devon [SS 950 222]: 5–6 m exposure of basal part of formation, comprising unfossiliferous, finely laminated mudstone and thin siltstone, locally micaceous and rich in plant debris (Whiteley, 2004). Underlain by 23 m of mudstone and limestone of the Bampton Limestone Formation.

Formal subdivisions

Ashton Mudstone Member

Lithology

Dark grey to black, rather soft, pyritous mudstones with scattered thin siltstone and sandstone beds (less than 10%). There are some thin chert beds on the north crop of the Culm synclinorium. The Ashton Mudstone Member is the lateral equivalent of the formation on the south crop; it is thought to be characterised by more abundant and thicker sandstones. Further work is needed to confirm this.

Lower and upper boundaries

In the north crop of the Culm synclinorium, between Brushford and Ashbrittle, the lower boundary is taken at the incoming of dark grey predominantly unfossiliferous finely laminated silty mudstones with scattered siltstones of the Dowhills Mudstone Formation above the highest limestone bed of the underlying Bampton Limestone Formation. Between Ashbrittle and Wellington, the lower boundary is taken above the highest limestone bed of the underlying Westleigh Limestone Formation. West of South Molton, the lower boundary is taken at the incoming of dark grey to black, pyritic mudstones above the streaky laminated cherts and mudstones of the underlying Codden Hill Chert Formation. The boundary is taken at the top of the highest chert bed. These pyritic mudstones, the Limekiln Beds of Prentice (1960b), were included by Edmunds et al. (1985) in the Crackington Formation. Further work is needed in this area. In the south crop of the Culm synclinorium, between Exeter and the Teign valley, the lower boundary is taken at the incoming of bluish grey micaceous mudstones with scattered thin sandstones and siltstones of the Ashton Mudstone Member above the fossiliferous interbedded cherts, limestones and mudstones (Posidonia Beds) of the Teign Chert Formation.

The upper boundary is gradational and taken at the incoming of more abundant and relatively thicker sandstones of the overlying Crackington Formation above the mudstones with less than 10% sandstone in the underlying Dowhills Mudstone Formation.

Thickness

From 210 to 430 m on the south crop, 30 m on the north crop.

Distribution

On the north crop of the Teign Valley Group between Bideford (SS 45 27), north Devon and Wellington (ST 13 20), Somerset. Between the Bideford area (SS 45 27) and Brushford (SS 92 26) west Somerset, the formation has not been mapped by BGS. In this area it probably equates with the Limekiln Beds (Prentice, 1960b), included in the Crackington Formation by Edmunds et al. (Edmunds et al., 1979). Further work is needed in this area to resolve this.

Due to thrusting along the south crop of the Teign Valley Group, the formation is only seen between the Teign valley [SX 84 84] and Exeter [SX 90 92], Devon. It may be present in the Okehampton area [SX 59 94] but has not been mapped, probably being included in the Crackington Formation. Further work is needed.

Genetic interpretation

Possibly starved basinal muds with some turbidite siltstones and sandstones.

Biostratigraphical characterisation

North crop: the basal parts of the formation in the Bampton area, north Devon yield Brigantian (P_{2a}) and early Namurian (E_2) goniatites. The youngest date from the formation in this area is R_1 and the earliest date in the overlying Crackington

Formation is R_{2c} . Between the Bideford and Brushford areas the upper part of the formation contains R_1 and R_2 goniatites while the top of the underlying Codden Hill Formation yields P_{2b} goniatites. The earliest date in the overlying Crackington Formation is H_{1b} suggesting diachroneity or structural complications.

South crop: the youngest date in the underlying Teign Chert Formation is P_{2a} , while E_{2b} goniatites have been obtained from the upper part the Dowhills Mudstone Formation in the Teign valley. This suggests that the formation may possibly range down into the topmost Brigantian. The top of the formation is diachronous ranging from H_{1a} to R_1 .

Age

Brigantian to Marsdenian

6.4.5.1 ASHTON MUDSTONE MEMBER (ANSH)

Name

Previously referred to as the Argillaceous Series (Morton, 1958), it was renamed the Ashton Formation (Chesher, 1968) and redefined the Ashton Shale Member (of Crackington Formation) (Edwards and Scrivener, 1999).

Type section

Road section, 230 m south of Spara Bridge, Lower Ashton, middle Teign valley, south Devon [SX 8432 8385]. The unpublished section exhibits 2 m of mudstones with plant fragments and thin black sooty beds with goniatites.

Lithology

Greish blue, rusty weathering mudstones with scattered thin sooty goniatite-bearing mudstones. Scattered thin siltstones and sandstones (up to 7 cm thick) form less than 10 per cent of the member. The sandstones are commonly medium grained, quartzitic and feldspathic and thought to be derived from the south. Plant fragments are locally abundant.

Lower and upper boundaries

The lower boundary is taken at the incoming of bluish grey micaceous mudstones with scattered thin sandstones and siltstones of the Ashton Mudstone Member above the fossiliferous interbedded cherts, limestones and mudstones (Posidonia Beds) of the Teign Chert Formation.

The upper boundary is taken at the gradational incoming of more abundant and relatively thicker sandstones of the overlying Crackington Formation above the mudstones with less than 10 per cent sandstone of the Ashton Mudstone Member.

Thickness

From 210 to 430 m

Distribution

Teign valley (SX 84 84), and Exeter (SX 90 92) areas, south Devon. May extend west into Okehampton area (SX 59 94), where it has been included in the Crackington Formation, but further work is needed.

Regional correlation

Passes north below Culm synclinorium into the Dowhills Mudstone Formation.

Genetic interpretation

Possibly starved basin deposits, but further work is needed as they may be dominantly turbiditic.

Biostratigraphical characterisation

The youngest age in the underlying Teign Chert Formation is P_{2a}, while E_{2b} goniatites have been obtained from the upper part the member in the Teign valley. This suggests that the member may possibly range down into the topmost Brigantian. The top of the member is diachronous ranging from H_{1a} to R₁.

Age

?Brigantian to Kinderscoutian

CENTRAL SUB-BASIN

6.4.6 Barras Nose Formation (BNF)

Name

Formerly known as the Lower Blue-black Slates (Parkinson, 1903), it was referred to as the Barras Nose Beds (Dewey, 1909) and subsequently formalised as the Barras Nose Formation (Edmonds, 1974).

Type section

Coastal cliff, on the west side of Barras Nose [SX 0525 8936], Tintagel, North Cornwall: the upper 12 m of the formation and the contact with the overlying Tintagel Volcanic Formation are proved in the section; the faulted base of the formation is also seen in the section (Freshney et al., 1972).

Lithology

Dark grey to black mudstones with variably abundant very thin beds and laminae of cross laminated and graded siltstone and sandstone. The mudstones contain scattered sideritic, carbonaceous silty sandstone and argillaceous limestone nodules, containing goniatites. A thin fossiliferous limestone is present at or very near the top of the formation. Volcanic material locally occurs as lenses of sheared vesicular lava and tuff.

Lower and upper boundaries

The depositional lower boundary is not seen as it is everywhere tectonic.

The upper boundary is taken at the sharp contact of tuffs, lavas and agglomerates of the overlying Tintagel Volcanic Formation with the mudstones and thin siltstones of the Barras Nose Formation.

Thickness

Low angle thrusts and slides, together with recumbent folding make thickness estimates extremely difficult. In excess of 21 m is recorded on the coast in the Boscastle/Tintagel area.

Distribution

The formation occurs between the Boscastle/Tintagel area [SX 07 89], north Cornwall and the Launceston area [SX 30 78], east Cornwall. The outcrop in east Cornwall (BGS 1993) needs further investigation.

Regional correlation

The formation passes eastwards into the lower part of the Meldon Shale and Quartzite Formation and possibly northwards into the Doddiscombe Formation on the northern limb of the Culm synclinorium.

Genetic interpretation

Starved basinal sediments

Biostratigraphical characterisation

The limestone at the top of the formation has been dated at two localities by conodonts as Cu 11δ/111α and Cu 11β/γ zones, suggesting that it is diachronous. This places the limestone within the range of the *Scaliognathus anchoralis*/*Dolignathus latus* Zone to the *Gnathodus texanus* Zone.

Age

Late Tournaisian to Viséan

6.4.7 Tintagel Volcanic Formation (TVF)

Name

Initially referred to as the Volcanic Series (Parkinson, 1903) was defined as the Tintagel Volcanic Formation by Freshney et al. (1972).

Type section

Craggs on the north side of the road leading to the beach at Trebarwith Strand [SX 053 865], 2 km south of Tintagel, north Cornwall: the section exposes about 70 m of tuffs with subordinate agglomerates overlying the mudstones of the Barras Nose Formation (Freshney et al., 1972). The basal contact is seen but the upper contact is not.

Lithology

Poorly sorted green fine- to coarse-grained basaltic calcareous tuffs with subordinate agglomerates and recrystallised carbonate-rich basaltic lavas. A few thin pink limestones occur scattered throughout the formation.

Lower and upper boundaries

The lower boundary is taken at the sharp contact of tuffs, lavas and agglomerates of the Tintagel Volcanic Formation with the siltstone-stripped mudstones of the underlying Barras Nose Formation.

The upper boundary is taken at the sharp contact of the finely banded dark to pale grey mudstones with thin siltstones of the overlying Trambley Cove Formation with the tuffs, lavas and agglomerates of the Tintagel Volcanic Formation.

Thickness

Up to 90 m

Distribution

Tintagel area [SX 06 89] to south of Launceston [SX 32 77], Cornwall.

Regional correlation

May be related to volcanic rocks in the Teign Chert Formation in east Dartmoor and in the Meldon Shale and Quartzite Formation in the Okehampton area, north Dartmoor. However, no continuity has been proved.

Genetic interpretation

Represents a major pulse of predominantly explosive volcanic activity in a starved basinal setting.

Biostratigraphical characterisation

Tournaisian–Viséan conodonts have been found in the formation but the best constraint comes from the limestone at the top of the underlying Barras Nose Formation. This has been dated at two localities by conodonts as Cu 11δ/111α and Cu 11β/γ suggesting that it is diachronous. This places the base of the Tintagel Volcanic Formation within the range of the *Scaliognathus anchoralis*/*Dolignathus latus* Zone to the *Gnathodus texanus* Zone i.e. Late Tournaisian to

mid Viséan. The overlying Trambley Cove Formation has yielded no dateable faunas.

Age

Late Tournaisian to Viséan

6.4.8 Trambley Cove Formation (TCF)

Name

Formerly known as the Upper Blue-black Slates (Parkinson, 1903), it was referred to as the Trambley Cove Beds (Dewey, 1909) and subsequently formalised as the Trambley Cove Formation (Edmonds, 1974).

Type section

Coastal cliff at Trebarwith Strand [SX 0506 8659], 2 km south of Tintagel, north Cornwall. The section exposes 15 m of mudstones with thin siltstones overlying the Tintagel Volcanic Formation (Freshney et al., 1972). Tuffaceous mudstones are common in the lowermost part. Basal contact seen; upper contact is a thrust seen in the section and overlain by Late Devonian slates.

Lithology

Pale to dark grey and black, finely colour-banded mudstone with thin beds of commonly cross-bedded siltstone. The siltstone and locally the mudstone are silicified, giving the succession a cherty appearance. Greenish brown tuffaceous mudstones are locally present, especially towards the base.

Lower and upper boundaries

The lower boundary is taken at the sharp contact of the finely banded dark to pale grey mudstones with thin siltstones of the Trambley Cove Formation with the underlying tuffs, lavas and agglomerates of the Tintagel Volcanic Formation.

The upper boundary is faulted. However, it is thought that as the formation is locally silicified, it may originally have passed up into the Teign Chert Formation (Freshney et al., 1972).

Thickness

At least 15 m

Distribution

Tintagel area [SX 06 89] to south of Launceston [SX 32 77], Cornwall. Outcrop in the Launceston area (BGS 1993) needs further investigation.

Regional correlation

Passes eastwards into the Meldon Shale and Quartzite Formation and possibly northwards into the Doddiscombe Formation on the northern limb of the Culm synclinorium.

Genetic interpretation

Starved basinal deposit

Biostratigraphical characterisation

Constrained by late Tournaisian to mid Viséan conodonts at the base of the underlying Tintagel Volcanic Formation and late Viséan ammonoids from the upper part of the possibly overlying Teign Chert Formation.

Age

Late Tournaisian to Viséan

6.4.9 Meldon Shale and Quartzite Formation (MQF)

Name

Historically, the formation has been referred to as part of

the Lower Culm Measures (Ussher, 1887, 1892; Dearman, 1959), the latter author also referring to it as Lower Shale and Quartzite Group, Volcanic Group, Upper Shale and Quartzite Group. The unit was defined as the Meldon Shale and Quartzite Formation (Edmonds et al., 1968).

Type section

Meldon Quarry [SX 5725 9305], 2 km south west of Okehampton, central Devon: the formation is exposed in several folds in the core of the Meldon Anticline. As the quarry is active, faces will vary with time. The entire sequence is usually exposed. The junction with the underlying Meldon Slate with Lenticles Formation is faulted but that with the overlying Teign Chert Formation is seen (Dearman, 1959).

Lithology

The formation comprises black shaly mudstones with variably abundant (locally exceeding 50 per cent) thin beds (up to 15 cm) and laminae of white and reddish brown quartzite. Radiolaria are abundant in the quartzites in the upper part of the formation. A 26–61 m-thick unit of thin-bedded to massive, locally cross-bedded ‘keratophytic’ tuffs and agglomerates is present in the upper part of the formation. Most of the outcrop occurs in the metamorphic aureole of the Dartmoor Granite, with dark brown hornfelsed mudstones.

Lower and upper boundaries

The lower boundary is taken at the incoming of black mudstones with abundant thin beds and laminae of quartzite above the dark brown hornfelsed mudstones with scattered thin beds and lenses of pale green feldspathic siltstone of the underlying Meldon Slate-with-Lenticles Formation. The latter informal unit may be referable to the Hyner Mudstone Formation or the Famennian Stouscombe Formation as suggested by Selwood (1971). The Meldon Slate-with-Lenticles Formation exhibits early ?D1 isoclinal folds deformed by later more open D2 structures. As the Meldon Shale and Quartzite Formation only exhibits open folds, it is possible that the boundary between the two formations is a thrust. Further work is needed.

Thickness

Between 126 and 161 m

Distribution

Mainly limited to the Meldon Anticline, of the Okehampton area [SX 59 94], central Devon. Mapped as far west as Launceston [SX 33 84] in thrust slices (BGS, 1993) but the status of this crop needs further investigation.

Regional correlation

Probably passes laterally into the Combe Mudstone Formation of the Teign valley area [SX 84 87] to the east and into the combined Barras Nose Formation, Tintagel Volcanic Formation and Trambley Cove Formation of the north Cornish coast [SX 05 89] to the west. It probably passes northwards beneath the Culm synclinorium into the Doddiscombe Formation of north Devon.

Genetic interpretation

The black mudstones represent starved basinal sediments, the quartzites are possibly turbidites derived from a tilt block ‘high’ to the south. Further work is needed.

Biostratigraphical characterisation

Brigantian (P_{1c}-P_{2a}) goniatites from the overlying Teign Chert Formation provide a maximum age. No fossils

have been obtained from the underlying Meldon Slate-with-Lenticles Formation, so a minimum age is unconstrained.

Age

Tournaisian–Visean

6.4.10 Combe Mudstone Formation (CMSH)

Name

Previously referred to as the Combe Formation (Chesher, 1968) and Combe Shale (Selwood et al., 1984), the unit is here redefined as the Combe Mudstone Formation.

Type sections

Road (B3193) cutting north-west of Lower Ashton [SX 8402 8476 to 8411 8446], Teign valley, south Devon: exposes most of the formation, which is intruded by two dolerite sills (Selwood et al., 1984).

Lithology

Very fissile bluish black or black ‘shales’, locally characterised by white, silty laminations and closely spaced vertical joints, particularly in higher horizons. Siliceous nodules become common in the upper part. The formation is unfossiliferous apart from questionable wood fragments.

Lower and upper boundaries

The lower boundary is taken at the incoming of bluish black and black mudstones of the Combe Mudstone Formation above the olive green and pale grey mudstones of the underlying Trusham Mudstone Formation.

The upper boundary is taken at the incoming of interbedded cherts and siliceous mudstones of the overlying Teign Chert Formation above the bluish black and black mudstones of the Combe Mudstone Formation. The boundary taken at the base of the first bedded chert.

Thickness

From 45 m in the Ilsington area, thickening northwards to 90–200 m in the Teign valley area. Tectonic thickening cannot be ruled out.

Distribution

Teign Valley [SX 84 84] and Ilsington area [SX 78 76], east Dartmoor, south Devon.

Regional correlation

Probably passes westwards into the Meldon Shale and Quartzite Formation of the Okehampton area [SX 59 94] and northwards beneath the Culm synclinorium into the Doddiscombe Formation of North Devon [SS 70 30].

Genetic interpretation

Starved basin with anoxic bottom conditions, though probably not particularly deep.

Biostratigraphical characterisation

No faunas, but constrained by *Gattendorfia* Zone faunas in the underlying Trusham Mudstone Formation and late Visean B₂ faunas in the base of the Posidonia Beds in the uppermost part of the overlying Teign Chert Formation. The age is therefore Tournaisian to possibly early Visean.

Age

Tournaisian to early Visean

6.4.11 Teign Chert Formation (TCH)

Name

Historically, the formation has been referred to as part of the Lower Culm Measures (Ussher, 1887, 1892) and Calcareous Group of the Lower Culm Measures (Dearman, 1959). Subsequently authors have referred to the unit as the Cannapark Limestone and Barracados Cherts (Selwood, 1958), the Spara Bridge Formation (Chesher, 1968) and Meldon Chert Formation (Edmonds et al., 1968). Whiteley (1983) variously referred to the unit as the Pillaton Chert Formation, chert bodies in Crocaden Sandstone Formation and Newton Chert Member (of Brendon Formation), with the term Newton Chert Formation adopted by Leveridge et al. (2002). Selwood et al. (1984) established a Mount Ararat Chert and Teign Chert in the Newton Abbot district. The plethora of nomenclatures is here rationalised as a single Teign Chert Formation.

Type sections

Road section (B3193), west of Lower Ashton [SX 8413 8439 to SX 8427 8415], Teign Valley, south Devon: most of the formation is exposed, from the junction with the underlying Combe Mudstone Formation up to the lowermost part of the Posidonia Beds (Selwood et al., 1984). Contact with the overlying Aston Mudstone Member of the Dowhills Mudstone Formation is not seen. The section mainly comprises cherts with subordinate siliceous shales. Two mapped tuff units are seen. Limestones are restricted to the Posidonia Beds.

Lithology

Thin- to medium-bedded cherts varying from white, grey and green to bluish black and black; rarely jasper red. Beds range from a few millimetres to 0.6 m, generally separated by siliceous mudstone beds and partings. Radiolaria are locally abundant in the cherts and siliceous mudstones. Also present are bluish black mudstones and thin- to medium-bedded argillaceous limestones. The internal stratigraphy is poorly understood, apart from the type area. Some areas are reported to be dominated by mudstone, others by chert or limestone. Manganiferous beds are present in the Teign valley. A variety of volcanic rocks are present in the Teign valley and Ilsington area, south Devon and in the St Mellion area of east Cornwall. They include quartz-keratophyre tuffs, basic spilitic and felsitic lavas. The spilitic lavas occur near the base of the formation in the Teign valley and are up to 12 m thick; units of tuff up to 12 m thick occur throughout.

In the Teign valley the succession comprises interbedded cherts and subordinate mudstones and is overlain by the 30–45 m-thick Posidonia Beds, a distinctive unit at the top of the formation of thin bedded cherts, limestones and shales with abundant pectinoid bivalves and spirally striated goniatites.

South of Ilsington south Devon, a 10 m-thick unit (the ‘Ararat Slate’) of black siliceous slaty mudstone, locally containing decalcified nodules, is present in the lowermost part of the formation.

In the Okehampton area, north Dartmoor, the formation comprises interbedded cherts, limestones and mudstones. Locally limestones and mudstones are dominant and reported to occur in mappable lenticular units. This suggests that some cherts may be silicified limestones. The Posidonia Beds have not been mapped but their fauna occurs in the limestone lenses.

In the St Mellion area of east Cornwall, the lower part of the formation comprises siliceous mudstone with or without scattered chert beds and the upper part comprises

cherts with thin mudstone interbeds. The Posidonia Beds are present.

In the Boscastle area, north Cornwall, the formation is dominated by mudstone; the Wilsey Down Borehole [SX 1797 8890] proved 385 m (not adjusted for dip or folding) of pyritic mudstones with thin crinoidal limestones and a few cherty mudstones and cherts that has been referred to the Teign Chert Formation on the basis of a late Visean goniatite fauna.

Lower and upper boundaries

In the Teign valley and Ilsington area the lower boundary is taken at the incoming of interbedded cherts and siliceous mudstones of the Teign Chert Formation above the bluish black and black mudstones of the underlying Combe Mudstone Formation. The boundary is taken at the base of the first bedded chert.

South of Ilsington, the lower boundary is taken at the sharp boundary of the black mudstones of the 'Ararat Slate' (Teign Chert Formation) or the buff weathering calcareous laminated siltstones at the top of the underlying 'Rora Slate' (?Torpoint Formation).

In the Okehampton area the lower boundary is taken at the incoming of black argillaceous limestones with subordinate black cherts and siliceous mudstones and mudstones of the Teign Chert Formation above the thin bedded mudstones and quartzites of the Meldon Shale and Quartzite Formation

Along the rest of the south crop of the Teign Valley Group, between Dartmoor and Bodmin moor and the north Cornish coast, the formation occurs in thrust slices and basal contacts are tectonic.

In the Teign valley the upper boundary is taken at the incoming of bluish grey micaceous mudstones with scattered thin sandstones and siltstones of the overlying Ashton Mudstone Member of the Dowhills Mudstone Formation above the fossiliferous interbedded cherts, limestones and mudstones (Posidonia Beds) of the Teign Chert Formation.

In the Okehampton and Ilsington areas, the Dowhills Mudstone Formation has not been recognised, the Crackington Formation being mapped overlying the Teign Chert Formation. Further work is needed in these areas at this level. Along the rest of the south crop of the Teign Valley Group, the formation occurs in thrust slices and the upper contact is tectonic.

Thickness

Between 150 and 230 m in the Teign valley, the variation being due to the presence of volcanic rocks. South of Ilsington the formation is at least 70 m thick. In the Okehampton area it is 73 m. Elsewhere along south crop of the Teign Valley Group, tectonics preclude thickness estimates of the formation; a structural thickness of 100 m has been calculated in the St Mellion area, east Cornwall. In the Boscastle area, north Cornwall, the formation proved in the Wilsey Down Borehole (SX 1797 8890) is 385 m thick (not adjusted for dip or folding).

Distribution

Between the north Cornish coast at Boscastle [SX 10 91] and east Dartmoor [SX 84 87], south Devon, including the Launceston area [SX 33 84], the St Mellion area [SX 39 65], Okehampton area [SX 59 94], Teign Valley area [SX 84 84], Ilsington area [SX 78 76] and south of Ilsington [SX 79 74].

Regional correlation

Probably passes northwards beneath the Culm synclino-

rium into the Codden Hill Chert Formation of North Devon [SS 58 30] and southwards into the Winstow Chert Formation of the Tamar valley [SX 43 61], east Cornwall and the Chudleigh area [SX 86 79], south Devon. Thought to pass laterally into and locally overlies the Brendon and St Mellion formations in the St Mellion area [SX 39 65] and to intertongue with the uppermost part of the Boscastle Formation in the Boscastle area [SX 10 91].

Genetic interpretation

The formation represents starved basinal and 'high' deposits. Siliceous lithologies are the result of silica-rich sea-water generated by radiolarian blooms. A wide depth range is suggested by condensed sequences. The limestones are probably turbiditic.

Biostratigraphical characterisation

In east Dartmoor (Teign valley, Ilsington and south of Ilsington) the basal age of the formation is constrained by *Gattendorfia* Zone faunas in the underlying Trusham Mudstone Formation and Rora Mudstone Formation. In the Teign valley, no faunas are present below the Posidonia Beds, which yield B₂ to P_{2a} goniatites. South of Ilsington, the basal 'Ararat Slate' contains a conodont considered to be no younger than the *anchoralis* Zone, while the Posidonia Beds yield P_{1b} to P_{2a} goniatites. In the Okehampton area, Brigantian (P_{1c}-P_{2a}) goniatites occur in the limestone dominant parts of the formation suggesting that the base is possibly much younger here, or there are structural complications. In the St Mellion area the formation contains *anchoralis* Zone (late Tournaisian) and *texanus* to *bilineatus* zone (early to mid Visean) conodont faunas as well as late Visean goniatites from the Posidonia Beds.

Age

Visean

SOUTHERN SUB-BASIN AND SOUTHERN MARGIN

6.4.12 Boscastle Formation (BOSC)

Name

Referred to as the Boscastle Measures (Ashwin, 1958), it has been considered part of the Crackington Formation (Freshney et al., 1972; McKeown et al., 1973).

Type section

Sea cliffs and crags on the south side of Boscastle Harbour [SX 0903 9139 to 0956 9142]. Section exposes the ?lower part of the formation which comprises mudstones with siltstones and packets of sandstones (Selwood et al., 1985). Low-angle faulting, folding and quartz veining is ubiquitous. At the western end of the section the formation tectonically overlies the Trambley Cove Formation.

Lithology

Dark grey to black pyritous mudstones with thin laminated siltstones. Packets of thin- to thick-bedded grey fine- to coarse-grained quartzose sandstones punctuate the formation. Adjacent to intertonguing contacts with the Buckator Formation, the sandstones are calcareous, locally shelly and locally accompanied by thick beds of bioclastic limestone and nodules of silicified limestone. The mudstones are locally burrowed. Rare thin beds of tuffaceous mudstone, and tuffs and lavas also occur.

Lower and upper boundaries

The lower boundary is not seen as it is tectonic. However, the

formation intertongues with the Buckator and Teign Chert formations. Lower boundaries with the Buckator Formation are taken at the gradational appearance of dark grey sandstones and mudstones of the Boscastle Formation above the green grey mudstones with thin calcareous siltstones and limestones of the underlying Buckator Formation. Only an upper boundary is seen with the Teign Chert Formation.

The upper boundary is not seen as it is tectonic. However, the formation intertongues with the Buckator and Teign Chert formations. Upper boundaries with the Buckator Formation are taken at the gradational appearance of green grey mudstones with thin calcareous siltstones and limestones of the underlying Buckator Formation above the dark grey sandstones and mudstones of the Boscastle Formation. Upper boundaries with the Teign Chert Formation are taken at the incoming of silicified siltstones, mudstones and scattered chert beds of the Teign Chert Formation above the interbedded sandstones and mudstones of the Boscastle Formation.

Thickness

Several hundred metres, but may be more or less due to the faulting, thrusting and folding.

Distribution

Between Boscastle (SX 95 91) and Lewannick (SX 27 81), north Cornwall.

Regional correlation

Intertongues with, and passes laterally into the Buckator, Laneast Quartzite and Teign Chert formations. Further work however, is needed on these relationships in inland areas. Mapped on Boscastle (Sheet 322) and Holsworthy (Sheet 323) sheets as Crackington Formation and therefore further work is needed in these areas.

Genetic interpretation

Near-shore setting

Biostratigraphical characterisation

Conodonts from limestones indicative of the *Gnathodus texanus* and *Gnathodus bilineatus* zones prove a mid to late Viséan age, while E_{2c} and H_{1a} goniatites from the mudstones in the upper part of the formation demonstrate it ranges into the early Namurian. It is suggested by Selwood et al. (1985) that on the basis of its intertonguing relationship with the late Famennian to Viséan Buckator Formation that it ranges down into the Famennian but there is no faunal evidence to confirm this.

Age

Viséan to Chokierian

6.4.13 Buckator Formation (BKF)

Name

The formation was named and defined by Freshney et al. (Freshney et al., 1972).

Type section

Low cliff promontory on the landslipped sea cliff, 500 m south-west of Buckator [SX 1175 9321], 3 km north-east of Boscastle, north Cornwall. The section exposes the upper part of a tongue of Buckator Formation overlain by the Boscastle Formation. The junction is said to be conformable by Selwood et al. (Selwood et al., 1985) but was mapped as a low angle fault by Freshney et al. (Freshney et al., 1972). The Buckator Formation comprises 35 m of folded, green

mudstones with two lenticular limestone units. The base of the tongue is not seen.

Lithology

Greenish grey mudstones with scattered thin calcareous siltstones. Several lenticular units of locally shelly limestone up to 0.6 m thick are present. The formation intertongues with the Boscastle Formation, two tongues being present on the north Cornish coast.

Lower and upper boundaries

Lower boundaries with the Boscastle Formation are taken at the gradational appearance of green grey mudstones with thin calcareous siltstones and limestones of the Buckator Formation above the dark grey sandstones and mudstones of the underlying Boscastle Formation.

Upper boundaries with the Boscastle Formation are taken at the gradational appearance of dark grey sandstones and mudstones of the overlying Boscastle Formation above the green-grey mudstones with thin calcareous siltstones and limestones of the Buckator Formation.

Thickness

At least 35 m. Full thickness of formation not exposed.

Distribution

Between Boscastle (SX 11 93) and Launceston (SX 33 85), north Cornwall.

Regional correlation

Intertongues with, and passes laterally into the Boscastle Formation. Further work however, is needed on this relationship in inland areas.

Genetic interpretation

Shallow marine, deposited on and adjacent to a high.

Biostratigraphical characterisation

The age of the formation, established by conodonts, ranges from the mid Famennian *Scaphignathus velifer* Zone to the mid/late Viséan *Gnathodus bilineatus* Zone.

Age

Famennian to Viséan

6.4.14 Brendon Formation (BREN)

Name

Originally termed the Middle Culm Measures (Ussher, 1907; Reid et al., 1911), it has subsequently been renamed the Upton Wood Formation (Stewart, 1981), the Greystone Formation (Turner, 1982) and Lydford Formation (Isaac, 1983). The Brendon Formation was first defined by Leveridge et al. (Leveridge et al., 2002).

Type section

Roadside exposures between Brendon Farm and Spur House [SX 3935 6840–SX 3938 6836], 3 km south-east of Callington. Unknown part of the formation exposed (Whiteley, 1983).

Lithology

Dark grey, locally siliceous, mudstone with laminae and thin beds of siltstone. Scattered packets of blue-grey to grey-green coarse-grained greywacke sandstone with interbedded dark grey mudstone. There are locally distributed units of tuff and basaltic lava. As mapped and defined, this formation may include parts of previously contiguous and

coeval formations. Further work is needed as this formation may represent a collection of mud-prone Mississippian lithologies brought together tectonically.

Lower and upper boundaries

The lower boundary is not seen; all observed contacts are tectonic.

The upper boundary is not seen; all observed contacts are tectonic.

Thickness

At least 450 m, but may more or less due to thrusting.

Distribution

Launceston/St Mellion area (SX 33 73), between, Bodmin Moor and Dartmoor, east Cornwall.

Regional correlation

Thought to pass laterally (on basis of dating) into St Mellion and Teign Chert formations between Bodmin Moor and Dartmoor but no exposures demonstrating lateral passage are known. Further work is needed.

Genetic interpretation

Turbidites and starved basin deposits.

Biostratigraphical characterisation

The presence of 'Posidonia Beds' has been used to suggest that the formation is partly late Viséan in age. However, such occurrences could simply be tectonic slices of Teign Chert Formation.

Age

Viséan

6.4.15 St Mellion Formation (SME)

Name

The formation was previously referred to as the Middle Culm Measures (Ussher, 1907; Reid et al., 1911), the Cothele Sandstone and Crocadon Sandstone Formation (Whiteley, 1983) and part of the Crackington Formation (Reid et al., 1912; Selwood et al., 1984). It was subsequently redefined as the St Mellion Formation by Leveridge et al. (2002).

Type section

Road section (A388) at Paynters Cross [SX 3998 6396], 1.5 km south-east of St Mellion, east Cornwall. The section exposes thin to medium bedded sandstones and mudstones with several units of massive to thick-bedded sandstones (Leveridge et al., 2002). Three fault slices of Teign Chert Formation occur in the recumbently folded and faulted sequence.

Lithology

Interbedded dark grey sandstone and mudstone with scattered siltstone beds. Sandstones tend to be concentrated in packets and are medium to thick bedded. Rare polymict conglomeratic sandstones and argillaceous sandstones are locally present.

Lower and upper boundaries

Both the lower and upper boundaries are not seen; all observed contacts are tectonic.

Thickness

In excess of 500 m, but uncertain due to thrusting.

Distribution

St Mellion area [SX 39 65], between Bodmin Moor and Dartmoor, east Cornwall. The area mapped as Crackington Formation on Sheets 338 and 339, between Holne [SX 715 695] and Haytor Vale [SX 770 770], south-east of Dartmoor may also be St Mellion Formation but further work is needed.

Regional correlation

The formation is thought to pass laterally (on basis of dating) into Brendon and Teign Chert formations between Bodmin Moor and Dartmoor, but no exposures demonstrating lateral passage are known. Further work is needed.

Genetic interpretation

Pro-delta turbiditic deposits.

Biostratigraphical characterisation

Gattendorfia Biozone conodonts (*sandbergi* Biozone) and Namurian E_{2c} goniatites give a range of early/mid Tournaisian to early Namurian.

Age

Tournaisian to Arnsbergian

6.5 CARBONIFEROUS OF THE TAVY BASIN

6.5.1 Laneast Quartzite Formation (LAQU)

Name

Formerly referred to as part of the Crackington Formation (Freshney et al., 1972; McKeown et al., 1973), the unit was defined as the Laneast Quartzite by Selwood et al. (1985).

Type section

Quarry on Laneast Downs [SX 2358 8479], 10 km west of Launceston, north Cornwall. Thick-bedded quartzites and subordinate mudstones from an unknown level in the formation (Reid et al., 1911).

Lithology

Thick-bedded, clean, coarse-grained, silica-cemented quartz sandstones with very subordinate dark grey to black mudstones, commonly containing plant debris.

Lower and upper boundaries

Both the lower and upper boundaries are not seen due to thrusting.

Thickness

Not known due to poor exposure and structure.

Distribution

Between Otterham [SX 15 91] and Stoke Climsland [SX 36 74], north Cornwall. In the Otterham area (Sheet 322), the formation has been mapped as Crackington Formation (Freshney et al., 1972; McKeown et al., 1973) and further work is needed to delimit the formation.

Regional correlation

Thought to interfinger with the Boscastle Formation. Further work needed.

Genetic interpretation

Shore zone environment on a high.

Age

?Famennian to Visean

6.6 CHUDLEIGH GROUP (CHUD)

Historically referred to as part of the Culm (Sedgwick and Murchison, 1840), the group is erected here to include the mainly Tournaisian to Visean pelagic and hemi-pelagic strata of the South Devon Basin, the **Winstow Chert Formation**, and the overlying early Namurian proximal turbidites of the **Ugbrooke Sandstone Formation**.

The group occurs in the Chudleigh (SX 870 784) and East Ogwell (SX 845 695) areas, south Devon and in the middle Tamar valley (SX 43 61) in the Plymouth area, on the Devon/Cornwall border.

6.6.1 Winstow Chert Formation (WCH)

Name

The formation was historically referred to as the Lower Culm Measures (Ussher, 1887, 1892), and part of the Saltash Formation (Leveridge et al., 2002). The unit was named the Winstow Cherts by House and Butcher (1973) and defined by Selwood et al. (1984), and is here defined formally as a formation.

Type section

The type section is a quarry near Winstow Cottages [SX 8630 7801], 1.5 km south-west of Chudleigh, south Devon: the quarry exposes 1.5 m of cherts with thin mudstone interbeds in the middle part of the formation (House and Butcher, 1973). Neither the basal or upper contact of the formation is exposed.

Formal subdivisions

Winstow Mudstone Member

Lithology

Thin-to medium-bedded green, grey-green, black and purple radiolarian cherts with interbeds of siliceous mudstones and shales. In the Chudleigh area, there is a thin (up to 14 m) basal unit of black siliceous and sooty mudstones (Winstow Mudstone Member). The uppermost part of the formation, the Posidonia Beds, comprises 10 m of thin bedded cherts, shales and limestones with an abundant fauna of posidoniid bivalves and spirally striated goniatites.

Lower and upper boundaries

In the Chudleigh area the lower boundary is taken at the incoming of black sooty and siliceous mudstones of the Winstow Mudstone Member (Winstow Chert Formation) above the purple, green and grey mudstones of the underlying Whiteway Mudstone Formation. The contact is generally sharp. In the Plymouth area it is taken at the incoming of dark grey cherts and siliceous mudstones of the Winstow Chert Formation above the medium grey silty mudstones of the Saltash Formation.

In the Chudleigh area the upper boundary is taken at the incoming of dark grey and greenish grey mudstones with thin siltstones and fine- to coarse-grained sandstones of the overlying Ugbrooke Sandstone Formation above the thin-bedded cherts, shales and limestones (Posidonia Beds) of the Winstow Chert Formation. In the Plymouth area the top of the formation is not exposed.

Thickness

Some 45 m in the Chudleigh area; at least 30 m in the Plymouth area.

Distribution

The formation occurs between Chudleigh [SX 870 784] and Kingsteignton [SX 88 74], south Devon and in the middle Tamar valley [SX 44 61] in the Plymouth area.

Regional correlation

The formation is thought to pass north into the Combe Mudstone Formation and Teign Chert Formation.

Genetic interpretation

The formation represents a starved condensed succession deposited on the crest and flanks of a high.

Biostratigraphical characterisation

The age of the formation is well constrained in the Chudleigh area. The base is probably topmost *Gattendorfia* Zone; the underlying Whiteway Mudstone Formation contains a *Gattendorfia* Zone fauna while conodonts in the lowermost part of the Winstow Mudstone Member (Winstow Chert Formation) are of the upper *Siphonodella crenulata* Biozone (and probably post-*Gattendorfia*, pre-*Pericyclus* Zone). The top is dated by goniatites from the Posidonia Beds as P_{2a}.

In the Plymouth area, in structurally complex sections, the formation has yielded palynomorphs ranging from late Famennian to early Tournaisian. The Winstow Chert Formation has not yielded a definitive fauna but probable Tournaisian palynomorphs have been obtained.

Age

Tournaisian to Brigantian

6.6.1.1 WINSTOW MUDSTONE MEMBER (WWM)

Name

Previously described as the Winstow Slate Member (Selwood et al., 1984), the unit is here redefined as the Winstow Mudstone Member.

Type section

South bank of a track near Winstow Cottages, Chudleigh [SX 8628 7801]: a few metres of black siliceous mudstones of the lowermost part of the Winstow Mudstone Member overlie purple and green mudstones of the underlying Whiteway Mudstone Formation (House and Butcher, 1973; Selwood et al., 1984).

Lithology

Black siliceous and sooty mudstone.

Lower and upper boundaries

The lower boundary is taken at the incoming of black sooty and siliceous mudstones of the Winstow Mudstone Members above the purple, green and grey mudstones of the underlying Whiteway Mudstone Formation.

The upper boundary is taken at the incoming of interbedded green-grey and black cherts and siliceous mudstones of the Winstow Chert Formation above the black sooty and siliceous mudstones of the Winstow Mudstone Member.

Thickness

Up to 14 m

Distribution

Between Chudleigh (SX 870 784) and Kingsteignton (SX 88 74), south Devon.

Regional correlation

Thought to pass north into the Combe Mudstone Formation.

Genetic interpretation

Starved condensed succession deposited on the crest and flanks of a high.

Biostratigraphical characterisation

The age of the Member is well constrained. The base is probably topmost *Gattendorfia* Zone; the underlying Whiteway Mudstone Formation contains a *Gattendorfia* Zone fauna while conodonts in the lowermost part of the Winstow Mudstone Member are of the upper *Siphonodella crenulata* Biozone (and probably post-*Gattendorfia*, pre-*Pericyclus* Zone s.l.).

Age

Tournaisian

6.6.2 Ugbrooke Sandstone Formation (UGST)

Name

Formerly known as the Ugbrooke Park Beds (Ussher, 1892) and Ugbrooke Park Sandstones (House and Butcher, 1973), the unit was defined by Selwood et al. (1984) and is here formally defined as a formation.

Type section

The type section is a quarry in Ugbrooke Park [SX 8690 7802], 0.75 km west of Ugbrooke House, Chudleigh, south Devon: the section exhibits about 10 m of thick-bedded sandstones in the middle of the exposed part of the formation (Selwood et al., 1984). Neither the top or the base of the formation are exposed.

Lithology

Thick-bedded to massive, grey, medium- to coarse-grained, locally pebbly and conglomeratic sandstones with impermanent thick units of pebble-cobble conglomerate, argillaceous sandstone and dark grey mudstones with thin sandstones and siltstones. Pebbly mudstones are also present. Conglomeratic clasts include chert and granite.

Lower and upper boundaries

The base is taken at the incoming of dark grey and greenish grey mudstones with thin siltstones and fine- to coarse-grained sandstones of the Ugbrooke Sandstone Formation above the thin bedded cherts, shales and limestones of the underlying Winstow Chert Formation.

The upper boundary is taken at an angular unconformity, where fine-grained glauconitic sandstone of the Upper Greensand Formation rests upon thick-bedded to massive, locally pebbly to conglomeratic sandstone of the Ugbrooke Sandstone Formation.

Thickness

Not known, but at least 500 m.

Distribution

The formation occurs at crop in the Chudleigh (SX 870 784) and East Oggwell (SX 845 695) areas, south Devon.

Genetic interpretation

The formation comprises proximal channelised turbidites, sourced from deformed Tournaisian–Visean and Devonian sequences to the south.

Biostratigraphical characterisation

Goniatites from the uppermost part of the Posidonia Beds in the upper part of the underlying Winstow Chert Formation are of Brigantian (P_{2a}) age. Immature goniatites from near

the base of the Ugbrooke Sandstone Formation are tentatively dated as Namurian E or H zone.

Age

?Brigantian to Namurian

6.7 HOLSWORTHY GROUP (HOWY)

The Holsworthy Group is referable to the deep water, turbidite-fronted, lobate delta subfacies of Millstone Grit facies (Figure 21). It broadly equates with the Pennsylvanian succession and broadly crops out in north Cornwall and central Devon, between the northern and southern outcrops of the Teign Valley Group.

A simple threefold subdivision of the group into the **Crackington**, **Bideford** and **Bude formations** (Edmonds et al., 1975) is maintained in the Culm and North Devon basins, except in the Launceston Sub-basin, where a single **Bealsmill Formation** is recognised. The group mainly comprises large scale, sandy turbidite systems, locally coarsening upwards from the Crackington Formation to Bude Formation. The turbidity currents present within the Crackington Formation mainly flowed towards the west or south-west (Edmonds et al., 1975), though there is a dominantly easterly flow within the Langsetian part of the formation. The delta slope proximal and distal turbidites of the Bude Formation show a dominant palaeocurrent towards the south. The Bude Formation passes northwards into upward-coarsening deltaic sequences of mudstone, siltstone and sandstone with smutty coals of the Bideford Formation. The presence of turbiditic sandstones within silty mudstones suggest the deltas were prograding southward into moderately deep water.

6.7.1 Bealsmill Formation (BEAL)

Name

Historically, the formation has been referred to as the Eggesford-type Culm and Middle or Exeter-type Culm (Ussher, 1887, 1892) and the Okehampton Sandstone Group (Dearman and Butcher, 1959). Subsequently, the formation has been equated with the Crackington Formation (Edmonds et al., 1968; Isaac, 1985), though is now considered a distinct formation.

Type section

Carthamartha Crags [SX 3670 7797 to 3699 7807], located about 700 m ENE of Rezare, south of Launceston, east Cornwall: only a small part of the formation (50 m thickness) is exposed, lacking a top and base (Turner, 1982; Selwood and Thomas, 1986).

Lithology

Thin- to thick-bedded commonly coarse and feldspathic sandstones interbedded with siltstones and dark grey mudstones. Scattered beds of ill-sorted pebble to cobble conglomerate up to 2 m thick contain clasts including chert, lava and limestone as well as derived Tournaisian–Visean and questionable Namurian fossils. Some channels are present.

Lower and upper boundaries

The depositional lower boundary is not seen as it is always faulted. The lower boundary is thought to post-date the D_1 deformation phase, with the formation resting unconformably on Visean sequences.

The depositional upper boundary is not seen but probably tectonic.

Thickness

Unknown, but a minimum thickness of 120 m is proved (Turner, 1982).

Distribution

The formation is mapped from Altarnun (SX 22 81), East Cornwall to north-west Dartmoor (SX 49 85), but is thought to extend into the south-western part of the Okehampton area (SX 53 87), mid Devon, where it has been mapped as Crackington Formation. Formational diagnosis needs further work, as does the area where it has not been mapped.

Regional correlation

A 'proximal' correlative of the Crackington Formation, constrained within the Launceston Sub-basin.

Genetic interpretation

The succession comprises turbidites supplied from Tournaisian–Visean and possibly Namurian sequences undergoing erosion. The presence of channels suggests a proximal environment of deposition.

Biostratigraphical characterisation

There is one record of H zone goniatites. As the formation contains derived *Gattendorfia* Zone faunas and postdates D₁ deformation (Visean–early Namurian) it is likely to be Namurian in age.

Age

Namurian

6.7.2 Crackington Formation (CKF)

Name

The formation was first defined as the Eggesford-type Culm and Middle or Exeter-type Culm (Ussher, 1887, 1892). Subsequently, various names have been proposed, including the Instow Beds (Prentice, 1960b), Limekiln Beds (Prentice, 1960b), part of the Cockington Beds (Prentice, 1960a), Okehampton Sandstone, Southerly Down Sandstone, Black Down Sandstone and Whitchurch Down Greywacke groups (Dearman and Butcher, 1959), Yahney Beds (Lucas, 1960), Holmingham Beds (Webby and Thomas, 1965), Appledore Formation (Money, 1966) and Kiddens Formation (Chesher, 1968). The term Welcome Measures used by Ashwin (1958) was subsequently reassigned as the Welcome Beds (Moore, 1929) and Welcome Formation (Edmonds et al., 1968; Edmonds et al., 1969). Crackington Measures was first used by Ashwin (1958) and reclassified as the Crackington Formation it became the widely accepted term for the succession (Edmonds, 1974).

Type section

Sea cliffs between Rusey Cliff and Wanson Mouth (about 10 km of coast) [SX 1230 9380 to SS 1900 0100], north Cornwall; named after Crackington Haven, 3 km north-east of Rusey Cliff: the section is pervasively folded and cut by low angle thrusts and faults. The lower two thirds of the formation is exposed, comprising predominantly mudstones with subordinate thin- to medium-bedded sandstones (Freshney et al., 1972). Neither the basal or upper contacts are seen due to faulting.

Lithology

Rhythmically bedded, dark blue-grey mudstones and subordinate predominantly grey sandstones and siltstones. Sandstone percentage varies from 20 to 75%, both vertically and geographically. The sandstones are parallel-sided 'Bouma-type'

turbidites with abundant well-developed sole structures. Individual beds are from a few centimetres to 0.4 m thick and rarely up to 1 m thick. Even thicker sandstones are locally present, mainly in the uppermost part, but tend to be massive and lack sole structures. Packets with abundant sandstones are commonly developed and mappable. On the north Cornwall and Devon coast, six named units of dark grey to black pyritic shale with goniatite- and fish-bearing calcareous nodules are present in the upper part of the formation. The thickest of these units is up to 7 m thick. A few thick units of slumped or de-stratified beds are also present in the uppermost part of the formation, as are scattered ironstone nodules.

Lower and upper boundaries

Due to thrusting along the south crop of the formation, the base is only seen between Okehampton [SX 59 94] and the Teign valley [SX 84 84], east Dartmoor, Devon. The base is gradational and taken at the incoming of more abundant and relatively thicker sandstones of the Crackington Formation above the mudstones with less than 10 per cent sandstone in the underlying Dowhills Mudstone Formation. Between the Bideford area [SS 45 27] north Devon and the Westleigh area [ST 06 17], west Somerset, the base is taken at a similar level. However, in the Bideford area, the base needs further work as the Dowhills Mudstone Formation (Limekiln Beds of Prentice (1960b)), was included in the Crackington Formation by Edmonds et al. (1979).

On the north Cornwall and north Devon coast, the top is taken at the top of the Hartland Quay Shale, the uppermost of the named goniatite bearing mudstones in the Crackington Formation. Inland, where the Hartland Quay Shale cannot be mapped in pervasively folded terrain as it is too thin, the top is taken at the incoming of softer, more silty and argillaceous thick-bedded sandstones of the overlying Bude Formation above the dominantly thin- to medium-bedded sandstones and mudstones of the Crackington Formation.

In the Bideford area the top is taken at the incoming of channels overlain by syndepositionally disturbed units and thick, locally cross-bedded sandstones of the Westward Ho! Member of the overlying Bideford Formation above the regularly interbedded mudstones and turbidite sandstones of the Crackington Formation.

Thickness

The thickness is difficult to estimate due to the folding and thrusting. Over 1000 m is estimated in the Exeter district. In the Hartland area on the north Devon coast, 400 m has been calculated for the upper part of the formation between the Clovelly Court Shale and the Hartland Quay Shale. A figure of 250 m has been calculated in the Bideford area for the entire formation (this figure has been deduced by removing the 400 m thick Westward Ho! Member of the Bideford Formation).

Distribution

North Cornwall [SX 15 97], Devon [SS 7010] and west Somerset [ST 06 17].

Regional correlation

The uppermost part of the formation passes into the Bideford Formation in north Devon.

Genetic interpretation

The formation represents large-scale turbidite systems deposited in a marine environment but becoming brackish in the uppermost part. The deposits accumulated in predominantly anoxic bottom conditions.

Biostratigraphical characterisation

All the dating is by goniatites. Along the southern limb of the Culm synclinorium the base is constrained as follows: in the Teign valley E_{2b} ages occur in the upper part of the overlying Dowhills Mudstone Formation and E_{2c} ages in the lower part of the Crackington Formation. In the Exeter area the base is diachronous ranging from H_{1a} to R_1 . In the Okehampton and Holsworthy districts it is uncertain whether the lowest E_2 ages are from the unmapped Dowhills Mudstone or the lowest Crackington Formation. On the north Cornish coast the base is faulted and the lowest age is H_{1a} . In north Devon, in the Bideford area, the base is constrained by R_2 dates in the underlying Dowhills Mudstone Formation (Limekiln Beds of Prentice (1960b), which were included in the Crackington Formation by Edmonds et al. (1979). However, farther east, possibly H_{1b} zone goniatites are recorded from near the base of undoubted Crackington Formation. In the Bampton area the youngest age in the underlying Dowhills Mudstone Formation is R_1 and the earliest date in the Crackington Formation is R_{2c} .

Along the southern limb of the Culm synclinorium the top of the formation is undated, apart from the coast, where the highest age below the faulted top is G_2 (*Gastrioceras listeri* Marine Band). In the Hartland area of the north Devon coast, the top is dated by the G_2 date (*Gastrioceras amaliae* Marine Band) from the Hartland Quay Shale. North of Bideford in the Appledore/Instow area, the *Gastrioceras listeri* and *Gastrioceras amaliae* Marine Bands occur in the upper part of the formation.

Age

Arnsbergian to Langsettian

6.7.3 Bideford Formation (BFF)

Name

The formation has variously been known as the Northam and Abbotsham beds (Prentice, 1960a) or Northam, Abbotsham and Westward Ho! formations (De Raaf et al., 1965) and part of the Crackington Formation (Edmonds et al., 1979). The term Bideford Group was used by De Raaf et al. (1965) and subsequently as the Bideford Formation became the established nomenclature (Edmonds, 1974).

Type section

Coastal cliffs from Westward Ho!, Bideford, west and south-westward for 3.5 km to Greencliffe Rock [SS 4030 2730 to 4320 2940], north Devon: all but the lowermost part of the formation is exposed, including the upper contact with the overlying Bude Formation (De Raaf et al., 1965; Walker, 1970; Edmonds et al., 1979; Xu Li, 1990). Some of the formation is repeated by folding.

Formal subdivisions

Westward Ho! Member

Lithology

Mudstones with abundant thin- to medium-bedded sandstones and siltstones with several thick units of thick-bedded sandstone. The upper two thirds of the sequence consists of nine coarsening upwards cycles (individually up to 180 m thick) comprising in upwards order, black mudstone, silty mudstone, silt and sand-streaked mudstones, interbedded thin sandstones and mudstones, thick-bedded channelised cross-bedded sandstones capped by burrowed horizons and locally rootlets. The lower parts of some cycles contain units of thin-bedded 'Bouma-type' sandstone turbidites. Three of the thick cross-bedded sandstones capping the

cycles are named, the topmost one being the Cornborough Sandstone. The lower third of the sequence (Westward Ho! Member) is not cyclic but comprises thin-bedded mudstones, siltstones and sandstones, some of which are turbiditic and others cross-laminated and wave rippled. The Westward Ho! Member includes several channels filled by slumped and disturbed strata, or more rarely cross-bedded or cross-laminated sandstones.

Lower and upper boundaries

The lower boundary is taken at the incoming of channels overlain by syndepositionally-disturbed units and thick, locally cross-bedded sandstones of the Westward Ho! Member above the regularly interbedded mudstones and turbidite sandstones of the Crackington Formation. This boundary is not exposed at the type section and has never been mapped, as the Westward Ho! Member was previously included in the Crackington Formation. Further work is needed on this boundary.

The upper boundary is taken at the sharp incoming of over 100 m of grey mudstones and siltstones with two thin anthracitic coals (culm) of the overlying Bude Formation above the thick cross-bedded Cornborough Sandstone that caps the topmost cycle of the Bideford Formation.

Thickness

At least 1220 m seen at the type section on the coast but needs to include several tens of metres more that is unexposed in the lowermost part of the formation and has never been mapped.

Distribution

Bideford area [SS 45 27] eastwards to 6 km west of South Molton [SS 71 26], mid Devon.

Regional correlation

Passes eastwards in part into the Bude Formation and possibly into the upper part of the Crackington Formation.

Genetic interpretation

The formation represents prodelta to delta-top; fluvial distributary environments represented by thick cross-bedded sandstones.

Biostratigraphical characterisation

The *Gastrioceras amaliae* Marine Band occurs about 250 m below the top of the formation. *Lenisulcata* Zone bivalves occur near the top of the formation.

Age

Langsettian.

6.7.3.1 WESTWARD HO! MEMBER (WDHO)

Name

Formerly considered part of the Crackington Formation (Edmonds et al., 1979) and part of the Northam Beds (Prentice, 1960a), the unit was named the Westward Ho! Formation by Walker (1970), but is here defined as a member.

Type section

Coastal cliffs and foreshore north of Mermaid's Pool at Westward Ho! [SS 4170 2907 to 4320 2940], north Devon: the upper 400 m is exposed in the section. The upper contact of Mermaid's Pool Sandstone with the rest of the overlying Bideford Formation is exposed, but the base of the member is not seen (Walker, 1970; Xu Li, 1990).

Lithology

Thin-bedded mudstones, siltstones and sandstones, some of which are turbiditic and others cross-laminated and wave rippled suggesting they are of shallower origin. The succession is cut by several channels, from 3 to 25 m deep, filled by slumped and disturbed strata, or more rarely cross-bedded or cross-laminated sandstones.

Lower and upper boundaries

The lower boundary is taken at the incoming of channels overlain by syndepositionally disturbed units and thick, locally cross-bedded sandstones of the Westward Ho! Member above the regularly interbedded mudstones and turbidite sandstones of the underlying Crackington Formation. This boundary is not exposed on the coast at the type locality and has never been mapped as the Westward Ho! Member was previously included in the Crackington Formation. Further work is needed on this boundary.

The upper boundary is taken at the incoming of coarsening upwards cycles (mudstone, interbedded mudstone and sandstone, cross-bedded sandstone) of the main part of the Bideford Formation above the top of the Mermaid's Pool Sandstone, a thick mappable cross-bedded sandstone at the top of the Westward Ho! Member.

Thickness

Over 400 m

Distribution

The member is present in the Westward Ho! area [SS 41 29], Bideford, north Devon. As the member is unmapped it is not known how far east it extends, but it is possible that it occupies the lower part of the Bideford Formation as far as the eastern limit of the latter to 6 km west of South Molton [SS 71 26], mid Devon.

Genetic interpretation

The member represents pro-delta deposits associated with a delta advancing into basin.

Biostratigraphical characterisation

No faunas have been recorded in the member, but the age is constrained by the presence of the marine band with *Gastrioceras listeri* present in the underlying Crackington Formation and the marine band with *G. amaliae* present about 250 m below the top of the overlying main part of the Bideford Formation.

Age

Langsettian

6.7.4 Bude Formation (BF)

Name

The formation was first defined as the Middle Culm or Morchard-type Culm (Ussher, 1887, 1892). Subsequently, the formation has been referred to as part of the Cockington Beds and the Greencliff Beds (Prentice, 1960a). The term Bude Sandstones (Owen, 1934) and subsequently as the Bude Formation became the established nomenclature (Edmonds, 1974).

Type section

Coast section, north of Bude, between Duckpool, near Steeple Point, Combe and Gull Rock 6 km to the north [SS 2000 1140 to 2050 1730]: the section exposes the entire known sequence (1290 m) including the base at Gull Rock (Freshney et al., 1972). The sequence is affected by pervasive upright folding.

Lithology

Grey thick-bedded, somewhat argillaceous sandstones and silty sandstones occur in laterally discontinuous, internally massive beds 1–5 m thick and commonly amalgamated into units up to 10 m thick. Weathered, the sandstones become buff and friable. Very thick beds of slumped and de-stratified strata are also present. Grey mudstones occur as interbeds up to 1 m but locally packets of darker mudstone up to 20 m thick with thin ironstone beds and bundles of thin sandstones are present, especially in the upper part of the formation. There are five named beds of black sulphurous 'shales' with goniatite-bearing calcareous nodules. Thin units of thin- to medium-bedded siltstone with Xithosurid trails are also present

Lower and upper boundaries

On the north Cornwall and north Devon coast, the base is taken at the top of the Hartland Quay Shale, the uppermost of the named goniatite-bearing mudstones in the underlying Crackington Formation. Inland, where the Hartland Quay Shale cannot be mapped in pervasively folded terrain, as it is too thin, the base is taken at the incoming of softer, siltier thick-bedded sandstones of the Bude Formation above the dominantly thin- to medium-bedded sandstones and mudstones of the underlying Crackington Formation.

In north Devon, south of Bideford, the base is taken at the sharp incoming of over 100 m of grey mudstones and siltstones with two thin anthracitic coals (culm) above the cross-bedded, thick-bedded Cornborough Sandstone that caps the top of the underlying Bideford Formation. Thick-bedded sandstones, typical of the Bude Formation, appear above these mudstones and siltstones.

The upper boundary is taken at an angular unconformity, where breccias of the Exeter Group rest upon sandstone and subordinate mudstone of the Bude Formation.

Thickness

At least 1290 m calculated on the north Cornwall and north Devon coast.

Distribution

Occupies large area in mid Devon between the coast at Bude [SS 21 06] and area west of Tiverton [SS 96 13].

Regional correlation

In north Devon the formation may pass laterally into the Bideford Formation.

Genetic interpretation

Deposited in a large-scale freshwater lake situated on a broad shelf. Sandstone deposition was within storm wave base and by river-fed turbidity currents. Also, there was probably deltaic progradation across part of the basin late in its development. The goniatite-bearing mudstones represent periodic marine invasions.

Biostratigraphical characterisation

In the Hartland area of the north Devon coast the base is dated by the G₂ date (*Gastrioceras amaliae* Marine Band fauna) from the Hartland Quay Shale at the top of the underlying Crackington Formation.

The highest proven date is from the Warren Gutter Shale near the exposed top of the formation north of Bude, which contains fauna of the Aegiranum Marine Band.

Age

Langsettian to Bolsovian

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Appendix 1 Tables showing lithostratigraphical hierarchies

Tables list units alphabetically, commencing with supergroup, then group, sub-group, formation and member.

Supergroup	Group	Sub-group	Formation	Member	
Carboniferous Limestone (CL)	Avon (AVO)		Castell Coch Limestone (CCL)		
			Cwmyniscoy Mudstone (CCM)		
			Jackie Parr Limestone (JPLS)		
			Shirehampton (SHB)		
			Tongwynlais (TGW)		
	Bowland High (BOHI)		Clitheroe Limestone (CLL)	Chatburn Limestone (CHL)	
				Bellman Limestone (BMNL)	
				Coplow Limestone (COPL)	
				Peach Quarry Limestone (PQL)	
	Clwyd Limestone (CLWYD)			Cefn Mawr Limestone (CFML)	Craig Rofft Sandstone (CRRS)
				Foel (FOF)	
				Leete Limestone (LEEL)	
				Llanarmon Limestone (LNML)	Llwyn-y-frân Sandstone (LYFS)
					Nant-y-Gamar Limestone (NYGL)
				Loggerheads Limestone (LGHL)	Graig Fawr Limestone (GFLS)
					Little Orme Limestone (LOLS)
				Minera (MRF)	
	Red Wharf Limestone (REL)				
	Holme High Limestone (HOHI)				
	Peak Limestone (PKLM)			Astbury (AYLS)	
				Bee Low Limestone (BLL)	Chee Tor Limestone (CT)
					Lower Miller's Dale Lava (LMB)
					Miller's Dale Limestone (MDA)
					Ravensdale Tuff (RDT)
				Belvoir Limestone (BVR)	
				Bowsey Wood (BOWO)	
				Cloud Hill Dolostone (CLHD)	Cloud Wood (CLWD)
					Scot's Brook (SCBR)
				Eyam Limestone (EYL)	
				Fallgate Volcanic (FV)	Conksbury Bridge Lava (CBB)
Lathkill Lodge Lava (LOB)					
Hopedale Limestone (HP)					
Kevin Limestone (KV)					
Lydebrook Sandstone (LYS)					
Milldale Limestone (MI)	Holly Bush (HYBH)				

Supergroup	Group	Sub-group	Formation	Member		
Carboniferous Limestone (CL)	Peak Limestone (PKLM)		Monsal Dale Limestone (MO)	Cressbrook Dale Lava (CBDL)		
				Lees Bottom Lava (LSBB)		
				Litton Tuff (LT)		
				Lower Matlock Lava (LRB)		
				Shacklow Wood Lava (SWB)		
				Shothouse Spring Tuff (ST)		
				Upper Matlock Lava (URB)		
				Upper Miller's Dale Lava (UMB)		
				Winstermoor Lava (WMB)		
			Plungar Limestone (PLLS)			
			Rue Hill Dolomite (RHD)			
			Sylvan Limestone (SYLV)	Little Wenlock Basalt (LWKB)		
	Ticknall Limestone (TIL)					
	Woo Dale Limestone (WDL)	Iron Tors Limestone (IT)				
		Pembroke Limestone (PEMB)	Abercriban Oolite (ABO)			
			Black Rock Limestone (BRL)	Undivided	Middle Hope Volcanic (MHVO)	
				Barry Harbour Limestone (BHL)		
				Berry Slade Formation (BRYS)		
				Brofiscin Oolite (BFO)		
				Friars Point Limestone (FPL)		
			Burrington Oolite (BO)			
			Clydach Valley (CLD)	Blaen Onnen Oolite (BLO)		
				Coed Ffyddlwn (COFYD)	Darren Ddu Limestone (DDLDM)	
				Gilwern Oolite (GWO)		
				Pantydarren (PYDN)		
				Pwll-y-Cwm Oolite (PWCO)		
		Sychnant Dolomite (SYCN)				
		Hunts Bay Oolite (HBO)	Cornelly Oolite (CNLL)	Argoed Limestone (ARL)		
				Cefnyrhendy Oolite (CEO)		
			Stormy Limestone (STYL)			
				Caswell Bay Mudstone (CBM)		
				Clifton Down Limestone (CDL)	Cheddar Limestone (CDRL)	
					Cheddar Oolite (CDRO)	
Clifton Down Mudstone (CDM)						
Cromhall Sandstone (CHSA)						
Dowlais Limestone (DWL)						
Garn Caws Sandstone (GACA)						
Goblin Combe Oolite (GCO)						
Gully Oolite (GUO)						
High Tor Limestone (HTL)				Flat Holm Limestone (FHL)		
				Spring Cove Lava (SCLA)		
Hobbyhorse Bay Limestone (HBL)						

Supergroup	Group	Sub-group	Formation	Member
Carboniferous Limestone (CL)	Pembroke Limestone (PEMB)		Linney Head (LHD)	
			Llanelly (LLY)	Cheltenham Limestone (CHLM)
				Clydach Halt (CLDH)
				Gilwern Clay (GWCL)
				Penllwyn Oolite (PENO)
			Oreton Limestone (ORTL)	
			Oxwich Head Limestone (OHL)	Honeycombed Sandstone (HNCS)
				Pant Mawr Sandstone (PMSA)
				Penderyn Oolite (PDO)
			Oystermouth (OB)	
			Pen-y-holt Limestone (PYHL)	
			Stackpole Limestone (STPL)	
	Vallis Limestone (VL)			
Trawden Limestone (TRL)				

Supergroup	Group	Formation	Member
Coal Measures (COME)	Pennine Coal Measures (PCM)	Gloddaeth Purple Sandstone (GPS)	
		Pennine Lower Coal Measures (PLCM)	
		Pennine Middle Coal Measures (PMCM)	
		Pennine Upper Coal Measures (PUCM)	Ackworth (ACKW)
			Badsworth (BADS)
			Black Band Ironstone (BBG)
			Brierley (BRIE)
			Clayband Ironstone (CBIF)
			Great Row (GTR)
			Hemsworth (HEMS)
	South Wales Coal Measures (SWCM)	South Wales Lower Coal Measures (SWLCM)	
		South Wales Middle Coal Measures (SWMCM)	
		South Wales Upper Coal Measures (SWUCM)	

Supergroup	Group	Formation	Member
Culm (CU)	Chudleigh (CHUD)	Ugbrooke Sandstone (UGST)	
		Winstow Chert (WCH)	Winstow Mudstone (WWM)
	Holsworthy (HOWY)	Bealsmill (BEAL)	
		Bideford (BFF)	Westward Ho! (WDHO)
		Bude (BF)	
		Crackington (CKF)	
	Teign Valley (TEVY)	Bampton Limestone (BPLM)	Kersdown Chert (KSDC)
		Barras Nose (BNF)	
		Boscastle (BOSC)	
		Brendon (BREN)	
		Buckator (BKF)	
		Codden Hill Chert (COH)	
		Combe Mudstone (CMSH)	
		Doddiscombe (DDC)	
		Dowhills Mudstone (DHLS)	Ashton Mudstone (ANSH)
		Meldon Shale and Quartzite (MQF)	
		St Mellion (SME)	
		Teign Chert (TCH)	
		Tintagel Volcanic (TVF)	
		Trambley Cove (TCF)	
Westleigh Limestone (WST)			

Group	Formation	Member	
Craven (CRAV)	Bowland Shale (BSG)	Park Style Limestone (PKSL)	
		Pendleside Sandstone (PNDS)	
		Ravensholme Limestone (RL)	
	Ecton Limestone (ECL)		
	Hodder Mudstone (HOM)	Hodder Mudstone (HOM)	Buckbanks Sandstone (BNKS)
			Chaigley Limestone (CHGL)
			Embsay Limestone (EML)
			Hetton Beck Limestone (HBEL)
			Leagram Mudstone (LEAM)
			Limekiln Wood Limestone (LMKL)
			Phynis Mudstone (PHS)
			Rain Gill Limestone (RNGL)
			Twiston Sandstone (TTS)
			Whitemore Limestone (WML)
	Hodderense Limestone (BOH)		
	Lockington Limestone (LOCL)		
	Long Eaton (LOE)		
	Pendleside Limestone (PDL)	Rad Brook Mudstone (RKM)	
Pentre Chert (PECH)			
Prestatyn Limestone (PRL)			
Teilia (TLB)			
Widmerpool Formation (WDF)	Widmerpool Formation (WDF)	Ratcliffe Volcanic (RAVO)	
		Tissington Volcanic (TIVO)	
Exmoor (EXM)	Pilton Mudstone (PLT)		
Marros (MARR)	Aberkenfig (ABKH)		
	Bishopston Mudstone (BISHM)		
	Quartzitic Sandstone (QSG)		
	Rodway Siltstone (RSI)		
	Telpyn Point Sandstone (TELPP)		
	Twrch Sandstone (TWR)		
Millstone Grit (MG)	Cefn-y-fedw Sandstone (CFS)		
	Cornbrook Sandstone (COS)		
	Hebden (HEBD)		
	Marsden (MARSD)		
	Morridge (MORRI)		
	Pendleton (PENDL)	Pendle Grit (PG)	
	Rosendale (ROSSE)		
	Samlesbury (SAML)		
	Silsden (SILS)	Silsden (SILS)	Claughton (CLAU)
Roeburndale (RBL)			

Group	Formation	Member	
Tamar (TAMA)	Rora Mudstone (RRAM)		
	Saltash (SAH)		
	Whiteway Mudstone (WWYM)		
	Yeolmbridge (YF)		
Warwickshire (WAWK)	Clent (CLT)		
	Deri (DER)		
	Etruria (ETM)		
	Halesowen (HA)	Dark Slade (DAR)	
	Pennant Sandstone (PES)	Brithdir (BD)	
		Coleford (COFD)	
		Downend (DN)	
		Hughes (H)	
		Llynfi (LLFB)	
		Mangotsfield (MGF)	
		Rhondda (RA)	
		Swansea (SW)	
	Salop (SAL)	Allesley (ASY)	
		Alveley (ALY)	
		Enville (EN)	
		Keresley (KRS)	
		Whitacre (WIT)	
	Grovesend (GDB)	Barren Red (BRR)	
		Burford Coal (BRFC)	
		Cinderford (CIFD)	
Crawley (CRW)			
Farrington (FRF)			

Group	Formation	Member
Warwickshire (WAWK)	Grovesend (GDB)	Publow (PUB)
		Radstock (RAD)
		Windrush (WNR)
		Witney Coal (WTC)
	Stallion Hill Sandstone (SLN)	
	Tile Hill Mudstone (TLM)	
	Trenchard (TRGP)	
Winterbourne (WINT)		
No parent	Arch Farm Sandstone (ARFS)	
	Calke Abbey Sandstone (CAAS)	
	Ffernant (FANT)	
	Fron-fawr (FRFA)	
	Hathern Anhydrite (HAA)	
	Hyner Mudstone (HYMU)	
	Laneast Quartzite (LAQU)	
	Lligwy Sandstone (LGY)	
	Menai Straits (MEST)	
	Middleton Dale Anhydrite (MIDA)	
	Pant (PANT)	
	Penbedw (PDW)	
	Redhouse Sandstone (RES)	
	Roddlesworth (RODD)	
	Scalford Sandstone (SFDS)	
	Stockdale Farm (STFA)	
	Trusham Mudstone (TMSH)	
Village Farm (VIFM)		

Appendix 2 Redundant lithostratigraphical names

Code	Redundant name	New Name or alternative
ACHS	Accerhill Sandstone Formation	Accerhill Sandstone
ARG	Ardwick Group	Warwickshire Group
AM	Ardwick Marls	Etruria Formation
ACF	Arenaceous Coal Formation	Pennant Sandstone Formation
BACB	Barncroft Beck Member	Barncroft Beck Beds
BRR	Barren Red Formation (Somerset)	Barren Red Member (Somerset)
BGM	Basal Grit (Millstone Grit of South Wales)	Twrch Sandstone Formation
BED	Basement Beds Formation	Lligwy Sandstone, Menai Straits, Ffernant, Penbedw, Fron-Fawr or Pant formations Lligwy Sandstone Formation
BCA	Basement Conglomerate	
BEAL	Bealsmill Formation	
BTD	Bettisfield Formation	Pennine Coal Measures Group
BBL	Birnbeck Limestone Formation	High Tor Limestone Formation
BQB	Bishop's Quarry Limestone Formation	Part of Cefn Mawr Limestone Formation
BRD	Black Rock Dolomite Formation	Black Rock Limestone Subgroup
BPGP	Black Rock Group	Black Rock Limestone Subgroup
BRL	Black Rock Limestone Formation	Black Rock Limestone Subgroup
BPL	Blucks Pool Limestone	Black Rock Limestone Subgroup
BSG	Bowland Shale Group	Bowland Shale Formation
BRNG	Brennand Grit Formation	Brennand Grit
BD	Brithdir Formation	Brithdir Member
BFC	Buckley Fireclay Formation	
BULL	Bullslaughter Limestone Formation	Oystermouth Formation
BRFC	Burford Coal Formation	Burford Coal Member
BO	Burrington Oolite Formation	Burrington Oolite Subgroup
CL	Carboniferous Limestone	Carboniferous Limestone Supergroup; or component groups: Peak Limestone Group; Clwyd Limestone Group; Pembroke Limestone Group; Bowland High Group; Holme High Group; Trawden Group
COLF	Careg-onen Limestone Formation	Leete Limestone Formation
CBO	Caswell Bay Oolite Formation	Gully Oolite Formation
CSH	Caton Shale Formation	Caton Shale
CW	Cawdor Group	Eyam Limestone Formation and part of Bowland Shale Formation
CWDL	Cawdor Group limestones	Eyam Limestone Formation
CBSH	Cefn Bryn Shales	Avon Group
CHL	Chatburn Limestone Group	Chatburn Limestone Formation
CYL	Cil-yr-ychen Limestone	Dowlais Limestone Formation
CIR	Cinderford Formation	Cinderford Member
CLAU	Claughton Formation	Claughton Member
CLMS	Claughton Moor Siltstone Member	Claughton Moor Siltstones
CDGP	Clifton Down Group	Burrington Oolite Subgroup & part of Hunts Bay Oolite Subgroup
CLHS	Close Hill Siltstone Member	Close Hill Siltstone
CLD	Clydach Valley Group	Clydach Valley Subgroup
CM	Coal Measures Group	Scottish Coal Measures Group; Pennine Coal Measures Group; South Wales Coal Measures Group
CP	Coalport Formation	Halesowen Formation
COSS	Cocklett Scar Sandstones Member	Cocklett Scar Sandstone
CYAF	Coed-yr-Allt Formation	Halesowen Formation
COFD	Coleford Formation	Coleford Member
COTS	Cotehele Sandstone Formation	St Mellion Formation
CRW	Crawley Formation	Crawley Member
CRL	Crease Limestone	Gully Oolite Formation
CKL	Crickmail Limestone	Oxwich Head Limestone
CROM	Crossdale Mudstone Formation	Crossdale Mudstone
DWIC	Dinorwic Formation	Red Wharf Limestone Formation
DLP	Dolphinholme Mudstone Formation	Dolphinholme Mudstone

DN	Downend Formation	Downend Member
DL	Drybrook Limestone Formation	Hunts Bay Oolite Subgroup
DS	Drybrook Sandstone Group	Cromhall Sandstone Formation
DLSL	Dulas Limestone Formation	Leete Limestone Formation
DUCS	Dure Clough Sandstones Member	Dure Clough Sandstone
DYL	Dyserth Limestone Group	Part of Clwyd Limestone Group
ESH	Edale Shale Group	Bowland Shale Formation
ELF	Eglwyseg Limestone Formation	Loggerheads Limestone Formation
EDG	Eldroth Grit Formation	Eldroth Grit
ELCR	Ellel Crag Sandstone Formation	Ellel Crag Sandstone
EB	Enville Formation	Enville Member
ERB	Erbistock Formation	Salop Formation
FRF	Farrington Formation	Farrington Member
FCF	Fire Beacon Chert Formation	Codden Hill Chert Formation
GVCS	Gavells Clough Sandstone Member	Gavells Clough Sandstone
GGF	Grassington Grit Formation	Grassington Grit
ORL	Great Orme Limestone Formation	Loggerheads Limestone Formation
GRGT	Greta Grits Formation	Greta Grit
GSTN	Greystone Formation	Brendon Formation
GF	Griffe Grange Bed	Woo Dale Limestone Formation
GRN	Gronant Group	Parts of Clwyd Limestone Group and Craven Group
GS	Gwespyr Sandstone Formation	Gwespyr Sandstone
HD	Hadley Formation	Etruria Formation
HAF	Halkyn Formation	Cefn-y-Fedw, Pentre Chert Formation and Bowland Shale formations & Gwespyr Sandstone
HHO	Heversham House Sandstone Member	Heversham House Sandstone
HEH	Heysham Harbour Sandstone Formation	Heysham Harbour Sandstone
HYG	Highley Formation	Halesowen Formation
HIS	Hind Sandstone Member	Hind Sandstone
HSH	Holywell Shale Formation { Wales }	Bowland Shale Formation
HW	Hoptonwood Group	Bee Low Limestone Formation
HOG	Hotwells Group	Part of Pembroke Limestone Group
HL	Hotwells Limestone Formation	Oxwich Head Limestone Formation
H	Hughes Formation	Hughes Member
HBO	Hunts Bay Oolite Group	Hunts Bay Oolite Subgroup
KE	Keele Formation	Alveley Member
KTB	Kinlet Formation	Etruria Formation
KBF	Kirkbeck Formation	Kirkbeck Member
LFOS	Lane Foot Sandstone Member	Lane Foot Sandstone
LHD	Linney Head Beds	Linney Head Formation
LPD	Llandudno Pier Dolomite Formation	Llanarmon Limestone Formation
LNDL	Llandulas Limestone Formation	Loggerheads Limestone Formation
LLB	Llandyfan Limestone Formation	Oxwich Head Limestone Formation
LLFB	Llynfi Formation	Llynfi Member
LLYL	Llysfaen Limestone Formation	Llanarmon Limestone Formation
LBS	Lower Bowland Shale Formation	Part of Bowland Shale Formation
LCDL	Lower Clifton Down Mudstone Formation	Clifton Down Mudstone Formation
LCM	Lower Coal Measures Formation	Scottish Lower Coal Measures Formation; Pennine Lower Coal Measures Formation; South Wales Lower Coal Measures Formation
LCS	Lower Cromhall Sandstone Formation	Cromhall Sandstone Formation
LD	Lower Dolomite Formation	Black Rock Limestone Subgroup
LDS	Lower Drybrook Sandstone	Part of Cromhall Sandstone Formation
LSH	Lower Limestone Shale Group	Avon Group
LPEM	Lower Pennant Sandstones	Part of Pennant Sandstone Formation
LPG	Lower Plompton Grit Formation	Lower Plompton Grit
MBYM	Maesbury Mudstone Formation	Avon Group
MAG	Matlock Group	Monsal Dale Limestone Formation
MNLS	Main Limestone Group [South Wales]	Pembroke Limestone Group
MGF	Mangotsfield Formation	Mangotsfield Member
MCF	Meldon Chert Formation	Codden Hill Chert Formation
MER	Meriden Formation	Salop Formation
MCM	Middle Coal Measures Formation	Scottish Middle Coal Measures Formation; Pennine Middle Coal Measures Formation; South Wales Middle Coal Measures Formation
MCS	Middle Cromhall Sandstone Formation	Cromhall Sandstone Formation
MX	Mixon Limestone - Shales Formation	Widmerpool Formation
MOCS	Moorcock Sandstone Member	Moorcock Sandstone

ACH	Mount Ararat Chert Formation	Codden Hill Chert Formation
MYGL	Mynydd-y-Gareg Limestone	Oxwich Head Limestone Formation
NSL	Nappa Shale and Limestone Member	Hodder Mudstone Formation
NCL	Newcastle Formation	Halesowen Formation
NCH	Newton Chert Formation	Codden Hill Chert Formation
NOT	Nottage Crag Grit Member	Nottage Crag Grit
OYFL	Ochr-y-foel Limestone Formation	Llanarmon Limestone Formation
PG	Pendle Grit Formation	Pendle Grit Member
PBL	Penmaen Burrows Limestone Formation	Black Rock Limestone Subgroup
PEL	Penmon Limestone Formation	Loggerheads Limestone Formation
PNNT	Pennant Formation [Forest of Dean]	Pennant Sandstone Formation
PTS	Pennant Group [South Wales Coalfield]	Warwickshire Group
PES	Pennant Sandstones	Pennant Sandstone Formation
PNWL	Penyllt Limestone Formation	Oxwich Head Limestone Formation
PUB	Publow Formation	Publow Member
RAD	Radstock Formation	Radstock Member
RWD	Radwood Formation	Salop Formation
RSG	Red Scar Grit Formation	Red Scar Grit
REL	Red Wharf Cherty Limestone	Red Wharf Limestone Formation
RA	Rhondda Formation	Rhondda Member
RBL	Roeburndale Formation	Roeburndale Member
RR	Rough Rock Formation	Rough Rock
RM	Ruabon Marl Formation	Etruria Formation
SDSH	Sabden Shales Formation	Sabden Shales
SPCS	Sapling Clough Sandstone Member	Sapling Clough Sandstone
SHB	Shirehampton Beds	Shirehampton Formation
SLVS	Silver Hills Sandstone Formation	Silver Hills Sandstone
SUL	Summit Limestone Formation	Red Wharf Limestone Formation
SLSH	Surgill Shale Member	Surgill Shales
SW	Swansea Formation	Swansea Member
TDL	Tandinas Limestone Formation	Leete Limestone Formation
TCH	Teign Chert Formation	Codden Hill Chert Formation
THM	Tollhouse Mudstone Formation	Tollhouse Mudstone
TRL	Traeth Bychan Limestone Formation	Cefn Mawr Limestone Formation
TREB	Treborth Formation	Loggerheads Limestone Formation
TLF	Trefor Limestone Formation	Cefn Mawr Limestone Formation
TNL	Ty-nant Limestone Formation	Leete Limestone Formation
UBS	Upper Bowland Shale Formation	Part of Bowland Shale Formation
UCDM	Upper Clifton Down Mudstone Formation	Clifton Down Mudstone Formation
UCM	Upper Coal Measures	Scottish Upper Coal Measures Formation; Pennine Upper Coal Measures Formation; South Wales Upper Coal Measures Formation
UCS	Upper Cromhall Sandstone Formation	Cromhall Sandstone Formation
UDS	Upper Drybrook Sandstone	Cromhall Sandstone Formation
ULSH	Upper Limestone Shales	Oystermouth Formation
UPEM	Upper Pennant Sandstones	Pennant Sandstone Formation (part) and Supra-Pennant Formation
UPG	Upper Plompton Grit Formation	Upper Plompton Grit
WRST	Ward's Stone Sandstone Formation	Ward's Stone Sandstone
WWG	Warley Wise Grit Formation	Warley Wise Grit
WCR	Wellington Crag Sandstone Formation	Accerhill Sandstone
WTHL	Whitehead Limestone	Llanelly Formation
WNR	Windrush Formation	Windrush Member
WCH	Winstow Chert Formation	Codden Hill Chert Formation
WTC	Witney Coal Formation	Witney Coal Member
WSG	Worston Shale Group	Part of Craven Group