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

Research Report RR/10/07

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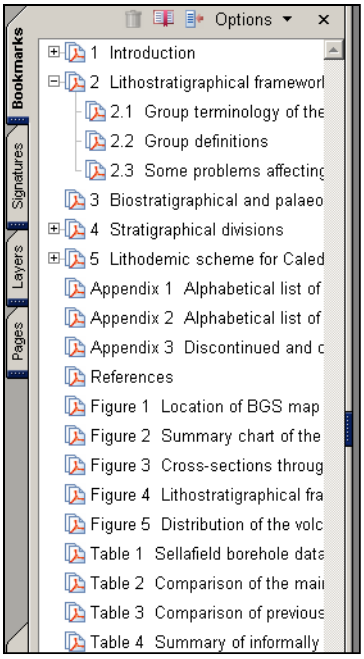

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from the principal section and subsection headings back to the contents page,

from each reference to a figure, plate or table directly to the corresponding figure, plate or table,

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

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Front cover

View of Kae Heughs, Garleton Hills, East Lothian. Showing Chadian to Arundian lavas and tuffs of the Garleton Hills Volcanic Formation (Strathclyde Group) exposed in a prominent scarp (P001032).

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

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Keyworth, Nottingham British Geological Survey 2011

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) Stratigraphical Framework Committee (SFC) of the Carboniferous rocks of northern 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 rocks of the entire onshore area of northern Great Britain.

The study draws upon a published overview report for the Carboniferous of Great Britain (Waters, et al., 2007), which identifies a group framework based upon the identification of nine major lithofacies associations across Britain. This framework report provides further, more-detailed descriptions of group and formation nomenclature, specifically for the onshore area of northern Great Britain (essentially north of the Craven Fault System) including the Midland Valley of Scotland, southern Scotland, northern England and the Isle of Man. It 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 onshore southern Great Britain (see Waters et al., 2009).

BGS Stratigraphical Framework reports are published in collaboration with the Stratigraphy Commission of the Geological Society of London through the BGS Internet website www.bgs.ac.uk where they are available as free downloads. Reports are peer-reviewed via the Geological Society of London's Stratigraphy Commission.

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 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. 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 northern Great Britain. The authors of and contributors to this report include those who produced the Lexicon entries for many of the units described. However, it is particularly important to acknowledge the contribution of D Stephenson in the compilation of Section 4.3.3 on the Clyde Plateau Volcanic Formation. The authors of the report gratefully 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 Gilbert Kelling (University of Keele), are also acknowledged. Joanna Thomas is thanked for editing the report and Louise Wilson, Stuart Horsburgh and Paul Lappage are thanked for the drafting of the figures.

Contents

FIGURES

TABLES

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 successions 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 Lexicon of Named Rock Units 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 often resulting in a plethora of local names. This complexity in nomenclature has, to an extent, hindered the regional understanding of the Carboniferous successions throughout Great Britain.

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., 2000) respectively. 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, which reviewed the entire Carboniferous successions throughout Great Britain.

This report summarises the SFC lithostratigraphical scheme for onshore Carboniferous successions of northern Great Britain. A further report summarises the scheme employed in southern Great Britain (see Waters et al., 2009).

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

The second part describes the key techniques of correlation of successions, principally biostratigraphy.

The third part indicates the principle for the development of the new lithostratigraphical scheme. This demonstrates how the group hierarchy has been linked to major lithofacies and the procedures for rationalising existing nomenclature.

The fourth and largest part of the report provides a full description of the group and formation framework for each of three regions; Scotland north of the Southern Upland Fault, southern Scotland, and the Northern England Province (including the Isle of Man). Each entry includes the rank of the nomenclature, and a description of its origin and history and key references, principal lithologies, environment of deposition, stratotypes, lower and upper boundaries, thickness, geographical extent, age range and any subdivisions to member level. The members themselves are similarly fully described.

An appendix (Appendix 1) provides an alphabetical listing of each supergroup, group, formation and member respectively, and shows the heirarchical relationship between the lithostratigraphical units. It also provides computer codes from the BGS Lexicon of Named Rock Units where these have been allocated. Appendix 2 gives the BGS Lexicon of Named Rock Units computer codes for the lithostratigraphical beds shown in Figures 6 and 8–15 and Appendix 3 lists all the obsolete lithostratigraphical terms mentioned in the text and provides the units they are now equivalent to or included within.

1 Introduction

The Carboniferous strata of Great Britain comprise a wide range of facies representing a large variety of depositional environments. This in part reflects a northward drift of Britain 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 the widespread development of commonly red, continental, alluvial, clastic-dominated facies during Tournaisian and late Westphalian to Stephanian times. The intervening time 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 Visean rifting produced a marked palaeorelief 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 Britain in the late Visean was followed by a period of regional subsidence when the resulting basins were infilled by widespread deposits.

1.1 TECTONIC SETTING

The tectonic setting and palaeogeography of the Carboniferous of Great Britain was summarised by Waters et al. (2007) (see also Browne et al., 1999 and Browne et al., 2003 regarding the Midland Valley of Scotland and Waters et al., 2009 regarding onshore southern Britain). For completeness, the sections in Waters et al. (2007) that are relevant to onshore northern Great Britain, are reproduced here virtually intact.

In the Late Devonian a phase of north–south rifting started to affect all of central and northern Britain, initiating the development of a series of grabens and half-grabens, separated by platforms and tilt-block highs (Leeder, 1982; 1988). From north to south these Carboniferous blocks and basins include the Midland Valley of Scotland, Northumberland Trough, Alston Block, Stainmore Trough, Askrigg Block and Craven Basin (Figure 1). The block and basin margins commonly reflected reactivation of pre-existing basement lineaments.

The Midland Valley of Scotland is an east-north-east-trending complex graben, controlled by Caledonian basement structures. In the early Devonian the graben was flanked to the north-west by the eroded remains of the Caledonian Mountains north of the Highland Boundary Fault and to the south-east by the Southern Uplands south-east of the Southern Upland Fault. The Midland Valley of Scotland was an active tectonic feature controlling sedimentation for much of the Carboniferous. Depocentres within the graben subsided at different rates, and their locations and trend also changed (Browne and Monro, 1989). Superimposed upon this are marked thickness variations resulting from synsedimentary movement on north-east- and east-trending faults in a strike-slip regime throughout the Carboniferous. Associated with this were minor phases of compression, most notably during the mid Carboniferous (Read, 1988).

The Southern Uplands separated the Northumberland Trough, including the Tweed and Solway basins, from the Midland Valley of Scotland. However, this barrier was breached by narrow basins of north-north-west trend. The Solway–Northumberland Trough was bounded to the north by the North Solway, Gilnockie and Featherwood faults and to the south by the Maryport–Gilcrux–Stublick–Ninety Fathom fault system. Both bounding structures were active during deposition (Chadwick et al., 1995).

The Alston Block lies to the south of the Northumberland Trough. This horst is bounded to the south by the Closehouse–Lunedale–Swindale Beck faults, active during the Tournaisian–Visean. The Stainmore Trough, a half-graben basin, lies immediately to the south, with the southern margin defined by the Stockdale Monocline (Dunham and Wilson, 1985). This structure also marks a transition in sedimentation between the basin and the tilt-block of the Askrigg Block to the south. The Craven Fault System defines the southern margin of the Askrigg Block. The Manx–Lake District Block occurs to the west of the Alston and Askrigg blocks and is separated from them by the broadly north–south trending strike-slip Pennine–Dent Fault System.

Transtensional rifting continued to be active in the graben of the Midland Valley of Scotland during the Namurian to Stephanian. Despite possible linkages to northern England across the Southern Uplands, the Midland Valley continued to evolve as a basinal entity distinct from the area to the south.

Cessation of rifting during the late Visean in the area between the Southern Uplands and the Wales–Brabant Massif resulted in a phase dominated by thermally induced subsidence during Namurian and Westphalian times (Leeder, 1982). The Pennine Basin formed as part of this regional subsidence.

1.2 PALAEOGEOGRAPHY

The palaeogeographical reconstructions presented for the Carboniferous of Great Britain (Figure 2) have been adapted from those illustrated by Cope et al. (1992) and, for the Midland Valley of Scotland, by Browne and Monro (1989) and Read et al. (2002).

1.2.1 Tournaisian

In the Midland Valley of Scotland axial flow of sediments from the south-west was established during the Late Devonian and continued into the early Carboniferous (Read and Johnson, 1967). The basin fill was composed largely of fluvial siliciclastic sediments transported along the axis of the graben, with significant contributions coming from the Scottish Highlands to the north (Browne et al., 1999). Input from the Southern Uplands, to the south, was minor (Figure 2a). Marine incursions were not common at this time. These strata were laid down whilst the climate was semi-arid and are characterised by the presence of calcareous and dolomitic pedogenic horizons (cornstones) formed on stable alluvial plains. During the mid Tournaisian a mudstone-dominated succession characterised by minor interbeds of ferroan dolostone beds (cementstones) and evaporites (mainly gypsum preserved) was deposited on alluvial plains and marginal marine flats (sabkhas) subject to periodic desiccation and fluctuating salinity.

In northern England a series of gulf-like, tideless, hypersaline basins, including the Northumberland and Stainmore troughs (Leeder, 1992), developed between evolving horst and tilt-block highs (Figure 2a). The basins developed with variable influx from river systems, notably fluvial and deltaic input into the Northumberland Trough from the Southern Uplands. The 'cementstone' and 'cornstone' deposits recognised in the Midland Valley are also developed along the southern margin of the Southern Uplands Massif, linking with the Midland Valley in the area of the Cheviot Block.

1.2.2 Visean

In the Midland Valley of Scotland during the early Visean there was a major reversal of the axial palaeoslope and flow from the north-east became established (Greensmith, 1965). Volcanic rocks dominate in the western half of the Midland Valley (Figure 2b). In the east, the succession is largely fluviodeltaic and lacustrine (Browne and Monro, 1989), with the development of oil shales and freshwater limestones as minor, but important, components. These reflect the development of lakes characterised by the accumulation of abundant algal remains. During the late Visean, the succession in the east of the Midland Valley was still dominated by fluviodeltaic and lacustrine deposits, but with intermittent marine incursions (Figure 2c) during the Asbian and the Brigantian. Marine incursions, associated with the formation of thin limestones, were at their most frequent during the late Brigantian, when shelf seas intermittently covered much of the Midland Valley.

The early Visean depositional environment of the Northumberland Trough was dominated by lacustrine and fluviodeltaic clastic sedimentation. The main deltaic deposits were derived from the north-east and prograded gradually along the axis of the trough (Figure 2b). Meanwhile, south of the Northumberland Trough, a period of marine transgression resulted in the establishment of platform carbonates, which gradually onlapped raised horst and tilt-block highs. During late Visean times a cyclic succession of fluviodeltaic clastic rocks, marine-reworked sandstones and shallow shelf marine carbonate rocks ('Yoredale' facies) built up across northern England (Figure 2c), terminating deposition of the platform carbonates.

1.2.3 Namurian

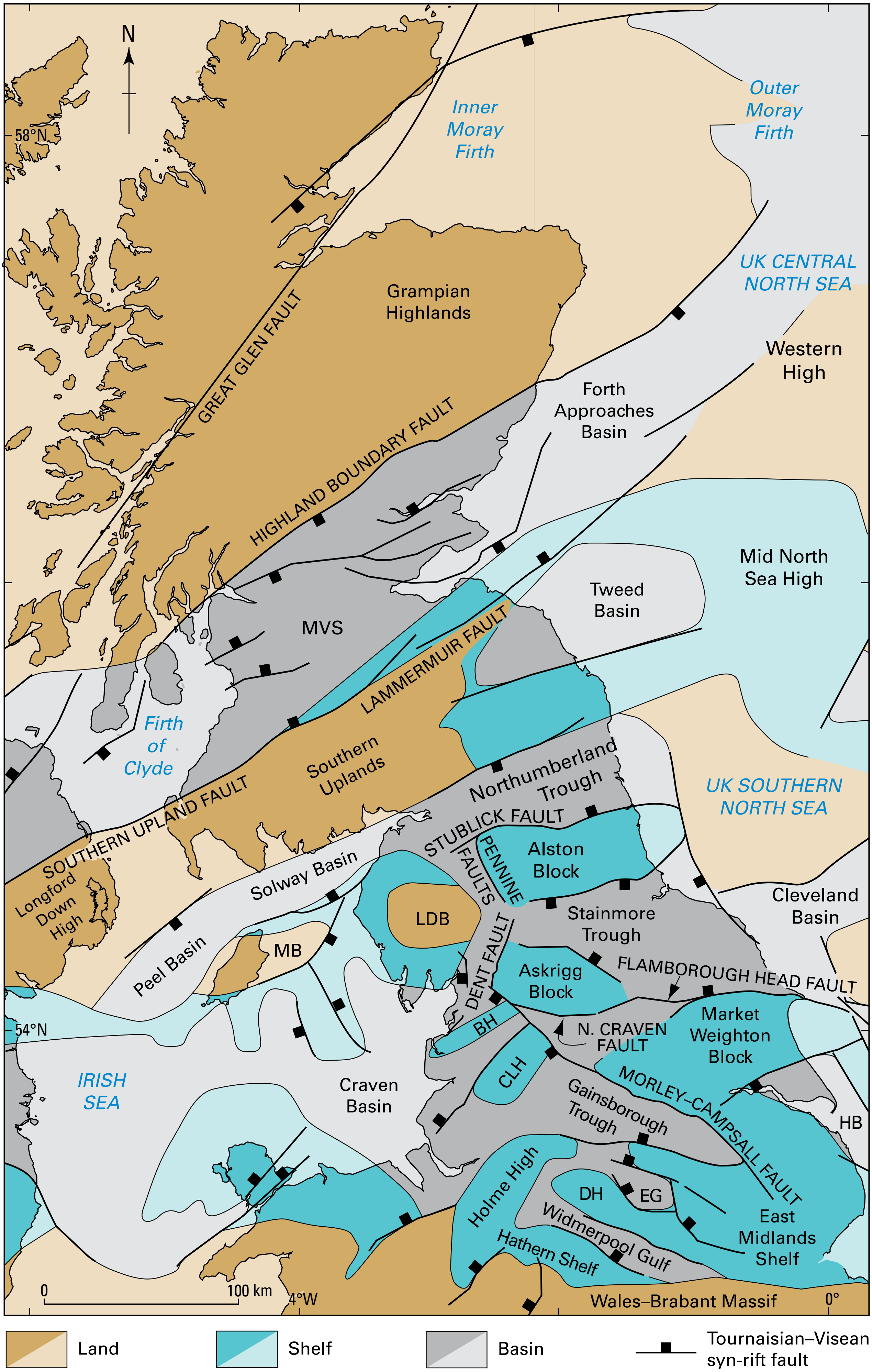
The Midland Valley of Scotland is characterised by a continuation of cyclic ('Yoredale' facies) sequences with interbedded fluviodeltaic clastic strata, coals and marine shelf limestones, the last mentioned marking highstands of sea level. This succession exhibits a progressive diminution of marine influence with time. Fluvial sediment input continued from the north-east (Figure 2d). During Pendleian times, coal-forming environments with *Lingula* and nonmarine bivalves were common, but with intermittent marine incursions. The mid to late Namurian succession is characterised by alluvial deposits (Browne and Monro, 1989), with palaeosols. In parts of Northumberland, major sand bodies elongated parallel to the axis of the trough, occupy tectonically controlled erosive channels cut through the 'Yoredale' facies succession (Young and Lawrence, 2002).

During Pendleian times a fluviodeltaic system ('Millstone Grit' facies) transported siliciclastic sediment into the northern margin of the Central Pennine sub-basin, located to the south of the area covered by this report (see Waters et al., 2009). Equivalent, though more condensed, successions are recorded on the Askrigg Block and in the Stainmore Trough. Although the term 'Millstone Grit' is widely used on old geological maps of the north Pennines and Northumberland, and remains embedded in the associated literature, the facies is absent from these areas. Major distributary channels of Pendleian and Arnsbergian age, present on the Alston Block (Dunham, 1990), may represent the feeder channels for the fluviodeltaic successions found farther to the south.

1.2.4 Westphalian

From early in the Westphalian a coal-forming delta-top environment became established across the Midland Valley of Scotland and the Pennine Basin. Although both 'Coal Measures' cyclic successions are lithologically similar, the basinal areas were, largely, isolated by the raised area of the Southern Uplands. Marine incursions were relatively rare during deposition of these successions (Figures 2e and 2f), but those that did occur gave rise to widespread marine bands.

Figure 1 *(opposite)* Principal structural features of the northern British Isles, onshore and offshore, that had significant influence on the deposition of Carboniferous strata. The depositional basins and highs shown are those that developed during the Mississippian. Note that some post-Carboniferous structures are shown within the North Sea to aid location of descriptions in the text. North Sea structure is taken from Cameron (1993a and b) and Bruce and Stemmerik (2003). See Figure 2 for palaeogeographical reconstructions through time.
BH Bowland High; CLH Central Lancashire High; DH Derbyshire High; EG Edale Gulf; HB Humber Basin; LDB Lake District Block; MB Manx Block; MVS Midland Valley of Scotland.



N
58°N
54°N
4°W
0°
0
100 km
Inner Moray Firth
Outer Moray Firth
UK CENTRAL NORTH SEA
Grampian Highlands
GREAT GLEN FAULT
HIGHLAND BOUNDARY FAULT
Western High
Forth Approaches Basin
Mid North Sea High
Tweed Basin
MVS
LAMMERMUIR FAULT
Firth of Clyde
Southern Uplands
SOUTHERN UPLAND FAULT
Northumberland Trough
STUBLICK FAULT
UK SOUTHERN NORTH SEA
Longford Down High
Solway Basin
PENNINE FAULTS
Alston Block
Cleveland Basin
LDB
Stainmore Trough
Peel Basin
MB
DENT FAULT
Askrigg Block
FLAMBOROUGH HEAD FAULT
BH
N. CRAVEN FAULT
Market Weighton Block
IRISH SEA
Craven Basin
CLH
Gainsborough Trough
MORLEY–CAMPSALL FAULT
HB
Holme High
DH
EG
East Midlands Shelf
Widmerpool Gulf
Hathern Shelf
Wales–Brabant Massif
Land
Shelf
Basin
Tournaisian–Visean syn-rift fault

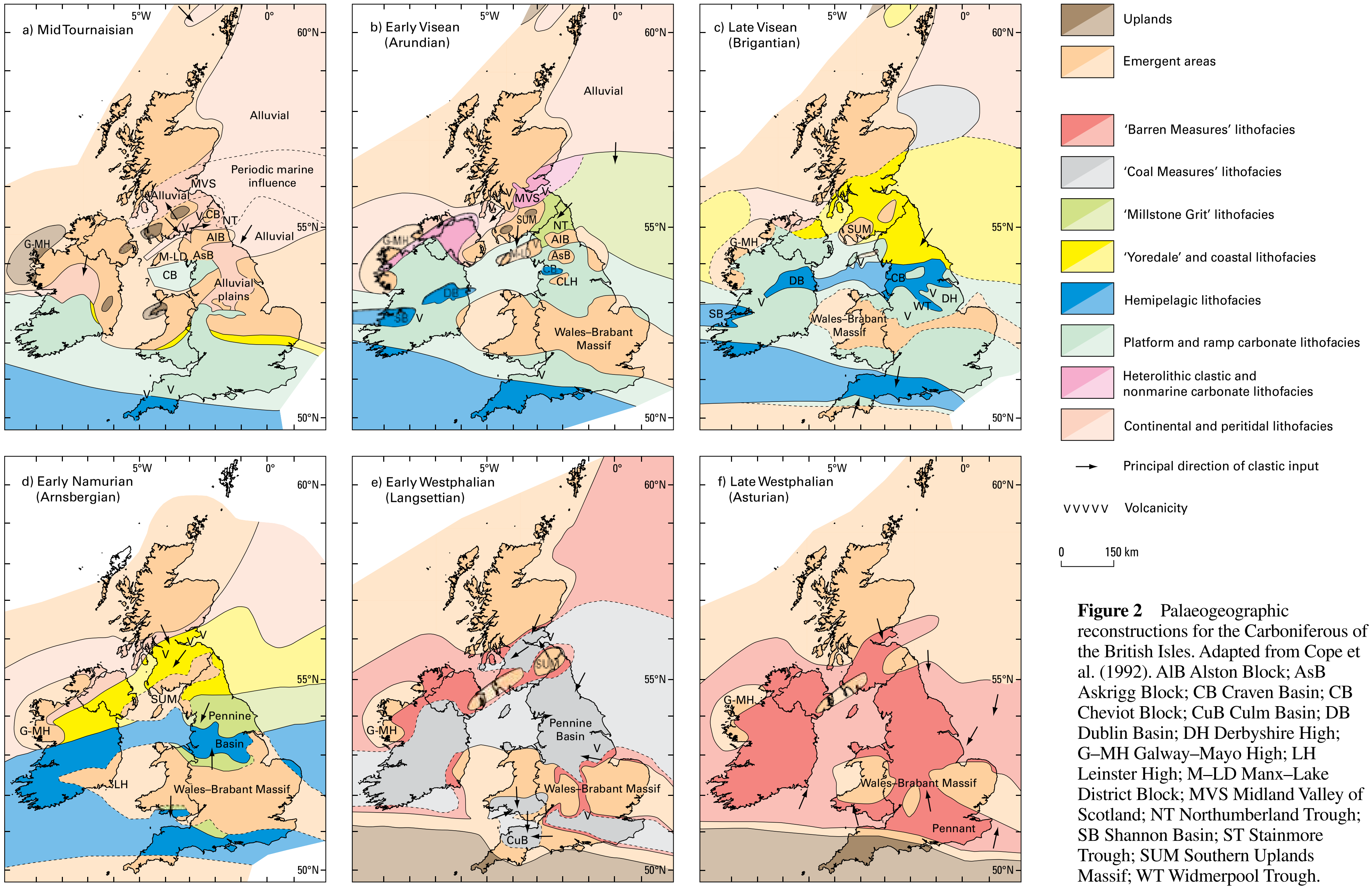


Figure 2 Palaeogeographic reconstructions for the Carboniferous of the British Isles. Adapted from Cope et al. (1992). AIB Alston Block; AsB Askrigg Block; CB Craven Basin; CB Cheviot Block; CuB Culm Basin; DB Dublin Basin; DH Derbyshire High; G–MH Galway–Mayo High; LH Leinster High; M–LD Manx–Lake District Block; MVS Midland Valley of Scotland; NT Northumberland Trough; SB Shannon Basin; ST Stainmore Trough; SUM Southern Uplands Massif; WT Widmerpool Trough.

2 Correlation and biostratigraphical framework

2.1 CHRONOSTRATIGRAPHY

The Carboniferous System in Western Europe comprises two subsystems, an older Dinantian and younger Silesian, traditionally 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 is defined as the base of the ammonoid *Cravenoceras leion* Zone.

The terms 'Dinantian' and 'Silesian' are now redundant and the Mississippian and Pennsylvanian of the USA have become recognised internationally as the only accepted main divisions (subsystems) of the Carboniferous, strictly representing the Lower and Upper Carboniferous, respectively, in international usage. The mid Carboniferous boundary separating the two subsystems occurs within the Chokierian Stage of the Namurian Series in Western Europe.

Difficulties in direct comparison between North America and Western Europe have resulted in Britain maintaining usage of the regional Western European chronostratigraphical nomenclature. The new, official subdivision of the Carboniferous System, as voted for by the Subcommission on Carboniferous Stratigraphy, and ratified by the International Commission on Stratigraphy and the International Union of Geological Sciences during the period 1999–2004, has not been applied to this report. However, the reader is referred to Davydov et al. (2004) and Heckel and Clayton (2006) for further information. Whilst the authors are fully aware of the changes to Carboniferous stratigraphical nomenclature, for sound practical reasons the old style has had to be maintained for the present.

The Dinantian is subdivided into the Tournaisian and Visean series, whereas the Silesian is subdivided into three series, the Namurian, Westphalian and Stephanian. These series do not represent global faunal or floral events, but were chosen to represent prominent facies variations in Western Europe. In northern Britain, the Tournaisian is dominated by continental and peritidal lithofacies, whilst the Visean is largely represented in the Midland Valley of Scotland by heterolithic clastic and nonmarine carbonate lithofacies, and in northern England by a mixture of open marine, platform and ramp carbonates, 'Millstone Grit' and 'Yoredale' lithofacies. In northern Britain the Namurian is dominated by 'Yoredale' and 'Millstone Grit' lithofacies, and the Westphalian is very largely represented by '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. However, *G. subcrenatum* has not been found in Scotland so the base of the Westphalian there cannot be defined accurately. In Scotland the base of the Coal Measures is taken at the base of the Lowstone Marine Band, its local correlative, or at a plane of disconformity. The Stephanian is restricted to strata of limited geographical extent in onshore northern Britain.

Internationally, the Tournaisian and Visean are now formally defined as stages, and work is in progress to define subsequent stages using nomenclatures defined in Russia. However, until this work is complete it is considered prudent to maintain usage of the well-established chronostratigraphical nomenclatures established in Britain and Western Europe.

Stage names for the Visean, Namurian and Westphalian are based on basal stratotypes defined by George et al. (1976) for the Visean, Ramsbottom et al. (1978) for the Namurian, and Owens et al. (1985) for the Westphalian, largely from localities in northern England. The distribution at outcrop of the main chronostratigraphical units and the location of the stage stratotypes is shown in Figure 3.

The Stephanian Series was originally defined in the Massif Central of France with three stages, referred to as Stephanian A, B and C. The Stephanian A has been formally renamed the Barruelian Stage. The recognition of a non-sequence in the Massif Central and identification of an additional Stephanian succession in Cantabria, northern Spain, led to the recognition of a Cantabrian Stage, which is older than the Barruelian. No strata of Cantabrian age have been recognised in northern Britain.

2.2 BIOSTRATIGRAPHY

Ammonoids (goniatites) are crucial to Carboniferous biostratigraphy, notably within the Visean, Namurian and early Westphalian series, where they provide the greatest biostratigraphical resolution. The nektopelagic habit of ammonoids allows biozones to be recognised across Western Europe and some are applicable globally. Thick-shelled ammonoids occur within thin hemipelagic marine beds (known as 'marine bands'), which developed during marine transgressions and typically comprise distinct ammonoid faunas. Ammonoid biozones are units defined by the successive first appearance of ammonoid taxa, with the base of the biozones coinciding with the bases of specific marine bands (Tables 2, 3 and 4). Very little is known of the early Courceyan ammonoid faunas in Britain and Ireland, and goniatite occurrences are rare in Britain in beds older than late Visean. Diagnostic goniatites are also uncommon in the Namurian of northern Britain, though work initiated by Currie (1954) showed that the classification of the Pennines area could be applied to part, at least, of the Scottish succession. Ramsbottom et al. (1978) applied a standard nomenclature based on the names of the principal diagnostic goniatites for the six most important marine bands in the coalfields of the British Isles. Apart from the Cambriense Marine Band, these bands can be traced throughout Western Europe, except in some marginal areas.

Foraminifers are of biostratigraphical importance within Tournaisian and Visean carbonates. They are particularly abundant in mid-ramp and platform settings, but also present within basinal deposits in limestone turbidites (Riley, 1993). The formal foraminiferal zonation for Belgium, established as the standard for north-west Europe, has been applied to British and Irish sequences by Conil et

Table 1 Chronostratigraphical framework for the Carboniferous System of Great Britain. Ages derived from Menning et al. (2000), Davydov et al. (2004) (the dates shown in brackets are international stage boundary determinations from Gradstein and Ogg, 2004); Carboniferous chronostratigraphy from Heckel and Clayton (2006); seismic sequences from Fraser et al. (1990); mesothems from Ramsbottom (1973, 1977a).

Age (Ma)	International Series	International Stages	European Subperiods	European Stages (former Series)	Heerlen Classification	European Substages (former Stages)	Seismic Stratigraphy	Mesothems
299 (299.0 ± 0.8)	PENNSYLVANIAN	GZHELIAN	SILESIAN (UPPER CARBONIFEROUS)	STEPHANIAN	C		V1	
(303.9 ± 0.9)		KASIMOVIAN			B			
					A	BARRUELIAN		
(306.5 ± 1.0)		MOSCOVIAN				CANTABRIAN		
				WESTPHALIAN	D	ASTURIAN		
310					C	BOLSOVIAN	LC2	
(311.7 ± 1.1)					B	DUCKMANTIAN		
		BASHKIRIAN			A	LANGSETTIAN		
				NAMURIAN	C	YEADONIAN	LC1	N11
					B	MARSDENIAN		N9–10
						KINDERSCOUTIAN		N6–8
					A	ALPORTIAN		N5
(318.1 ± 1.3)	MISSISSIPPIAN	SERPUKHOVIAN				CHOKIERIAN		N4
320						ARNSBERGIAN		N3
								N2
						PENDLEIAN		N1
		VISEAN	DINANTIAN (LOWER CARBONIFEROUS)	VISEAN	V3c	BRIGANTIAN	EC6	D6b
							EC5	D6a
330					V3b	ASBIAN	EC4	D5b
								D5a
					V3a, V2b	HOLKERIAN	EC3	D4
340					V2a, V1b	ARUNDIAN		D3
					V1a	CHADIAN		D2b
(345.3 ± 2.1)		TOURNAISIAN		TOURNAISIAN		IVORIAN / COURCEYAN	EC2	D2a
								D1c
350						HASTARIAN / COURCEYAN	EC1	D1b
								D1a
359 (359.2 ± 2.5)								

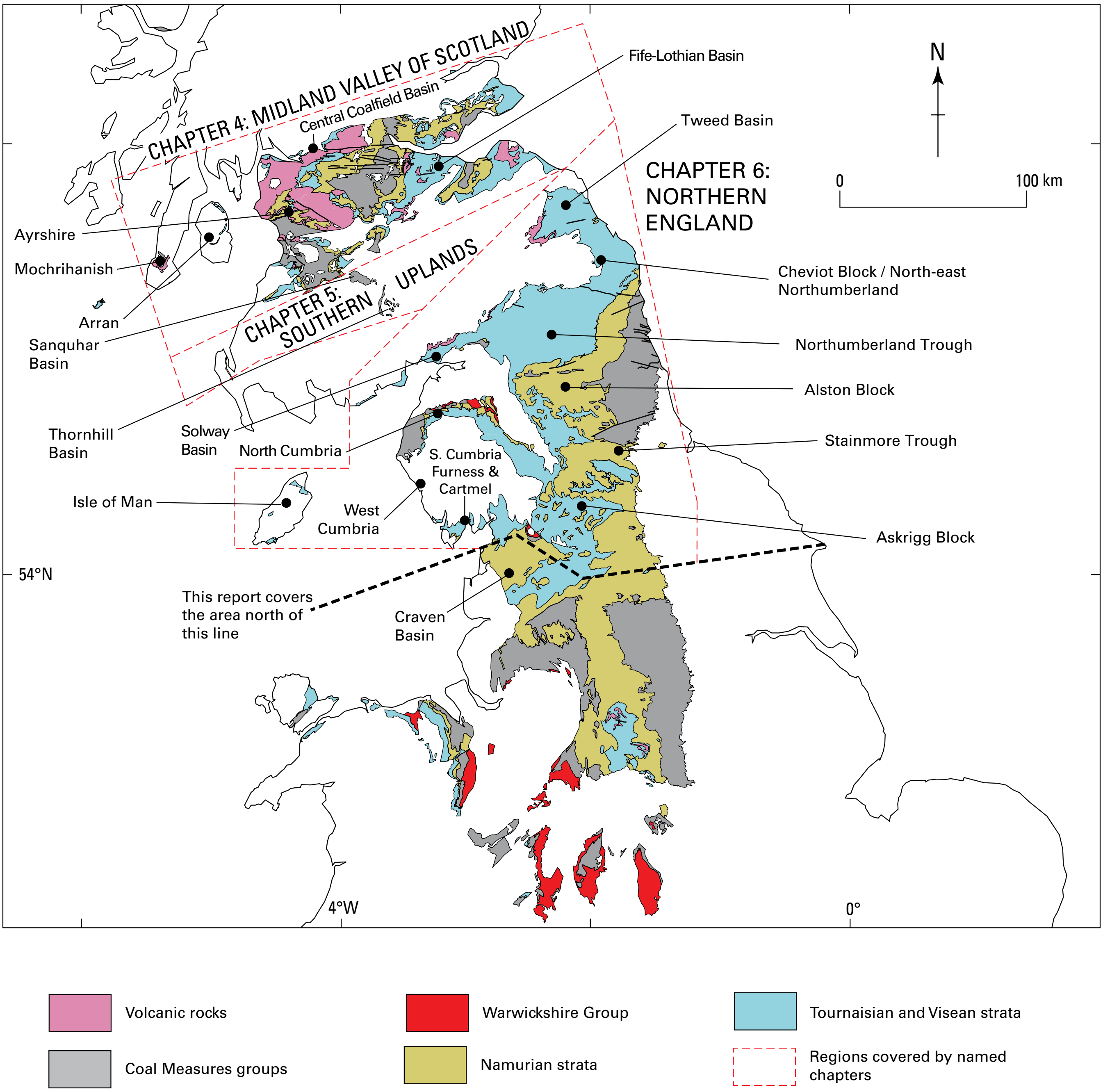


Figure 3 Extent of Carboniferous rocks of onshore northern Great Britain. The approximate area covered by this report is indicated as is the location of regions discussed in the various chapters in the text.

al. (1980) and Conil et al. (1991) and is summarised in Table 2.

Conodonts are present within marine facies, notably carbonate turbidites and hemipelagic shales, and conodont zones are particularly important for Tournaisian and Visean correlation. Varker and Sevastopulo (1985) included zonations for both 'shelf margin and basin facies' and 'shelf facies'. Conodonts are also important in recognising the mid Carboniferous boundary and the base of the Pennsylvanian Subsystem.

Palynomorphs (miospores) are present in both marine and terrestrial environments and have been used for biozonation up to and including the Asturian (Westphalian D) (Tables 2, 3 and 4). They are particularly useful for facilitating correlation in nonmarine rocks lacking stratigraphically useful macrofossils, and they can be used to correlate between nonmarine and marine sequences. Recent advances in macrofloral zonation show the importance of plant fossil biostratigraphy, particularly for the Asturian (Westphalian D) and Cantabrian (Cleal, 1991).

Coral/brachiopod 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) is still widely used and was summarised by George et al. (1976) and Riley (1993). Riley (1993, fig. 1) showed the interrelationship between the coral/brachiopod zones of Vaughan (1905) and the modified conodont zones of Varker and Sevastopulo (1985) and the relationship of these and other zones to the former stages (now partly redefined substages) of the Tournaisian and Visean.

In the Visean to Namurian, marine bivalves present within hemipelagic shales and occurring in association

Table 2 Tournaisian and Visean biostratigraphical zonations, derived from Riley (1993). Grey shading indicates interzones (conodonts and miospores) or non-sequences (brachiopods). *anch. bis. 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. mononodosa; Neoglyph. Neoglyphioceras; Parag. Paraglyphioceras; prae. Mestognathus praebeckmanni; Ps. Pseudopolygnathus; S. Siphonophyllia; Siph. Siphonodella; spic. Polygnathus spicatus; V. Vaughania; Z. Zaphrentis.*

Stages	Substages	Conodonts	Ammonoids	Foraminifera	Coral / brachiopod: Mitchell (1981, 1989)	Coral / brachiopod: Vaughan (1905)	Coral / brachiopod: Garwood (1913)	Miospores	Macroflora
Visean	Brigantian	*Gn.collinsoni*	*Lyrog. georgiensis* P2c	*Neoarchaediscus* Cf6 (part) δ	K	Horizon E	Dγ	NC (part)	*Lyginopteris bermudensiformis / Neuropteris antecedens*
		L. mono	*Neoglyph. subcirculare* P2b						
		Gn.bilineatus	*Lusit. granosus* P2a			D2		VF	
			Parag. koboldi P1d		J		D2		
			Parag. elegans P1c		I				
			Arnsb. falcatus P1b	γ	H				
			G. crenistria P1a						
	Asbian		*Beyrichoceras*: *G. globostriatus* B2b		G	D1	D1	NM	
			Beyrichoceras: *G. hudsoni* B2a						
		L. commutata	*Beyrichoceras*: B1	α – β	F			TC	
	Holkerian		*B. hodderense*	*Koskinotextularia-Pojarkovella nibelis* Cf5	E	S2 (part)	S2	TS	
	Arundian		*Bollandites-Bollandoceras* BB	*Eoparastaffella* Cf4 δ	D	S2 (part) / S1 / C2 (part)	S1	Pu	
				γ	C		C2		
				β	B				
		hom.		α2	A	C2 (part)	C2 (part)		
	Chadian late	*prae.* / *Polygnathus mehli*	*Fascipericyclus-Ammonellipsites* FA			C1	C1		
Tournaisian (part)	Chadian early			α1	*S. cylindrica*				*Triphyllopteris*
		anch. bis			*C. patulum*			CM	
	Courceyan	*bur.*	*Pericyclus*	*Tetrataxis-Eotextularia* Cf3	*Z. delanouei*				
		lat.							
		bouc.		*Paraendothyra* Cf2		Z	Z?		
		bul.							
		cf. bul. / *Ps. multistriatus*							
		has.						PC	
		Siph. / *in.*	*Gattendorfia*	*Chernyshinella* Cf1	*V. vetus*	K			*'Adiantites'*
		Siph. / *spic.*				M		BP	
								HD	
								VI	

with ammonoids are of greatest stratigraphical importance (Riley, 1993). However, this lithofacies is unknown in the Midland Valley of Scotland and is very rare in northern England. In the former region, the relatively diverse molluscan fauna is considered and treated as part of the total assemblage of macrofossils in marine facies.

Nonmarine bivalves are fundamentally important to the zonation of late Namurian and Westphalian sequences in the Midland Valley of Scotland and the Northumberland Trough (Table 4). They tend to occur in association with fish material and ostracods.

Estheriids are small crustaceans that occupied brackish waters. They can occur in prominent marker 'bands' in the Westphalian.

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

EUROPEAN REGIONAL SUBSTAGE	ZONE		WESTERN EUROPEAN MARINE BANDS		MIOSPORES	CONODONTS
	Index	**Ammonoid**	**Ammonoid**	**Index**	**(Index)**	
Yeadonian	G_{1b}	*Cancelloceras cumbriense*	*Ca. cumbriense*	$G_{1b}1$	*Raistrickia fulva – Reticulatisporites reticulatus* (FR)	
	G_{1a}	*Cancelloceras cancellatum*	*Ca. cancellatum*	$G_{1a}1$		
Marsdenian	R_{2c}	*Bilinguites superbilinguis*	*Verneulites sigma*	$R_{2c}2$		
			B. superbilinguis	$R_{2c}1$		*Idiognathoides sinuatus – Idiognathoides primulus*
	R_{2b}	*Bilinguites bilinguis*	*B. metabilinguis*	$R_{2b}5$		
			B.eometabilinguis	$R_{2b}4$		
			B. bilinguis	$R_{2b}3$		
			B. bilinguis	$R_{2b}2$		
			B. bilinguis	$R_{2b}1$		
	R_{2a}	*Bilinguites gracilis*	*B. gracilis*	$R_{2a}1$		
Kinderscoutian	R_{1c}	*Reticuloceras reticulatum*	*R. coreticulatum*	$R_{1c}4$		
			R. reticulatum	$R_{1c}3$		
			R. reticulatum	$R_{1c}2$	*Crassispora kosankei – Grumosisporites varioreticulatus* (KV)	
			R. reticulatum	$R_{1c}1$		
	R_{1b}	*Reticuloceras eoreticulatum*	*R. stubblefieldi*	$R_{1b}3$		
			R. nodosum	$R_{1b}2$		*Idiognathoides corrugatus – Idiognathoides sulcatus*
			R. eoreticulatum	$R_{1b}1$		
	R_{1a}	*Hodsonites magistrorum*	*R. dubium*	$R_{1a}5$		
			R. todmordenense	$R_{1a}4$		
			R. subreticulatum	$R_{1a}3$		
			R. circumplicatile	$R_{1a}2$		
			Ho. magistrorum	$R_{1a}1$		
Alportian	H_{2c}	*Vallites eostriolatus*	*Homoceratoides prereticulatus*	$H_{2c}2$		
			V. eostriolatus	$H_{2c}1$		
	H_{2b}	*Homoceras undulatum*	*H. undulatum*	$H_{2b}1$		
	H_{2a}	*Hudsonoceras proteum*	*Hd. proteum*	$H_{2a}1$	*Lycospora subtriquetra – Kraeuselisporites ornatus* (SO)	*Declinognathus noduliferus*
Chokierian	H_{1b}	*Homoceras beyrichianum*	*I.* sp. nov.	$H_{1b}2$		
			H. beyrichianum	$H_{1b}1$		
	H_{1a}	*Isohomoceras subglobosum*	*I. subglobosum*	$H_{1a}3$		
			I. subglobosum	$H_{1a}2$		
			I. subglobosum	$H_{1a}1$		
Arnsbergian	E_{2c}	*Nuculoceras stellarum*	*N. nuculum*	$E_{2c}4$		
			N. nuculum	$E_{2c}3$	*Lycospora subtriquetra – Kraeuselisporites ornatus* (SO)	
			N. nuculum	$E_{2c}2$		
			N. stellarum	$E_{2c}1$		
	E_{2b}	*Cravenocera–toides edalensis*	*Ct. nititoides*	$E_{2b}3$		
			Ct. nitidus	$E_{2b}2$		*Gnathodus bilineatus bollandensis*
			Ct. edalensis	$E_{2b}1$		
	E_{2a}	*Cravenoceras cowlingense*	*Eumorphoceras yatesae*	$E_{2a}3$	*Stenzonotriletes triangulus – Rotaspora knoxi* (TK)	
			C. gressinghamense	$E_{2a}2a$		
			Eumorphoceras ferrimontanum	$E_{2a}2$		
			C. cowlingense	$E_{2a}1$		
Pendleian	E_{1c}	*Cravenoceras malhamense*	*C. malhamense*	$E_{1c}1$	*Bellispores nitidus – Reticulatisporites carnosus* (NC) *pars.*	
	E_{1b}	*Cravenoceras brandoni*	*Tumulites pseudobilinguis*	$E_{1b}2$		*Kladognathus – Gnathodus girtyi simplex*
			C. brandoni	$E_{1b}1$		
	E_{1a}	*Emstites (Crav-enoceras) leion*	*E. leion*	$E_{1a}1$		

Table 4 Westphalian chronostratigraphy and biostratigraphical zonations.

European Regional Substage	Ammonoids	Conodonts	Palynomorphs		Non-marine bivalves	
			Index	**Zone**	**Zone**	**Sub-zone**
Cantabrian	*Donetzoceras cambriense*		OT	*Thymospora obscura – T. thiessenii*	*Anthraconauta tenuis*	
Asturian						
Bolsovian	*Donetzoceras aegiranum*		SL	*Torispora securis – T. laevignata*	*Anthraconauta phillipsii*	
					'Upper similis- pulchra'	
			NJ	*Microreticulati-sporites nobilis – Florinites junior*		*adamsi-hindi*
Duckmantian	*Anthracoceratites vanderbeckei*				*'Lower similis-pulchra'*	*atra*
						caledonica
						phrygiana
					Anthraconaia modiolaris	*ovum*
						regularis
Langsettian			RA	*Radiizonates aligerens*		*cristagalli*
					Carbonicola communis	*pseudorobusta*
						bipennis
						torus
			SS	*Triquitrites sinani-Cirratriradites saturni*	*Carbonicola lenisulcata*	*proxima*
	Gastrioceras listeri	*Idiognathoides sulcatus parvus*				*extenuata*
	Gastrioceras subcrenatum	*Idiognathoides sinuatus – Idiognathoides primulus (pars.)*				*fallax-protea*

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 Great Britain.

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 lithostratigraphical procedures (Rawson et al., 2002). 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, commonly 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 British Isles. 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) and more recently, Geological Society of London guidance (Rawson et al., 2002), as these are commonly accepted standards. The nomenclature chosen should aid communication of British Carboniferous 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, this report uses existing nomenclature where suitable, whilst providing full definitions consistent with the guidance from the NASC and the Geological Society of London.

An alphabetical listing of all the groups and formations present within northern Britain are provided in Appendix 1. Redundant or obsolete names are listed in Appendix 3.

3.1 GROUP FRAMEWORK

In rationalising the stratigraphy it was decided to follow a 'top-down' approach by which the group nomenclature was based upon the recognition of major lithofacies. The committee considered the possibility of having a single group name for each lithofacies applicable to all Great Britain. However, the lithofacies were commonly developed within distinct basinal areas and a single Britain-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. Where it was believed useful to provide a single term for a Britain-wide lithofacies, it was recommended it should be defined as a supergroup.

Nine major lithofacies associations (Figure 4) have been identified for the Carboniferous of onshore Great Britain, all of which are recognised in the northern provinces. The main lithologies, environments of deposition, distribution and age ranges were first described by Waters et al. (2007; see also Figure 2).

A *continental and peritidal facies* is widespread across northern Britain including from the Midland Valley of Scotland to central England. It was deposited from Late Devonian to Visean times. There are two subfacies, which are commonly found to interdigitate. A continental fluvioclastic ('cornstone') subfacies commonly forms the first basin infill and extends onto horst and tilt-block highs. A peritidal marine and evaporite ('cementstone') subfacies is generally limited to troughs associated with grabens and half-grabens.

A *heterolithic clastic and nonmarine carbonate facies*, of Visean age, is principally present in the eastern part of the Midland Valley of Scotland where it passes laterally westward into dominantly volcanic rocks. It is also present as early Visean strata in parts of the Northumberland Trough.

An *open marine, platform and ramp carbonates facies* accumulated during the Visean on platforms and ramps that developed on horst blocks and half-graben tilt blocks over the Alston and Askrigg blocks, and fringing the Manx–Lake District Block.

A *hemipelagic facies* was deposited in quiet and relatively deep basinal prodelta and carbonate slope environments that developed in the Furness and Cartmell area (south Cumbria) and the Askrigg Block–Craven Basin 'Transition Zone' during the early Namurian.

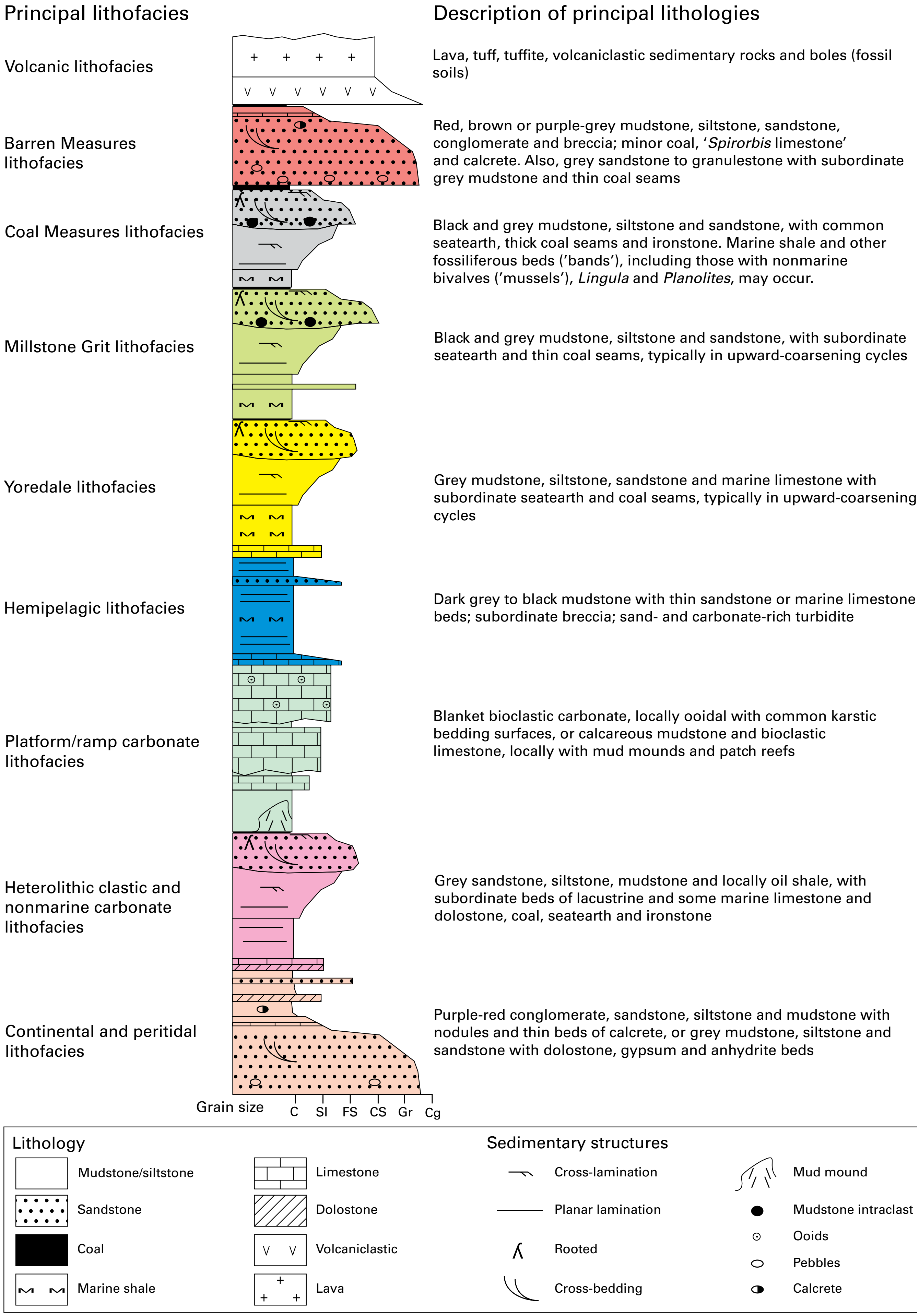
A *mixed shelf carbonate and deltaic ('Yoredale') facies* is widespread across the Midland Valley of Scotland and northern England as far south as the Craven Fault System. It is found in strata of Visean to Namurian age.

A *fluviodeltaic ('Millstone Grit') facies* extends from the Midland Valley of Scotland, across northern and central England in strata of Namurian to early Westphalian age. Similar deposition may have occurred within the Northumberland Trough during early Visean times.

A *fluviodeltaic ('Coal Measures') facies* extends from the Midland Valley of Scotland across northern England in strata of Westphalian age.

An *alluvial ('Barren Measures') facies* occurs as two subfacies in Britain (see Waters et al., 2007). However, only the 'red-bed' subfacies occurs in northern Britain in west Cumbria, the Ingleton Coalfield and the Solway Basin. It was deposited during the Westphalian.

A *volcanic facies* is most thickly present as the Clyde Plateau Volcanic Formation (Arundian to Asbian) and Bathgate Group (Asbian to Arnsbergian) of the Midland Valley of Scotland, but it is also significantly developed in the Tournaisian and Visean age rocks of the Solway and Tweed basins (Cockermouth, Birrenswark and Kelso vol-


Principal lithofacies
Description of principal lithologies
Volcanic lithofacies
Lava, tuff, tuffite, volcaniclastic sedimentary rocks and boles (fossil soils)
Barren Measures lithofacies
Red, brown or purple-grey mudstone, siltstone, sandstone, conglomerate and breccia; minor coal, '*Spirorbis* limestone' and calcrete. Also, grey sandstone to granulestone with subordinate grey mudstone and thin coal seams
Coal Measures lithofacies
Black and grey mudstone, siltstone and sandstone, with common seatearth, thick coal seams and ironstone. Marine shale and other fossiliferous beds ('bands'), including those with nonmarine bivalves ('mussels'), *Lingula* and *Planolites*, may occur.
Millstone Grit lithofacies
Black and grey mudstone, siltstone and sandstone, with subordinate seatearth and thin coal seams, typically in upward-coarsening cycles
Yoredale lithofacies
Grey mudstone, siltstone, sandstone and marine limestone with subordinate seatearth and coal seams, typically in upward-coarsening cycles
Hemipelagic lithofacies
Dark grey to black mudstone with thin sandstone or marine limestone beds; subordinate breccia; sand- and carbonate-rich turbidite
Platform/ramp carbonate lithofacies
Blanket bioclastic carbonate, locally ooidal with common karstic bedding surfaces, or calcareous mudstone and bioclastic limestone, locally with mud mounds and patch reefs
Heterolithic clastic and nonmarine carbonate lithofacies
Grey sandstone, siltstone, mudstone and locally oil shale, with subordinate beds of lacustrine and some marine limestone and dolostone, coal, seatearth and ironstone
Continental and peritidal lithofacies
Purple-red conglomerate, sandstone, siltstone and mudstone with nodules and thin beds of calcrete, or grey mudstone, siltstone and sandstone with dolostone, gypsum and anhydrite beds
Grain size
C
Sl
FS
CS
Gr
Cg
Lithology
Mudstone/siltstone
Sandstone
Coal
Marine shale
Limestone
Dolostone
Volcaniclastic
Lava
Sedimentary structures
Cross-lamination
Planar lamination
Rooted
Cross-bedding
Mud mound
Mudstone intraclast
Ooids
Pebbles
Calcrete

canic formations), in the Namurian of the western Midland Valley (Troon Volcanic Member) and in Namurian to Westphalian rocks of the eastern Midland Valley.

It will be noted in the report that some groups designated in northern Britain may comprise two or more lithofacies associations (excluding volcanics). For example, in the case of the Clackmannan Group of Scotland, this resulted from a desire not to have a large number of single-formation groups where several main lithofacies are represented, and in the case of the Yoredale Group of northern England it dealt with local variances in the main lithofacies.

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. In these circumstances the new formation names generally utilise an existing, widely used name, which conforms to the NASC criteria (Anon., 1983). In relatively few cases, formation names did not exist and new terms have been introduced as part of this study.

A formation is a mappable unit that possesses internal lithological homogeneity or distinctive lithological features that distinguish it from adjacent formations (see Rawson et al., 2002; Anon., 2005 for a full definition). Individual coals, sandstones and limestones, whilst they may be 'mappable units' are treated as beds of informal level and are not described in this report. Some limestones within the Yoredale Group were considered to be amalgamated units of great lateral extent that warranted member status.

Figure 4 *(Opposite)* Schematic graphic log summarising the nine main lithofacies. Although the lithofacies are shown broadly in their order of superposition, youngest at the top, they may interdigitate. The bases of the beds as shown are also highly schematic. C claystone; Sl siltstone;FS fine-grained sandstone; CS coarse-grained sandstone; Gr granulestone; Cg conglomerate.

The text in this report is largely based on entries in the BGS Lexicon of Named Rock Units for which lithological information has been compiled from many different sources using different classifications. Where possible, limestone nomenclature uses the Dunham (1962) scheme based on texture, modifying other terminologies where obvious. Otherwise the Folk (1959; 1962) scheme, based mainly on composition, has been used.

Where possible, the nomenclature used for all igneous and sedimentary rock names follows the recommendations of the BGS Rock Classification Scheme (RCS). However, in some circumstances it has been necessary to use the original descriptions and 'legacy' names.

Where relevant, the classification of basaltic rock in the Midland Valley of Scotland devised by MacGregor (1928) is included to permit comparison with previous maps and literature. To avoid repetition the six classes are listed here with their RCS-compatible translations for reference:

Markle: plagioclase-macrophyric basalt to trachybasalt (hawaiite)
Dunsapie: olivine-clinopyroxene-plagioclase-macrophyric basalt
Craiglockhart: olivine-clinopyroxene-macrophyric basalt to basanite (referred to formerly as ankaramite)
Jedburgh: plagioclase-microphyric basalt to trachybasalt (hawaiite)
Dalmeny: olivine-microphyric basalt
Hillhouse: olivine-clinopyroxene-microphyric basalt to basanite.

These translations are compatible with the approach to rock classification and nomenclature set out in the BGS Rock Classification Scheme (Volume 1 Igneous rocks) by Gillespie and Styles (1999).

4 Carboniferous rocks of Scotland north of the Southern Upland Fault

4.1 MIDLAND VALLEY OF SCOTLAND

The group and formation nomenclature for the Midland Valley of Scotland proposed by Browne et al. (1999) has been retained. There are four main groups, in ascending order, the Inverclyde (partly Devonian in age), Strathclyde, Clackmannan and Scottish Coal Measures groups (Figure 5; see also Figure 6). The boundaries between the youngest three groups are defined by marker horizons that are widespread within the Midland Valley. Volcanic rocks are common, ranging from thin local beds to widespread thick accumulations. The major occurrences of Carboniferous lavas are in the Strathclyde and Bathgate groups. Those of the Inverclyde and Strathclyde groups exhibit a full range of compositions from basaltic to rhyolitic, whereas later magmatism was entirely basaltic or basanitic.

4.2 INVERCLYDE GROUP (INV)

The Inverclyde Group (Paterson and Hall, 1986) (Figure 5; see also Browne et al., 1999, fig. 1), of *continental and peritidal facies* comprises, in ascending order, the Kinnesswood, Ballagan and Clyde Sandstone formations. It is characterised by sandstones with pedogenic carbonate (the *continental and peritidal facies* 'cornstone' subfacies) and by silty mudstones containing thin beds of dolostone and limestone (the *continental and peritidal facies* 'cementstone' subfacies). There may be some lateral passage of the two subfacies.

The base of the group is taken at the base of the Kinnesswood Formation where the dominantly sandstone lithologies of the underlying Stratheden Group (Late Devonian: defined by Paterson and Hall, 1986) are succeeded by pedogenic carbonate-bearing strata. Typically transitional, the base is locally defined by an unconformity in the west of the Midland Valley. The base of the Strathclyde Group (*heterolithic clastic and nonmarine carbonate facies*) defines the top of the Inverclyde Group, and the youngest formation, the Clyde Sandstone Formation, that itself represents a return to fluviatile pedogenic facies similar to the basal Kinnesswood Formation.

The type area of the Inverclyde Group is Greenock, Inverclyde District (see Paterson and Hall, 1986). The group extends across the Midland Valley and occurs at Machrihanish and on Arran, the Cumbrae isles and Bute and Cowal. It also extends across and along the southern margin of the 'Southern Uplands Terrane' from Eyemouth to Dalbeattie. Tournaisian (Famennian? to Chadian) in age, it is about 1500 m thick.

4.2.1 Kinnesswood Formation (KNW)

Name

The name Kinnesswood Formation was introduced by Chisholm and Dean (1974) and has since been extended throughout the Midland Valley of Scotland and, by this report into the Northern England Province (see Section 6.3.1). It replaces the former term 'Cornstone Beds', a unit at the top of the 'Upper Old Red Sandstone'.

Lithology

In the Midland Valley of Scotland the Kinnesswood Formation consists predominantly of purple-red, yellow, white and grey-purple, fine- to coarse-grained sandstones which are mostly cross-bedded and arranged in upward-fining units. Fine-grained, planar or poorly bedded sandstones, red mudstones and nodules and thin beds of concretionary carbonate (calcrete or 'cornstone') also occur. The cornstones range from immature, in which the sandstones have a partly carbonate matrix with ill-defined concretions, to mature, in which well-defined nodules (glaebules) are elongated in a vertical sense and are overlain by laminar and pisolitic structures. The laminar structures, which develop parallel to the bedding, may be brecciated and the carbonate replaced by chert. In the Northern England Province the formation comprises mainly red sandstones, siltstones and conglomerates.

Genetic interpretation

In the Midland Valley of Scotland the Kinnesswood Formation was laid down in fluviatile environments. The cross-bedded sandstones were deposited in river channels and the fine-grained sandstones and mudstones represent overbank deposits formed on the associated floodplains. The cornstones, which characterise the formation, were developed in soil profiles on the floodplains and channel margins under the influence of a fluctuating water table in a semi-arid climate. In the Northern England Province the original sediments were laid down in calcrete-rich (cornstone) alluvial fans that were deposited in a series of small, linked basins with internal drainage that developed during early stages of crustal extension (Chadwick et al., 1995). The beds are dominantly fluvial with a palaeocurrent towards the north-east.

Stratotype

The type section is the hillside to the east of the village of Kinnesswood at Kinnesswood Row, base of unit at [NO 1805 0363], top at [NO 1814 0362] (see Browne et al., 1999, fig. 1, col. 11). Intra-Carboniferous erosion has removed the top part of the formation in the type area, but the BGS Glenrothes Borehole (BGS Registration Number NO20SE/385) [NO 25617 03144] provides a complete reference section from 362.4 to 449.3 m depth (see Browne et al., 1999, fig. 1, col. 12).

Lower and upper boundaries

In the Midland Valley of Scotland the transitional base of the Kinnesswood Formation is taken in the type area between strata with cornstones and the underlying aeolian sandstones without cornstones, the Knox Pulpit Formation (Stratheden Group). In most areas the top is conformable beneath the grey mudstone and siltstone with ferroan dolostones of the Ballagan Formation (Figure 6, Columns 1–3, 4B), but in the type area it is erosional beneath strata of the Strathclyde Group (Pathhead Formation).

In the Northern England Province the base of the formation is typically unconformable upon Silurian strata of the Riccarton Group. In the Berwick-upon-Tweed area and Solway Basin, the Kelso Volcanic and Birrenswark

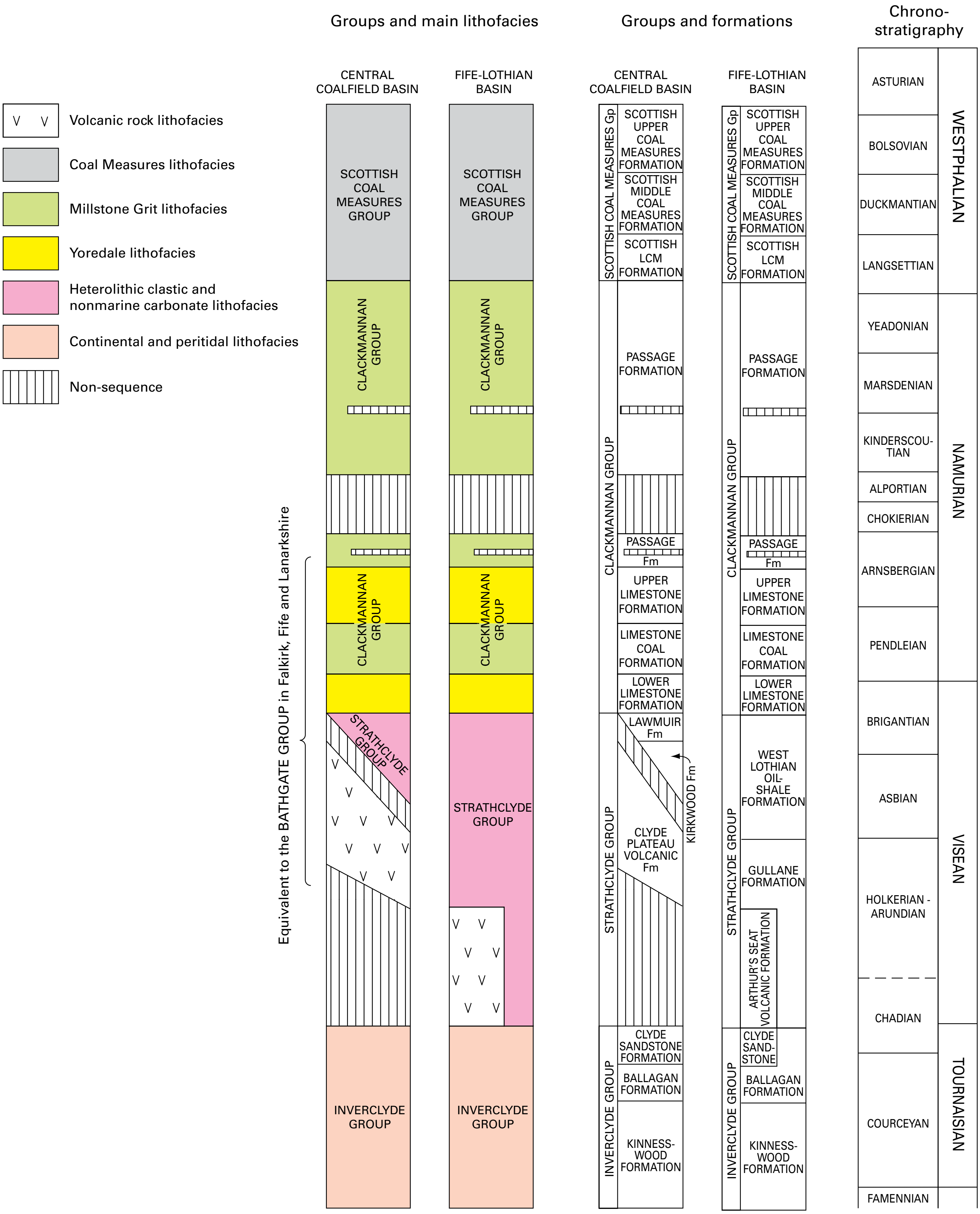


Figure 5 Lithostratigraphical nomenclature for the Midland Valley of Scotland. See Section 3 for description of lithofacies, and Figures 6 and 10 for other localities discussed in text. This figure is not intended to name all the formations in the region. Fm formation; Gp group; LCM Lower Coal Measures.

Volcanic formations respectively, overlie it (Figure 8, Column 12; Figure 10, Columns 2, 3).

Thickness
About 640 m (maximum) in the Edinburgh area (based on Mitchell and Mykura (1962, p. 31), and up to 200 m thick in the Northern England Province. Generally, 40 m on Arran (BGS, 1987a), 68 m at Bute and Cowal, and 250 m in the Cumbrae isles (BGS, 2008).

Distribution and regional correlation
Throughout the Midland Valley, on Arran, at Bute and Cowal and in the Cumbrae isles. It is now extended across and south of the Southern Uplands from Eyemouth to

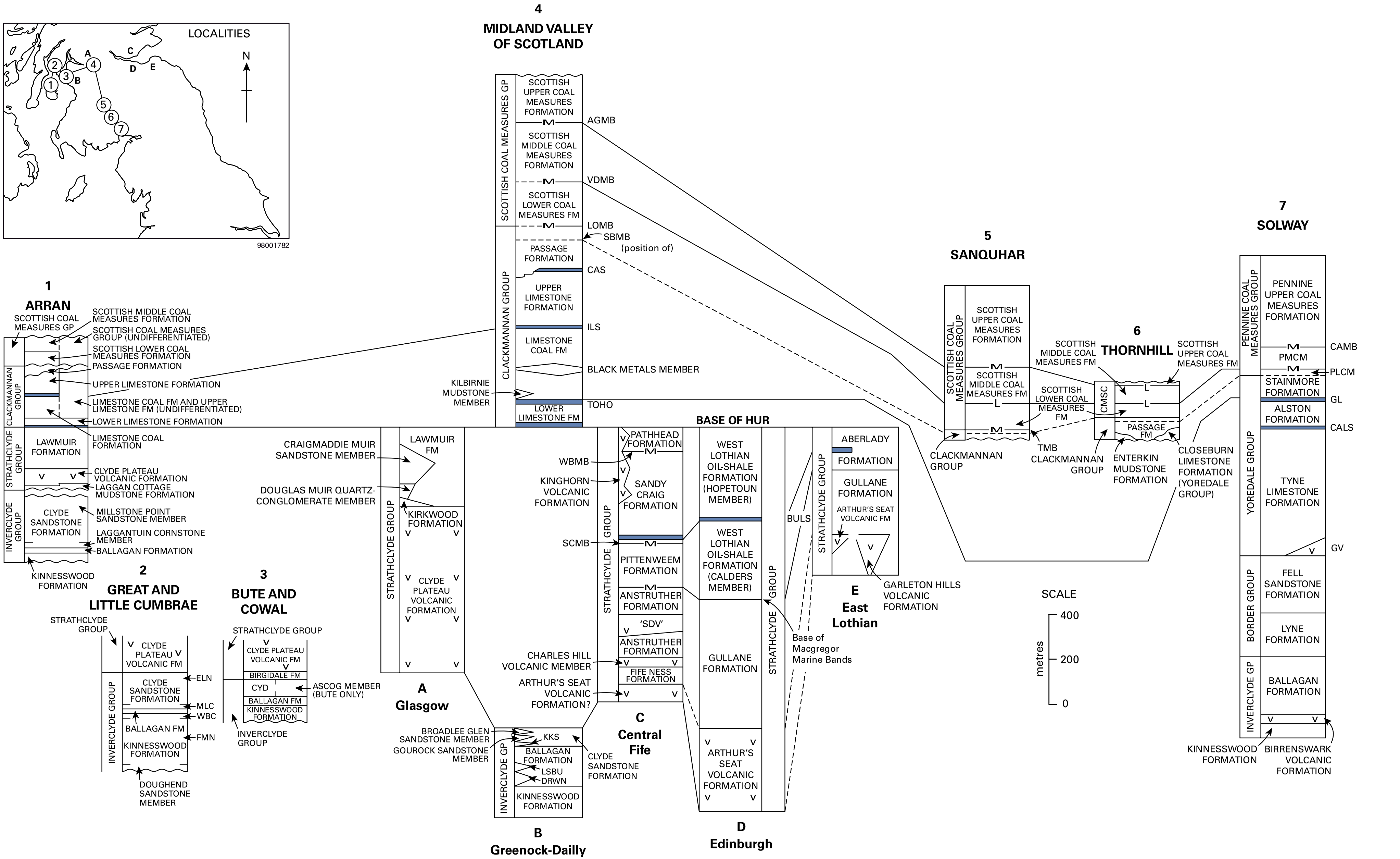


Figure 6 Generalised vertical sections and correlation for Carboniferous strata in Scotland. Based on Lumsden et al. (1967), BGS (1987a), Browne et al. (1999), McMillan (2002) and BGS (2008). The profiled location of the numbered and lettered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band; L *Lingula* band. v indicates named volcanic rock units; blue colour indicates named limestone beds; dashed lines indicate conjecture; wavy lines indicate unconformity surfaces.

Dalbeattie, where it crops out narrowly along the northern margin of the Northumberland Trough in the Langholm area (Lumsden et al., 1967) and west of the Cheviot Hills.

Age and biostratigraphical characterisation
In the Midland Valley of Scotland the formation is mostly early Carboniferous (Courceyan) in age, but the discovery of miospores of Tournaisian age (LN–PC biozones) from near the base of the formation (Smith, 1996) confirms that it may straddle the Devonian–Carboniferous boundary. In the Northern England Province it is considered to be Late Devonian (Famennian) to early Tournaisian (Courceyan) in age, Lumsden et al. (1967) and George et al. (1976) having postulated an early Carboniferous age for the upper part of the formation.

Formal subdivisions
See also Appendix 1. Members of the Kinnesswood Formation, in ascending order, include:

4.2.1.1 DOUGHEND SANDSTONE MEMBER (DHS)

Name
Previously named the Dug Head Sandstone Member, which is considered to be a misspelling. See Monro (1999); British Geological Survey (2002a; 2002b; 2002c; 2005).

Lithology
Mainly sandstone with a few cornstone concretions.

Stratotype
The type section comprises coastal exposures on the south-west side of Great Cumbrae Island, North Ayrshire [NS 149 549 to 149 544]. There the boundaries with over and underlying strata are faulted, though they have been mapped as stratiform elsewhere across the island (see Monro, 1999).

Lower and upper boundaries
The lower boundary is inferred to disconformably overlie red-brown sandstone of the Late Devonian Kelly Burn Sandstone Formation, Stratheden Group (Browne et al., 2001).

The upper boundary is conformably overlain by red-brown silty mudstone, with carbonate-cemented concretions, of the Foulport Mudstone Member of the Kinnesswood Formation (Figure 6, Column 2).

Thickness
About 30 m. BGS (2008) gave a generalised thickness of 36 m for the member.

Distribution and regional correlation
The Doughend Sandstone Member is known only on the island of Great Cumbrae, where it is exposed on the south-west of the island in the vicinity of Doughend Hole [NS 149 544]. The member is mapped at outcrop north-eastwards across the island. The outcrop is limited to the east by the Kaimes Bay Fault where the member is part of the hanging-wall sequence.

Age
Late Devonian?

4.2.1.2 FOULPORT MUDSTONE MEMBER (FMN)

Name
From Foul Port, Millport Bay, Great Cumbrae, Strathclyde.

Lithology
Red-brown silty mudstone with a few sandstones and beds with nodules of pedogenic limestone. See Paterson and Hall (1986); BGS (in press); BGS (in preparation).

Stratotype
The type area is the coast section at Foul Port [NS 157 546], Millport Bay, Great Cumbrae, Strathclyde.

Lower and upper boundaries
The lower boundary is conformable on the underlying Doughend Sandstone Member. It is marked by a change from yellow sandstone with a few concretionary nodules to red-brown mudstone and siltstone of the Foulport Mudstone Member (Monro, 1999; BGS in preparation).

The upper boundary is conformable and overlain by variegated sandstones with concretions of the West Bay Cornstone Member (Figure 6, Column 2).

Distribution and regional correlation
Cumbrae isles, Strathclyde

Thickness
About 200 m. BGS (2008) gave a generalised thickness of 198 m for the member.

Age
Late Devonian? to Courceyan

4.2.1.3 WEST BAY CORNSTONE MEMBER (WBC)

Name
The West Bay Cornstone Member is known from the south coast of the island of Great Cumbrae, adjacent to West Bay Road, Millport. See Monro (1999); BGS (2002a; 2002b; 2002c; 2005).

Lithology
Sandstone, yellow with red and green mottling, with carbonate-cemented ('cornstone') concretions.

Stratotype
The type section is coastal exposures on the southern side of Great Cumbrae Island, Strathclyde region. The entire member, including the lower and upper boundaries, is exposed on the coast at the south-west end of the town of Millport [NS 157 543 to 156 542] (see Monro, 1999).

Lower and upper boundaries
The lower boundary conformably overlies the red-brown silty mudstone, with carbonate-cemented concretions, of the Foul Port Mudstone Member, Kinnesswood Formation.

The upper boundary is conformably overlain by a grey mudstone sequence with ferroan dolostone beds of the Ballagan Formation (Figure 6, Column 2).

Thickness
Approximately 16 m

Distribution and regional correlation
The West Bay Cornstone Member is known only on the island of Great Cumbrae, where it is exposed on the south coast of the island adjacent to West Bay Road, Millport. The member is mapped at outcrop to underlie the town of Millport. The outcrop is limited to the east by the Kaimes Bay Fault where the member is part of the hanging-wall sequence.

Age
Tournaisian

4.2.2 Ballagan Formation (BGN)

Name
The name Ballagan Formation was first introduced by Browne (1980) to replace the traditional term Ballagan Beds

(or Series), which referred, informally, to the mudstone-cementstone sequence at Ballagan Glen (Young, 1867 a, b). The name now encompasses strata in the Lothians that were earlier (Chisholm et al., 1989) called the Tyninghame Formation (and in so doing acknowledges the presence of locally thick sandstones) and also part of the Cementstone Group of previous literature in Northern England, the Tweed Basin and the Solway Basin (see Peach and Horne, 1903; Craig, 1956; Craig and Nairn, 1956; Nairn, 1956, 1958) and part of the Lower Border Group of Lumsden et al. (1967).

Lithology
In the Midland Valley of Scotland the Ballagan Formation is characterised by generally grey mudstones and siltstones, with nodules and beds (generally less than 0.3 m thick) of ferroan dolostone ('cementstone'). Gypsum, and to a much lesser extent anhydrite, and pseudomorphs after halite occur. Desiccation cracks are common and the rocks frequently show evidence of brecciation during diagenesis. Both these features are associated with reddening of the strata. Thin ripple-marked sandstones are present in many areas, and thick localised sandstones are also now included in the formation. In the Northern England Province the Ballagan Formation comprises interbedded sandstone, mudstone, limestone ('cementstone') and anhydrite, the latter being present in the subsurface only. There are also pseudomorphs after evaporite minerals, some rootlet beds and thin coals.

Genetic interpretation
In the Midland Valley of Scotland the Ballagan Formation formed in a peritidal environment associated with intermittent emergence. In the Northern England Province, deposition of the formation was dominated by the influx of alluvial fans and fluvial and fluviodeltaic sediments from the Southern Uplands, intercalated with lacustrine and arid coastal plain deposits (Deegan, 1973; Leeder, 1974). Hypersaline lacustrine and floodplain facies include pseudomorphs after evaporite minerals, some rootlet beds and thin coals.

Stratotype
The partial type section, in the Midland Valley of Scotland, is defined south of Perth in the East Dron Borehole (BGS Registration Number NO11NW/24) [NO 1360 1572] from the bedrock surface at 15.26 to 224.80 m depth (see Browne et al., 1999, fig. 1, col. 7). The formation is also well exposed in Ballagan Glen [NS 5731 8022]. In the Northern England Province (see Section 6.3.6 for full locality and stratigraphical details) partial type sections include disused quarries on Whita Hill, the River Esk from Longwood to Broomholm, the River Annan from Rochell to Hoddom Castle, the Tarras Water, Kirkbean Glen and the coastal section from Port Mary to Castle Muir. A reference section occurs in the BGS Hoddom No.2 Borehole (BGS Registration Number NY17SE/3) [NY1641 7285].

Lower and upper boundaries
In the Midland Valley of Scotland the base of the formation is taken at the lithological boundary between strata characterised by a mudstone–cementstone association and the underlying cornstone bearing sandstone of the Kinnesswood Formation (Figure 6, Column 4B). The top is drawn at the highest unit of mudstone and cementstone in any particular area. The mainly white sandstones of the Clyde Sandstone Formation usually overlie the Ballagan Formation, except in parts of the Lothians where the mainly conformable base of the sandstones, mudstones and siltstones of the Gullane Formation, or volcanic rocks of the Arthur's Seat or Garleton Hills volcanic formations, overlie the Ballagan Formation.

In the Northern England Province the base of the formation is faulted or irregularly conformable upon the Birrenswark Volcanic Formation in the Solway Basin (Figure 10, Columns 2, 3), it is conformable on the Kelso Volcanic Formation in the Berwick area (Figure 8, Column 12), and elsewhere it is unconformable upon Devonian and older strata. The top of the formation is presumed to be conformable beneath the Lyne Formation of the Northumberland Trough and Solway Basin (Figure 6, Column 7; Figure 10, Columns 2, 3), but it is unconformable beneath the Fell Sandstone Formation in the north-east part of the Northumberland Trough (Figure 8, Column 12; Figure 11, Column 1; Figure 12, Columns 1, 2; Figure 13, Column 3).

Thickness
About 900 m (maximum) in the West Lothian area (based on Mitchell and Mykura, 1962, p. 38), and up to 250 m thick in the Northern England Province. Generally, 20 m on Arran (BGS, 1987a), 23 m in the Cumbrae isles and 38 m at Bute and Cowal (BGS, 2008).

Distribution and regional correlation
The formation occurs throughout the Midland Valley of Scotland, on Arran, in the Cumbrae isles and at Bute and Cowal. It also also crops out in the north-eastern margins of the Northumberland Trough and at Kirkbean in the Solway Firth area. In the central part of the Northumberland Trough a lateral facies change sees the Ballagan Formation pass into the Lyne Formation of the Border Group.

Age and biostratigraphical characterisation
Tournaisian (Courceyan to Chadian). In the Midland Valley of Scotland the Ballagan Formation typically contains miospores indicative of the CM Biozone, although Smith (1996) also recorded a sample from the PC Biozone. Where present, the restricted fauna is characterised by the bivalve *Modiolus latus*, but ostracods are more abundant. In the Northern England Province the fauna is also characterised by bivalves (including a modiolid fauna) and the annelid *Serpula* sp.

Formal subdivisions
See also Appendix 1. Members of the Ballagan Formation in the Midland Valley of Scotland, in ascending order, include:

4.2.2.1 Drumwhirn Member (DRWN)

Name
The member was previously referred to by Eyles et al. (1949) as the 'Basal Sandstone' of the Cementstone Group of the Calciferous Sandstone Measures. The present unit was named after Drumwhirn Farm and defined by Monaghan (2004).

Lithology
White-buff and yellow, medium- to fine-grained, thinly planar-bedded sandstone intercalated with finely laminated grey calcareous siltstone, calcareous mudstone, grey silty mudstone and rare, thin, nonmarine, muddy ferroan dolostone ('cementstone').

Stratotype
The type area is in the hills east and south of Lindsayston Burn south-east of Dailly between Craig and Drumwhirn

farms and east of Whitehill Farm [NS 275 005 to 300 016] (see Eyles et al., 1949; Floyd, 1999; Monaghan, 2004).

Lower and upper boundaries
The basal contact is faulted in the type area (see above). The presence of grey silty mudstone and dolomitic limestone ('cementstone') interbedded with sandstone distinguishes this basal member of the Ballagan Formation from the underlying sandstone-dominated Kinnesswood Formation (Figure 6, Column 4B).

The upper boundary is mapped as a conformable contact on 1:10 000 scale Geological Sheet NS20SE in the Lindsayston Burn section at [NS 2824 0080] but is not actually exposed. The boundary is defined as the lithological change from yellow sandstone with grey silty mudstone to red-purple sandstone with conglomerate and pedogenic carbonate typical of the Lindsayston Burn Member.

Thickness
The member is at least 275 m thick in the type area (see above), but the base is faulted. The unit is interpreted to be of laterally variable thickness.

Distribution and regional correlation
The member occurs on 1:50 000 scale Geological sheets Scotland 14W (Ayr) and Scotland 8W (Carrick), and 1:10 000 scale Geological sheets NS20SE and NS30SW (part of) near Dailly, South Ayrshire. The lateral extent of the unit is not yet finalised.

Age
Tournaisian (Courceyan)

4.2.2.2 Lindsayston Burn Member (LSBU)

Name
After Lindsayston Burn, south-east of Dailly. The member was defined by Monaghan (2004), having previously been referred to as 'cornstone-bearing beds' of the Cementstone Group of the Calciferous Sandstone Measures by Eyles et al. (1949). See also Floyd (1999).

Lithology
Between [NS 2821 0082 and 2272 0089], the strata are characterised by buff-white-grey, hard, flaggy sandstone, interbedded with soft red-green sandstone with pedogenic carbonate nodules and pipes, and rarer red-green siltstone and mudstone with pedogenic carbonate nodules. Thick channelised sandstone and conglomerate, a few metres thick and tens of metres wide, is observed at several localities. In the north-western part of the Lindsayston Burn section [NS 2272 0089 to 2749 0097] the upper part of the member records a gradational change. Medium- to coarse-grained sandstone interbedded with red-grey siltstone with pedogenic carbonate is still common, but intercalations of grey calcareous siltstone and mudstone and thinly bedded fine-grained sandstone in packages up to about 0.7 m thick are also observed.

Stratotype
The type section occurs along the Lindsayston Burn [NS 2824 0080 to 2735 0112], south-east of Dailly on 1:10 000 scale Geological Sheet NS20SE (see Eyles et al., 1949; Monaghan, 2004).

Lower and upper boundaries
The lower boundary is defined as the lithological change from the underlying Drumwhirn Member of yellow sandstone with grey silty mudstone, to red-purple sandstone with conglomerate and pedogenic carbonate (Figure 6, Column 4B). It is mapped as a conformable contact on 1:10 000 scale Geological Sheet NS20SE in the type stream section at [NS 2824 0080] but it is not actually exposed.

The upper boundary is defined as the lithological change from red-purple sandstone with conglomerate and pedogenic carbonate, to the grey-green mudstone with thin nonmarine limestones and sandstone that is typical of the Ballagan Formation in the Midland Valley of Scotland. It is mapped as a conformable contact on 1:10 000 scale Geological Sheet NS20SE in the type stream section at [NS 2735 0112] but it is not actually exposed.

Thickness
About 200 m at the type section (see above) with 134 m proved by logging where exposed. Interpreted to be laterally variable and up to 285 m thick in other parts of 1:10 000 scale Geological Sheet NS20SE.

Distribution and regional correlation
The member occurs on 1:10 000 scale Geological sheets NS20SE, NS20SW, and NS30SW near Dailly, South Ayrshire. The lateral extent of the unit is not yet known.

Age
Tournaisian (Courceyan)

4.2.3 Clyde Sandstone Formation (CYD)

Name
From the River Clyde. The name Clyde Sandstone Formation was introduced by Paterson and Hall (1986) for sandstone-dominated strata, with 'cornstones', overlying the Ballagan Formation in the west of the Midland Valley.

Lithology
The Clyde Sandstone Formation consists predominantly of white, fine- to coarse-grained sandstone, commonly pebbly, with beds of red-brown or grey mudstone. Pedogenic limestone, as nodules or beds, and calcite cemented concretionary sandstones are also present in some areas. In more northerly areas some of the sandstones are conglomeratic, with pebbles of quartz and 'Highland' rock types (Browne et al., 1999). Elsewhere the clasts are largely of intrabasinal limestone or mudstone.

Genetic interpretation
The strata were laid down in a wide range of fluviatile environments ranging from braided stream to floodplain with well developed overbank deposits.

Stratotype
The partial type sections (composite stratotype) of the Clyde Sandstone Formation are in the Barnhill Borehole (BGS Registration Number NS47NW/2) [NS 4269 7571], just east of Dumbarton where the base and top of the formation occur at 161.5 and 104.9 m depth respectively, and in the Knocknairshill Borehole (BGS Registration Number NS37SW/10) [NS 3056 7438], east of Greenock, where the base and top of the formation occur at 222.9 and 50.7 m depth respectively.

Lower and upper boundaries
The transitional base of the formation is taken at the lithological boundary between strata consisting predominantly of white sandstone with pedogenic limestone and the underlying mudstone and cementstone

association of the Ballagan Formation (Figure 6, Columns 1–3, 4B). The top is overlain variously by sedimentary or volcanic formations of the Strathclyde Group.

Thickness
The maximum thickness is greater than 300 m in the Glasgow area (Paterson and Hall, 1986, p. 11). 250 m on Arran (BGS, 1987a), 75 m at Bute and Cowal and 148 m in the Cumbrae isles (BGS, 2008).

Distribution and regional correlation
The Clyde Sandstone Formation now extends throughout the Midland Valley and occurs on Arran, at Bute and Cowal and in the Cumbrae isles. It replaces the term Balcomie Formation (Browne, 1986) in Fife. The 'Upper Sandstone' of the Pentland Hills (Mitchell and Mykura, 1962, p. 38) may also belong to it.

Age
Late Tournaisian

Formal subdivisions
See also Appendix 1. Members of the Clyde Sandstone Formation in ascending stratigraphical order within the following geographical areas include:

ISLE OF ARRAN

4.2.3.1 Laggantuin Cornstone Member (LGT)

Name
The member is named after Laggantuin on the north-east side of the Isle of Arran. See Paterson and Hall (1986); GSGB (1924); Tyrell (1928).

Lithology
Interbedded white sandstone and red claystone (shale) in fining-upwards cycles, with many small lenticular calcareous nodules ('cornstone') in the claystone. The upper beds recorded on the shore at Laggantuin have fairly good continuous pedogenic nodular limestones about 0.3–0.6 m thick. The overlying upper part of the member, comprising thick-bedded white sandstone and pebbly sandstone, is exposed north of Laggantuin.

Stratotype
The type section occurs in coastal exposures near Laggantuin on the north-east side of the Isle of Arran, Strathclyde [NS 0015 4855 to NR 9959 4914] (see Paterson and Hall, 1986).

Lower and upper boundaries
The lower boundary is mapped at the base of a white nodular limestone bed ('cornstone') that is approximately 0.6 m thick, overlying the alternating sequence of grey mudstone (shale), nodular limestone ('cornstone') and thin grey sandstone that comprises the Ballagan Formation (Figure 6, Column 1).

The upper boundary is conformably overlain by the pebbly coarse-grained white sandstone (grit) of the Millstone Point Sandstone Member. An occurrence of pebbly sandstone recorded as 'Millstone Point Grits' is exposed toward the northern part of the mapped extent of the Laggantuin Cornstone Member.

Thickness
Approximately 30 m. However, BGS (1987a) gave a generalised thickness of 50 m.

Distribution and regional correlation
The vicinity of Laggantuin, north-east coast of the Isle of Arran, Strathclyde.

Age
Tournaisian

4.2.3.2 Millstone Point Sandstone Member (MPS)

Name
From Millstone Point, north-east Arran. See Paterson and Hall (1986).

Lithology
Mainly white, cross-bedded sandstone with thin beds of red-brown or grey mudstone (BGS, 1987a).

Stratotype
The type section is the Laggan shoreline on the north-east coast of the Isle of Arran [NR 9995 4875 to 9887 5013].

Lower and upper boundaries
The member conformably overlies the Laggantuin Cornstone Member (Figure 6, Column 1), which comprises sandstone and red-brown silty mudstone in fining-upward cycles with nodules and beds of concretionary limestone. The base is seen at [NR 9995 4875].

The stratigraphical top of the Millstone Point Sandstone Member is not seen. It is either faulted or unconformably overlain by grey mudstones with plant remains of the Laggan Cottage Mudstone Formation of the Strathclyde Group.

Thickness
About 150–200 m. BGS (1987a) gave a generalised thickness of 200 m.

Distribution and regional correlation
Laggan shoreline on the north-east coast of the Isle of Arran.

Age
Tournaisian

ISLE OF BUTE

4.2.3.3 Ascog Member (ASO)

Name
From Ascog, Isle of Bute. The member was defined by Paterson and Hall (1986).

Lithology
Red-brown siltstone and sandstone with pedogenic limestone.

Stratotype
The type section occurs in the BGS Ascog Borehole (BGS Registration Number NS06SE/8) [NS 0986 6302] from 133.6 to 219.8 m depth.

Lower and upper boundaries
At the lower boundary, sandstone of the Ascog Member is interbedded with grey mudstone and dolomitic limestone ('cementstone') of the Ballagan Formation. The boundary is picked where beds of dolomitic limestone ('cementstone') are absent and sandstone becomes the predominant lithology.

At the upper boundary there is a sharp change at the probably erosional base of the overlying Birgidale Formation, which comprises mudstone, sandstone, seatrock and coal.

Thickness
Some 86 m. However, BGS (2008) gave a generalised thickness of 75 m for the member on the Isle of Bute.

Distribution and regional correlation
Isle of Bute, Strathclyde.

Age
Tournaisian

CUMBRAE ISLES

4.2.3.4 Millport Cornstones Member (MLC)

Name
From Millport, Great Cumbrae, Strathclyde.

Lithology
Grey sandstone and red-brown silty mudstone with pedogenic limestone. See Paterson and Hall (1986); Monro (1999); BGS (in press); BGS (in preparation).

Stratotype
The type area is Millport Bay [NS 157 545], Great Cumbrae, Strathclyde.

Lower and upper boundaries
The lower boundary is conformable (Monro, 1999) and is described as 'transitional' (likely to be interbedded) with grey mudstone and dolomitic limestone of the Ballagan Formation (Paterson and Hall, 1986) (Figure 6, Column 2). It crops out in Millport Bay at [NS 1561 5416].

The top of the member is not seen, but is presumed to be transitionally overlain by the Eileans Sandstone Member that crops out on the Eileans in Millport Bay (Paterson and Hall, 1986; Monro, 1999).

Thickness
About 70 m. However, BGS (2008) gave a generalised thickness of 20 m for the formation.

Distribution and regional correlation
Cumbrae isles, Strathclyde.

Age
Tournaisian

4.2.3.5 Eileans Sandstone Member (ELN)

Name
Named after the Eileans, Millport Bay, Great Cumbrae, Strathclyde.

Lithology
Mainly white, cross-bedded sandstone (see Paterson and Hall, 1986; BGS, in preparation).

Stratotype
The type area is the Eileans [NS 164 546], Millport Bay, Great Cumbrae, Strathclyde.

Lower and upper boundaries
Base not seen, but presumed transitional on the Millport Cornstones Member (Figure 6, Column 2).

Top not seen, but presumed overlain by extrusive igneous rocks of the Clyde Plateau Volcanic Formation.

Thickness
About 150 m. However, BGS (2008) gave a generalised thickness of 128 m for the formation.

Distribution and regional correlation
Cumbrae isles, Strathclyde

Age
Tournaisian

SOUTH OF THE RIVER CLYDE

4.2.3.6 Knocknairshill Member (KKS)

Name
From Knocknairshill, Port of Glasgow, Strathclyde.

Lithology
Mainly white or pale red cross-bedded sandstone with beds of red-brown silty mudstone; nodules and beds of pedogenic limestone (Paterson and Hall, 1986). The member comprises well-developed upward-fining fluvial cycles including pedogenic carbonate ('cornstone') within the mudstone deposits in most cycles (Paterson and Hall, 1986; Paterson et al., 1990; see also IGS, 1978).

Stratotype
A type section is exposed on the coast between Gourock and Clough, Strathclyde [NS 2340 7726 to 2082 7617]. An additional section occurs in the Knocknairshill BGS Borehole No. 4 (BGS Registration Number NS37SW/10) [NS 3056 7438] from 92.3 to 222.9 m depth (see Paterson et al., 1990).

Lower and upper boundaries
The member at its lower boundary is interbedded with grey mudstone and dolomitic limestone ('cementstone') of the underlying Ballagan Formation (Figure 6, Column 4B). The base is picked where dolomitic limestone and grey mudstone beds are absent, and at the base of the first thick interval of sandstone containing medium, fining-upward beds of brownish grey, fine-grained sandstone and reddish brown, silty mudstone.

The upper boundary of the member with the white cross-bedded sandstones of the overlying Gourock Sandstone Member is mapped in the vicinity of Gourock Golf Course [NS 2230 7630] but it is not exposed. In the Knocknairshill BGS Borehole No. 4 (see above) the member is unconformably overlain by volcaniclastic strata of the Clyde Plateau Volcanic Formation.

Thickness
The member is 130.58 m thick in the Knocknairshill BGS Borehole No. 4 (see above).

Distribution and regional correlation
The Greenock district south of the River Clyde to east and west of the Largs Fault Zone, Strathclyde.

Age
Tournaisian

4.2.3.7 Gourock Sandstone Member (GKA)

Name
From the town of Gourock on the south side of the Clyde Estuary. Previously known as the Gourock Formation.

Lithology
The Gourock Sandstone Member comprises white, cross-bedded sandstone with thin beds of red-brown, silty mudstone, and nodules and beds of pedogenic limestone. It is distinguished from other units of the Clyde Sandstone

Formation by the presence of thicker beds of sandstone, a lesser proportion of mudstone and less abundant calcareous nodules (Paterson and Hall, 1986; BGS, 1990). Paterson et al. (1990) described the member as comprising thick multistorey bodies of white pebbly sandstone.

Stratotype
The type area is at [NS 205 761] on 1:50 000 scale Geological Sheet Scotland 29E.

Lower and upper boundaries
The lower boundary of the member with the underlying Knocknairshill Member (Figure 6, Column 4B) is mapped in the vicinity of Gourock Golf Course [NS 2230 7630]. It is recognised by the presence of thick beds of white pebbly sandstone in the overlying Gourock Sandstone Member, but the boundary itself is not exposed.

The upper boundary is not seen but it is presumed to be overlain by sandstone and mudstone strata of the Broadlee Glen Sandstone Member (Paterson and Hall, 1986), which distinctively include plant debris and beds of grey mudstone (BGS, 1990).

Thickness
About 300 m.

Distribution and regional correlation
The Greenock district south of the River Clyde, and also west of the Largs Fault Zone, Strathclyde.

Age
Tournaisian

4.2.3.8 Broadlee Glen Sandstone Member (BRLG)

Name
The member was previously known as the Broadlee Glen Sandstones Formation. See Paterson and Hall (1986); Paterson et al. (1990); BGS (1990).

Lithology
Grey and white, cross-bedded sandstones with thin, lenticular beds of grey mudstone and carbonised plant debris (Paterson and Hall, 1986; BGS, 1990). In the northern part of Leapmoor Plantation [NS 221 715] the member consists of white and cream-coloured, trough cross-stratified sandstone with lenticular beds of grey siltstone and abundant coalified wood fragments (Paterson et al., 1990).

Stratotype
The type area is Broadlee Glen near Greenock, Strathclyde [NS 2210 7150 to 2260 7140].

Lower and upper boundaries
Base not seen. The member was mapped in Broadlee Glen [NS 2258 7134] and distinguished from underlying strata of the undivided Clyde Sandstone Formation by the presence of plant debris and beds of grey mudstone (BGS, 1990). Paterson and Hall (1986) presumed that the unseen base of the Broadlee Glen Sandstone Member is transitional on white sandstones and red-brown mudstones of the Gourock Sandstone Member.

Top not seen, but the Broadlee Glen Sandstone Member was presumed to be overlain by strata of the Clyde Plateau Volcanic Formation by Paterson and Hall (1986) (Figure 6, Column 4B).

Thickness
Greater than 100 m.

Distribution and regional correlation
South of the River Clyde and also west of the Largs Fault Zone in Strathclyde.

Age
Tournaisian.

NORTH OF THE RIVER CLYDE

4.2.3.9 Overtoun Sandstone Member (OVS)

Name
Derived from Overtoun, the member was previously known as the Overtoun Sandstone Formation (IGS, 1978). The present definition was published by Paterson et al. (1990).

Lithology
The lower part of the Overtoun Sandstone Member, approximately 36 m thick, is dominated by grey, fine-grained, thin-bedded or partly concretionary sandstone. There are also intervals of mudstone, up to 3.3 m thick, commonly with calcareous concretions and uncommon beds of concretionary limestone or dolomitic limestone (‘cementstone’). The upper part, approximately 20 m thick, largely comprises pale grey, mostly fine-grained sandstone with clasts of carbonate. Unlike the lower part of the member, sandstones with concretions and mudstones are uncommon.

Stratotype
The type section is the BGS Barnhill Borehole, near Overtoun (BGS Registration Number NS47NW/2) [NS 4269 7571] from 104.89 to 161.48 m depth.

Lower and upper boundaries
The lower boundary of the member is conformable and overlies strata of the Ballagan Formation that are characterised by grey mudstone and dolomitic limestone (‘cementstone’). In the Barnhill Borehole (see above) the base is picked, at 161.48 m depth, at the top of a unit dominated by grey mudstone with gypsum veins, overlain by a sequence dominated by thick packages of sandstone.

In the same borehole at 104.89 m depth, the upper boundary of the Overtoun Sandstone Member is sharp and picked at a marked change from grey sandstone and mudstone to grey tuff, with volcanic lapillae, of the overlying Clyde Plateau Volcanic Formation. Correlation within the Greenock district demonstrates that the base of the Clyde Plateau Volcanic Formation is unconformable.

Thickness
Some 56.6 m in the type section (see above).

Distribution and regional correlation
Area around Overtoun House, north of the River Clyde near Dumbarton, Strathclyde.

Age
Early Visean.

4.3 STRATHCLYDE GROUP (SYG)

The ascending sequence of the Strathclyde Group (Paterson and Hall, 1986) (Figures 5, 6); see also Browne et al., 1999, fig. 2) includes:

In the *western Midland Valley of Scotland*, the Birgidale, Laggan Cottage Mudstone, Clyde Plateau Volcanic, Kirkwood, and Lawmuir formations;

In *Fife*, the Fife Ness, Anstruther, Pittenweem, Sandy Craig, and Pathhead formations;

In *West Lothian*, the Arthur's Seat Volcanic, Gullane, and West Lothian Oil-Shale formations.

In *East Lothian*, the Garleton Hills Volcanic, Gullane, and Aberlady formations.

The group comprises mainly *heterolithic clastic and nonmarine carbonate facies* strata deposited in fluviatile, deltaic and lacustrine or lagoonal environments. Lithologies are laterally variable. The sedimentary rocks consist of interbedded sandstone, siltstone and mudstone (including oil shales) with common seatearth, coal and sideritic ironstone. The volcanic successions comprise typically transitional to mildly alkaline lavas, pyroclastic rocks and volcaniclastic sedimentary rocks. Thin bioclastic limestone occurs within the uppermost part of the group that is characterised by the incoming of 'Yoredale'-type cyclothems representing increasing marine conditions (Francis, 1991).

The base of the group is taken, in Fife, at the conformable base of the Fife Ness Formation; in the Lothians, at the mainly conformable base of the Gullane Formation or Arthur's Seat Volcanic Formation; and in Central and Western parts of the Midland Valley, at the sharp, irregular, unconformable base of the Clyde Plateau Volcanic Formation. The group represents a lithological change from the 'cornstone'- and 'cementstone'-bearing strata of the Inverclyde Group to a seatrock and/or coal-bearing sequence in which volcanic rocks may be common. The base of the Clackmannan Group (*mixed shelf carbonate and deltaic ('Yoredale') facies* of a variable succession) defines the top of the Strathclyde Group.

The type area of the Strathclyde Group is the Glasgow area of the Strathclyde Region (see Paterson and Hall, 1986). Reference sections include coastal sections in east Fife, and the group extends across the Midland Valley of Scotland to include Machrihanish, the Isle of Arran, the Cumbrae isles and Bute and Cowal. It also includes Whitecleuch (Leadhills, Southern Uplands).

Visean (Chadian to Brigantian) in age, the Strathclyde Group exceeds 1250 m in thickness. Paterson and Hall (1986) suggested it is about 1500 m thick in the type area. It may locally exceed 2000 m.

WEST CENTRAL SCOTLAND (Arran, Bute and Cowal, and Glasgow) (Figure 6, Columns 1, 3 and 4A)

4.3.1 Birgidale Formation (BID)

Name
From Birgidale Knock Farm, South Bute, Strathclyde Region (Paterson and Hall, 1986).

Lithology
The Birgidale Formation consists of cyclically deposited grey mudstone, quartz pebble-bearing sandstone and seatearth with coal seams.

Genetic interpretation
The depositional environment was fluviodeltaic, mainly river channel and floodplains.

Stratotype
The type section is from 32.8 to 54.1 m depth in the Birgidale Knock Borehole (BGS Registration Number NS05NE/2) [NS 0725 5990], the type area being around Birgidale Knock about [NS 074 599] in south Bute.

Lower and upper boundaries
The base of the formation is sharp, probably erosional, on the Ascog Member of the Clyde Sandstone Formation (Figure 6, Column 3).

The top is overlain by lava, tuff and volcaniclastic sedimentary rocks of the Clyde Plateau Volcanic Formation.

Thickness
About 16 m (Paterson and Hall, 1986, p. 13). However, BGS (2008) gave a generalised thickness of 25 m for the formation.

Distribution and regional correlation
Isle of Bute

Age
Visean

4.3.2 Laggan Cottage Mudstone Formation (LNT)

Name
Taken from Laggan Cottage, north-east Arran (Paterson and Hall, 1986, p.14).

Lithology
The Laggan Cottage Mudstone Formation consists of grey carbonaceous mudstone with subordinate sandstones. Plant remains occur but no coal seams are developed.

Genetic interpretation
The depositional environment was fluviodeltaic, mainly floodplain or lacustrine.

Stratotype
The type area is in the neighbourhood of Laggan Cottage, north-east Arran [NR 986 501] where the entire thickness of the formation is present.

Lower and upper boundaries
The base of the formation is taken at the faulted or unconformable top of the white sandstone forming the Millstone Point Sandstone Member of the Clyde Sandstone Formation at [NR 9887 5013] (Figure 6, Column 1).

The formation is overlain by lava and tuff of the Clyde Plateau Volcanic Formation at [NR 9855 5035].

Thickness
About 7 m (Paterson and Hall, 1986, p.14). However, BGS (1987a) gave a generalised thickness of 10–20 m.

Distribution and regional correlation
North-east Arran

Age
Visean

4.3.3 Clyde Plateau Volcanic Formation (CPV)

Name
Taken from the River Clyde. The name was introduced by Monro (1982) to replace earlier terms such as the Clyde Plateau Lavas.

Lithology
The Clyde Plateau Volcanic Formation consists of lavas, pyroclastic rocks and volcaniclastic sedimentary rocks. The lavas are transitional to mildly alkaline and show a wide range in composition. The 'basic' rocks

are mostly hypersthene-normative with a few being silica-undersaturated nepheline-normative. The more-fractionated rocks are almost all quartz-normative in composition, although rare nepheline-normative trachytic lavas have been identified and phonolitic rocks form some intrusions. The range in rock type is olivine+pyroxene-phyric basalt and basanite–olivine+clinopyroxene+plagioclase-phyric basalt–plagioclase-phyric hawaiite–mugearite–benmoreite–trachyte–rhyolite. Benmoreite is rare and the end members of the range are uncommon. In the north-west part of the Midland Valley, in the Kilpatrick–Campsie–Gargunnock blocks, the sequence is dominated by plagioclase-phyric hawaiites. Plagioclase-phyric basalts are less abundant and clinopyroxene-phyric types are uncommon. In the south-western part of the Midland Valley, Renfrewshire Hills and Lanark blocks, a full range of compositions and petrographical variations are present.

Genetic interpretation
The formation was produced by one major episode of sub-aerial volcanic activity.

Stratotype
The type area is Campsie Glen [NS 6098 8001] where the local base is in exceptionally sharp contact with the underlying Ballagan Formation (rather than the Clyde Sandstone Formation). The Lawmuir 1A Borehole (BGS Registration Number NS57SW/162) [NS 5182 7309], west of Bearsden in Glasgow, provides a partial type section where the top of the formation occurs at 281.12 m, shortly above the bottom of the hole at 286.5 m depth.

Lower and upper boundaries
The base of the formation is taken at the lithological change from the underlying clastic sedimentary rocks into lava, tuff or volcaniclastic sedimentary rocks. This contact, where seen, is normally sharp, representing a gentle but irregular unconformity. Locally, the formation is underlain by the Birgidale Formation on Bute, and by the Laggan Cottage Mudstone Formation on Arran (Figure 6, Columns 3, 1).

The top is marked by a change to the volcaniclastic sedimentary rocks of the Kirkwood Formation (Figure 6, Column 4A).

Thickness
The maximum thickness exceeds 420 m in the Campsie Fells (Forsyth et al., 1996, p. 9). Paterson and Hall (1986, p.13) suggest up to 800 m. It may be more than 900 m thick in the Renfrewshire Hills (Paterson et al., 1990). More than 40 m thick in the main coalfield area at Machrihanish (BGS, 1996). Generally 70–80 m thick on the Isle of Arran (BGS, 1987a). 150 m and 175 m thick at Bute and Cowal and in the Cumbrae isles respectively (BGS, 2008).

Distribution and regional correlation
Western Midland Valley of Scotland, on Arran, at Bute and Cowal, in the Cumbrae isles and at Machrihanish.

Age
Mid Visean (Arundian to Asbian).

Formal subdivisions
See also Appendix 1. Members of the Clyde Plateau Volcanic Formation in approximate stratigraphical order within the following geographical areas include:

RENFREWSHIRE HILLS (including the Kilburnie Hills)

4.3.3.1 Noddsdale Volcaniclastic Member

Name
Previously named the Noddsdale Volcaniclastic Beds (Paterson et al., 1990, Monro, 1999). Part of the 'Lower Group' of Richey (1928) and 'unit 1' of Johnstone (1965).

Lithology
Purple basaltic tuff, agglomerate and pyroclastic-breccia with some bedded volcaniclastic sandstone. A complete section through the unit is recorded in the Largs Borehole (BGS Registration Number NS25NW/5) [NS 2158 5936] with about 44 m of volcanic detritus, fine- to coarse-grained with basaltic lava blocks up to 0.2 m long, bedded in places. Fine-grained with accretionary lapilli in basal 3 m. The volcanic detritus is underlain by 11 m of silty mudstone and then 7 m of tuffaceous sandstone containing clasts of lava and quartz. Clasts of lava in sandstones and agglomerates are locally derived. Fine-grained tuffs are commonly well bedded and grade into water-laid volcaniclastic and quartzose sandstones containing some carbonised plant debris.

Stratotype
The type section comprises a complete sequence, about 62.1 m thick, through the Noddsdale Volcaniclastic Member in the Largs Borehole (see above) from about 107.4 to 169.5 m depth. See description above and Paterson et al. (1990).

Lower and upper boundaries
In the area between Loch Thom [NS 26 72] and Largs [NS 20 59] east of the Largs Fault-zone, the basal tuffs, agglomerates and breccias of the Noddsdale Volcaniclastic Member rest upon 'cornstone'-bearing sandstones of the Kinnesswood Formation. Farther north and to the west of the Largs Fault-zone between Outerwards Reservoir [NS 232 654] and Rottenburn Bridge [NS 25 69], the Noddsdale Volcaniclastic Member overlies strata from the Clyde Sandstone Formation of late Devonian to Tournaisian to early Visean age. This basal contact represents a regional erosional unconformity prior to the onset of the mid Visean volcanism in the Renfrewshire Hills.

The tuffs, agglomerates and pyroclastic breccias of the Noddsdale Volcaniclastic Member are overlain by the olivine-microphyric basalt ('Dalmeny') lavas of the Largs Lava Member. In the Largs Borehole (see above) about 107 m of grey feldspar-phyric lava of the Largs Lava Member overlie the volcaniclastic sedimentary rocks of the Noddsdale Volcaniclastic Member.

Thickness
Between 0 and 200 m.

Distribution and regional correlation
Renfrewshire and Kilbirnie hills. The member forms the base of the Clyde Plateau Volcanic Formation in the area between Loch Thom [NS 26 72] and Largs [NS 20 59]. It does not crop out south of Largs but is inferred to occur beneath the Largs Lava Member as far as the A760 road [NS 21 57].

Age
Mid Visean (Arundian to Asbian).

4.3.3.2 Largs Lava Member

Name
Previously named the Largs Lavas (Paterson et al. 1990, Monro 1999), part of the 'Lower Group' of Richey (1928), and part of 'unit 2' of Johnstone (1965).

Lithology
Olivine-microphyric basalt lavas ('Dalmeny' type) with a few flows of clinopyroxene-olivine-microphyric basalt ('Hillhouse' type). Some clinopyroxene-olivine-macrophyric basalts or basanites are intercalated in the upper part of sequence.

Stratotype
The type area of the member occurs as a major scarp on the east side of Noddsdale, to the south of the Muirshiel Fault, which can be traced northwards along the east side of Noddsdale Water to the Rotten Burn [NS 252 682].

Lower and upper boundaries
The Largs Lava Member overlies the Noddsdale Volcaniclastic Member. In the Largs Borehole (BGS Registration Number NS25NW/5) [NS 2158 5936] from about 8.2 to 107.4 m depth, the lavas of the Largs Lava Member overlie the volcanic detritus, silty mudstone and tuffaceous sandstone of the Noddsdale Volcaniclastic Member. South of Largs [NS 20 59] the Largs Lava Member is not exposed, but is inferred to occur beneath the Greeto Lava Member (Monro, 1999).

Lavas of the Largs Lava Member are more mafic than those of the overlying Greeto Lava Member with the boundary defined by the petrographical change from olivine-microphyric basalts ('Dalmeny' type) of the Largs Lava Member, to the plagioclase-phyric basalts and hawaiites ('Jedburgh' and 'Markle' types) of the Greeto Lava Member.

Thickness
Up to 130 m

Distribution and regional correlation
Renfrewshire and Kilbirnie hills: the member occurs as a scarp slope east of Noddsdale Water from Largs [NS 21 58] to the Murishiel Fault [NS 23 65], on the eastern side of Knockencorsan Hill [NS 24 67], and south of Largs on the lower slopes of Douglas Park as far as the A760 road [NS 21 57].

Age
Mid Visean (Arundian to Asbian).

4.3.3.3 Greeto Lava Member

Name
The name is derived from exposures in the valley of the Greeto Water. Previously named the Greeto Lavas (Paterson et al. 1990, Monro 1999). Part of the 'Lower Group' of Richey (1928) and part of 'unit 2' of Johnstone (1965).

Lithology
Plagioclase-microphyric basaltic to hawaiite lava ('Jedburgh' type) with a few flows of plagioclase-macrophyric basaltic to hawaiite lava ('Markle' type). At the base of the member in the Kilbirnie Hills thin beds of purple nodular tuff with intercalated fine-grained red 'marls' are developed locally, for example east and south-east of Bradshaw [NS 240 530]. A single flow of more-mafic olivine-pyroxene-macrophyric basalt or basanite occurs within the member on the north slope of Castle Hill at Largs [NS 220 589]

Stratotype
A reference section is well exposed in the valleys of the Greeto and Gogo Waters, close to their confluence [NS 230 593].

Lower and upper boundaries
The member is underlain by the more-mafic olivine-microphyric basalts ('Dalmeny' type) of the Largs Lava Member.

It is overlain by the aphyric mugearites and olivine-free plagioclase-macrophyric hawaiites ('Markle' type) of the Strathgryfe Lava Member.

Thickness
Up to 110 m in the Largs area

Distribution and regional correlation
Renfrewshire and Kilbirnie hills: crops out extensively along the top of the scarp slope east of Noddsdale Water from Largs [NS 210 590] north to the Muirshiel Fault. Exposed in the valley of the Greeto Water [NS 230 600]. To the south of Largs the Greeto Lava Member forms a scarp feature at the top of the hills behind Largs and Fairlie [NS 230 550]. The scarp extends south-south-east on the east side of the Caaf Water valley [NS 230 530]. The member is about 100 m thick in the Largs area but thins southwards and lenses out at Wardlaw [NS 250 510]. An outlier caps Kaim Hill [NS 220 530] to the west of the Caaf Water valley.

Age
Mid Visean (Arundian to Asbian)

4.3.3.4 Misty Law Trachytic Member

Name
Previously named the Misty Law Trachytic Centre (Paterson et al., 1990). Part of the 'Lower Group' of Richey (1928) and part of 'unit 3' of Johnstone (1965).

Lithology
The member comprises trachyte and rhyolite lavas with associated volcaniclastic rocks, including pyroclastic breccia and tuff, minor amounts of trachyandesite and trachybasalt (capping Totterie Law [NS 293 621]) and one major basaltic intercalation.

Stratotype
Reference sections or type areas are described for six main phases of the extrusive activity:

1. Trachyte lavas exposed in streams south-east of Waterhead Moor [NS 263 621] and around the headwaters of the River Calder;
2. Pyroclastic rocks in the scarp to the east of Waterhead Moor [NS 269 624], also in Gogo Burn, Routdane Burn, Murchan Burn [NS 290 609] (including lenses of carbonaceous mudstone and plant fragments) and Surge Burn;
3. Trachytic lavas and welded tuffs forming high land that extends north and north-east from the Gogo Water headwaters [about NS 264 596];
4. Basaltic and intermediate lavas forming outliers in The Tongue [NS 280 610] and more continuous outcrops around East Girt Hill [NS 279 627], Burnt Hill [NS 270 634] and Queenside Loch [NS 292 642];
5. Massive flows of trachyte and rhyolite overlying the basic lavas on and west of Queenside Hill [NS 293 638], on Hill of Stake [NS 274 630] and south-east from East Girt Hill [NS 279 627] to Little Misty Law [NS 299 621];
6. Trachyandesite and trachybasalt capping Totterie Law [NS 293 621] and Misty Law [NS 295 620].

Lower and upper boundaries
Along the western margin of the 'centre', the contact of the Misty Law Trachytic Member with the underlying Strathgryfe Lava Member is not exposed but appears to be conformable and to dip gently to the south-east.

The more steeply dipping upper boundary of the Misty Law Trachytic Member is believed to be overstepped by the overlying lavas of the Strathgryfe Lava Member but, where exposed, the contacts are generally faulted. Unfaulted junctions are seen only in the River Garnock [NS 293 593] and in the Rough Burn [NS 315 617].

The distal parts of the cone, where it interdigitates with more mafic rocks, are mainly obscured by faulting but may be represented by thin developments of trachyte and trachytic tuff at South Burnt Hill [NS 255 651], Feuside Hill [NS 252 597] and at Lang Hill [NS 250 612].

Thickness
Up to 300 m.

Distribution and regional correlation
In the Renfrewshire Hills, the member's outcrop is 8 km wide in the area around Misty Law [NS 295 620], extending from the headwaters of the River Calder [NS 258 646] in the north-west, to Muirshiel Country Park [NS 315 630] in the south-east, to the Knockside Hills [NS 256 582] in the south.

Age
Mid Visean (Arundian to Asbian).

4.3.3.5 Strathgryfe Lava Member

Name
The member is named after the valley of the Gryfe Water. It was previously referred to as the Strathgryfe Lavas (with informal lower and upper parts) by Paterson et al. (1990). Part of the 'Lower Group' of Richey (1928) and 'unit 3' of Johnston (1965). See also Monro (1999); Stephenson in Stephenson et al. (2003).

Lithology
Aphyric lava (mugearites) and olivine-free plagioclase-macrophyric hawaiite lava ('Markle' type), in roughly equal proportions and commonly in composite flows. Thin olivine-pyroxene-macrophyric basalt lava and olivine-bearing plagioclase-macrophyric basalt ('Markle' type) occur in the upper part of the member. Boreholes near Clovenstone [NS 33 16] show individual flows between 3 and 20 m thick, with an average of about 10 m. In the boreholes, the flows are almost invariably separated by boles (dark red weathered horizons, fossil soil), up to 1 m thick, which are rarely seen at outcrop. Most flows contain layers of fresh, massive lava, amygdaloidal lava and hydrothermally altered, autobrecciated, 'slaggy' material. The altered and slaggy material is commonly soft, friable and in some cases makes up 90 per cent of the flow.

Stratotype
The type area includes a large number of site investigation boreholes that were drilled around the River Calder [NS 3244 6165]. These boreholes penetrated the 'Markle' type basalt and mugearite of the Strathgryfe Lava Member down to 60 m. Geological logs of the boreholes are available together with a site investigation report. A reference section is at the Dunrod Hill SSSI and GCR site, Inverclyde [NS 23 72] with excellent exposures of feldspar-phyric hawaiite lavas and aphyric mugearite lavas, often as composite flows. Aphyric basal parts of individual flows grade sharply but uninterrupted into feldspar-phyric upper parts suggesting that they were emplaced in rapid succession as pulses of the same eruption (see Stephenson in Stephenson et al., 2003).

Lower and upper boundaries
From Cloch Point [NS 20 75] and Dunrod Hill [NS 24 72] to Port Glasgow [NS 32 74] the Strathgryfe Lava Member rests disconformably upon sedimentary rock of the underlying Clyde Sandstone Formation. To the south and south-east of there, from Loch Thom [NS 25 71] to Largs [NS 20 59], the Strathgryfe Lava Member is conformably underlain by earlier lavas and tuffs of the Clyde Plateau Volcanic Formation. In that area the underlying Greeto Lava Member consists dominantly of flows of plagioclase-microphyric basalt ('Jedburgh' type). To the south, in the Kilbirnie Hills, the Strathgryfe Lava Member extends southwards beyond the limit of the Greeto Lavas and rests unconformably on the Late Devonian Kelly Burn Sandstone Formation, Stratheden Group (Browne et al., 2001).

In the Renfrewshire Hills, the dominantly olivine-free lavas (mugearite and hawaiite) of the upper part of the Strathgryfe Lava Member are overlain by the more-mafic olivine-bearing basalts ('Dunsapie' and 'Craiglockhart' types) of the Marshall Moor Lava Member. The change is abrupt and could imply a significant time interval between the two volcanic episodes. To the south, on the south-eastern edge of the Kilbirnie Hills, the thinning Strathgryfe Lava Member is overlain directly by the volcaniclastic Kirkwood Formation and the Lower Limestone Formation. To the south of the Muirshiel Fault, upper and lower parts to the Strathgryfe Lava Member have been informally identified (Paterson et al., 1990). In this area the Strathgryfe Lava Member is separated by the lavas and volcaniclastic deposits of the Misty Law Trachytic Member (Paterson et al., 1990).

Thickness
The member is estimated to be up to 750 m thick in the northern and central part of of the Renfrewshire Hills (Paterson et al., 1990, table 6) and up to 250 m thick in the Kilbirnie Hills (Monro, 1999, p. 32).

Distribution and regional correlation
The member occurs in the northern and central parts of the Renfrewshire Hills from Greenock [NS 28 76] to the Muirshiel Fault [NS 23 65] to east Queenside Muir [NS 31 65] and underlies the length of the valley of the Gryfe Water. South of the Muirshiel Fault, the Strathgryfe Lava Member underlies the River Calder Valley [NS 31 64 to 35 60] and Ladyland Moor [NS 30 59]. In this region the member has been informally split into upper and lower parts (Paterson et al.,1990) separated by the Misty Law Trachytic Member. The unit extends south into the Kilbirnie Hills but thins markedly south and into the area of the Busbie Muir [NS 24 46] and Munnoch [NS 25 47] reservoirs. It is represented by only a few flows where it is cut out by the extension of the Paisley Ruck fault system [around NS 25 44].

Age
Mid Visean (Arundian to Asbian).

4.3.3.6 Marshall Moor Lava Member

Name
Previously named the Marshall Moor Lavas (Paterson et al., 1990). Part of the 'Lower Group' of Richey (1928) and 'unit 4' of Johnstone (1965). See also Monro (1999).

Lithology
Macroporphyritic mafic basalts; olivine-clinopyroxene-plagioclase-macrophyric basalt ('Dunsapie' type) and olivine-bearing plagioclase-macrophyric basalt ('Markle' type) with some olivine-pyroxene macrophyric basalt ('Craiglockhart' type or 'ankaramite').

Stratotype
The type area includes the thickest part of the unit between Peockstone [NS 357 610] and Bridge of Weir [NS 388 655] (see Paterson et al., 1990).

Lower and upper boundaries
Lavas of the Marshall Moor Lava Member are considerably more mafic than those of the underlying Strathgryfe Lava Member. The abrupt change may imply a significant time interval between the two petrologically distinct volcanic episodes.

A marked petrographical change distinguishes the macroporphyric mafic basalts ('Dunsapie' and 'Craiglockhart' types) of the Marshall Moor Lava Member from the overlying microporphyric mafic basalts (mainly 'Dalmeny' type) of the Kilbarchan Lava Member.

Thickness
Up to 75 m

Distribution and regional correlation
In the south-eastern Renfrewshire Hills: the thickest development of the member occurs in the area between Peockstone [NS 357 610] and Bridge of Weir [NS 388 655] and it is well exposed around Marshall Moor [NS 375 625]. To the north it becomes discontinuous in faulted outcrops between Yonderton [NS 390 667] and Barochan [NS 420 693]. To the south, outliers occur around Lochwinnoch golf course [NS 344 597] and a single flow occurs beneath the Kilbarchan Lava Member between Glenlora and the Maich Water [NS 324 587]. The most southerly outcrops are on the east side of the Maich Water around Ladyland [NS 325 578].

Age
Mid Visean (Arundian to Asbian)

4.3.3.7 KILBARCHAN LAVA MEMBER

Name
Previously named the Kilbarchan Lavas (Paterson et al., 1990). Part of the 'Lower Group' of Richey (1928) and 'unit 5' of Johnstone (1965).

Lithology
Microporphyritic mafic basalts; olivine-microphyric basalt ('Dalmeny' type) with rare flows of clinopyroxene-olivine-microphyric basalt ('Hillhouse' type). Around Castle Semple and at Gladstone (see below) a few isolated flows of olivine-pyroxene-macrophyric basalt ('ankaramite' or 'Craiglockhart' type) occur.

Stratotype
The unit crops out over a wide type area between Castle Semple Loch [NS 360 595] and Ranfurly [NS 395 650] (see Paterson et al., 1990).

Lower and upper boundaries
At the lower boundary, a marked petrographical change occurs from macroporphyric mafic basalts ('Dunsapie' and 'Craiglockhart' types) of the underlying Marshall Moor Lava Member to the microporphyric mafic basalts (mainly 'Dalmeny' type) of the overlying Kilbarchan Lava Member.

The Kilbarchan Lava Member is overlain across an erosional boundary by volcaniclastic sedimentary rocks of the Kirkwood Formation, which contain detrital material from the underlying lavas.

Thickness
Up to 75 m

Distribution and regional correlation
The member crops out over a wide area in the Renfrewshire and Beith–Barrhead hills, between Castle Semple Loch [NS 36 59] and Ranfurly [NS 39 65] and extends east to the town of Kilbarchan [NS 40 63]. It continues northwards, somewhat thinned, to Barochan [NS 410 690] where the outcrop is terminated by a system of major east-north-east- and west-north-west-trending faults. In the south, outcrops of the Kilbarchan Lava Member are terminated by a major east–west fault system at Lochwinnoch [NS 36 59], but thin outliers occur at the top of the lava succession between Glenlora [NS 324 587] and south of Ladyland [NS 325 575].

Age
Mid Visean (Arundian to Asbian)

BEITH–BARRHEAD HILLS

4.3.3.8 GLENBURN VOLCANICLASTIC MEMBER (GBV)

Name
Named from Glen Park, Paisley. The Glenburn Volcaniclastic Member, which appears on current printed BGS publications, including the Glasgow district memoir and bedrock geology map, was defined and recorded as the now obsolete Glenburn Volcanic Detrital Member by IGS (1981). It also replaces the now obsolete Glen Park Volcanic Detrital Member. See Hall et al. (1998).

Lithology
The Glenburn Volcaniclastic Member comprises interbedded purplish red medium-grained sandstone, with subordinate reddish purple silty mudstone and reddish purple muddy siltstone. Some of the sandstone grains are described as volcaniclastic. In the Glenburn Borehole (BGS Registration Number NS46SE/164) [NS 4783 6065] volcaniclastic sedimentary rocks and agglomerates are interbedded with several (thin) lava flows.

Stratotype
The type section is the Glenburn Borehole (see above) from 17.35 to 43.54 m depth, where volcaniclastic sedimentary rocks and agglomerates are interbedded with several (thin) lava flows. A partial type section occurs in the bed of the Craigie Linn [NS 4743 6047 to 4744 6053] within Glen Park, Paisley.

Lower and upper boundaries
The lower boundary of the member is seen in the Glenburn Borehole (see above) at 43.54 m depth (IGS, 1981). It is sharp, faulted and marked by a lithological change from the red-brown sedimentary rocks of the Kinneswood Formation (Inverclyde Group) to basalt lavas ('Markle' and mugearite types).

The upper boundary is exposed and clearly seen at Craigie Linn waterfall [NS 475 605] in Glen Park, Paisley. The top of the member is sharp and marked by a lithological change from well-bedded purple tuffs and volcaniclastic sedimentary rocks to grey plagioclase-microphyric basalt lava ('Jedburgh' type) of the overlying Gleniffer Lava Member (Clyde Plateau Volcanic Formation). Elsewhere the unit is overlain by the distinctive olivine-bearing plagioclase-macrophyric basalts ('Markle' type) that are most characteristic of this overlying member. The top of the member is also seen in the Glenburn Borehole (see above) at 17.59 m depth (IGS, 1981) where white to grey sandstone with slump structures is overlain by agglomerate of the Gleniffer Lava Member (Clyde Plateau Volcanic Formation) that comprises subangular clasts of yellowish sandstone and basalt in a fine-grained purplish grey matrix.

Thickness
The thickness is variable from over 26 m in the Glenburn Borehole, to more than 30 m at outcrop in Glen Park (see above).

Distribution and regional correlation
The Glenburn Volcaniclastic Member is exposed at intervals along the base of the lava scarp from Craigie Linn [NS 475 605] to Harelaw Burn [NS 49 60] including the Glen Park, Paisley.

Age
Mid Visean (Arundian to Asbian).

4.3.3.9 GLENIFFER LAVA MEMBER

Name
Previously known as the 'Gleniffer Lavas' (Hall et al., 1998, Monro, 1999; Paterson et al., 1990), 'Lower Group (a)' (Richey et al., 1930).

Lithology
The member comprises distinctive olivine-bearing plagioclase-macrophyric basalts ('Markle' type). Characterised by lavas with abundant, platy phenocrysts of plagioclase up to 25 mm long and microphenocrysts of red-brown olivine. A massive flow of plagioclase-microphyric basalt ('Jedburgh' type) forms the base of the member at Linn Well [NS 475 605]. The lavas are interbedded with volcaniclastic sedimentary rocks at the base.

Stratotype
The Gleniffer Lava Member crops out in a prominent scarp in its type area along the north side of Gleniffer Braes to Brownside Braes [NS 450 607 to 485 605] (see Hall et al., 1998).

Lower and upper boundaries
The Gleniffer Lava Member is underlain by the sedimentary rocks of the Glenburn Volcaniclastic Member to the north and east of Brownside Braes [NS 485 605].

The member is overlain and may be cut out or overlapped, by the mafic basalts of the Sergeantlaw Lava Member around Sergeantlaw [NS 455 597] and to the east of Middleton [NS 445 579], and to the west of Barcraigs Reservoir [NS 39 57] and Walls Hill [NS 41 59].

Thickness
The thickness is not stated.

Distribution and regional correlation
The Gleniffer Lava Member crops out in the Beith–Barrhead Hills to the east of Barcraigs Reservoir [NS 39 57] and is faulted against the Kirkwood Formation and Lawmuir Formation in the north, to the north of High Burnside [NS 42 60]. It extends eastwards through Gleniffer Braes [NS 450 607] to Brownside Braes [NS 485 605]. To the south the unit is faulted against the Upper Limestone Formation in Loch Libo [NS 435 556], and the Limestone Coal Formation by the Dusk Water Fault.

Age
Mid Visean (Arundian to Asbian).

4.3.3.10 SERGEANTLAW LAVA MEMBER

Name
Previously known as the 'Sergeantlaw Lavas' (Hall et al., 1998; Monro, 1999; Paterson et al., 1990), 'Lower Group (b)' (Richey et al., 1930).

Lithology
Olivine-microphyric basalt ('Dalmeny' type) and olivine-clinopyroxene-plagioclase-macrophyric basalt ('Dunsapie' type). In the closure of the Beith Anticline the basal flow of the member is a distinctive clinopyroxene-olivine-macrophyric basalt ('ankaramite' or 'Craiglockhart' type). In Boylestone Quarry [NS 495 597] hydrothermal veins and cavities contain a wide variety of minerals including calcite, analcime, prehnite, heulandite, bowlingite, thomsonite and natrolite. Native copper, cuprite and malachite are also found.

Stratotype
The Sergeantlaw Lava Member is well seen in its type area between Sergeantlaw [NS 455 596] and Greenfieldmuir [NS 456 583] (Hall et al., 1998). Also between Townhead of Threepwood [NS 39 55] and Gillies Hill [NS 38 54] (see Monro, 1999).

Lower and upper boundaries
The Sergeantlaw Lava Member overlies the plagioclase-macrophyric basalts ('Markle' type) of the Gleniffer Lava Member. South of Wester Gavin [NS 380 589] the mafic basalts of the Sergeantlaw Lava Member appears to rest upon volcaniclastic sedimentary rocks and it is possible that in this area the underlying Gleniffer Lava Member has been overlapped. To the north of Harelaw Reservoir [NS 485 590] the Sergeantlaw Lava Member appears to cut out or overlap most of the Gleniffer Lava Member.

Resting upon the Sergeantlaw Lava Member and forming a broad dip slope outcrop south of Muirdykes [NS 395 591] are the plagioclase-macrophyric basalts ('Markle' type) and olivine-clinopyroxene-plagioclase macrophyric basalts ('Dunsapie' type) of the Fereneze Lava Member.

Thickness
Not stated.

Distribution and regional correlation
The Renfrewshire and Beith–Barrhead hills: the Sergeantlaw Lava Member crops out to the north and south of Barcraigs Reservoir [NS 39 57]. It is well seen between Townhead of Threepwood [NS 39 55] and Gillies Hill [NS 38 54] and forms scarp features around Walls Hill [NS 412 589]. It is also present in the area between Sergeant Law [NS 455 596] and Greenfieldmuir [NS 456 583] and in the Lochliboside Hills [NS 450 575].

Age
Mid Visean (Arundian to Asbian).

4.3.3.11 Ferenze Lava Member

Name
Previously known as the 'Fereneze Lavas' (Hall et al., 1998; Monro, 1999; Paterson et al., 1990) and equated with 'Lower Group (c)' (Richey et al., 1930).

Lithology
Mainly plagioclase-macrophyric basalt ('Markle' type) and olivine-clinopyroxene-plagioclase macrophyric basalts ('Dunsapie' type). Several flows of mugearite are present, two were encountered in a borehole at Crummock Park [NS 350 540], Beith and three in Loanhead Quarry [NS 365 555] where a discontinuous bed of tuff is also seen. These flows are 15 m, 8 m and over 10 m thick and are separated by boles up to 0.5 m thick. The basalts are amygdaloidal with much hydrothermal alteration giving a range of secondary minerals such as calcite, prehnite, analcime, thomsonite, natrolite, bowlingite and heulandite. The quarry is well known for copper mineralisation with native copper, malachite and cuprite recorded.

Stratotype
The best exposure of the Fereneze Lava Member is in its type area on the north-west limb of the Beith Anticline, to the west of Barcraigs Reservoir [NS 38 57]. Here flows of mainly olivine-basalts form good scarp and dip slope topography ('trap features'). A reference section is the Crummock Park Borehole [NS 350 540] which penetrated 120 m of the Fereneze Lava Member, but no detailed geological log is available (see Monro, 1999).

Lower and upper boundaries
The 'Markle' and 'Dunsapie' basalts of the Fereneze Lava Member appear to cut or overlap most of the underlying 'Dalmeny' and 'Dunsapie' basalts of the Sergeantlaw Lava Member in the area of the Fereneze Hills.

In the west of the Beith–Barrhead Hills, Bog Hall [NS 362 540] to Newton of Belltrees [NS 372 582], the Fereneze Lava Member is overlain by the olivine-microphyric basalts ('Dalmeny' type) of the Beith Lava Member. The upper boundary of the unit is not seen in the eastern Beith–Barrhead Hills.

Thickness
The maximum thickness is greater than 120 m.

Distribution and regional correlation
North-west limb of the Beith Anticline, to the west of Barcraigs Reservoir [NS 384 570] where the member forms good scarp and dip slope topography. It is faulted out in the south against the Blackhall Limestone and Lower Limestone Formation (Clackmannan Group) by the Dusk Water Fault to the south of Blaelochhead [NS 395 532]. In the east (south-east limb of the Beith anticline), the member underlies the Fereneze Hills between Capellie Farm [NS 465 583] and the top of Boylestone Quarry [NS 495 597].

Age
Mid Visean (Arundian to Asbian)

4.3.3.12 Beith Lava Member

Name
The Beith Lava Member was previously known as the 'Beith Lavas' (Paterson et al. 1990; Monro 1999), and the 'Upper Group' (Richey et al. 1930).

Lithology
The formation comprises olivine-microphyric basalt ('Dalmeny' type). Red boles are common between flows and interbedded chocolate-coloured 'marls' are present. Evidence from outcrop and the Crummock Park borehole [NS 3503 5392] suggests large parts of the flows are extensively altered and decomposed. South of Roebank Glen [NS 353 554] a flow of plagioclase-macrophyric basalt ('Markle' type) crops out within the member.

Stratotype
The Beith Lava Member crops out in its type area on lower slopes at the south-west limit of the Beith–Barrhead Hills between [NS 35 54] and [NS 36 57] (see Monro, 1999). A reference section is the Crummock Park Borehole (see above) which penetrates the lowest 50 m of the Beith Lava Member, but no detailed geological log is available (see Monro, 1999).

Lower and upper boundaries
The member is underlain by the 'Markle' and 'Dunsapie' -type basalts of the Fereneze Lava Member.

The member is overlain by volcaniclastic sedimentary rocks of the Kirkwood Formation (Strathclyde Group) wherever the top of the member crops out.

Thickness
About 90 m

Distribution and regional correlation
The member occurs to the west and south-west of the Beith–Barrhead Hills, on the north-west limb of the Beith Anticline, but is faulted out on the south-eastern limb. The unit underlies the town of Beith [NS 35 54] and extends north-east until it is faulted out against the Paisley Ruck Fault just north of East Gavin [NS 389 599].

Age
Mid Visean (Arundian to Asbian)

DUNLOP–EAGLESHAM BLOCK

4.3.3.13 Lower Flow Moss Lava Member

Name
Previously known as the Flow Moss lavas (lower). See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Lower Flow Moss Lava Member consists of alkali basalt and subordinate basanite.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, limited to the southern part of the area between Stewarton [NS 4200 4500] in the west and Craufurdland Water [NS 510 448] in the east.

Lower and upper boundaries
The nature of the base is unknown but may be unconformable on the Inverclyde Group or older strata.

The member is overlain by and interbedded with the Moyne Moor Lava Member in the western part of the area of occurrence. Elsewhere, where locally known, a thick bole is developed on the uppermost flow at [NS 510 448] and the Upper Flow Moss Lava Member rests on this.

Thickness
Not stated

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, limited to the south of the area between Stewarton [NS 4200 4500] in the west and Craufurdland Water [NS 510 448] in the east.

Age
Mid Visean (Arundian to Asbian).

4.3.3.14 Moyne Moor Lava Member

Name
Previously named the Moyne Moor lavas. See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Moyne Moor Lava Member consists of plagioclase-phyric trachybasalt (hawaiite) with discrete subordinate alkali basalt and rare basaltic-trachyandesite (mugearite) near the top of the member. These may represent the initiation of the more evolved trachytic volcanism of the overlying Harelaw Lava Member.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, irregularly shaped, but in continuous outcrop from Balgray Reservoir [NS 5100 5700] to Over Auchentibber Farm [NS 4560 4980].

Lower and upper boundaries
The member rests upon and is interbedded with the Lower Flow Moss Lava Member in the south but elsewhere its base is possibly unconformable on the sedimentary strata of the Ballagan Formation (Inverclyde Group) but the contact is not seen due to faulting.

The member is overlain by the geographically separate (and laterally equivalent) alkali basalts of the Eaglesham and Neilston Lava members and the trachytic Harelaw Lava Member. The contacts are considered conformable, but may also be locally unconformable.

Thickness
More than 100 m

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, irregularly shaped, but continuous outcrop from Balgray Reservoir [NS 5100 5700] to Over Auchentibber Farm [NS 4560 4980].

Age
Mid Visean (Arundian to Asbian)

4.3.3.15 Neilstone Lava Member (NNLA)

Name
Previously named the Neilston lavas. See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Neilston Lava Member consists of alkali basalts with minor basanite in the lower part and trachybasalt in the upper.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, in the western part of the area between Neilston [NS 4800 5700] and Stewarton [NS 4300 4800].

Lower and upper boundaries
The base is apparently conformable (though it may locally be unconformable) on the Moyne Moor Lava Member, which consists predominantly of trachybasalt.

The member is overlain by the trachytic Harelaw Lava Member. The contact is unconformable.

Thickness
More than 100 m.

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, in the western part of the area between Neilston [NS 4800 5700] and Stewarton [NS 4300 4800].

Age
Mid Visean (Arundian to Asbian).

4.3.3.16 Darvel Lava Member

Name
Previously named the Darvel lavas. See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Darvel Lava Member consists of alkali basalts and basanites. Near the unit top, trachybasalt also occurs.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, limited to around Darvel [NS 6000 4000] and Newmilns [NS 5000 3700] just north of the Inchgottrick Fault.

Lower and upper boundaries
The Darvel Lava Member is unconformable on the mainly lithic arenite succession of the Lower Devonian Swanshaw Sandstone Formation (see Browne et al., 2002).

The member is mainly overlain by the Kirkwood Formation of the Strathclyde Group. The contact is considered unconformable with the volcaniclastic sedimentary rocks draping an eroded land surface formed from the member. Locally, the member is interbedded with, or overlain by, the Gowk Stane Volcaniclastic Member.

Thickness
Not known

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, limited in area around Darvel [NS 6000 4000] and Newmilns [NS 5000 3700] just north of the Inchgottrick Fault.

Age
Mid Visean (Arundian to Asbian)

4.3.3.17 Dumdruff Hill Lava Member (DHLA)

Name
Previously named the Dumdruff Hill lavas. See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Dumdruff Hill Lava Member consists of trachyandesite and trachytic lava.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, around Ballageich [NS 5200 5200] and Braidley Moss [NS 6100 4100] south of Dumdruff Hill.

Lower and upper boundaries
The base is unconformable on the Eaglesham Lava Member that consists of basaltic lavas.

The member is overlain in part by the Gowk Stane Volcaniclastic Member and the Harelaw Lava Member, with which it is partly interbedded. The Upper Flow Moss Lava Member also rests on this member locally.

Thickness
Between 45 and 70 m

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton around Ballageich [NS 5200 5200] and Braidley Moss [NS 6100 4100] south of Dumdruff Hill.

Age
Mid Visean (Arundian to Asbian)

4.3.3.18 Harelaw Lava Member

Name
Previously named the Harelaw Lavas. See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Harelaw Lava Member consists of trachyte, trachyandesite and trachybasalt lava.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, discontinous across an area around Halker [NS 4100 5000], Neilston [NS 5200 5800], Glenouther Rig [NS 4800 4800] and Blackwood Hill [NS 5500 4700].

Lower and upper boundaries
The base is unconformable on the Moyne Moor and Neilston lava members that consist of basaltic lavas.

The member is overlain by the Upper Flow Moss Lava Member. The contact is considered unconformable and locally intrusive. The trachytic lava flows are thought to have had significant dome-like topographical expression immediately after eruption.

Thickness
More than 70 m

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, discontinous across an area around Halker [NS 4100 5000], Neilston [NS 5200 5800], Glenouther Rig [NS 4800 4800] and Blackwood Hill [NS 5500 4700].

Age
Mid Visean (Arundian to Asbian)

4.3.3.19 Eaglesham Lava Member

Name
Previously named the Eaglesham lavas. See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Eaglesham Lava Member is dominated by alkali basalt, but also includes basanite and feldspar-phyric trachybasalt. One trachytic flow is known.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, in the eastern part of the area between Newton Mearns [NS 5750 5180] and Eaglesham [NS 5360 5570].

Lower and upper boundaries
The base is apparently conformable on the Moyne Moor Lava Member that consists predominantly of trachybasalt but may locally be unconformable.

The member is overlain by the Dumdruff Hill Lava Member. The contact is considered conformable.

Thickness
Up to 250 m

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, in the eastern part of the area between Newton Mearns [NS 5750 5180] and Eaglesham [NS 5360 5570].

Age
Mid Visean (Arundian to Asbian)

4.3.3.20 Gowk Stane Volcaniclastic Member (GOWK)

Name
The definition was published by MacPherson and Phillips (1997) and MacPherson et al. (2000). See also MacPherson and Phillips (1998).

Lithology
Mixed sequence of pyroclastic rocks and volcaniclastic sedimentary rocks, which are locally derived and mainly trachytic in composition (MacPherson and Phillips, 1997). There is a marked lateral variation in deposits within the Gowk Stane Volcaniclastic Member. In the northern part of the outcrop, south of Eaglesham [NS 570 520] to the vicinity of Carrot Farm [NS 575 481], and north-east of Darvel the member consists of primary pyroclastic rocks with limited reworking. These include rocks of trachytic and basaltic composition. The pyroclastic rocks are poorly sorted, grey to grey-green, lapilli-tuff and/or agglomerate. Beds are generally less than 0.5 m thick and exhibit normal grading, either within the lapilli-tuff matrix or in the distribution of blocks in typically matrix-supported agglomerate. In the southern part of the outcrop, such as that exposed in Glen Water [NS 587 432 to 579 413], the Gowk Stane Volcaniclastic Member is dominated by volcaniclastic sedimentary rocks (MacPherson and Phillips, 1997). This thickly bedded sedimentary sequence consists of interbedded mudstone, siltstone and tuffaceous sandstone with sporadic conglomerate units. The mudstones and siltstones are pinkish brown, the sandstones are greenish grey to buff coloured and poorly to locally well sorted with fragments of volcanic rock.

Genetic interpretation
In the northern part of the outcrop (see above) and north-east of Darvel, the member is dominated by primary pyroclastic deposition, but in the south (see above), fluviatile processes dominated. Here the volcaniclastic sedimentary rocks, locally derived by penecontemporaneous weathering and

erosion of the pyroclastic deposits and lavas, include channel and chaotic mass movement (lahar-type) deposits (see MacPherson and Phillips, 1997).

Stratotype
The type section comprises exposures at [NS 5692 5092] of pyroclastic strata on an approximately 20 m high, partially grassed, north-facing slope, and in a small, disused quarry at the crest of the slope 600 m north of East Revoch Farm [NS 569 508], 1.2 km south-south-west of Eaglesham, East Renfrewshire (Macpherson and Phillips, 1998). A partial type section includes exposures of volcaniclastic strata in the Glen Water river valley, near Laigh Overmuir Farm, 6 km north-north-east of Darvel, Strathclyde [NS 5790 4140 to 5860 4320] (MacPherson and Phillips, 1997; MacPherson et al., 2000).

Lower and upper boundaries
The pyroclastic and volcaniclastic strata of the Gowk Stane Volcaniclastic Member are inferred to overlie and be penecontemporaneous with the Eaglesham and Dumdruff Hill Lava members within the Clyde Plateau Volcanic Formation (MacPherson and Phillips, 1997; Macpherson et al., 2000). Volcaniclastic sedimentary breccia and pyroclastic breccia of the Gowk Stane Volcaniclastic Member appear directly to overlie trachyandesite of the Dumdruff Hill Lava Member at East Revoch Farm [NS 569 508] although the contact is not exposed (MacPherson and Phillips, 1998).

The upper boundary of the Gowk Stane Volcaniclastic Member is not seen, but is inferred to be overlain by the Upper Flow Moss Lava Member, within the Clyde Plateau Volcanic Formation (MacPherson and Phillips, 1997; MacPherson et al., 2000).

Thickness
Based on the vertical section on 1:10 000 scale Geological Sheet NS54SE (Whitelee Forest), the minimum thickness is 60 m.

Distribution and regional correlation
The type area is in the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, specifically between Eaglesham [NS 570 520] and Darvel [NS 565 375].

Age
Mid Visean (Arundian to Asbian).

4.3.3.21 Upper Flow Moss Lava Member

Name
Previously known as the Flow Moss lavas (upper). See MacPherson and Phillips (1997); Phillips and MacPherson (1996); MacPherson et al. (2000).

Lithology
The Upper Flow Moss Lava Member consists of alkali basalts and subordinate basanites and 'ankaramites'.

Stratotype
The type area is the Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, limited to the southern part of the area between Craufurdland Water [NS 510 448] in the north-west and Darvel [NS 6100 3900] in the south-east.

Lower and upper boundaries
The base is apparently unconformable on the Harelaw Lava Member that consists of trachytic lavas and the volcaniclastic rocks of the Gowk Stane Volcaniclastic Member. A thick bole formed on the top flow of the Lower Flow Moss Lava Member at [NS 510 448] marks the contact with this underlying member.

The member is overlain unconformably by the Kirkwood Formation (Strathclyde Group).

Thickness
Not stated

Distribution and regional correlation
Dunlop–Eaglesham moors between Glasgow, Kilmarnock and Hamilton, limited to the southern part of the area between Craufurdland Water [NS 510 448] in the north-west and Darvel [NS 6100 3900] in the south-east.

Age
Mid Visean (Arundian to Asbian)

KILPATRICK HILLS

4.3.3.22 Burncrooks Volcaniclastic Member

Name
Previously known as the Burncrooks Pyroclastic Member (Hall et al., 1998).

Lithology
Volcaniclastic sedimentary rocks, some lacustrine, tuff and agglomerate. Pyroclastic rocks include cones which in some places coalesce. Lacustrine sedimentary rocks in the form of mudstone containing fish scales, overlying a discontinuous coal seam, are exposed south of Rigangower [NS 438 757].

Stratotype
The member crops out around Fyn Loch [NS 460 772] and Lily Loch [NS 473 780] where it is 10–20 m thick and consists mainly of tuff and volcaniclastic sedimentary rocks. A reference section is the Loch Humphrey Borehole (BGS Registration Number NS47NE/1) [NS 4582 7555] that penetrates the entire 70 m thickness of the Burncrooks Volcaniclastic Member, which is overlain by the Auchineden Lava Member and underlain by sedimentary rocks of the Clyde Sandstone Formation. In the borehole, the member mainly consists of tuff and lapilli-tuff, with a few thin lavas and sandstone beds. A full geological description of the core is available.

Lower and upper boundaries
The Burncrooks Volcaniclastic Member is underlain by the sedimentary rocks of the Clyde Sandstone Formation (Inverclyde Group).

The member is overlain by the lavas of the Auchineden Lava Member and Saughen Braes Lava Member.

Thickness
Between 0 and 80 m, very variable, thins to the north-east and south.

Distribution and regional correlation
The Burncrooks Volcaniclastic Member crops out along the north-western and western margins of the Kilpatrick Hills lava block. It stretches from north-east of Bowling [NS 455 739] to Burncrooks Reservoir [NS 482 796] with more isolated patches along the northern margin of the faulted block as far east as [NS 5500 8000].

Age
Mid Visean (Arundian to Asbian).

4.3.3.23 Saughen Braes Lava Member

Name
Previously named the Saughen Braes Lavas (Hall et al., 1998).

Lithology
Plagioclase-macrophyric basalts ('Markle' type).

Stratotype
The unit crops out in its type area on Saughen Braes [NS 462 783], where it consists of about five flows.

Lower and upper boundaries
The Saughen Braes Lava Member interdigitates with the Auchineden Lava Member and in places underlies it, for example around Black Linn Reservoir [NS 443 772]. To the west of Lang Craigs [NS 430 760] the sequence is only represented by the Auchineden Lava Member. Where the Saughen Braes Lava Member is fully developed to the north-east of the area, it is underlain by the Burncrooks Volcaniclastic Member. The Saughen Braes Lava Member interdigitates with and is overlain by the Auchineden Lava Member.

Thickness
Between 0 and 40 m

Distribution and regional correlation
Kilpatrick Hills: the unit occurs on Saughen Braes [NS 462 783], thinning out to the south near Fynloch [NS 458 770].

Age
Mid Visean (Arundian to Asbian)

4.3.3.24 Auchineden Lava Member

Name
Previously known as the Auchineden Lavas (Hall et al., 1998).

Lithology
The member comprises plagioclase-microphyric basalts ('Jedburgh' type), with some mugearites and interbedded cone-facies tuffs. On the Langs Craigs [NS 430 760] there is an olivine-clinopyroxene-macrophyric basanite lava ('Craiglockhart' type).

Stratotype
The member is well exposed in its type area on the west flank of Auchineden Hill [NS 493 805]. A reference section was encountered in the Loch Humphrey Borehole (BGS Registration Number NS47NE/1) [NS 4582 7555]. Here it is 45 m thick and lies below the Carbeth Lava Member and above the Burncrooks Volcaniclastic Member. It consists of mainly aphyric and microporphyritic lavas of 'Jedburgh' type with a flow of 'Markle' type. A geological description of the core is available.

Lower and upper boundaries
In the area around Saughen Braes [NS 462 783] the Auchineden Lava Member is underlain by, and interdigitates with, the Saughen Braes Lava Member. In the north and west of the Kilpatrick Hills the Auchineden Lava Member is directly underlain by the Burncrooks Volcaniclastic Member. The Auchineden Lava Member is overlain by the plagioclase-macrophyric lavas of the Carbeth Lava Member.

Thickness
Between 0 and 100 m, very variable.

Distribution and regional correlation
Kilpatrick Hills: well exposed on the west flank of Auchineden Hill [NS 493 805]. The Auchineden Lava Member thins out towards the north-east and is absent at Arlehaven [NS 535 802]. West of Burncrooks [NS 468 785] the member interdigitates with and overlies the Saughen Braes Lava Member and becomes the only member present farther west on Langs Craigs [NS 430 760].

Age
Mid Visean (Arundian to Asbian)

4.3.3.25 Carbeth Lava Member

Name
Previously named the Carbeth Lavas (Hall et al., 1998).

Lithology
Mainly plagioclase-macrophyric basalt ('Markle' type). There are also some plagioclase-microphyric basalts ('Jedburgh' type) and olivine-clinopyroxene-plagioclase-macrophyric basalts ('Dunsapie' type), as well as some mugearites near the base.

Stratotype
The lavas are well exposed in the type area around Carbeth [NS 527 796] and in the scarps around the Birny Hills [NS 495 770] (see Hall et al., 1998). A reference section was encountered in the Loch Humphrey Borehole (BGS Registration Number NS47NE/1) [NS 4582 7555] beneath the Greenside Volcaniclastic Member and above the Auchineden Lava Member. In the borehole, it is 20 m thick and consists of 'Markle' type lavas with some 'Jedburgh' type and some thin beds of tuff. A geological log is available.

Lower and upper boundaries
The Carbeth Lava Member overlies the plagioclase-microphyric basalts ('Jedburgh' type) of the Auchineden Lava Member.

The member is unconformably overlain by the Greenside Volcaniclastic Member. West of Loch Humphrey [NS 455 760] the member is reduced to one lava flow, which is preserved only in isolated patches below the volcaniclastic sedimentary rocks of the Greenside Volcaniclastic Member.

Thickness
Between 0 and 150 m. From the central part of the Kilpatrick Hills the member thins out towards the SW, partly due to erosion. It is some 80 m thick in the north-east of the region (Hall et al., 1998, table 5).

Distribution and regional correlation
The Carbeth Lava Member is geographically widespread in the Kilpatrick Hills, stretching from Strath Blane [NS 560 790] in the north-east to Brown Hill [NS 445 764] in the south-west. The member is well exposed around Carbeth and in the Birny Hills (see above).

Age
Mid Visean (Arundian to Asbian)

4.3.3.26 Greenside Volcaniclastic Member

Name
The unit is known from outcrops in the area around Greenside Reservoir (see Hall et al., 1998).

Lithology
Volcaniclastic sedimentary rocks, tuff and agglomerate, organic and clastic sedimentary rocks. West of Greenside,

lacustrine mudstones containing fossil fish and well-preserved plant remains and thin coal seams occur near the top of the member.

Stratotype
The unit is known from outcrops in its type area around Greenside Reservoir [NS 475 755] (See Hall et al., 1998). A reference section of the lower 21.35 m of the Greenside Volcaniclastic Member was penetrated by the Loch Humphrey Borehole (BGS Registration Number NS47NE/1) [NS 4582 7555] (from 0–21.35 m depth). In the borehole it consists mainly of tuff.

Lower and upper boundaries
The Loch Humphrey Borehole (see above) penetrated the lowest 21.35 m of the Greenside Volcaniclastic Member, which overlies the lavas and pyroclastic rock of the Carbeth Lava Member. There is an unconformity between the two units and elsewhere the Greenside Volcaniclastic Member rests directly upon the Auchineden Lava Member.

The Greenside Volcaniclastic Member is overlain by the lavas of the Cochno Lava Member.

Thickness
Between 0.5 and 55 m, but usually 5–10 m. Cones of pyroclastic rock at Clachan of Campsie [NS 610 797] and Craigton [NS 525 770] cause the member to thicken to over 50 m.

Distribution and regional correlation
The Greenside Volcaniclastic Member (usually 5–10 m thick) forms a thin outcrop in the Kilpatrick Hills that runs north-east from Bowling [NN 454 370], through Greenside Reservoir [NS 474 755] and High Craigton [NS 525 766] to Blanefield [NS 555 795]. The unit also crops out at the west end of Loch Humphrey [NS 451 762].

Age
Mid Visean (Arundian to Asbian).

4.3.3.27 Cochno Lava Member

Name
Previously named the Cochno Lavas (Hall et al., 1998).

Lithology
The Cochno Lava Member includes a wide range of lava types but is characterised by mafic varieties, particularly near the base. These include olivine-microphyric basalts ('Dalmeny' type), olivine-clinopyroxene-macrophyric basalts ('Craiglockhart' type) and olivine-clinopyroxene-plagioclase-macrophyric basalts ('Dunsapie' type). Localised plagioclase-macrophyric basalts ('Markle' type) and plagioclase-microphyric basalts ('Jedburgh' type) occur around Bowling [NS 445 738].

Stratotype
The Cochno Lava Member crops out in its type area between Cochno Loch [NS 500 760] and Craigton [NS 520 770].

Lower and upper boundaries
The Cochno Lava Member overlies the Greenside Volcaniclastic Member and represents the recommencement of lava extrusion after a major break in activity. It is overlain by the Mugdock Lava Member.

Thickness
Between 100 and 250 m thick in the Kilpatrick Hills region. The member thins towards the north-east of the region, but is thicker adjacent to the Campsie Fault (Hall et al., 1998, table 5).

Distribution and regional correlation
The Cochno Lava Member stretches north-east from Bowling [NS 450 738] in the south-west of the Kilpatrick Hills to the south of Clachan of Campsie [NN 610 790] where the lavas are correlated with the Knowehead Lava Member of the Western Campsie Fells area. Associated vents are located at Burnside [NS 474 741], Black Loch [NS 500 765], and Craigton [NS 525 770].

Age
Mid Visean (Arundian to Asbian).

4.3.3.28 Mugdock Lava Member

Name
Previously named the Mugdock Lavas (Hall et al., 1998).

Lithology
Predominantly plagioclase-macrophyric basalts ('Markle' type). Near Devil's Craig Dam [NS 560 782] a few lavas have abundant feldspar phenocrysts of about 5 mm and some up to 2 cm in length. Near Craigend Castle [NS 548 777] a thin olivine-clinopyroxene-macrophyric basalt ('Craiglockhart' type) occurs and in the western part of the Kilpatrick Hills, mugearite lavas are present.

Stratotype
The Mugdock Lava Member is well exposed in its type area between Mugdock Loch [NS 554 773] and Devil's Craig Dam [NS 560 782].

Lower and upper boundaries
The Mugdock Lava Member overlies the more-mafic olivine-microphyric basalts ('Dalmeny' type), olivine-clinopyroxene-plagioclase-macrophyric basalts ('Dunsapie' type) and olivine-clinopyroxene-macrophyric basalts ('Craiglockhart' type) of the underlying Cochno Lava Member.

The Mugdock Lava Member is overlain by the olivine-microphyric basalts ('Dalmeny' type) of the Tambowie Lava Member in the south of the Kilpatrick Hills. To the north, the Tambowie Lava Member is absent and the Mugdock Lava Member is directly overlain by the sedimentary rocks of the Lawmuir Formation (Strathclyde Group).

Thickness
About 200 m thick in the north-east Kilpatrick Hills, thinning to about 100 m in the south-west of that area.

Distribution and regional correlation
Kilpatrick Hills. The Mugdock Lava Member is present in the south of the area, between Old Kilpatrick [NS 465 730], where it is continuous with the upper part of the Strathgryfe Lava Member of the Renfrewshire Hills lava block south of the River Clyde, and the area around Mugdock [NS 56 77]. The lavas might have been derived from the Waterhead Volcano-complex in the Campsie Fells lava block.

Age
Mid Visean (Arundian to Asbian).

4.3.3.29 Tambowie Lava Member

Name
Previously named the Tambowie Lavas (Hall et al., 1998).

Lithology
Mainly olivine-microphyric basalt ('Dalmeny' type) interbedded with mugearite. Distal facies characteristics such as lava toes and thin reddened lavas with interbedded boles are well developed near Edinbarnet [NS 503 745]. The highest flow seen in the Douglas Muir area [NS 525 751] is an olivine-clinopyroxene-plagioclase-macrophyric basalt ('Dunsapie' type) with an unusual cumulate texture.

Stratotype
The type area is the Kilpatrick Hills in limited extent between Tambowie [NS 525 755] and Muirhouses [NS 506 754].

Lower and upper boundaries
The Tambowie Lava Member is underlain by the predominantly plagioclase-macrophyric basalts ('Markle' type) of the Mugdock Lava Member.

The Tambowie Lava Member is the youngest unit in the Clyde Plateau Volcanic Formation of the Kilpatrick Hills. It is overlain by the sedimentary rocks of the Lawmuir and Kirkwood formations (Strathclyde Group).

Thickness
Maximum 30 m

Distribution and regional correlation
Only present in the southern part of the Kilpatrick Hills area, from east of Tambowie [NS 525 755] west to Muirhouses [NS 506 754], and north of Cochno [NS 497 745]. Absent from the north-east end of the Kilpatrick Hills around Mugdock [NS 56 77], and not present in the south-west of the Kilpatrick Hills area where it may be cut out by faulting. The lavas were possibly derived from the south or south-east.

Age
Mid Visean (Arundian to Asbian)

CAMPSIE BLOCK (Campsie Fells, Kilsyth Hills, Denny Muir)

Note that there are local variations in the general stratigraphy as presented. This is related to the occurrence of interdigitation, the presence of unconformities, and the restricted distribution and multiple sources of some of the members.

4.3.3.30 North Campsie Pyroclastic Member

Name
Previously referred to informally as the North Campsie tephra deposits (BGS, 1993) and associated with the North Campsie Linear Vent System.

Lithology
The member consists of pyroclastic material deposited largely in tephra cones, as ashfall tuffs and lapilli tuffs and reworked volcaniclastic sedimentary rocks derived from the erosion of coallescing tephra cones. Typically, finely stratified tuffs pass upwards into coarse, unstratified spatter deposits and agglomerates. The lower agglomerates are composed largely of accidental and accessory material, including large blocks (up to 2 m) of basalt, variously weathered and textured smaller lava fragments and rare sandstone boulders. Higher agglomerates tend to be composed of essential tephra and scoria bombs in an upward progression that is typical of tephra cones. Impersistent tongues and lenses of highly vesicular basaltic lava occur locally. Since fragmental rocks that form subaerial tephra cones are indistinguishable from those occupying necks, it is possible that some of the tephra is actually neck agglomerate (Craig, 1980).

Stratotype
Corrie of Balglass on the north side of the Campsie Fells [NS 586 849 to NS 595 854]. 2.5 km of cliffs, reaching a height of up to 200 m reveal an upward succession from tuffs and lapilli-tuffs with accidental and accessory clasts into agglomerates with an increasing proportion of essential scoria. Large blocks (over 1 m) of dolerite are derived from the explosive brecciation of early-formed intrusions within the conduit system. Impersistent tongues of scoriaceous lava increase in abundance upwards until the succession is composed largely of microporphyritic lavas but still with significant beds of pyroclastic rock (Craig, 1980).

Lower and upper boundaries
Rests unconformably on Inverclyde Group strata of the Clyde Sandstone Formation and overlain conformably or locally disconformably by the Campsie Lava Member of the Clyde Plateau Volcanic Formation.

Thickness
Unspecified and probably highly variable.

Distribution and regional correlation
Continuous along lower parts of the northern escarpment of the Campsie Fells, from Canny Tops [NS 551 833] in the west to Gonachan Cottage [NS 629 860], on the south side of the Endrick valley, in the east. Best exposures are in the type area around the Corrie of Balglass [NS 586 849 to NS 595 854] and in precipitous cliffs on either side of the Black Spout [NS 610 863] and extending north-west towards Dunmore [NS 606 865].

Age
Mid Visean (Arundian to Asbian)

4.3.3.31 Drumnessie Lava Member

Name
Previously named the Drumnessie Lavas (see Forsyth et al., 1996).

Lithology
The Drumnessie Lava Member consists of several lavas with intercalations, which make up to half the total thickness of the member, of agglomerate (including breadcrust bombs) and variably stratified lapilli-tuff. The lavas are mostly plagioclase-, plagioclase-olivine- and olivine-microphyric basalts (of 'Jedburgh' transitional to 'Dalmeny' types), but there is also one clinopyroxene-olivine-macrophyric basalt ('ankaramite' of 'Craiglockhart' type). The latter forms the second lava in the Garrel Burn section [NS 701 805], where the tuff and several lavas are well exposed. The lavas exhibit proximal characteristics. Several nearby necks of the South Campsie Linear Vent-swarm are plugged by basalt of similar type (e.g. near St Mirren's Well [NS 721 795]), and are probable sources of the lavas.

Stratotype
The type area is the south-central Kilsyth Hills, north-east of Glasgow [NS 6954 7900 to 7414 8092] (Forsyth et al., 1996). A reference section is the BGS Tak-ma-doon Borehole (BGS Registration Number NS78SW/5) [NS 7291 8053] in the south-central Kilsyth Hills, where a 43 m

section penetrated the middle and basal lavas of the member (Craig, 1980). These notably included (in the upper part of the core) a 12.45 m-thick, vesicular, aphyric to plagioclase-microphyric basalt, and a 6.47 m-thick, aphyric to olivine-microphyric basalt, separated by more than 6 m of lapilli-tuff. In the Banton Burn, the lower part of the member is exposed, upstream from the waterfall [NS 731 804]. Three intensely jointed and locally scoriaceous plagioclase-microphyric basalt lavas pass upwards into lapilli-tuff, before the sequence is truncated by the Drumnessie Fault (Craig, 1980). To the north-east of the fault, there is a more-felsic flow, which forms a prominent feature below the topmost lapilli-tuff unit of the member, which is poorly exposed.

Lower and upper boundaries
The base is unconformable. In the BGS Tak-ma-doon borehole (see above) the basal lava of the Drumnessie Lava Member was seen to overlie the Ballagan Formation, comprising 20 m of dominantly grey mudstone and siltstone, interbedded with many dolomitic cementstones, generally 10–15 cm thick but ranging up to 0.5 m. However, 2 km to the west, in the Bachille Burn [NS 707 793], the Ballagan Formation is absent, and the Drumnessie Lava Member rests directly on the Kinnesswood Formation, which comprises sandstone and nodular limestone (cementstone).

The Drumnessie Lava Member is overlain conformably or disconformably by the Laird's Loup Lava Member. The lithological change is to plagioclase-macrophyric basalt lava ('Markle' type).

Thickness
Up to 60 m.

Distribution and regional correlation
The member is restricted to the southern part of the Campsie Block (Forsyth et al., 1996) and specifically to the southern side of the central Kilsyth Hills, north-east of Glasgow. These rocks crop out to the north of the Campsie Fault, in faulted ground below the escarpment on the southern side of the Kilsyth Hills, north of Kilsyth, from east of Corrie [NS 6954 7900], eastwards to beyond Drumnessie [NS 7414 8092].

Age
Mid Visean (Arundian to Asbian).

4.3.3.32 Burnhouse Lava Member

Name
Previously named the Burnhouse Lavas (see Forsyth et al., 1996).

Lithology
The Burnhouse Lava Member consists mainly of thin (2–3 m-thick), 'carbonated' and relatively decomposed, heavily oxidised with much red veining, locally autobrecciated, plagioclase-macrophyric trachybasalt (hawaiite of 'Markle' type) and a few thin intercalated plagioclase-microphyric trachybasalt lavas (hawaiite of 'Jedburgh' type) and intercalated tuff. The lavas have proximal facies characteristics, are irregular in form, and commonly amygdaloidal. To the north-east, along the southern shores of the Carron Valley Reservoir [NS 705 830], the plagioclase-macrophyric lavas are more massive and the plagioclase phenocrysts vary in size and concentration. The microporphyritic trachybasalt lavas are exposed on the southern slopes of Haugh Hill [NS 680 832], in the Burnhouse area [NS 688 823], and in the March Burn [NS 709 830]. The associated tuffs are also well exposed in the Burnhouse area and in the March Burn section where they comprise a series of well-stratified, red-weathered lapilli-tuffs and tuff-breccias with blocks and bombs, commonly up to 0.5 m in diameter and composed of various macroporphyritic and microporphyritic lava types. Scoria and cementstone blocks are also incorporated within the tuffs, which are typically cut by numerous small faults and intruded by dykes. Two possible source necks have been identified at [NS 682 825] and [NS 708 824] on the basis of the coarseness of the tuffs (Craig, 1980).

Stratotype
The type area is the central Kilsyth Hills, north-east of Glasgow [NS 6852 8196 to 7084 8316] (Forsyth et al., 1996). A reference section is the Burnhouse Burn, central Kilsyth Hills, north-east of Glasgow [NS 6897 8251 to 6850 8199] (Craig, 1980). Here at [NS 687 822] the tuffs are so coarse as to suggest the proximity of a source vent. The lavas are also well exposed at this locality, although they are subordinate to the tuffs.

Lower and upper boundaries
The basal plagioclase-macrophyric trachybasalt of the Burnhouse Lava Member is unconformable on sandstone of the underlying Clyde Sandstone Formation (Inverclyde Group).

The Burnhouse Lava Member is overlain conformably, or disconformably, by the Campsie Lava Member. The change in lithology is to mainly plagioclase-microphyric basalt lavas ('Jedburgh' type).

Thickness
Some 20 m.

Distribution and regional correlation
The member is restricted to the central part of the Campsie Block (Forsyth et al., 1996) and specifically to the central Kilsyth Hills, north-east of Glasgow. The largest area of outcrop is to the south-west of the Carron Valley Reservoir, from Burnhouse Burn area [NS 6852 8196] north towards Haugh Hill [NS 6800 8357] and east to beyond the March Burn [NS 7120 8304]. The other area of outcrop lies to the north of Garrel Hill [NS 7036 8228 to 7122 8204].

Age
Mid Visean (Arundian to Asbian).

4.3.3.33 Laird's Loup Lava Member

Name
Previously named the Laird's Loup Lavas (Forsyth et al., 1996).

Lithology
The Laird's Loup Lava Member consists of plagioclase-macrophyric trachybasalt lavas of 'Markle' type). Individual lavas range in thickness from 6–15 m. The lavas are massive, and there is a lack of significant tuff between the lavas, suggesting that the flows are relatively distal. The lavas are variably altered and some are characterised by an ophitic texture. No specific source vent has been identified for the lavas, although the vent at Craigdouffie is a possible source (Craig, 1980), since the neck of the vent is infilled with breccia of similar material and exposures of the member near to the vent show proximal-facies characteristics.

Stratotype
The type area is the south-central Kilsyth Hills, north-east of Glasgow [NS 6920 7974 to 7224 8068] (Forsyth et al.,

1996). A reference section, 50 m thick, occurs in the Laird's Loup area of the Garrel Burn, south-central Kilsyth Hills [NS 7032 8025 to 6992 8059] (Craig, 1980). Here, at least six lava flows are well exposed, and whilst the base of the member is not exposed, the topmost lava is.

Lower and upper boundaries
The basal trachybasalt of the Laird's Loup Lava Member appears to be either conformable or disconformable on the underlying microporphyritic basalt lava of the Drumnessie Lava Member.

At the western end of its outcrop, the Laird's Loup Lava Member is overlain by the Campsie Lava Member. The lithological change is to mostly plagioclase-microphyric basalt to trachybasalt (basalt to hawaiite of 'Jedburgh' type). At the eastern end of its outcrop, the member is overlain by the Tappetknowe Lava Member, the lithological change being to microporphyritic basaltic-trachyandesite (mugearite) and trachybasalt and rare plagioclase-macrophyric trachybasalt ('Markle' type).

Thickness
Some 65 m

Distribution and regional correlation
The member is restricted to the southern part of the Campsie Block (Forsyth et al., 1996) and specifically to the southern side of the central Kilsyth Hills, north-east of Glasgow. These rocks crop out along the escarpment on the southern side of the Kilsyth Hills, north of Kilsyth, from the southern flank of Laird's Hill [NS 6920 7974], eastwards to Green Bank [NS 7224 8068]. A further small area of outcrop in the Craigdouffie Burn [NS 7424 8088 to 7437 8073] is tentatively correlated with the member.

Age
Mid Visean (Arundian to Asbian)

4.3.3.34 Carron Bridge Lava Member

Name
Previously named the Carron Bridge Lavas (see Forsyth et al., 1996).

Lithology
The Carron Bridge Lava Member consists predominantly of plagioclase-macrophyric trachybasalt lava (transitional from basalt to hawaiite of 'Markle' type). The principal exposure of the member is in the River Carron, above and below the bridge [NS 734 837 to 748 838], in the Faughlin area to the south [NS 735 827], and near Langhill [NS 775 844]. The lavas are relatively thick, some flows being in excess of 15 m, although in the Langhill area, they are comparatively thinner, with about five lavas being present in the approximately 40 m-thick succession. All of the lavas are massive, moderately altered, and in the Carron Bridge and Faughlin areas, have particularly high concentrations of plagioclase phenocrysts, which tend to be elongate, up to 6 mm in length, and aligned in the presumed direction of flow. Fairly large pseudomorphed olivine phenocrysts are also present, but are less common than the plagioclase phenocrysts. Craig (1980) regarded these lavas as having distal-facies characterisitics. There is no indication of the source of the lavas.

Stratotype
The type area is in the eastern Kilsyth Hills, north-east of Glasgow [NS 7346 8254 to 7484 8384] (Forsyth et al., 1996). A reference section is the River Carron, above and below the bridge, north-west Kilsyth Hills, north-east of Glasgow [NS 7348 8375 to 7480 8380] (Craig, 1980).

Lower and upper boundaries
The base has not been seen but is likely to be unconformable on sedimentary rocks of the Inverclyde Group.

In the section of the River Carron, below the bridge [NS 748 838], and in the Faughlin area to the south [NS 735 827], the Carron Bridge Lava Member is overlain, apparently conformably, or disconformably, by the Faughlin Lava Member. The lithological change is to tuff and agglomerate and basaltic-trachyandesite (mugearite). However, in the Carron River section above the bridge, and on its southern bank, the Faughlin Lava Member is absent, and the Carron Bridge Lava Member is overlain, disconformably or unconformably, by the Campsie Lava Member.

Thickness
More than 50 m, base not seen

Distribution and regional correlation
The member is restricted to the eastern part of the Campsie Block (Forsyth et al., 1996), specifically to the eastern Kilsyth Hills, north-east of Glasgow. These rocks crop out in inliers: in, and around, the Faughlin Burn [NS 734 825] to [NS 737 828]; in the River Carron [NS 7348 8375 to 748 838], and along the Faughlin Burn south to Faughlin Reservoir [NS 7411 8295] and south-east to a locality at [NS 7446 8248]; and east of Langhill [NS 7705 8300] to the River Carron [NS 778 841], where the outcrop is truncated by the Carron Glen Fault (Craig, 1980).

Age
Mid Visean (Arundian to Asbian)

4.3.3.35 Faughlin Lava Member

Name
Previously named the Faughlin Lavas (Forsyth et al., 1996).

Lithology
The Faughlin Lava Member, which is poorly exposed, consists predominantly of microphyric trachybasalt and basaltic-trachyandesite lava (hawaiite to mugearite). A single plagioclase-macrophyric trachybasalt (hawaiite of 'Markle' type) is also present and tuff and agglomerate are present at the base of the member in the small stream due south of the bridge over the River Carron [NS 748 838].

Stratotype
The type area is in the north-eastern Kilsyth Hills, north-east of Glasgow [NS 7334 8238 to 7783 8401] (Forsyth et al., 1996). A reference section is an unnamed tributary of the River Carron, north-east Kilsyth Hills [NS 7479 8376 to 7486 8365] (Craig, 1980). This shows the base of the member.

Lower and upper boundaries
The lower boundary of the Faughlin Lava Member is conformable or disconformable on the underlying Carron Bridge Lava Member, and is marked by a tuff overlying trachybasalt in the small stream due south of the bridge over the River Carron [NS 748 838].

The Faughlin Lava Member is overlain by the Campsie Lava Member. The lithological change is to mostly plagioclase-microphyric basalt and trachybasalt ('Jedburgh' type).

Thickness
Some 35 m

Distribution and regional correlation
The member is restricted to the eastern part of the Campsie Block (Forsyth et al., 1996), specifically to two small areas of the north-eastern Kilsyth Hills, north-east of Glasgow. The rocks crop out in a small area south and east of the Faughlin Reservoir, from Faughlin Burn [NS 7336 8242] to the east of Carron Bridge [NS 7484 8378], and in a separate area between Langhill [NS 7698 8426] and the west bank of the River Carron [NS 7783 8401]. The source of this member is probably local.

Age
Mid Visean (Arundian to Asbian).

4.3.3.36 TAPPETKNOWE LAVA MEMBER

Name
Previously named the Tappetknowe Lavas (Forsyth et al., 1996).

Lithology
The Tappetknowe Lava Member consists of several lavas with a total thickness of approximately 40 m. These include, near Tappetknowe [NS 750 815], microporphyritic basaltic-trachyandesite (mugearite) and trachybasalt and rare plagioclase-macrophyric trachybasalt ('Markle' type). The rocks are intensely faulted and jointed and deeply weathered, and there are no good sections, exposure being limited to small crags.

Stratotype
The type area is the central Kilsyth Hills, north of Glasgow [NS 7176 8064 to 7622 8197] (Forsyth et al., 1996).

Lower and upper boundaries
The lower boundary is conformable or locally disconformable on the underlying Laird's Loup Lava Member, which comprises plagioclase-macrophyric trachybasalt, and is taken as the incoming of microporphyritic lavas (basaltic-trachyandesite to trachybasalt). The Tappetknowe Lava Member is overlain to the north-east of the Tak-ma-doon Fault (Craig, 1980) by the Denny Muir Lava Member. The lithological change here is to massive, well-featured plagioclase-macrophyric basalt (of 'Markle' type), trachybasalt and rare basaltic-trachyandesite (mugearite).

To the south-west of the Tak-ma-doon Fault, the Tappetknowe Lava Member is overlain by the Kilsyth Hills Lava Member, and the lithological change is mainly to plagioclase-macrophyric basalts and trachybasalts (hawaiites of 'Markle' type).

Thickness
Some 40 m.

Distribution and regional correlation
The member is restricted to the southern part of the Campsie Block (Forsyth et al., 1996) and specifically to the southern side of the central Kilsyth Hills, north-east of Glasgow. These rocks crop out in the escarpment on the southern side of the Kilsyth Hills, north-east of Kilsyth, from south of Tomtain [NS 7179 8062], eastward to the Tak-ma-doon Fault (Craig, 1980), thence to the north and south of Doups [NS 7494 8138] and as far east as Tappetknowe [NS 7620 8196]. Craig (1980) inferred that the source of the lavas was near to the present outcrop.

Age
Mid Visean (Arundian to Asbian).

4.3.3.37 CAMPSIE LAVA MEMBER

Name
Previously referred to as four separate successions named the Lower South Campsie Lavas, Lower North Campsie Lavas, Upper South Campsie Lavas and Upper North Campsie Lavas (Craig, 1980; Forsyth et al., 1996; Hall et al., 1998).

Lithology
The Campsie Lava Member has been divided stratigraphically into lower and upper sequences and geographically into northern and southern sequences that reflect petrographically their source vent systems. Although the various sequences are distinctive in some areas, enabling their boundaries to be identified, elsewhere they interdigitate laterally and have no distinctive stratigraphical markers to separate them vertically. Hence it is not possible to draw continuous boundaries between them on a map and therefore they have all been assigned to a single formal member. The four sequences have been given informal names that have been widely used on maps and in literature (Craig, 1980; Forsyth et al., 1996; Hall et al., 1998). The informal sequences are the lower south Campsie lavas, the lower north Campsie lavas, the upper south Campsie lavas and the upper north Campsie lavas.

The distinctive characteristic of the whole member is that it is composed almost entirely of plagioclase-microphyric basalt and trachybasalt (basaltic hawaiite and hawaiite) lavas (i.e. of 'Jedburgh' type). Within this restricted range there is considerable petrographical variation and there are systematic variations between the south and north Campsie lavas. The south Campsie lavas contain significant amounts of clinopyroxene, whereas in the north Campsie lavas it is present only as small granules in the groundmass. The plagioclase microphenocrysts also differ, being labradorite to calcic andesine in the south but sodic andesine in the north. These variations reflect the whole-rock compositions, which are dominantly basalt to basaltic hawaiite in the south and hawaiite to mugearite in the north. The lower and upper Campsie lava sequences can be identified where they are separated locally by one of several other lava members of distinctly different petrography. These are the Craigentimpin Lava Member, the Loup of Fintry Lava Member, the Laird's Hill Lava Member and the Overton Lava Member. Since it is not certain if those four members are contemporaneous, the boundaries between the lower and upper Campsie lavas, where drawn, do not necessarily involve lavas of exactly the same age everywhere.

The lower south Campsie lavas are microporphyritic trachybasalts (basaltic hawaiite and hawaiite of 'Jedburgh type') with microphenocrysts of sodic labradorite and a generally quite high content of mafic minerals which have been extensively replaced, especially in the case of olivine and augite, by carbonate, as has some plagioclase. Basalt lavas also occur. In the western Campsie Fells, in the Forking Burn [NS 653 790], there are ten proximal-facies lavas, totalling 80 m in thickness, showing toe structures and other features typical of pahoehoe lavas. These are separated by 'slaggy' agglomerates which make up about 25 per cent of the total thickness of the section. The individual lavas are generally thin (3 to 8 m) and highly amygdaloidal. Viriditic material is prominent in the groundmass. In the Garrel Burn [NS 697 807], the lavas are thicker, more massive, less amygdaloidal, and more distal in character, and the total thickness is reduced to approximately 50 m.

The lower north Campsie lavas consist mainly of olivine-microphyric basalt and trachybasalt (basaltic hawaiite and hawaiite of 'Jedburgh' type). There is considerable modal variation but clinopyroxene is generally lacking except as very small grains in the groundmass. Plagioclase microphenocrysts tend to be in the sodic andesine range. The best section is in the western escarpment overlooking the Blane Water valley at Black Craig [NS 558 812] where nine lavas are present, although the lowest of these is interpreted as part of the lower south Campsie lavas (Craig, 1980; Hall et al., 1998). These form a near-vertical face with well-developed tuff and scoria, up to 2 m thick, at the top of each lava. The lowest three lavas are each approximately 15 m thick, while the remainder are noteably thinner, averaging about 10 m each. Crude columnar jointing is evident in most of the lavas, except the second which locally has irregular subvertical platy jointing and comprises several 'flow units separated by rather impersistent slaggy layers' (Craig, 1980). Despite petrographical differences between the north and south Campsie lavas, it is not readily possible to distinguish between the two in all areas, and the two sequences are interpreted as interdigitating in many sections between the northern and southern Campsie Fells and Kilsyth Hills (Craig, 1980).

The upper south Campsie lavas consist of microporphyritic trachybasalt (hawaiites of 'Jedburgh' type), transitional to basaltic-trachyandesite (mugearite) with a very low content of augite. These lavas are well exposed in the Goat Burn [NS 637 793], above the southern escarpment in the eastern Campsie Fells, where a sequence of lavas, 40 m thick, is developed. The sequence comprises four lavas, the lower three averaging 12 m in thickness, and the fourth 5 m. The third lava is compound, as may also be the lowest, which is poorly exposed. The uppermost lava, and one of the flow units of the compound third lava, die out eastwards, as does the sequence as a whole.

The upper north Campsie lavas consists of plagioclase-microphyric trachybasalt and some basalt (basalt to hawaiite of 'Jedburgh' type) with scoriaceous agglomerates and tuffs. Basaltic trachyandesite (mugearite) also occurs. The lavas are generally poorly exposed and there are few sections through them. In the Muir Toll Burn [NS 628 828] the total thickness is about 40 m, part of which is repeated by the South Campsie Muir Fault. Farther east, on Cairnoch Hill [NS 690 852], Haugh Hill [NS 682 842] and Little Bin [NS 674 830], thick distal facies sequences occur, but are poorly exposed. In the Gonachan [NS 602 838] and Clachie [NS 612 840] burns, faulted sections, partly obscured by superficial deposits, occur. These are of proximal-facies lavas which are thin and carbonated, with considerable scoriaceous agglomerates and tuffs between the lavas. Interdigitation with lavas derived from the south, which are more mafic and more basaltic than those of the upper north Campsie lavas, is characteristic. This appears likely to be the case in the central and western Campsie Fells, including Ballagan Burn Glen [north of NS 5726 8043], Finglen [north of NS 5956 8043] and Campsie Glen [north of NS 6239 8080]. Similar interdigitation is seen in the River Carron [between NS 766 848 and NS 771 846] in the easternmost Kilsyth Hills, where a sequence, dipping to the east, of five or six relatively thin trachybasalts, transitional to basaltic trachyandesite, is exposed.

Stratotype
The Campsie Fells and Kilsyth Hills, between Strathblane [NS 555 797] and the Carron Valley, east to [NS 785 833], north and north-east of Glasgow.

Lower and upper boundaries
In the northern Campsie Fells, the lower boundary of the Campsie Lava Member is taken as the first appearance of basalt or trachybasalt lava on the underlying North Campsie Pyroclastic Member of the Clyde Plateau Volcanic Formation, and the contact appears to be conformable or disconformable. However, in the western and south-western Campsie Fells, the North Campsie Pyroclastic Member is absent and the Campsie Lava Member overlies the Clyde Sandstone Formation of the Inverclyde Group. Farther east in the southern Campsie Fells, at three localities between the Finglen Burn [NS 599 800] and the Forking Burn [NS 653 790], it rests directly, and unconformably, on argillaceous rock, dolostone and sandstone of the older Ballagan Formation of the Inverclyde Group, suggesting that the lower boundary is an unconformity, both there and maybe also in the northern Campsie Fells. To the east of the East Bachille Fault [NS 6915 7974] and west of the Chapmen's Graves Fault [NS 7063 8046], the lower boundary is taken as the first appearance of basalt or trachybasalt on the plagioclase-macrophyric trachybasalt (hawaiite) lavas of the Laird's Loup Lava Member.

In the central and western Campsie Fells, the Campsie Lava Member is overlain with apparent unconformity by the Fin Glen Lava Member. The lithological change is to trachyte, with basaltic trachyandesite (mugearite), trachybasalt (hawaiite) and basalt. In the eastern Campsie Fells and western Kilsyth Hills, the member is overlain variably disconformably to unconformably by the Lower Lecket Lava Member, and in some places the member was probably entirely removed by erosion prior to emplacement of the Lower Lecket Lava Member; for example south-east of Cort-ma Law [NS 6515 7995], south and east of Brown Hill [NS 6645 7897] and around Laird's Hill [NS 6957 8018]. In the north-eastern Kilsyth Hills, the Campsie Lava Member is overlain, probably unconformably by the lavas of the Gargunnock Hills Lava Member, or in the south-east Kilsyth Hills, by the Kilsyth Lava Member.

Thickness
Between 80 and 265 m

Distribution and regional correlation
The Campsie Lava Member accounts for over 30 per cent of the outcrop of volcanic rocks in the structural Campsie Block, which comprises the Campsie Fells and Kilsyth Hills, north and east of Glasgow. It is present throughout the block with the exception of the southern escarpment between Garrel Hill [NS 704 805] and Tappetknowe [NS 761 819].

The lower south Campsie lavas are generally restricted to the southern part of the block and are developed along most of the length of the southern Campsie Fells and southern Kilsyth Hills. They also crop out from the western Campsie Fells [NS 5540 7977] eastwards, immediately to the north of the Campsie Fault, to the south sides of Lairs [NS 640 791] and Brown Hill [NS 665 785], to the south side of Garrel Hill [NS 7068 8053]. They are also interdigitated with and undivided from, the lower north Campsie lavas, eastwards across the Kilsyth Hills, from the north-east of Little Bin [NS 6726 8339], to the south of the Carron Valley Reservoir [NS 700 825] to the lower western, southern and eastern flanks of Dundaff Hill [NS 7273 8486] to [NS 7467 8470], north of Denny Muir [NS 7505 8254] and along the River Carron, north of Tarduff Hill [NS 7486 8387] to [NS 7580 8463], and to the west and east of Northshields [NS 762 838] to [NS 7783 8396]. The extent to which they extend farther northwards across the Campsie Fells and Kilsyth Hills is uncertain, but they are likely to be interdigitated with the lower north Campsie lavas across most of that area.

The lower north Campsie lavas are generally restricted to the northern part of the Campsie Block and are developed along most of the length of the northern Campsie Fells and northern Kilsyth Hills. They crop out from the western Campsie Fells [NS 5520 8180] eastwards, across Craigbarnet Muir [NS 575 835] to the Endrick Water [NS 6617 8619]. They are also interdigitated with and undivided from, the lower south Campsie lavas southwards across the Campsie Fells and Kilsyth Hills as detailed above.

The upper south Campsie lavas are restricted to the southern part of the Campsie Block and are developed along most of the length of the southern Campsie Fells and southern Kilsyth Hills. They crop out in the escarpment north of the Campsie Fault, and extend westwards across the southern Campsie Fells to the Ballagan Burn [NS 5726 8043]. They also extend eastwards across the Kilsyth Hills to the River Carron [NS 766 848] and [NS 771 846], where they are interdigitated with the upper north Campsie lavas. The extent to which they extend northwards across the Campsie Fells and Kilsyth Hills is uncertain, but they might be interdigitated with the upper north Campsie lavas across most of the area.

The upper north Campsie lavas are generally restricted to the northern part of the Campsie Block and are developed along most of the length of the northern Campsie Fells and northern Kilsyth Hills. These rocks crop out from the western Campsie Fells [NS 562 820] eastwards, across Craigbarnet Muir [NS 575 830] to the Gonachan [NS 602 830] and Clachie [NS 612 840] burns. They also extend eastwards across the Kilsyth Hills, where they are interdigitated with the upper south Campsie lavas as detailed above.

Age
Mid Visean (Arundian to Asbian).

4.3.3.38 Craigentimpin Lava Member

Name
Previously named the Craigentimpin Lavas (see Forsyth et al., 1996; also Hall et al., 1998; Whyte and Macdonald, 1975).

Lithology
The Craigentimpin Lava Member consists of plagioclase-macrophyric basalt to trachybasalt ('Markle' type) characterised by large phenocrysts of calcic labradorite. Two lava flows are present in the Sloughmuclock area [NS 627 795]. Elsewhere, it generally consits of only one lava.

Stratotype
The type area is the central Campsie Fells, north of Glasgow [NS 6316 8244 to 6224 8399] (Forsyth et al., 1996). A reference section is the Alvain Burn [NS 6180 8053 to 6179 8060] (Craig, 1980). The member is also well exposed in Craigentimpin Quarry [NS 616 802].

Lower and upper boundaries
The base is conformable or disconformable on the underlying plagioclase-microphyric trachybasalt (hawaiite) lava of the lower north Campsie lavas (Campsie Lava Member) in the north of its outcrop, and by plagioclase-microphyric trachybasalt (hawaiite) lavas of the lower north Campsie and lower south Campsie lavas (Campsie Lava Member) in the south of its outcrop.

The Craigentimpin Lava Member is overlain with apparent conformity by the upper north Campsie lavas (Campsie Lava Member) in the north of its outcrop and by the upper north Campsie and upper south Campsie lavas (Campsie Lava Member) in the south of its outcrop. The lithological change is to mostly plagioclase-microphyric basalt to trachybasalt (hawaiite) lavas ('Jedburgh' type).

Thickness
Between 0 and about 30 m. The maximum thickness of the member is developed in the Sloughmuclock area [NS 627 795], but it thins out completely to the west.

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the central and eastern Campsie Fells, north of Glasgow. These rocks crop out north of the Campsie Fault in two areas. The southernmost of the two areas extends along the lower part of the escarpment north of the Campsie Fault, to the south-west of Lairs [NS 6424 7994], from west of Sloughneagh [NS 6532 7909] westwards to Craigentimpin Quarry [NS 616 802] and west to near Allanhead [NS 6070 8036]. The northernmost of the two areas of outcrop is faulted and extends northwards, discontinuously, from the south side of Campsie Muir [NS 6316 8244], thence to its east and north, and to the eastern flanks of Dunbrach [NS 6224 8399]. According to Whyte and MacDonald (1974) the orientation of the feldspar phenocrysts suggest that the source of the lava was the Waterhead Centre ('Waterhead Central Volcanic-Complex').

Age
Mid Visean (Arundian to Asbian).

4.3.3.39 Loup of Fintry Lava Member

Name
Previously named the Loup of Fintry Lavas (Forsyth et al., 1996).

Lithology
The Loup of Fintry Lava Member consists of two lavas, separated by a thin bed of basaltic lapilli-tuff. The lower lava is a plagioclase-macrophyric trachybasalt ('Markle' type). The upper lava is a composite flow of similar overall composition, with intermingling of aphyric and feldspar-phyric components [NS 656 858]. Other exposures of the member include plagioclase-macrophyric lava at the north-west end of Loch Carron [NS 673 856] and near the Spout of Dalbowie [NS 641 869].

Stratotype
The type area is the north-eastern Campsie Fells, north-east of Glasgow [NS 641 869 to 673 856] (Forsyth et al., 1996). A reference section is the Loup of Fintry (waterfall), in the Endrick Water, north-eastern Campsie Fells, north-east of Glasgow from [NS 6618 8617 to 6645 8612] (Craig, 1980). Here the full thickness of the member is evident.

Lower and upper boundaries
The lower (basal) plagioclase-macrophyric trachybasalt lava is conformable or disconformable on the underlying plagioclase-microphyric trachybasalt of the lower north Campsie lavas (Campsie Lava Member).

The upper composite lava of the Loup of Fintry Lava Member is overlain apparently conformably, or disconformably, by the upper north Campsie lavas (Campsie Lava Member). The lithological change is mostly to plagioclase-microphyric basalt ('Jedburgh' type), trachybasalt and basaltic-trachyandesite (mugearite).

Thickness
Nearly 30 m in the vicinity of the Loup of Fintry [NS 662 862].

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the north-eastern Campsie Fells, north-east of Glasgow. These rocks crop out in small isolated areas, in the vicinity of the Loup of Fintry [NS 662 862], at the north-west end of Loch Carron [NS 673 856], and near the Spout of Dalbowie [NS 641 869].

Age
Mid Visean (Arundian to Asbian).

4.3.3.40 LAIRD'S HILL LAVA MEMBER

Name
Previously named the Laird's Hill Lavas (Forsyth et al., 1996).

Lithology
The Laird's Hill Lava Member consists of only one or two lavas. In the stream sections to the north and west of Corrie Reservoir [NS 674 791] it is represented by a single flow of plagioclase-macrophyric basalt ('Markle' type), which is not shown on 1:50 000 scale Sheet 31W (BGS, 1992). Farther north-east it consists of a similar flow, underlain by a basaltic-trachyandesite (mugearite) lava, both of which crop out near the summit of Laird's Hill [NS 696 801] (the boundaries of the member here are difficult to delineate on both 1:50 000 and 1:10 000 scale maps). The two flows are also seen in various stream headwaters draining northwards to Loch Carron, although relationships here are less clear due to poor exposure, and it is possible that there is interdigitation with other members. The source of the lavas is uncertain.

Stratotype
The type area is the central Kilsyth Hills, north-east of Glasgow [NS 6670 7913 to 7042 8158] (Forsyth et al., 1996). A reference section is the Birken Burn, central Kilsyth Hills [NS 6900 8046 to 6867 8051] (Craig, 1980). Here, good exposures of the lavas are found in the stream section.

Lower and upper boundaries
The basal plagioclase-macrophyric basalt, or locally basaltic-trachyandesite (mugearite), of the member is conformable or disconformable in the south on the underlying microporhyritic trachybasalt lava of the lower south Campsie lavas (Campsie Lava Member), and in the north, on the undivided microporphyritic trachybasalt lavas of the lower north Campsie and lower south Campsie lavas (Campsie Lava Member).

The Laird's Hill Lava Member is overlain in the north by the undivided upper north Campsie and upper south Campsie lavas (Campsie Lava Member) and the lithological change is to microporphyritic trachybasalt. However, in the south, the Campsie Lava Member is absent due to erosion prior to deposition of the Lower Lecket Hill Lava Member, and the Laird's Hill Lava Member is overlain unconformably by basaltic-trachyandesite of the Lower Lecket Hill Lava Member. Locally also, in the south, the Laird's Hill Lava Member is absent, presumably due to erosion prior to deposition of the Lower Lecket Hill Lava Member.

Thickness
Some 20 m

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the central part of the Kilsyth Hills, north-east of Glasgow. These rocks crop out in two main areas. One, on the northern side of the Campsie Fault extends eastwards from the east flank of Brown Hill [NS 6670 7913]. It is locally absent on the south-west flank of Laird's Hill from [NS 6844 7964 to 6938 7996], but reappears on the south-east, east and north flanks of Laird's Hill [NS 6957 8018]. The member is absent on Plea Muir [NS 6934 8076]. The second area of outcrop extends from the north flank of Barrel Hill [NS 7042 8158] westwards as far as the Burnhouse Burn on the south-east side of Meikle Bin [NS 6746 8194].

Age
Mid Visean (Arundian to Asbian)

4.3.3.41 OVERTON LAVA MEMBER

Name
Previously named the Overton Lavas (Forsyth et al., 1996).

Lithology
The Overton Lava Member consists of at least one plagioclase-macrophyric basalt lava ('Markle' type) overlying a basaltic-trachyandesite lava (mugearite). Several lava flows, including trachybasalt, may be present. No source for the lavas has been identified.

Stratotype
The type area is the eastern Kilsyth Hills, north-east of Glasgow [NS 7532 8120 to 7706 8434] (Forsyth et al., 1996). Best exposures are in the faulted River Carron section, to the north-west of Nicholswalls [NS 764 843] and in the reference section in the Overton Burn [NS 7745 8353 to 7673 8344], east of Overton, eastern Kilsyth Hills (Craig, 1980).

Lower and upper boundaries
The basal basaltic-trachyandesite (mugearite) lava of the member is conformable or disconformable in the north on the trachybasalt lavas of the undivided lower north Campsie and lower south Campsie lavas (Campsie Lava Member). Elsewhere the base is not seen.

The Overton Lava Member in the east is overlain conformably or disconformably by the undivided upper north Campsie and upper south Campsie lavas (Campsie Lava Member), and in the north the member is overlain specifically by the upper north Campsie lavas (Campsie Lava Member). The transition is from plagioclase-macrophyric basalt lava to plagioclase-microphyric trachybasalt and some basalt lava (basalt to hawaiite of 'Jedburgh' type) with scoriaceous agglomerate and tuff.

Thickness
Some 35 m

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the eastern part of the Kilsyth Hills, north-east of Glasgow. These rocks crop out in two main areas. The first and principal area is in faulted ground to the south, east and north of Darrach Hill [NS 7537 8276], from the east of Doups [NS 7533 8122], east to near Meadowgreens [NS 7765 8297], north to Langhill [NS 7706 8432] and a stream east of Glenhead [NS 759 852], with a small outlier west of the River Carron [NS 7529 8460]. The second area is a small outlier in the Earl's Burn [NS 7175 8597 to 7129 8650].

Age
Mid Visean (Arundian to Asbian).

4.3.3.42 Langhill Lava Member

Name
Previously named the Langhill Lavas (Forsyth et al., 1996).

Lithology
The Langhill Lava Member consists of four flows of typically fine-grained, platy-jointed basaltic-trachyandesite (mugearite). The only exposures are in the River Carron [NS 773 845] 500 m north-east of Langhill. The lowest lava has a relatively coarse grain size and is about 15 m thick, with well-developed columnar jointing. The other lavas are very fine grained and intensely jointed. At least one of these has an autobrecciated base, consisting of buckled and disrupted tabular blocks of the lava.

Stratotype
The type area is the eastern part of the Kilsyth Hills [NS 7750 8442 to 7616 8539] (Forsyth et al., 1996). A reference section is the River Carron, eastern Kilsyth Hills, north-east of Glasgow [NS 7726 8454 to 7749 8439] (Craig, 1980).

Lower and upper boundaries
The member overlies plagioclase-microphyric trachybasalt of the Campsie Lava Member, but the nature of the contact is unknown.

The Langhill Lava Member is overlain by the Gargunnock Hills Lava Member, but the nature of the contact is unknown. The lithological change is to mostly plagioclase-macrophyric basalt to hawaiite ('Markle' type) with some plagioclase- and olivine-microphyric basalts ('Jedburgh' and 'Dalmeny' types).

Thickness
Some 35 m.

Distribution and regional correlation
The member is restricted to the eastern part of the Kilsyth Hills (Forsyth et al., 1996). The rocks mostly crop out on the northern side of the Carron Glen [NS 7750 8442 to 7616 8539] with the outcrop extending locally to the base of the valley [NS 7739 8450] and on to the southern side [NS 7709 6446].

Age
Mid Visean (Arundian to Asbian).

4.3.3.43 Lower Lecket Hill Lava Member

Name
Previously named the Lower Lecket HiIl Lavas (Forsyth et al., 1996).

Lithology
The Lower Lecket Hill Lava Member consists of lavas of plagioclase-microphyric trachybasalt (hawaiite) (of 'Jedburgh' type) to basaltic-trachyandesite (mugearite) and trachyandesite (benmoreite). Basaltic tuff-breccia and lapilli-tuff are present between the lavas. Along the southern escarpment of the Campsie Fells, the pyroclastic rocks are up to 4 m thick, and incorporate large scoria bombs. Craig (1980) interpreted these deposits as indicating derivation of at least some of the Lower Lecket Hill Lava Member from eruptive sources associated with the South Campsie Linear Vent System. In addition, in the vicinity of Meikle Bin [NS 6672 8217] and nearby to the south, the member is apparently interdigitated with tuff, interpreted as a tuff cone deposit (Craig, 1980). In the Alnwick Burn [NS 628 807 to 636 803] there are at least seven successive lava flows. These are transitional between trachybasalt (hawaiite) and basaltic-trachyandesite (mugearite) and platy-jointing is common. Only three lavas are present in the Goat Burn [NS 637 793] on the southern escarpment north of the Campsie Fault. The lowest of these is a trachyandesite (benmoreite) lava (Craig, 1980), 12 m thick, with well-developed platy jointing near its base and a crude columnar structure throughout the remainder of the unit. This is separated from a second lava, which is 5 m thick, by 2 m of 'coarse and scoriaceous' tuff (Craig, 1980). The third lava is of basaltic-trachyandesite (mugearite), and is approximately 10 m thick. To the north of Little Bin [NS 673 831], the member is represented by a single lava of basaltic-trachyandesite (mugearite).

Stratotype
The type area is the easternmost Campsie Fells, and western Kilsyth Hills, north of Glasgow [NS 6178 8000 to 6764 8240] (Forsyth et al., 1996). A reference section is the Alnwick Burn, western Kilsyth Hills from [NS 6284 8071 to 6365 8057] where at least seven successive lavas have been identified (Craig, 1980).

Lower and upper boundaries
Across the northern and north-western parts of its outcrop, the base of the Lower Lecket Hill Lava Member appears to be conformable or disconformable on the underlying Campsie Lava Member. However, in the southern and south-eastern parts of its outcrop [NS 6489 7904 to 7034 8060] the base is unconformable on older members; on the southern flanks of Cort-ma Law, the Lower Lecket Hill Lava Member rests unconformably on progressively older members from west to east, including the Loup of Fintry Lava Member, and eventually [NS 6548 7914] the Campsie Lava Member; and between the east flank of Brown Hill [NS 6598 7890] and the south-west flank of Garrel Hill [NS 7030 8065] the member rests unconformably either on the Laird's Hill Lava Member, or on the Campsie Lava Member. The unconformity may extend to the western limit of outcrop [NS 6178 8000] where there appears to be thinning of the underlying Campsie Lava Member.

The Lower Lecket Hill Lava Member is generally overlain with apparent conformity or disconformity by the Boyd's Burn Lava Member, whose geographical extent is similar to that of the Lower Lecket Hill Lava Member. The lithological change is mostly to plagioclase-macrophyric hawaiite lavas ('Markle' type). However, in the Meikle Bin area [NS 667 822], lavas of the Lower Lecket Hill Lava Member pass directly upwards into the remnant of the tephra cone associated with the Meikle Bin Trachytic Vent (Waterhead Centre).

Thickness
Some 50 m at Alnwick Burn [NS 628 807 to 636 803]; 29 m thick at Goat Burn [NS 637 793] (Craig, 1980).

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and has a limited geographical extent in the easternmost Campsie Fells and western Kilsyth Hills, north of Glasgow. These rocks mostly crop out in the escarpment north of the Campsie Fault, to the south-west of Lairs [NS 6424 7994], and on the southern flanks of Cort-ma Law [NS 6515 7995]. They also crop out: on the upper flanks of Brown Hill [NS 6645 7897], but not on the summit; on the upper flanks of Laird's Hill [NS 6957 8018]; on Plea Muir

[NS 691 808] east to the south flank of Garrel Hill [NS 7044 8104]; on the lower eastern, northern and western flanks of Lecket Hill [NS 6445 8121], including the Alnwick Burn Valley [NS 632 805] ; and on the lower slopes of Meikle Bin [NS 6672 8217].

Age
Mid Visean (Arundian to Asbian)

4.3.3.44 Boyd's Burn Lava Member

Name
Previously named the Boyd's Burn Lavas (see Forsyth et al., 1996).

Lithology
The Boyd's Burn Lava Member consists of plagioclase-macrophyric trachybasalt (hawaiite of 'Markle' type) lavas. These show a marked variation in the concentration and size of the plagioclase phenocrysts both between and within flows. There are basaltic lapilli-tuffs between the lavas. In the Boyd's Burn area [NS 650 814], at least four lavas with proximal-facies characteristics occur and tuffs between the lavas are well developed. These lavas have a rather 'slaggy' and decomposed nature, and are thought to be derived from the Waterhead Centre ('Waterhead Central Volcanic Complex') (see Craig, 1980). In the Goat Burn section [NS 637 793] a lava, 12 m thick, of plagioclase-macrophyric trachybasalt (hawaiite) is overlain by a compound flow with three 'flow units' (Craig, 1980) totalling almost 15 m in thickness. These lavas are texturally quite variable with rather sparsely distributed plagioclase phenocrysts in a pale groundmass. Farther to the east, a similar sequence is exposed in the Burniebraes Burn [NS 662 794], although faulting and the coincidence of stratigraphical dip and topographical slope partly obscure the relationships. Here, however, a third lava with numerous large plagioclase phenocrysts overlies the two lavas seen in the Goat's Burn section.

Stratotype
The type area is the eastern Campsie Fells, and westernmost Kilsyth Hills, north of Glasgow [NS 6186 8004 to 6750 8294] (Forsyth et al., 1996). A reference section is Boyd's Burn, westernmost Kilsyth Hills [NS 6527 8167 to 6487 8126] (Craig, 1980). The member is also quite well exposed in cliff sections along the southern escarpment of the Campsie Fells, north of the Campsie Fault.

Lower and upper boundaries
The basal plagioclase-macrophyric hawaiite lava of the member is conformable or disconformable on the underlying basaltic-trachyandesite (mugearite) of the Lower Lecket Hill Lava Member.

The Boyd's Burn Lava Member is overlain conformably or disconformably by the Upper Lecket Hill Lava Member. The lithological change is to mostly more-felsic lavas, including two basal basaltic-trachyandesite (mugearite) lavas, trachybasalt, and trachyte, but also including plagioclase-microphyric basalt to trachybasalt ('Jedburgh' type).

Thickness
Between 37 and 50 m. The maxium thickness is developed in the Boyd's Burn area [NS 650 814].

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and has a limited geographical extent, (reflecting the proximal character of the lavas) in the eastern Campsie Fells and westernmost Kilsyth Hills, north of Glasgow. These rocks mostly crop out in the escarpment north of the Campsie Fault, to the south-west of Lairs [NS 6424 7994], and on the southern flanks of Cort-ma Law [NS 6515 7995]. They also crop out: in a small outlier on Brown Hill [NS 6645 7897]; to the south, east and north-east of Box Law [NS 6669 7973]; on the eastern, northern and western flanks of Lecket Hill [NS 6445 8121]; and in an outlier at Little Bin [NS 6725 8285].

Age
Mid Visean (Arundian to Asbian)

4.3.3.45 Fin Glen Lava Member

Name
Previously named the Fin Glen Lavas (Forsyth et al., 1996; see also Craig, 1980; Hall et al., 1998).

Lithology
The Fin Glen Lava Member consists of trachyte and feldspar-microphyric varying to aphyric basaltic-trachyandesite (mugearite) transitional to trachybasalt (hawaiite) to basalt (of 'Jedburgh' type). Basaltic pyroclastic rock is present between many of the lavas. In all but the south-west and south-east, the base of the member is a phonolitic trachyte lava, characterised by well-developed planar jointing. This may be derived from a phonolite intrusion in the 'North Campsie Linear Vent System' near Fintry [NS 614 863], to the north (Craig, 1980), which is one of very few phonolitic lavas in the Carboniferous and Permian successions of northern Britain. In the southern part of its outcrop, another trachyte lava occurs near the top of the member. The wide variation in characteristics of the lavas and high degree of their interdigitation suggests individual lavas may have been erupted from different sources, some local and others more distant (Craig, 1980). Between the Fin Glen and the tributary of the Almeel Burn, and near the summit of Owsen Hill [NS 571 823] and Dumbreck [NS 574 815], to the east of Fin Glen, the lavas are highly scoriaceous and rubbly breccias are present. These resemble autobrecciated aa lavas, and have been interpreted (Craig, 1980) as distal lavas. In the Aldessan Burn [NS 608 807] at least five lavas are exposed. The basal trachyte is pink weathering and intensely platy-jointed, with extensive brecciation, some of which appears to be autobrecciation. The remainder of the lavas are thinner and often sparsely feldspar-phyric. Significant thicknesses of basaltic scoriaceous tuff-breccia and lapilli-tuff occur between most of the lavas.

Stratotype
The type area is western and central Campsie Fells, north of Glasgow [NS 5760 8058 to 6210 8405] (Forsyth et al., 1996). A reference section is Aldessan Burn, central Campsie Fells, north of Glasgow [NS 6079 8066 to 6072 8091] (Craig, 1980).

Lower and upper boundaries
The basal phonolitic trachyte lava is conformable or disconformable on plagioclase-microphyric trachybasalt (hawaiite) lava of the Campsie Lava Member.

The Fin Glen Lava Member is overlain by the Holehead Lava Member. The lithological change is mostly to plagioclase-macrophyric olivine basalts and trachybasalts (basalts to hawaiites of 'Markle' type), characterised by the presence of variable amounts of generally small plagioclase macrophenocrysts.

Thickness
Between 60 and 110 m. The thickest development is on the east side of Fin Glen Burn [NS 581 816], but this area is faulted, and exposure is only sporadic.

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the western and central Campsie Fells, north of Glasgow. These rocks crop out in high ground north of the Campsie Fault, on the summits of: Dumbreck [NS 5736 8149], and including the ridge to its south [NS 5835 8066]; Owsen Hill [NS 5714 8233]; Hog Hill [NS 592 822], including the area to the north and the lower flanks to the south-west and south; and Hart Hill [NS 6043 8266], including the flanks to the north and east. The rocks also crop out around Fassis [NS 604 806] and extending both to its north-west [NS 5970 8165] and east [NS 6226 8101]; on the lower flanks to the south-east, east and north-east of Holehead [NS 6176 8262]; and in crags to the north-east, and on the eastern, northern and western flanks, of Dunbrach [NS 6147 8375].

Age
Mid Visean (Arundian to Asbian).

4.3.3.46 Upper Lecket Hill Lava Member

Name
Previously named the Upper Lecket HiIl Lavas (Forsyth et al., 1996).

Lithology
The Upper Lecket Hill Lava Member consists generally of relatively felsic lavas, including trachybasalt (hawaiite), basaltic trachyandesite (mugearite), trachyte and rare plagioclase-microphyric basalt transitional to trachybasalt (of 'Jedburgh' type). The member is generally poorly exposed, but a reasonable section is present in the Back Burn [NS 640 803], where at least seven platy-jointed and rather 'slaggy' lavas are present. In Goat Burn [NS 637 794] two lavas (or 'flow units' of Craig, 1980) of basaltic-trachyandesite (mugearite) are overlain by a lava, 6 m thick, of trachybasalt (hawaiite), above which is a compound 15 m-thick lava of very fine-grained 'slaggy' trachybasalt (hawaiite) or basaltic-trachyandesite (mugearite) with scattered small feldspar phenocrysts, and a pale-weathered, platy-jointed basaltic-trachyandesite (mugearite), 5 m thick. The top of the section is obscured by peat. North-east of the summit of Lecket Hill [NS 6445 8121], lapilli-tuffs and agglomerates locally predominate over lavas, which include trachyte.

Stratotype
The type area is the eastern Campsie Fells, and westernmost Kilsyth Hills, north of Glasgow [NS 6192 8005 to 6696 8094] (Forsyth et al., 1996). A reference section through the member is seen at Back Burn [NS 6371 8021 to 6489 8033] (Craig, 1980), and an incomplete section is present along the southern escarpment of the Campsie Fells, north of the Campsie Fault at Goat Burn [NS 637 794].

Lower and upper boundaries
The basal basaltic-trachyandesite (mugearite) lava of the member is conformable or disconformable on the underlying plagioclase-macrophyric trachybasalt (hawaiite) lava of the Boyd's Burn Lava Member.

The Upper Lecket Hill Lava Member is overlain apparently conformably or disconformably by the Kilsyth Hills Lava Member, which has a similar geographical distribution. The lithological change is to plagioclase-macrophyric transitional to plagioclase-microphyric basalt and trachybasalt (hawaiite) lavas (of 'Markle' type transitional to 'Jedburgh' type).

Thickness
Some 65 m

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and has a limited geographical extent, (reflecting the proximal character of the lava flows) in the eastern Campsie Fells and westernmost Kilsyth Hills, north of Glasgow. These rocks mostly crop out immediately above the escarpment north of the Campsie Fault, to the south-west of Lairs [NS 6424 7994], and on the southern, eastern and northern flanks of Cort-ma Law [NS 6515 7995], and on the upper flanks, but not the summit area, of Lecket Hill [NS 6445 8121]. They also crop out in a very small outlier on the summit of Little Bin [NS 6725 8285]. Craig (1980) inferred that the source of the member was the nearby Waterhead Centre ('Waterhead Central Volcanic Complex').

Age
Mid Visean (Arundian to Asbian)

4.3.3.47 Holehead Lava Member

Name
Previously named the Holehead Lavas (Forsyth et al., 1996; see also Craig, 1980; Hall et al., 1998).

Lithology
The Holehead Lava Member consists mainly of plagioclase-macrophyric olivine basalts and trachybasalts (basalts to hawaiites of 'Markle' type), characterised by the presence of variable amounts of relatively small plagioclase phenocrysts. In addition, one lava of transitional trachybasalt to mugearite composition is exposed in the middle of a lava sequence in the Alvain Burn [NS 614 815]. In the Aldessan Burn [NS 607 809 to NS 605 816], there is a sequence of seven lavas. The flows tend to be relatively thin with 'slaggy' tops and locally rubbly bases.

Stratotype
The type area is central Campsie Fells, north of Glasgow [NS 5894 8166 to 6200 8341] (Forsyth et al., 1996). A reference section is Aldessan Burn, central Campsie Fells, north of Glasgow [NS 6072 8092 to 6039 8224] where seven lavas are seen (Craig, 1980).

Lower and upper boundaries
The basal plagioclase-macrophyric basalt, and/or trachybasalt, is conformable or disconformable on basaltic-trachyandesite (mugearite) of the Fin Glen Lava Member.

The Holehead Lava Member occupies summit areas across its outcrop and the top of the member has been eroded.

Thickness
More than 100 m, top eroded.

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and has a limited geographical extent in the Central Campsie Fells, north of Glasgow. These rocks

mostly crop out: in an outlier on the upper, southern flanks of Hog Hill [NS 592 822]; around Inner Black Hill [NS 6101 8164]; and around the summit of Holehead [NS 6176 8262]. The lavas were thought by Craig (1980) to have been derived from the Waterhead Centre ('Waterhead Central Volcanic Complex').

Age
Mid Visean (Arundian to Asbian)

4.3.3.48 Kilsyth Hills Lava Member

Name
Previously named the Kilsyth Hills Lavas (Forsyth et al., 1996).

Lithology
The Kilsyth Hills Lava Member consists predominantly of plagioclase-macrophyric basalts and trachybasalts (hawaiites of 'Markle' type). The lower of these lavas tend to have sparse and small plagioclase phenocrysts and are transitional to plagioclase-microphyric basalts and trachybasalts (hawaiites of 'Jedburgh' type). Some higher lavas in the sequence are olivine-augite-macrophyric basalts (of 'Dunsapie' type) although these are always subordinate to the plagioclase-phyric lavas. Also, there is a local intercalation of variably olivine- and olivine-augite-microphyric basalt lava ('Jedburgh' to 'Dalmeny' type).

Stratotype
The type area is in the central Kilsyth Hills, north-east of Glasgow [NS 6220 7992 to 7396 8109] (Forsyth et al., 1996). A reference section is the crags on the southern flanks of Tomtain Hill, central Kilsyth Hills [NS 7231 8072 to 7212 8140] (Craig, 1980).

Lower and upper boundaries
Over most of its outcrop, the base is conformable or disconformable on basaltic-trachyandesite (mugearite) and/or trachybasalt (hawaiite) of the Upper Lecket Hill Lava Member. However, towards the south-east, the member rests unconformably on progressively older members until, in the Garrel Hill area [NS 698 810], it rests on basaltic-trachyandesite (mugearite) of the Lower Lecket Hill Lava Member. South of Garrel Hill [NS 750 806] it is directly underlain by plagioclase-microphyric trachybasalt (hawaiite) lava of the Campsie Lava Member, and to the south of Tomtain [NS 7179 8062] and as far east as the Tak-ma-doon Fault [NS 7396 8106] it is underlain by basaltic-trachyandesite (mugearite) and/or trachybasalt (hawaiite) of the Tappetknowe Lava Member.

The Kilsyth Hills Lava Member occupies summit areas across its outcrop and the top of the member has been eroded.

Thickness
The member is most thickly developed on Tomtain [NS 721 814], where its apparent thickness is 160 m. Top eroded.

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the central Kilsyth Hills, north-east of Glasgow. The rocks crop out in the highest ground above the escarpment north of the Campsie Fault, to the west and around the summits of Lairs [NS 6424 7994], Cort-ma Law [NS 6515 7995] and Lecket Hill [NS 6445 8121]. The member also crops out in a separate area extending from the west of Garrel Hill [NS 7044 8105], around its north and south flanks, and around those of Tomtain Hill [NS 721 814], as far east as the Tak-ma-doon Fault [NS 7396 8109 to 7300 8196]. It is exposed in crags on high ground from Crighton's Cairn [NS 625 799] and Lecket Hill [NS 645 812] eastwards to the Tak-ma-doon Fault [NS 7396 8109 to 7300 8196] (Craig, 1980). The member is equivalent laterally to the Denny Muir Lava Member which is recognised to the east of the Tak-ma-doon Fault. The lavas were thought by Craig (1980) to have been derived from the Waterhead Centre ('Waterhead Central Volcanic Complex').

Age
Mid Visean (Arundian to Asbian)

4.3.3.49 Denny Muir Lava Member

Name
Previously named the Denny Muir Lavas (see Forsyth et al., 1996).

Lithology
The Denny Muir Lava Member consists mostly of massive, well-featured plagioclase-macrophyric basalt or trachybasalt ('Markle' type), trachybasalt lavas and rare basaltic trachyandesite (mugearite) lavas. The basal lava east of Darrach Hill [NS 754 827] is composite, with intermingled components of plagioclase-macrophyric and plagioclase-microphyric basalt or trachybasalt ('Markle' and 'Jedburgh' types respectively). The remainder of the lavas are massive and well featured, for example west of Birns [NS 761 823]. An intensely jointed and 'slaggy' basaltic-trachyandesite (mugearite) lava occurs in faulted ground in the headwaters of the Garvald Burn [NS 758 825].

Stratotype
The type area is the eastern Kilsyth Hills, north-east of Glasgow [NS 7406 8099 to 7584 8392] (Forsyth et al., 1996). A reference section is the crags west of Birns, eastern Kilsyth Hills [NS 7555 8228 to 7559 8228] (Craig, 1980).

Lower and upper boundaries
To the north and east, the base, locally a composite lava, is conformable or disconformable on underlying plagioclase-microphyric trachybasalt lavas of the Campsie Lava Member, but towards the south-west, where these lavas are absent, the member rests directly on plagioclase-microphyric basaltic-trachyandesite and/or trachybasalt, of the Tappetknowe Lava Member, suggesting that the boundary is an unconformity.

The Denny Muir Lava Member occupies summit areas across its outcrop and the top of the member has been eroded.

Thickness
Up to 85 m

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the eastern Kilsyth Fells, north-east of Glasgow. These rocks crop out in high ground north of the Campsie Fault, and to the east of the Tak-ma-doon Fault [NS 7396 8109 to 7300 8196], across Denny Muir [NS 750 830], and around Darrach Hill [NS 7538 8275]. In addition, there is a small outlier around the top of Tarduff Hill [NS 756 836]. The lavas are essentially continuous with those of the Kilsyth Hills Lava Member which lie to the west of the Tak-ma-doon Fault (Craig,

1980). The lavas were thought by Craig (1980) to have been derived from the Waterhead Centre ('Waterhead Central Volcanic Complex').

Age
Mid Visean (Arundian to Asbian).

4.3.3.50 Knowehead Lava Member

Name
Previously named the Knowehead Lavas (Forsyth et al., 1996; see also Craig, 1980; Hall et al., 1998).

Lithology
The Knowehead Lava Member consists of a broad range of petrographical types, including plagioclase-macrophyric trachybasalt lavas (hawaiites of 'Markle' type), olivine- augite-plagioclase-macrophyric basalt ('Dunsapie' type), plagioclase-microphyric trachybasalt (hawaiite), basaltic-trachyandesite (mugearite), and a rhyolite lava of restricted extent of exposure. The rhyolite has fine platy joints 'with streaky flow-banding picked out in pale and red weathering colours' (Craig, 1980). The outcrop is extensively faulted and it has not been possible to erect an internal stratigraphy for the member. The numerous intercalations of coarse tuff and the 'slaggy' tongue-like character of some of the lavas, led Craig (1980) to suggest that at least some of the lavas are close to their eruptive source, although no vents have been identified.

Stratotype
The type area is the south side of the central Campsie Fells, north of Glasgow [NS5660 7965 to 6238 7940] (Forsyth et al., 1996). The member is best exposed in the Fin Glen Burn [NS 604 794]. Craig (1980) made no attempt to erect a lava flow stratgraphy within the member due to the heavily faulted nature of the exposed section.

Lower and upper boundaries
The Knowehead Lava Member is fault bounded and the lower and upper boundaries are not seen.

Thickness
Greater than 50 m.

Distribution and regional correlation
The member is restricted to the southern part of the Campsie Block (Forsyth et al., 1996) and specifically to the southern side of the Campsie Fells, north of Glasgow. These rocks crop out on the south side of the Campsie Fault, in lower ground below the escarpment, bounded by the Campsie Fault to the north, and another west-north-west-trending fault to the south. The crop extends from east of Clachan of Campsie [NS 6238 7940], to the north-east of Lennoxtown, westwards to the Fin Glen Burn [NS 604 794] and beyond to Strathblane [NS 5660 7965]. The outcrop was thought by Craig to extend farther west (Craig, 1980), but correlation in that area with the similar Cochno Lava Member of the Kilpatrick Hills succession (Hall et al., 1998), and farther to the south, is uncertain.

Age
Mid Visean (Arundian to Asbian)

4.3.3.51 Craigdouffie Lava Member

Name
Previously named the Craigdouffie Lavas (see Forsyth et al., 1996).

Lithology
The Craigdouffie Lava Member consists of a sequence of at least four lavas, comprising alternating plagioclase-macrophyric basalt or trachybasalt (basalt to hawaiite of 'Markle' type) and aphyric basaltic-trachyandesite (mugearite), all with proximal-facies characteristics (Craig, 1980).

Stratotype
The type area is the south-eastern Kilsyth Hills, north-east of Glasgow [NS 7442 8070 to 7479 8078] (Forsyth et al., 1996). The only reference section is Craigdouffie Burn, south-eastern Kilsyth Hills [NS 7484 8074 to 7438 8072] where at least four lavas, at least 15 m thick in total, are seen at the top of the member (Craig, 1980; Forsyth et al., 1996).

Lower and upper boundaries
The base of the Craigdouffie Lava Member is faulted and unseen. It is overlain by poorly exposed volcaniclastic sedimentary rocks of the Kirkwood Formation of the Strathclyde Group. The lithological change is from basalt or trachybasalt to tuffaceous mudstone and tuff, but the nature of the contact is not known.

Thickness
More than 15 m, base not seen.

Distribution and regional correlation
The member is restricted to a small area adjacent to the south side of the Campsie Fault and adjacent to the north-east side of the Tak-ma-doon Fault (Craig, 1980), in the south-eastern Kilsyth Hills, north-east of Glasgow. These rocks crop out east-north-east of Drumnessie, mainly in the Craigdouffie Burn [NS 7448 8072 to 7484 8074] and on its northern side to [NS 7479 8078]. The source is probably an undetected vent in the immediate vicinity (Craig, 1980).

Age
Mid Visean (Arundian to Asbian).

4.3.3.52 Corrie Lava Member

Name
Previously named the Corrie Lavas (see Forsyth et al., 1996).

Lithology
The Corrie Lava Member consists of plagioclase-macrophyric basalt and trachybasalt lavas ('Markle' type), aphyric basaltic-trachyandesite (mugearite) lava, and lapilli-tuff and tuff-breccia beds.

Stratotype
The type area is in the south-western Kilsyth Hills, north of Glasgow [NS 6820 7909 to 6947 7957] (Forsyth et al., 1996). A reference section is an unnamed burn crossing the escarpment north of Corrie, south-western Kilsyth Hills [NS 6904 7939 to 6892 7966] (Craig, 1980), but neither the lower nor upper boundary is seen.

Lower and upper boundaries
The Corrie Lava Member is fault-bounded and neither the lower or upper boundary is seen.

Thickness
More than 30 m (Forsyth et al., 1996, table 3). Neither top nor base is seen.

Distribution and regional correlation
The member is restricted to the southern part of the Campsie Block (Forsyth et al., 1996) and specifically to the southern side of the south-western Kilsyth Hills, north of Glasgow. The outcrop is bounded to the south by the Campsie Fault, to the north by the Bachille Fault and to the north-east by the East Bachille Fault (Craig, 1980). These rocks crop out in faulted ground below the escarpment on the southern side of the Kilsyth Hills, north-west of Kilsyth, from the west of Corrie Plantation [NS 6820 7909], eastwards to the north-east of Corrie [NS 6952 7957]. Derivation is thought to have been from local vents (Craig, 1980).

Age
Mid Visean (Arundian to Asbian)

4.3.3.53 Garvald Lava Member

Name
Previously named the Garvald Lavas (Forsyth et al., 1996).

Lithology
The Garvald Lava Member is well exposed in sections in the River Carron [NS 781 838] and the Overton Burn [NS 7789 8350], where the member consists, in downward succession, of plagioclase-microphyric basalts or trachybasalts (basalts or hawaiites of 'Jedburgh' type), an olivine-augite-plagioclase-macrophyric trachybasalt (hawaiite of 'Dunsapie' type), a prominently exposed microporphyritic basaltic-trachyandesite (mugearite), two plagioclase-macrophyric trachybasalts (hawaiite of 'Markle' type), and a plagioclase-microphyric trachybasalt (hawaiite of 'Jedburgh' type) with pillow structures, indicating subaqueous emplacement (Craig, 1980).

Stratotype
The type area is the easternmost Kilsyth Hills, north-east of Glasgow [NS 7720 8210 to 7744 8530] (Forsyth et al., 1996). A reference section is the Overton Burn, eastern Kilsyth Hills [NS 7854 8324 to 7750 8355] though, as elsewhere, the base is not seen (Craig, 1980).

Lower and upper boundaries
The base is not seen, due to faulting. The Garvald Lava Member is overlain with angular unconformity by the Kirkwood Formation of the Strathclyde Group. In the Garvald Burn section [NS 781 838] the lithological change is from plagioclase-microphyric basalt or trachybasalt to volcaniclastic conglomerates and sandstones, which rest on progressively older lavas of the Garvald Lava Member towards the south.

Thickness
More than 50 m

Distribution and regional correlation
The member is restricted to the Campsie Block (Forsyth et al., 1996) and specifically to the easternmost Kilsyth Fells, north-east of Glasgow. These rocks crop out in faulted ground north of the Campsie Fault, from west of Myot Hill [NS 7720 8210], north-eastwards to Garvald [NS 7849 8335], north-north-west along the Carron Glen and then towards Buckleside [NS 7744 8530]. The source is thought to be local, either a neck exposed in the River Carron, north-east of Northshields [NS 779 840] or some other obscured source (Craig, 1980).

Age
Mid Visean (Arundian to Asbian)

FINTRY–TOUCH BLOCK (Fintry Hills, Gargunnock Hills, Touch Hills)

Note that there are local variations in the general stratigraphy as presented. This is related to interdigitation and unconformities, and the restricted distribution and multiple sources of some of the members.

4.3.3.54 Slackdown Lava Member

Name
Previously known as the Basal Group (Francis et al., 1970).

Lithology
The Slackdown Lava Member consists of a varied assemblage of dominant trachybasalt lavas, with plagioclase-macrophyric basalt lavas ('Markle' type) and plagioclase-microphyric basalt lavas ('Jedburgh' type). In crags north of Scout Head (see *Stratotype* below) a basaltic-trachyandesite (mugearite), or albitised trachybasalt lava, which is variably massive to platy-jointed, is overlain in succession by a thin and impersistent plagioclase-macrophyric basalt lava, a plagioclase-microphyric basalt lava, and a generally massive trachybasalt, transitional to plagioclase-microphyric basalt lava.

Stratotype
The type area is in the northern Touch Hills, and the northern and north-eastern Gargunnock Hills, north-east of Glasgow [NS 6576 9125 to 7410 9372] (Francis et al., 1970). A reference section is provided by the crags north of Scout Head, northern Touch Hills [NS 7311 9352 to 7315 9340]. Largely obscured by drift, it is 31 m thick. The lavas form a series of cliffs at the foot of the escarpment and the basal mugearite forms a particularly prominent and laterally extensive crag (Francis et al., 1970).

Lower and upper boundaries
The basal basaltic-trachyandesite (mugearite) of the member unconformably overlies sedimentary rocks, including sandstone, siltstone and mudstone of the Clyde Sandstone Formation, of the Inverclyde Group.

The Slackdown Lava Member is overlain, conformably or disconformably, by the Baston Burn Lava Member. The lithological change is from trachybasalt to plagioclase-macrophyric basalt ('Markle' type), except in the north-western Gargunnock Hills, where the uppermost Slackdown Lava Member is represented by plagioclase-microphyric basalt ('Jedburgh' type).

Thickness
Between 30 and 79 m

Distribution and regional correlation
The member is restricted to the Fintry–Touch Block (Francis et al., 1970) and specifically to the northern Touch Hills and the north-eastern Gargunnock Hills. These rocks crop out east-north-eastwards, from the north of Lees Hill [NS 6576 9125] to the north-north-east, to the Baston Burn [NS 7410 9372].

Age
Mid Visean (Arundian to Asbian)

4.3.3.55 Skiddaw Lava Member

Name
Previously named the Skiddaw Group (Francis et al., 1970).

Lithology
The Skiddaw Lava Member consists predominantly of plagioclase-macrophyric basalt ('Markle' type) and composite lavas with some plagioclase-microphyric basalt ('Jedburgh' type). In the east of the outcrop [NS 6572 9122] the member comprises coarse olivine basalt at the base, above which the sequence comprises: a plagioclase-macrophyric basalt lava, a composite lava composed of massive, rounded bodies mostly of plagioclase-macrophyric basalt, but also including near the centre of the lava some transitional plagioclase-microphyric to olivine-microphyric basalts, in a matrix of 'slaggy', highly vesicular microporphyritic basalt; and a massive, transitional plagioclase-microphyric to plagioclase-macrophyric basalt with traces of columnar jointing.

Stratotype
The type area is in the northern and western Fintry Hills, and the north-western Gargunnock Hills, north-east of Glasgow [NS 6304 8712 to 6577 9122] (Francis et al., 1970). A reference section is at Slackgun, north-western Gargunnock Hills [NS 6572 9122] where a section 34 m thick (apparently the full thickness at this locality) was given by Francis et al. (1970).

Lower and upper boundaries
The basal basalt lava of the member unconformably overlies sedimentary rocks, including sandstone, siltstone and mudstone of the Clyde Sandstone Formation, of the Inverclyde Group.

The Skiddaw Lava Member is overlain unconformably by the Slackgun Volcaniclastic Member. The lithological change is from transitional plagioclase-macrophyric to plagioclase-microphyric basalt lava or composite basalt lava to a dull red bole reflecting prolonged weathering of the lavas.

Thickness
Between 0 and 37 m.

Distribution and regional correlation
The member is restricted to the northern Fintry–Touch Block (Francis et al., 1970) and specifically to the northern and western Fintry Hills and to the north-western Gargunnock Hills, north-east of Glasgow. These rocks crop out from below Double Craigs [NS 6304 8712] north-north-west towards Skiddaw [NS 622 891] and then north-east, to the north-west side of Lees Hill [NS 6577 9122].

Age
Mid Visean (Arundian to Asbian)

4.3.3.56 Baston Burn Lava Member

Name
Previously named the Baston Burn Group (see Francis et al., 1970).

Lithology
The Baston Burn Lava Member consists predominantly of plagioclase-macrophyric basalt lavas ('Markle' type) with a few plagioclase-microphyric lavas, or microporphyritic components of composite lavas ('Jedburgh' type). The member has eroded to form a prominent and wide step in the cliffs above the Slackdown Lava Member in the northern Touch and Gargunnock hills. In the extreme east [NS 7315 9339 to 7318 9331], the member comprises three plagioclase-macrophyric basalt lavas, but farther west [NS 7232 9320 to 7234 9297] comprises four such lavas, the lower and upper two being separated by a thin lava composed of microporphyritic basalt ('Jedburgh' type) (although this may be a component of a composite lava). In the Gargunnock Burn [NS 7073 9292 to 7060 9267], the member lies in a shallow synclinal structure and comprises more than ten lavas. All are of plagioclase-macrophyric basalt except for the highest and lowest, which are transitional between macroporphyritic and microporphyritic basalt. The lowest lava is composite elsewhere [NS 7154 9305].

Stratotype
The type area is in the northern Touch Hills and Gargunnock Hills, north-east of Glasgow [NS 6580 9120 to 7351 9352] (Francis et al., 1970). A reference section is in the Gargunnock Burn, central northern Gargunnock Hills [NS 7073 9292 to 7060 9267], comprising a 67 m-thick succession with ten lavas (Francis et al., 1970).

Lower and upper boundaries
In the northern Touch Hills, and north-eastern Gargunnock Hills, the basal macroporphyritic lava of the member is conformable or disconformable on a trachybasalt lava of the Slackdown Lava Member. Farther west, where the trachybasalt is absent, the basal lava of the Baston Burn Lava Member is a transitional plagioclase-macrophyric to plagioclase-microphyric basalt, which overlies conformably or disconformably a microporphyritic basalt of the Slackdown Lava Member.

In the northern Touch Hills and north-eastern Gargunnock Hills, the Baston Burn Lava Member is overlain unconformably by the Spout of Ballochleam Lava Member, and the Baston Burn Lava Member is progressively truncated towards the west. The lithological change is to microporphyritic basalt ('Jedburgh' type). In the north-western Gargunnock Hills, the Baston Burn Lava Member is overlain unconformably by the Slackgun Volcaniclastic Member, and the lithological transition is to weathered basalt (bole) and well-bedded tuff.

Thickness
Between 9 and 67 m. In the extreme east [NS 7315 9339 to 7234 9297] the member is 15 m thick. It is thickest in the Gargunnock Burn [NS 7073 9292 to 7060 9267].

Distribution and regional correlation
The member is restricted to the northern part of the Fintry–Touch Block (Francis et al., 1970) and specifically to the northern Fintry Hills and the north-eastern Gargunnock Hills. These rocks crop out on a wide step in the escarpment above the cliffs formed by the Slackdown Lava Member, extending north-east from the north side of Lees Hill [NS 6580 9120] to Standmilane Craig [NS 670 918] and Black Craig [NS 685 924] and east to the Gargunnock Burn [NS 7073 9292 to 7060 9267] and Baston Burn [NS 7351 9352].

Age
Mid Visean (Arundian to Asbian).

4.3.3.57 Slackgun Volcaniclastic Member

Name
Previously named the Slackgun Interbasaltic Beds (see Francis et al., 1970).

Lithology
The Slackgun Volcaniclastic Member consists predominantly of bedded tuff and/or volcaniclastic sedimentary rock, with weathered basalt lava (including bole) and a local olivine-microphyric basalt lava.

Stratotype
The type area is in the northern, western and south-western Fintry Hills, and the north-western Gargunnock Hills, north-east of Glasgow [NS 6224 8636 to 6878 9241] (Francis et al., 1970). A reference section is the corrie-like scar of Slackgun, immediately north-west of Lees Hill, northern Fintry Hills [NS 6576 9118 to 6577 9112] where Francis et al. (1970) recorded a partially obscured, 34 m-thick, section up the scarp.

Lower and upper boundaries
The Slackgun Volcaniclastic Member unconformably overlies the Skiddaw Lava Member. The lithological change is from transitional plagioclase-macrophyric to plagioclase-microphyric basalt lava or composite basalt lava to a dull red bole reflecting prolonged weathering of the underlying lavas.

The Slackgun Volcaniclastic Member is overlain, conformably or disconformably, by the Spout of Ballochleam Lava Member. The lithological change is from tuff or volcaniclastic sedimentary rock to plagioclase-microphyric basalt lava ('Jedburgh' type).

Thickness
Between 0 and 80 m

Distribution and regional correlation
The member is restricted to the northern Fintry–Touch Block (Francis et al., 1970) and specifically to the Fintry Hills and the north-western Gargunnock Hills, north-east of Glasgow. These rocks crop out from north-east of Spittalhill [NS 6521 8669] to the west-north-west to below Double Craigs [NS 631 875], north-north-west to below Stronend [NS 626 895], and east-north-east to Black Craig [NS 6878 9241].

Age
Mid Visean (Arundian to Asbian)

4.3.3.58 Spout of Ballochleam Lava Member

Name
Previously named the Spout of Ballochleam Group (see Francis et al., 1970).

Lithology
The Spout of Ballochleam Lava Member consists predominantly of plagioclase-microphyric basalt lavas ('Jedburgh' type) and forms prominent crags. The lavas are comparatively impersistent and hard to correlate between adjacent sections, and some are divided into 'flow-units' (Francis et al., 1970). Many of the basalt lavas have a relatively coarse grain size and are massive. The lavas are also variably slaggy, vesicular with sporadic amygdales, platy, and sporadically columnar jointed, and spheroidally weathered. Boles, some with nodules of decomposed lava, are developed on the tops of some lavas. The member also includes, near the base, rare olivine-microphyric basalt lavas ('Dalmeny' type) [NS 7061 9266], and higher within the member isolated plagioclase-macrophyric basalt lavas ('Markle' type). North of Scout Head [NS 735 634] in the Touch Hills, the member comprises only three or four lavas, but farther west [NS 7233 9297 to 7240 9276] it includes five or more lavas. At the Gargunnock Burn [NS 7061 9266 to 7064 9250] there are seven lavas.

Stratotype
The type area is in the northern and western Fintry Hills, and the northern Gargunnock and Touch hills, north-east of Glasgow [NS 6365 8701 to 7437 9374] (Francis et al., 1970). A reference section is a gully in steep cliffs, east end of Standmilane Craig, north-east Gargunnock Hills [NS 6757 9210 to 6762 9200] (Francis et al., 1970). Here the member is 82 m thick, but contacts between units are generally obscured.

Lower and upper boundaries
In the northern Touch Hills and the north-eastern Gargunnock Hills, the basal plagioclase- or olivine-microphyric basalt lava of the member lies unconformably on the eroded plagioclase-macrophyric lavas of the Baston Burn Lava Member, progressively overstepping them to the west. In the north-western Gargunnock Hills and in the Fintry Hills, the member overlies, conformably or disconformably, tuffs of the Slackgun Volcaniclastic Member.

In the north and west Fintry Hills, the member is overlain, apparently conformably or disconformably, by the Shelloch Burn Lava Member and the lithological change is to trachybasalt lava. In the northern Gargunnock Hills and north-western Touch Hills, however, the member is overlain, possibly disconformably, by trachybasalt lava of the Lees Hill Lava Member and in the north-eastern Touch Hills, possibly disconformably, by the Gargunnock Hills Lava Member. In the latter case, the lithogical change is to plagioclase-macrophyric basalt lava.

Thickness
Between 24 and 91m. The member is of varible thickness, but generally thickens to the west. North of Scout Head [NS 735 634], in the Touch Hills, it is less than 30 m thick, but farther west [NS 7233 9297 to 7240 9276] it is more than 50 m thick. In the Gargunnock Burn [NS 7061 9266 to 7064 9250] the member is about 45 m thick. The member is thickest, at more than 80 m, in the headwaters of the Easter Blackspout [NS 6912 9252 to 6911 9242].

Distribution and regional correlation
The member is restricted to the Fintry–Touch Block (Francis et al., 1970) and specifically to the western and northern parts of the Fintry Hills, and the northern parts of the Gargunnock and Touch hills. These rocks crop out from the crest of the crags at Double Craig [NS 6365 8701], westwards to Ballmenoch Burn [NS 6485 8692 to 6464 8752], and northwards to the prominent crags below Stronend [NS 6266 8950] which extend eastwards to the Spout of Ballochleam [NS 6526 8998] and on to the north-north-east, below Lees Hill [NS 6587 9106] and east-north-east to Standmilane Craig [NS 6704 9176] and Black Craig [NS 6841 9228]. From there, the outcrop continues to the east, passing through more crags and then to Baston Burn [NS 7437 9374].

Age
Mid Visean (Arundian to Asbian)

4.3.3.59 Stronend Volcaniclastic Member

Name
Previously known as the Stronend Interbasaltic Beds (see Francis et al., 1970).

Lithology
The Stronend Volcaniclastic Member consists predominantly of volcaniclastic sedimentary rocks and possible tuff, with weathered basalt lava (including bole). It weathers back to form a prominent shelf in the escarpment on the western side of the Fintry Hills.

Stratotype
The type area is in the western Fintry Hills, north-east of Glasgow [NS 6322 8808 to 6274 8953] (Francis et al.,

1970). A reference section is 0.5 km south of Stronend summit, western Fintry Hills [NS 6288 8885] (Francis et al., 1970). Here more than 1.5 m of bole lying near the base of the member is exposed.

Lower and upper boundaries
Weathered basalt (bole) at the base of the member is conformable or disconformable on plagioclase-microphyric basalt lava of the Spout of Ballochleam Lava Member within which the Stronend Volcaniclastic Member is interdigitated.

Volcaniclastic rocks of the Stronend Volcaniclastic Member are overlain by plagioclase-microphyric basalt lava of the Spout of Ballochleam Lava Member, within which the Stronend Volcaniclastic Member is interdigitated.

Thickness
Uncertain. Francis et al. (1970) stated that the member seems to be relatively thin and local. At Stronend summit [NS 6288 8885] more than 1.5 m of bole is exposed, lying near the base of the member. In a tributary of Cammal Burn [NS 6399 8764] more than 2.7 m of bole crops out, probably at the top of the member.

Distribution and regional correlation
The member is restricted to the Fintry–Touch Block (Francis et al., 1970) and specifically to the western Fintry Hills, north-east of Glasgow. These rocks crop out out in a restricted area from the western side of Stronend [NS 6274 8953] to the south-south-east, to north of Double Craig [NS 6322 8808].

Age
Mid Visean (Arundian to Asbian).

4.3.3.60 Lees Hill Lava Member

Name
Previously named the Lees Hill Group (Francis et al., 1970).

Lithology
The Lees Hill Lava Member consists predominantly of trachybasalt but also includes a plagioclase-macrophyric basalt lava ('Markle' type), and the rocks generally form the crest of the escarpment at the top of the cliffs formed by the Spout of Ballochleam Lava Member. The trachybasalt is typically fine grained, massive, locally 'slaggy' and highly vesicular, and with local platy jointing. A single trachybasalt lava is present in the east [NS 7184 9247], which occurs as an intercalation within the macroporphyritic basalt lavas of the Gargunnock Hills Lava Member, near to its base. In the Gargunnock Burn [NS 7065 9249 to 7059 9222] two trachybasalt lavas are present, separated by a plagioclase-macrophyric basalt lava that is absent farther west, where the member consists entirely of trachybasalt lavas.

Stratotype
The type area is in the northern Gargunnock Hills and northern Touch Hills, north-east of Glasgow [NS 6616 8971 to 7184 9247] (Francis et al., 1970). A reference section is Gargunnock Burn, central northern Gargunnock Hills [NS 7065 9249 to 7059 9222] (Francis et al., 1970). Here the entire thickness (about 40 m) of the member exists and is largely exposed, though parts, including the top 1.5 m and basal 0.6 m, are obscured.

Lower and upper boundaries
The basal trachybasalt of the member lies possibly disconformably on plagioclase-microphyric basalt ('Jedburgh' type) of the Spout of Ballochleam Lava Member. In the east of its outcrop, the member is represented by a single trachybasalt lava that overlies, apparently conformably or disconformably, a plagioclase-macrophyric basalt ('Markle' type) of the Gargunnock Hills Lava Member.

The Lees Hill Lava Member is overlain, apparently conformably or disconformably, by the Gargunnock Hills Lava Member, and in the east of its outcrop, the Lees Hill Lava Member is represented by a single trachybasalt lava, which is intercalated with lavas of the Gargunnock Hills Lava Member. The lithological change is to plagioclase-macrophyric basalt lava ('Markle' type).

Thickness
Between 0 and about 40 m

Distribution and regional correlation
The member is restricted to the northern part of the Fintry–Touch Block (Francis et al., 1970) and specifically to the northern Gargunnock Hills and northern Touch Hills, north-east of Glasgow. These rocks generally form the crest of the escarpment at the top of the cliffs formed by the Spout of Ballochleam Lava Member and crop out northwards from Gourlay's Burn [NS 6628 8974 to 6625 9003] to Lees Hill [NS 660 910], east-north-east to Standmilane Craig [NS 6722 9180] and Black Craig [NS 6829 9219], and then eastwards through crags to the east of Gargunnock Burn [NS 7195 9244].

Age
Mid Visean (Arundian to Asbian).

4.3.3.61 Shelloch Burn Lava Member

Name
Previously named the Shelloch Burn Group (Francis et al., 1970).

Lithology
The Shelloch Burn Lava Member consists of a varied assemblage of lavas including: trachybasalt that is variably massive to locally platy-jointed, slaggy and vesicular; basaltic-trachyandesite (mugearite); plagioclase-microphyric basalt ('Jedburgh' type); plagioclase-macrophyric basalt ('Markle' type); and transitional plagioclase-microphyric to plagioclase-macrophyric basalts. The member is best developed in the northern Fintry Hills and its upper part is well exposed in Shelloch Burn [NS 6509 8913 to 6523 8924] where the sequence comprises a basaltic-trachyandesite, a plagioclase-macrophyric basalt that is deeply weathered to a dull red bole basalt, and a basaltic-trachyandesite (mugearite) that is deeply weathered to a dull red bole. The lower part of the member is best exposed in Boquhan Burn [NS 6468 8967 to 6490 8963] where the sequence comprises a trachybasalt lava, which is deeply weathered to a dull red bole and a basaltic-trachandesite (mugearite). West of the Balmenoch Fault (Francis et al., 1970) the member forms the highest part of the Fintry Hills but is not well exposed. However, a good section through all but the highest lavas in the member is seen in the highest of the crags that form the western edge of the Fintry Hills [NS 6281 8910 to 6304 8870] where the sequence comprises a trachybasalt, two transitional plagioclase-macrophyric to plagioclase-microphyric basalts, another trachybasalt, two basaltic-trachyandesites (mugearites) and a further trachybasalt.

Stratotype
The type area is in the Fintry Hills, north-east of Glasgow [NS 6361 8794 to 6489 8991] (Francis et al., 1970). A

reference section is in crags forming the western edge of the Fintry Hills [NS 6281 8910 to 6304 8870] that shows all but the highest lavas in a section 60 m thick (Francis et al., 1970). The member is well exposed in Shelloch Burn [NS 6509 8913 to 6523 8924] where a section 21 m thick includes the top of the member. The lower part of the member, including its base, is best exposed in Boquhan Burn [NS 6468 8967 to 6490 8963]. Here the section is 18 m thick (Francis et al., 1970).

Lower and upper boundaries
The basal trachybasalt lava of the member is conformable or disconformable on the underlying plagioclase-microphyric basalts of the Spout of Ballochleam Lava Member.

The member is overlain unconformably by the Fintry Hills Lava Member. The lithological change is from basaltic-trachyandesite (mugearite) or trachybasalt to plagioclase-microphyric basalt.

Thickness
Between 40 and 61m

Distribution and regional correlation
The member is restricted to the Fintry–Touch Block (Francis et al., 1970), specifically to the Fintry Hills, north-east of Glasgow. These rocks crop out from around Stronend [NS 6290 8946] in the north-west of the Fintry Hills towards the east, in the Boquhan Burn and its headwaters [NS 6388 8988 to 6490 8965] and the Shalloch Burn [NS 6513 8920 to 6541 8939], and south-east to the Balmenoch Burn [NS 6465 8771 to 6464 8753] and beyond, although the limits of the member to the south-east are uncertain.

Age
Mid Visean (Arundian to Asbian)

4.3.3.62 FINTRY HILLS LAVA MEMBER

Name
Previously named the Fintry Hills Group (see Francis et al., 1970).

Lithology
The Fintry Hills Lava Member consists predominantly of plagioclase-macrophyric basalt lavas ('Markle' type) with a fairly high proportion of microporphyritic basalts and rare basaltic-trachyandesite (mugearite). Tuff occurs locally at [NS 6409 8794].

Stratotype
The type area is in the highest parts of the Fintry Hills, north-east of Glasgow [NS 6369 8867 to 6321 8911] (Francis et al., 1970).

Lower and upper boundaries
The basal basalt of the member lies apparently conformably or disconformably on trachybasalt of the Shelloch Burn Lava Member. The upper boundary is eroded but not exposed.

Thickness
More than 122 m. The top of the member is eroded.

Distribution and regional correlation
The member is restricted to the Fintry–Touch Block (Francis et al., 1970) and specifically to the Fintry Hills, north-east of Glasgow. These rocks crop out across the hilltops of the central part of the Fintry Hills [NS 6369 8867 to 6321 8911].

Age
Mid Visean (Arundian to Asbian)

4.3.3.63 CRINGATE VOLCANICLASTIC MEMBER

Name
Previously named the Cringate Interbasaltic Beds (Francis et al., 1970).

Lithology
The Cringate Volcaniclastic Member consists of variably stratified volcaniclastic sedimentary rocks and/or tuffs. An exposure in the north-east bank of the Endrick Water at [NS 6800 8750] shows poorly stratified dull red tuff or volcaniclastic sedimentary rock with persistent beds of red mudstone, interspersed with lenticular masses, up to 1.5 m thick, of unsorted lava fragments set in a matrix of greenish clay. The fragments include decomposed basalt up to 20 cm across, commonly rounded but with irregular margins that seem to interlock. Some are scoriaceous with small irregular amygdales filled with chlorite or carbonate minerals. The matrix includes carbonate minerals but also contains some grains of quartz and feldspar.

Stratotype
The type section is in the Endrick Water, between the Fintry Hills and the south-western Gargunnock Hills, north-east of Glasgow [NS 678 879 to 682 873] (Francis et al., 1970). A reference section is in a left-bank tributary of the Endrick Water near Cringate [NS 683 874 to 6858 8756].

Lower and upper boundaries
In the Endrick Water at [NS 6807 8742], the Cringate Volcaniclastic Member overlies highly decomposed microporphyritic basalt, thought to be roughly equivalent to middle parts of the Spout of Ballochleam Lava Member (Francis et al., 1970). In a left-bank tributary of the Endrick Water at [NS 6858 8756], about 40 m of tuff or volcaniclastic sedimentary rock is overlain by 6m of microporphyritic basalt that forms a waterfall (Francis et al., 1970). The basalt is probably one of the highest lavas of the Spout of Ballochleam Lava Member.

Thickness
At least 45 m

Distribution and regional correlation
The member is restricted to the Fintry-Touch Block (Francis et al., 1970) and specifically to the valley of the Endrick Water around Cringate [NS 685 873], between the Fintry Hills and the south-western Gargunnock Hills, north-east of Glasgow.

Age
Mid Visean (Arundian to Asbian)

4.3.3.64 GARGUNNOCK HILLS LAVA MEMBER

Name
Previously named the Gargunnock Hills Group (Francis et al., 1970).

Lithology
The Gargunnock Hills Lava Member consists predominantly of plagioclase-macrophyric basalt ('Markle' type) and composite lavas, with subordinate plagioclase-microphyric basalt ('Jedburgh' type) and rare basaltic-trachyandesite (mugearite) lavas. The topmost part of the member is well exposed in the gorge of the Touch Burn, downstream from the waterfall of Gilmour's Linn [NS 7395 9252] where

there are three massive to variably 'slaggy', plagioclase-macrophyric basalt lavas, with weathered tops (dark red boles with nodules of decomposed, 'slaggy' basalt). The remainder of the member is reasonably well exposed on the northern and eastern slopes of Scout Head [NS 7354 9337 to 7350 9313] where plagioclase-microphyric basalt lava flows (several of which are transitional to plagioclase-macrophyric basalt), and plagioclase-macrophyric basalt basalt lava flows are present.

Stratotype

The type area is in the Gargunnock and Touch hills, and the northern Kilsyth Hills, north-east of Glasgow [NS 6970 8456 to 7515 9360] (Francis et al., 1970). Partial type sections occur in the Touch Burn [NS 7395 9252] and on the northern and eastern slopes of Scout Head, northern Touch Hills, north-east of Glasgow [NS 7354 9337 to 7386 9301] (Francis et al., 1970). It is 75 m thick in all but the topmost flows of the member.

Lower and upper boundaries

In the northern Gargunnock Hills, the basal plagioclase-macrophyric basalt flow of the member lies, apparently disconformably, on trachybasalts of the Lees Hill Lava Member. In the northern Touch Hills, the Gargunnock Hills Lava Member interdigitates with the Lees Hill Lava Member and lies, probably disconformably, on microporphyritic basalts ('Jedburgh' type) of the Spout of Ballochleam Lava Member. In the eastern part of the Kilsyth Hills, Campsie Block, the Gargunnock Hills Lava Member overlies the Langhill Lava Member, but the nature of the contact is unknown. In the north-eastern Kilsyth Hills the member overlies, probably unconformably, the Campsie Lava Member.

In the Gargunnock Hills and north-western Touch Hills, the member occupies the highest ground and its top is eroded. However, in the north-eastern and eastern Touch Hills, the member is overlain by the Black Mount Lava Member. The change in lithology is from plagioclase-macrophyric basalt to plagioclase-microphyric basalts and subordinate basaltic trachyandesite (mugearite).

Thickness

From 91 m in the east, to more than 150 m in the west, where the top of the member is eroded.

Distribution and regional correlation

The member is restricted to the Fintry–Touch Block (Francis et al., 1970) and the north-eastern part of the Campsie Block (Forsyth et al., 1996) and specifically to the north-eastern Kilsyth Hills, and the Gargunnock and Touch hills, north-east of Glasgow. These rocks crop out in the north-eastern Kilsyth Hills on the upper parts of Cairnoch Hill [NS 697 857], Craigannet Hill [NS 712 848] and Dundaff Hill [NS 735 844] and over much of the area to the north of Shielwalls Fault (Craig, 1980), including Craigengelt Hill [NS 7240 6852], Earl's Hill [NS 7175 8842] and Cringate Law [NS 6834 8830], and the area to the north, south and west of Loch Coulter [NS 764 860]. The rocks also crop out extensively across the upper parts of the Gargunnock Hills, from Burnfoot [NS 675 883] in the south-east, north-north-east to Carleatheran [NS 6877 9186] and east, across the Touch Hills to Craigniven [NS 7515 9360].

Age

Mid Visean (Arundian to Asbian).

4.3.3.65 BLACK MOUNT LAVA MEMBER

Name

Previously named the Black Mount Group (see Francis et al., 1970).

Lithology

The Black Mount Lava Member consists predominantly of plagioclase-microphyric basalt lavas ('Jedburgh' type) with subordinate basaltic-trachyandesite (mugearite) lavas. The microporphyritic basalt lavas are variably albitised, slaggy, vesicular, and platy-jointed and are locally transitional to a partly plagioclase-macrophyric lithology.

Stratotype

The type area is in the eastern Touch Hills, north-east of Glasgow [NS 7391 9175 to 7600 9327] (Francis et al., 1970). The member is best exposed in the steep cliff that fringes the northern edge of Black Mount [NS 7436 9226] and forms the south side of the Touch Burn gorge [NS 7438 9244] where, in a reference section, it includes at least three microporphyritic basalt flows and a very fine-grained, platy-jointed, slaggy, basaltic-trachyandesite (mugearite). The section is 27 m thick and includes the base of the member (Francis et al., 1970).

Lower and upper boundaries

The basal plagioclase-microphyric basalt of the Black Mount Lava Member is apparently conformable or disconformable on plagioclase-macrophyric basalt lava of the Gargunnock Hills Lava Member.

The Black Mount Lava Member is overlain by plagioclase-macrophyric basalt lava ('Markle' type) of the Touch House Lava Member. The lithological transition is from plagioclase-microphyric basalt to plagioclase-macrophyric basalt.

Thickness

More than 24 m

Distribution and regional correlation

The member is restricted to the north-eastern part of the Fintry–Touch Block (Francis et al., 1970) and specifically to the eastern Touch Hills, north-east of Glasgow. These rocks crop out from the west side of Black Mount [NS 7391 9175] to near Seton in the north-east [NS 7600 9327] and Garter Wood in the east [NS 7652 9189].

Age

Mid Visean (Arundian to Asbian).

4.3.3.66 TOUCH HOUSE LAVA MEMBER

Name

Previously named the Touch House Group (see Francis et al., 1970).

Lithology

The Touch House Lava Member consists only of plagioclase-macrophyric basalt or trachybasalt lavas (basalt to hawaiite of 'Markle' type) and only the lowest part of the member is well exposed, near the edge of the low-lying fertile land between Touch Home Farm [NS 7518 9331] and Touch House [NS 7535 9276].

Stratotype

The type area is in the eastern Touch Hills, north-east of Glasgow [NS 7520 9277 to 7524 9340] (Francis et al., 1970). A reference section in the lowest part of the member is provided by exposures between Touch Saw Mill and Touch House, eastern Touch Hills, north-east of Glasgow [NS 7518 9331 to 7535 9276].

Lower and upper boundaries

The basal plagioclase-macrophyric basalt lava of the member is apparently conformable, or disconformable, on the underlying plagioclase-microphyric basalt of the Black Mount Lava Member. The top of the member is not exposed.

Thickness
Uncertain. The thickness of the member is difficult to estimate because of drift cover, and the lack of knowledge about its upper part (Francis et al., 1970).

Distribution and regional correlation
The member is restricted to the north-eastern part of the Fintry–Touch Block (Francis et al., 1970) and specifically to a small area in the eastern Touch Hills, north-east of Glasgow. These rocks crop out in an outlier that extends northward from Touch House [NS 7535 9276] to near Touch Home Farm [NS 7524 9340] and westwards to north of Mill Linn [NS 9495 9302].

Age
Mid Visean (Arundian to Asbian)

AYR

4.3.3.67 GREENAN CASTLE PYROCLASTIC MEMBER (GCP)

Name
The Greenan Castle Pyroclastic Member was previously known as 'bedded agglomerate of Greenan Castle' by Eyles et al. (1949), and Greenan Castle Ash by Whyte (1964). The present member was defined by Williamson and Monaghan in Stephenson et al. (2002). See also Sowerbutts (1999); Whyte (1992).

Lithology
The member comprises bedded volcaniclastic coarse sandstone, with subsidiary lithic lapilli-tuffs and tuffs.

Stratotype
The type section is on the shore and in the cliff at Greenan Castle, south of Ayr [NS 2311 6195 to 2313 6195], where the full thickness of the member is seen (see Eyles et al., 1949; Whyte, 1964; 1992).

Lower and upper boundaries
Where seen on the shore at Greenan Castle the lower boundary is possibly disconformable on sandstones, mudstones and 'cementstones' of the underlying Ballagan Formation (Inverclyde Group).

The upper boundary at the same locality is seen to pass upwards unconformably into mudstones and sandstones of the Lawmuir Formation.

Thickness
Some 23 m at Greenan Castle in the Ayr district, dying out laterally.

Distribution and regional correlation
A local unit on the shore and around Greenan Castle south of Ayr, which dies out about 1 km inland. It has been correlated on lithological grounds with the nearby Heads of Ayr Vent.

Age
Chadian to Asbian

4.3.4 Kirkwood Formation (KRW)

Name
Taken from Kirkwood Farm, Strathclyde Region. The name was introduced by Monro (1982).

Lithology
The Kirkwood Formation consists of tuffaceous mudstones and tuffs, locally intercalated with non-tuffaceous sedimentary rocks, with some marine horizons developed. The tuffaceous mudstones and tuffs vary in colour from dark reddish brown to greenish grey. Non-tuffaceous sedimentary rocks, sandstones, siltstones and limestones, generally grey in colour, also occur within a restricted area intercalated with volcaniclastic rocks.

Genetic interpretation
The strata were largely formed by the reworking of materials derived from the underlying volcanic rocks but some primary ash-fall tuffs may be present. The formation shows extensive lateritisation, the product of a period of intense subaerial tropical weathering. There are some marine incursions.

Stratotype
The type section of the Kirkwood Formation occurs between 38.9 and 75.45 m depth in the Kirkwood Borehole (BGS Registration Number NS34NE/11) [NS 3885 4716], near Kilmarnock (Monro, 1999). This is the complete thickness of the formation at this locality.

Lower and upper boundaries
The base of the formation is taken at the lithological change from the underlying lavas of the Clyde Plateau Volcanic Formation into volcaniclastic sedimentary rocks (Figure 6, Column 4A).

The top is generally taken at the base of the overlying mudstones, siltstones and sandstones of the Lawmuir Formation or the cyclical limestones and clastic lithologies of the Lower Limestone Formation (Clackmannan Group). This boundary is commonly irregular and transitional with an interdigitation of lithologies.

Thickness
The Kirkwood Formation varies in thickness, from about 6 to more than 41 m (Monro, 1999, fig. 9) with thinning generally taking place towards the areas where the Clyde Plateau Volcanic Formation is thick. In the Irvine district, Monro (1999, p. 35, fig. 11) recorded a thickness of 41.39 m encountered in the Coalhill No. 2 Borehole (BGS Registration Number NS24NW/20) [NS 2432 4653] (a minimum thickness since the borehole did not reach the Clyde Plateau Volcanic Formation), and referred to localised thinning in boreholes close to the Dusk Water Fault. In the Kilmarnock district MacPherson et al. (2000, p. 9) stated that the thickness of the formation averages around 15 m. BGS (1996) gave a generalised thickness of 18.75 m for the formation in the main coalfield area at Machrihanish.

Distribution and regional correlation
Western Midland Valley and Machrihanish

Age
Visean (Asbian to early Brigantian) (Monro, 1999; Browne et al., 1999)

4.3.5 Lawmuir Formation (LWM)

Name
Taken from Lawmuir, Strathclyde Region. The name was introduced by Paterson and Hall (1986).

Lithology
The Lawmuir Formation consists of a sequence of mudstones, siltstones and sandstones with seatrocks, coals

and limestones. To the north of Glasgow around Milngavie, the lower part is dominated by fluvial sandstones with a local development of quartz conglomerate. In the south of Glasgow around Paisley, fluvial sandstones are interbedded with thick, poorly bedded siltstones and mudstones with a few thin coals. In one small area these coals coalesce to form a single seam 20 m thick. The upper part of the formation is partly arranged in cyclothems, with several marine incursions represented by marine limestones over a large area. A non-marine limestone (the Baldernock Limestone) also occurs near the top of the sequence.

Genetic interpretation
Fluvial lower part becoming partly cyclothemic upwards with several marine incursions.

Stratotype
The type section of the Lawmuir Formation (complete thickness) is between 11.75 and 266.2 m depth in the Lawmuir Borehole (BGS Registration Number NS57SW/162) [NS 5183 7310] west of Bearsden near Glasgow.

Lower and upper boundaries
The base of the formation is taken at the lithological change from the underlying volcaniclastic strata of the Kirkwood Formation into clastic sedimentary rocks. The boundary is commonly transitional, with interdigitation between sedimentary and volcaniclastic rocks. It can also rest directly on the lavas of the Clyde Plateau Volcanic Formation in the west of the Midland Valley of Scotland (see Paterson and Hall, 1986) (Figure 6, Columns 1, 4A) and on the apparently conformable but probably erosive surface of the characteristic mudstone, siltstone and ferroan dolostone lithologies of the Ballagan Formation (Inverclyde Group) in Ayrshire (see Monro, 1999, p. 39).

The top of the Lawmuir Formation is drawn at the base of the Hurlet Limestone of the Lower Limestone Formation (Clackmannan Group).

Thickness
The maximum thickness of the formation is about 300 m in the Glasgow area. BGS (1987a) gave a generalised thickness of 185 m for the formation on the Isle of Arran.

Distribution and regional correlation
Western Midland Valley and the Isle of Arran. The precise relationship between the Lawmuir Formation and the Pathhead Formation in Fife is not known because of a major geographical gap in information between the two areas. It is possible that the marine bands in the upper part of the Lawmuir Formation are equivalent to all the marine bands in the Pathhead Formation, in which case the nonmarine lower part of the Lawmuir Formation would be equivalent to the Sandy Craig Formation in Fife.

Age
Visean (Monro, 1999; Browne, 1999).

Formal subdivisions
See also Appendix 1. Members of the Lawmuir Formation in ascending stratigraphical order include:

4.3.5.1 Douglas Muir Quartz-Conglomerate Member (DMQ)

Name
From Douglas Muir, Strathclyde. See Paterson and Hall (1986); Hall et al. (1998).

Lithology
The Douglas Muir Quartz-Conglomerate Member consists mainly of hard, white conglomerates with subordinate pebbly sandstones and a few lenses of purplish grey mudstone up to 30 cm thick. Trough cross-bedding is common in sets from 0.2–1.0 m thick. Many of the units are upward-fining in grain size. The clasts and pebbles are almost exclusively of vein quartz and well rounded, averaging 2 cm, but up to 10 cm in diameter, with some blocks of sandstone up to 15 cm across also present.

Genetic interpretation
Palaeocurrent directions indicate transport of the original sediment towards the south-south-west.

Stratotype
The type section is at the Douglas Muir Quarry in the type area at Douglas Muir [NS 525 746], near Milngavie, Strathclyde where 20 m, being part of the member, are exposed.

Lower and upper boundaries
The base of the member is drawn at the base of the conglomerate of the Douglas Muir Quartz-Conglomerate where it rests apparently unconformably on volcaniclastic sediments of the Kirkwood Formation (Figure 6, Column 4A), as seen at a natural exposure at [NS 5307 7752].

The top of the member is transitional by upward passage by interbedding from conglomerate of the Douglas Muir Quartz-Conglomerate Member to white and pale grey sandstone of the Craigmaddie Muir Sandstone Member, as seen at a natural exposure at [NS 5730 7774].

Thickness
Incomplete thickness of 20 m at the type locality at Douglas Muir Quarry and up to 70 m maximum elsewhere.

Distribution and regional correlation
Strathclyde. North of the River Clyde and eastwards from the the type area at Douglas Muir [NS 525 746] to the site of the Strathblane–Balmore Tunnel No. 8 Borehole (BGS Registration Number NS57NE/28) [NS 5712 7731], but not in the adjacent parts of 1:50 000 scale Geological Sheet 31W (Airdrie).

Age
Late Visean (Asbian?)

4.3.5.2 Craigmaddie Muir Sandstone Member (CRMS)

Name
The member was previously named the Craigmaddie Sandstone Formation by Tait (1973), and the Craigmaddie Sandstones (of the Upper Sedimentary Group, Calciferous Sandstone Series) by Clough et al. (1925).

Lithology
Sandstone, white, cross bedded, with pebbly ‘bands’ (beds) in places. Locally, interbedded with mudstone and rare intercalations of volcanic detritus. Strata within the member were described by Tait (1973) as fine-grained, buff-weathering quartz arenite with conglomerate lenses that consist mainly of mudstone intraclasts.

Genetic interpretation
Tait (1973) interpreted the sandstone member as the deposits of a meandering river system.

Stratotype
Partial type sections were described by Hall et al. (1998), who referred to the prominent outcrops of bedrock on Craigmaddie Muir exposing strata from the base and the middle parts of the member [NS 580 766 to 588 764]. The type section of the upper part of the member (about 68 m thick), to its upper boundary placed at the base of the Balmore Marine Band, is recorded from exposures in the subsurface beneath Craigmaddie Muir in the Strathblane–Balmore tunnel (BGS Registration Number NS57NE/30) [NS 5895 7521].

Lower and upper boundaries
The lower boundary of the Craigmaddie Muir Sandstone Member is mapped on Craigmaddie Muir [NS 5820 7652] and Muirhouse Muir [NS 5723 7785] and placed where sandstones without interbeds of conglomerate are observed at outcrop (BGS, 1987b; see also BGS, 1987c). The underlying Douglas Muir Quartz-Conglomerate Member is typically conglomerate with sandstone interbeds and, toward the top of the member, sandstone with pebbles or conglomerate beds (Figure 6, Column 4A). The lower boundary of the Craigmaddie Muir Sandstone Member had previously been mapped slightly lower in the sequence by Tait (1973) who noted it to be gradational containing 'lenses of conglomerate of similar composition' to the underlying Douglas Muir Quartz-Conglomerate Member near the base.

The upper boundary of the Craigmaddie Muir Sandstone is placed at the base of the Balmore Marine Band (Hall et al., 1998, fig. 9). This is at a higher position than that of Clough et al. (1925, fig. 2) who placed it at the top of the main sequence of sandstones about 45 m below the Craigenglen Beds, but at a lower position than Tait (1973) who placed the boundary beneath the Balgrochan Beds. Tait's (1973) informal division 'lower Craigmaddie Muir Sandstone Member' equates with the Craigmaddie Muir Sandstone Member as presented here.

Thickness
Between 170 and 180 m

Distribution and regional correlation
The member is confined to the fault-bounded block south of the Craigend and Campsie faults and north of the Bankend and Glorat faults, extending from Muirhouse Muir [NS 576 777] eastwards to Craigmaddie Muir [NS 590 765], Craigend Muir [NS 585 776], and the vicinity of Lennoxtown [NS 626 780], north-east of Milngavie, Strathclyde.

Age and biostratigraphical characterisation
Visean (?Asbian–Brigantian). The Balmore Marine Band immediately above the Cragmaddie Muir Sandstone Member has a relatively sparse fauna including brachiopods. Correlatives of this bed contain the bivalve *Posidonia becheri*, which is thought to be of P_{1b} or P_{1c} age (Hall et al., 1998).

FIFE (Figure 6, Column 4C)

4.3.6 Fife Ness Formation (FNB)

Name
From Fife Ness, east Fife. The unit was originally described by Forsyth and Chisholm (1977) and first given formation status by Browne (1986).

Lithology
The Fife Ness Formation consists dominantly of off-white and reddish brown or purplish grey sandstone arranged in upward-fining cycles. Argillaceous beds are commonly poorly bedded and seatearths are present, but there are no coal seams. Bedded dolostone is rare and the associated nonmarine faunas comprise ostracods, spirorbids and algal nodules. Marine strata are absent.

Genetic interpretation
The formation is essentially fluvial and lacustrine in origin.

Stratotype
The type sections are those on the Fife coast at Fluke Dub [NO 6228 1061 to 6205 1071] and at Fife Ness [NO 6328 1014 to 636 054]. The Fluke Dub section includes some 60–90 m of alternating sandstone and grey mudstone with a few thin beds of bedded carbonate (one containing ostracods) from the base of the formation to the Wormistone Fault. The Fife Ness section (which does not appear to overlap with that at Fluke Dub) runs from the eastern margin [NO 6328 1014] of a cryptovolcanic disturbance near Constantine's Cave, round Fife Ness to the Dane's Dike Fault. It includes about 180 m of mainly thick white sandstones with grey and red mudstones and some siltstones. Four beds of dolomite occur with faunas of *Spirorbis* sp., ostracods and fish remains. Algal material is present in one bed at [NO 6358 1015] (Forsyth and Chisholm, 1977).

Lower and upper boundaries
In east Fife, the conformable base of the Fife Ness Formation lies in a lithological transition and is taken above the highest bed of carbonate conglomerate in the Clyde Sandstone Formation of the Fluke Dub section. The top is faulted against the Anstruther Formation in the Fife Ness type section (see Browne et al., 1999, fig. 2.19).

Thickness
The maximum thickness of the formation exceeds 230 m in east Fife (Forsyth and Chisholm, 1977, table 1).

Distribution and regional correlation
Fife

Age
Early Visean

4.3.7 Anstruther Formation (ARBS)

Name
From Anstruther, east Fife. The unit was originally described by Forsyth and Chisholm (1977) and first given formation status by Browne (1986).

Lithology
The Anstruther Formation consists dominantly of mudstone, siltstone and sandstone in thin upward-coarsening cycles. Nonmarine limestone and dolostone are also developed, usually as thin beds, some of which contain oncolites and stromatolites. Minor components include marine mudstone and siltstone and a few algal-rich oil-shale beds. Sandstone, generally off-white and fine- to medium-grained, is subordinate to the argillaceous rocks, but thick, upward-fining, multistorey sandstones are locally developed. Thin beds of coal and ironstone are present. The formation is distinguished from the Fife Ness Formation, below, by the lower proportion of sandstone in it, and from the overlying Pittenweem Formation by the relative paucity of its marine faunas. Locally, basalt lavas and lapilli-tuff of the Charles Hill Volcanic Member are present at the base of the formation.

Genetic interpretation
The pattern of sedimentation is of upward-coarsening lake-delta cycles, with thinner upward-fining fluvial units erosively capping them, and minor marine incursions.

Stratotype
Partial type sections in the Anstruther Formation occur on the Fife coast at Anstruther Wester [NO 5670 0310 to 5635 0300], at Billow Ness [NO 5590 0269] and at Cuniger Rock [NO 5598 0265 to 5566 0271]. A representative section was cored in the Anstruther Borehole (BGS Registration Number NO50SE/5) [NO 5653 0350].

Lower and upper boundaries
The base of the formation is not known at outcrop in east Fife but would be taken at the lithological change from sandstone-dominated sequences of the underlying Fife Ness Formation into mudstone-rich cyclical deposits. The top is drawn at the base of the Cuniger Rock Marine Band at the base of the Pittenweem Formation (see Browne et al., 1999, fig. 2.19).

Thickness
The maximum thickness of the formation exceeds 810 m (Forsyth and Chisholm, 1977, table 1).

Distribution and regional correlation
Fife

Age and biostratigraphical characterisation
Visean. The marine faunas are usually restricted. The abundant but restricted nonmarine faunas are dominated by *Naiadites obesus*, with *Paracarbonicola* in the lower part of the formation.

Formal subdivisions
See also Appendix 1. Member of the Anstruther Formation:

4.3.7.1 CHARLES HILL VOLCANIC MEMBER (CHVO)

Name
From Charles Hill, Fife. Previously known as the Charles Hill Volcanic Beds. See Browne et al. (1987); Browne et al. (1999).

Lithology
The Charles Hill Volcanic Member consists of pale greenish grey to grey, amygdaloidal, earthy, weathered to hard olivine-microphyric basalt ('Dalmeny' type) lavas and beds of grey and pink ash-fall and/or waterlain lapilli-tuff. Beds of limestone and mudstone are known very locally (as on the island of Meadulse).

Stratotype
The type area is on Charles Hill at Barnhill Bay [NT 1860 8380 to 1850 8365] near Aberdour in Fife where more than 30 m of beds of lava and volcaniclastic rocks are seen (see Browne et al., 1987, fig. 15; Browne et al., 1999, fig. 2:18). Reference sections are also seen in the Firth of Forth on the islands of Craigdimas [NT 1920 8400], Meadulse [NT 1895 8305], Car Craig [NT 1985 8305] and on the western shore and in skerries off Inchcolm [NT 185 824].

Lower and upper boundaries
The lower boundary is defined at the base of the lowest lava or bed of volcaniclastic rock resting on noncyclic fluvial and lacustrine sedimentary rocks of the underlying Fife Ness Formation that consists of sandstones and mudstones with beds of carbonate rock (limestone and dolostone) (Figure 6, Column 4C). This contact is nowhere seen and therefore may be transitional, sharp or unconformable.

The top of the member is defined by the highest tuff bed that is overlain by the noncyclic sedimentary rocks of the overlying Anstruther Formation consisting of dark grey to black lacustrine mudstones with thin beds of argillaceous ostracod-bearing limestone and dolostone and pale grey sandstone.

Thickness
Tens of metres but very uncertain. Assessed as more than 30 m thick at Charles Hill.

Distribution and regional correlation
Known at Aberdour on the Fife coast, and on various islands in the Firth of Forth. Volcanic rocks, now no longer exposed at Silverknowes [NT 205 776] on the shore at Granton–Cramond, Edinburgh have also been assigned to the Charles Hill Volcanic Member, here interbedded with the Gullane Formation. This outcrop of basaltic lavas and tuffs, once quarried on the coastline, extends the supposed occurrence of the member across the Inchkeith Fault and intercalating it with the 'Abbeyhill Shales Beds' (Gullane Formation).

Age
Asbian.

4.3.8 Pittenweem Formation (PMB)

Name
From Pittenweem, east Fife. The unit was originally described by Forsyth and Chisholm (1977) and given formation status by Browne (1986).

Lithology
The Pittenweem Formation consists dominantly of mudstone and siltstone. Beds of nonmarine limestone and dolostone are less common than in the Anstruther Formation. Marine mudstone (including 'marine bands'), siltstone and limestone occur as minor, but important, components. A few algal-rich oil-shale beds are also present. Generally fine- to medium-grained sandstone is subordinate to the argillaceous rocks, but locally thick, upward-fining, multistorey sandstones occur as well as thin beds of coal and ironstone. The formation is distinguished from those adjacent to it by the comparative diversity of the marine faunas, which probably all belong to the Macgregor Marine Bands (see Browne et al. 1999, p.10, table 3).

Genetic interpretation
The pattern of sedimentation is of upward-coarsening deltaic cycles, with thinner upward-fining fluvial units erosively capping them, and minor marine incursions.

Stratotype
Type sections in the Pittenweem Formation occur on the shore near Pittenweem at Cuniger Rock (basal contact) [NO 5566 0271 to 5510 0249] and from 700 m (top contact) to 830 m depth in the Kilconquhar Bore No. 79/1 (BGS Registration Number NO40SE/26) [NO 4845 0305] near Elie. A good section of the full succession is also exposed on the shore at St Andrews [NO 506 173 to 513 169].

Lower and upper boundaries
The conformable base of the Pittenweem Formation lies in a transitional sequence, and is drawn at the base of the

Cuniger Rock Marine Band above the mudstone, siltstone and sandstone of the Anstruther Formation (Figure 6, Column 4C).

The top of the formation is at the top of the St Andrews Castle Marine Band (SCMB), which is overlain by mudstone and siltstone of the Sandy Craig Formation.

Thickness
The maximum thickness of the formation is now known to be more than 260 m in east Fife based on its development in the partial type sections (see above). Forsyth and Chisholm (1977, table 1) state that the formation is over 220 m thick.

Distribution and regional correlation
Fife

Age and biostratigraphical characterisation
Visean (Asbian). The marine faunas, which occur in thin 'marine bands', are usually diverse and sometimes abundant. The abundant but restricted nonmarine faunas are dominated by the bivalve *Naiadites obesus*.

4.3.9 Sandy Craig Formation (SCB)

Name
From Sandy Craig, east Fife. The unit was originally described by Forsyth and Chisholm (1977) and given formation status by Browne (1986).

Lithology
The Sandy Craig Formation is characterised by mudstone and siltstone with a minor percentage of algal rich oil shale. Thin beds of non-marine limestone and dolostone are also developed, some of which contain oncolites and stromatolites. The Burdiehouse Limestone of the Lothians is represented in central Fife by at least three beds of limestone (Geikie, 1900, p. 46). Multicoloured, mainly fine- to medium-grained sandstone is subordinate to the argillaceous rocks, but thick, upward-fining, multi-storey sandstones are locally developed. Greenish grey clayrock and calcareous mudstone occur, as do thin beds of coal and ironstone. Nodular beds of pedogenic limestone and dolomite ('cornstone') are also present. The formation is distinguished from its neighbours by the relative rarity of marine beds, and by the local presence of cornstones.

Genetic interpretation
The pattern of sedimentation within the formation is of upward-coarsening deltaic cycles, with thinner upward-fining fluvial units erosively capping them, and rare marine incursions.

Stratotype
Partial type sections in the Sandy Craig Formation occur at Pittenweem Harbour [NO 5518 0236 to 5452 0238], nearby at Sandy Craig [NO 5453 0215 to 5419 0226] and from 203 to 700 m depth in the Kilconquhar Bore 79/1 (BGS Registration Number NO40SE/26) [NO 4845 0305] near Elie.

Lower and upper boundaries
The conformable base of the Sandy Craig Formation lies in a transitional sequence and is taken at the top of the St Andrews Castle Marine Band (SCMB) above the mudstone and siltstone of the Pittenweem Formation (Figure 6, Column 4C).

The top of the formation is now drawn at the base of the West Braes Marine Band (WBMB) (Browne, 1986, fig. 2), marking the base of the Pathhead Formation.

Thickness
The maximum thickness of the formation as now defined is about 670 m in east Fife (Browne, 1986, fig. 2).

Distribution and regional correlation
Fife

Age and biostratigraphical characterisation
Visean (Asbian). Marine faunas are very rare, and are usually restricted, consisting in some cases only of the brachiopod *Lingula*. The bivalve *Curvirimula* dominates the abundant, but restricted, nonmarine faunas.

4.3.10 Pathhead Formation (PDB)

Name
From Pathhead, east Fife. The unit was originally described by Forsyth and Chisholm (1977) and given formation status by Browne (1986).

Lithology
The Pathhead Formation consists predominantly of mudstone and siltstone with beds of limestone and dolostone. Pale coloured, fine- to medium-grained sandstone is subordinate to the argillaceous rocks. Thin beds of coal and ironstone also occur.

Genetic interpretation
The overall pattern of sedimentation within the formation is of upward-coarsening deltaic cycles, with thinner upward-fining fluvial units erosively capping them, and relatively common marine incursions.

Stratotype
The type section is on the coast at Pathhead [NO 5419 0226 to 5381 0212] between St Monans and Pittenweem.

Lower and upper boundaries
The conformable base of the formation lies in a transitional sequence, the boundary being drawn at the base of the West Braes Marine Band (WBMB) above the Sandy Craig Formation (Figure 6, Column 4C), stratigraphically a little higher (Browne, 1986, fig. 2) than that originally described by Forsyth and Chisholm (1977).

The top of the formation is at the base of the Hurlet Limestone, present at the base of the Lower Limestone Formation (Clackmannan Group).

Thickness
The maximum thickness of the formation is about 220 m (Browne, 1986, fig. 2).

Distribution and regional correlation
Fife

Age and biostratigraphical characterisation
Visean (Brigantian). Marine bands are more common than in the underlying formations and their faunas are usually diverse and abundant. *Curvirimula* dominates the nonmarine faunas.

WEST LOTHIAN AND EDINBURGH (Figure 6, Column 4D):

4.3.11 Arthur's Seat Volcanic Formation (ASV)

Name
From Arthur's Seat, Edinburgh. The formation name was established by Chisholm et al. (1989).

Lithology
The Arthur's Seat Volcanic Formation consists of lavas, tuffs and volcaniclastic sedimentary rocks. The lavas are mildly alkaline and show a limited range of composition. The basic rocks are silica-undersaturated. They are macroporphyritic in the range olivine-pyroxene-phyric basalt and basanite–olivine-clinopyroxene-plagioclase-phyric basalt–plagioclase-phyric hawaiite–mugearite.

Genetic interpretation
The formation was produced by one short-lived episode of volcanic activity. The depositional environment was terrestrial, probably on a coastal plain.

Stratotype
The type area is in Holyrood Park, Edinburgh [NT 28 73], but the natural sections here are incomplete.

Lower and upper boundaries
The base of the formation, though nowhere exposed or seen in boreholes, is considered to occur at a lithological change from underlying clastic sedimentary rocks of the Ballagan Formation (Inverclyde Group) to lavas, tuffs or volcaniclastic sedimentary rocks of the Arthur's Seat Volcanic Formation.

The top of the formation, a presumed transition to the sedimentary lithologies of the Gullane Formation, is likewise concealed (Figure 6, Column 4D).

Thickness
The maximum thickness may be in excess of 300 m (Mitchell and Mykura, 1962, p. 43).

Distribution and regional correlation
Lothians. The main outcrop is in Holyrood Park, Edinburgh with a faulted block on Calton Hill. The Craiglockhart Hills in Edinburgh may be a faulted outlier of the same rocks. Volcanic rocks at Corston Hill, Torweaving Hill, Black Hill, Harperrig, Buteland Hill and Cock Burn may belong to the same eruptive episode. Other smaller separated outcrops are correlated with the Arthur's Seat Volcanic Formation (see Browne et al., 1999). A confidential borehole at D'Arcy in the Midlothian Coalfield may have proved an eastward extension of the formation, though this lithostratigraphical unit should now be referred to as the Garleton Hills Volcanic Formation (M A E Browne, verbal communication, 01 March 2007).

Age
Chadian to Arundian.

4.3.12 Gullane Formation (GUL)

Name
From Gullane, East Lothian. The formation name was established by Chisholm et al. (1989).

Lithology
The Gullane Formation consists of a cyclical sequence predominantly of pale, fine- to coarse-grained sandstone interbedded with grey mudstone and siltstone. Subordinate lithologies are coal, seatrock, ostracod-rich limestone/dolostone, sideritic ironstone and rarely, marine beds with restricted faunas.

Genetic interpretation
The depositional environment was predominantly fluvio-deltaic, into lakes that only occasionally became marine.

Stratotype
The type section is from 155.44 to 287.27 m depth in the Spilmersford Borehole (BGS Registration Number NT46NE/73) [NT 4570 6902]. The formation is also notably recorded from 47.93 to 197.94 m depth in the Birnieknowes Borehole (BGS Registration Number NT77SE/9) [NT 7580 7317] and on the coast at Cove (see Browne et al., 1999, fig. 2, col. 12) near Cockburnspath [NT 79 71] in the Oldhamstocks Basin (Lagios, 1983; Andrews and Nabi, 1994; see also Browne et al., 1999, p. 12).

Lower and upper boundaries
The base of the formation is taken at the top of the Garleton Hills or Arthur's Seat volcanic formations, where present (Figure 6, Columns 4D, E). Where volcanic rocks are absent, it is taken at the lowest coal, or carbonaceous, or rooty beds above strata consisting predominantly of white sandstone with pedogenic limestone of the Clyde Sandstone Formation (Inverclyde Group).

The top of the formation is drawn at the base of the Macgregor Marine Bands (Wilson, 1989), located at the base of the West Lothian Oil-Shale and Aberlady formations.

Thickness
The estimated maximum thickness of the formation is about 560 m in West Lothian (see Browne et al. 1999, fig. 2, col. 8; Mitchell and Mykura, 1962, fig. 9).

Distribution and regional correlation
Lothians.

Age and biostratigraphical characterisation
Visean, mainly TC Miospore Zone of Neves et al. (1973; see also Chisholm et al., 1989; Chisholm and Brand, 1994).

4.3.13 West Lothian Oil-Shale Formation (WLO)

Name
The formation name was established by Chisholm et al. (1989).

Lithology
The West Lothian Oil-Shale Formation is characterised by seams of oil shale in a cyclical sequence predominantly of pale coloured sandstones interbedded with grey siltstones and mudstones. Subordinate lithologies are coal, ostracod-rich limestone/dolostone, sideritic ironstone and marine beds, including bioclastic limestones with rich and relatively diverse faunas. Thick pale green-grey or grey argillaceous beds supposedly containing derived volcanic-detrital calcareous mudstone are present.

Genetic interpretation
The environment of deposition was similar to that of the Aberlady Formation, but with oil shales formed in large freshwater lakes, rich in algae and other organic matter.

Stratotype
The type area is West Lothian, where a composite section of the formation has been built up from numerous boreholes drilled to prove the oil-shale seams. The base is well exposed in the Water of Leith near Redhall in Edinburgh (see Chisholm and Brand, 1994, p. 100, localities 1–4; Browne et al., 1999, fig. 2, col. 9). Most parts of the formation are partly exposed on the coast from South Queensferry to Blackness [NT 13 78 to 05 80].

Lower and upper boundaries
The base of the formation is taken at the base of the Humbie Marine Band, the local equivalent of the lowest Macgregor Marine Band and is underlain by the predominantly sandstone, mudstone and siltstone of the Gullane Formation (Figure 6, Column 4D). The formation is laterally equivalent to the Aberlady Formation to the east, and to the Kinghorn Volcanic Formation to the north. It is also laterally equivalent to part of the Bathgate Hills Volcanic Formation to the west.

The top of the formation is drawn at the base of the Hurlet Limestone, located at the base of the Lower Limestone Formation (Clackmannan Group).

Thickness
The maximum thickness of the formation is in excess of 1120 m in West Lothian (see Browne et al., 1999; Chisholm et al., 1989, section 4.5).

Distribution and regional correlation
Lothians

Age and biostratigraphical characterisation
Visean (Asbian to Brigantian). Miospores of the TC, NM and VF zones of Neves et al. (1973) are represented. The Macgregor Marine bands at the base of the formation have rich and distinctive faunas including *Punctospirifer scabricosta*, *Pteronites angustatus* and *Streblopteria redesdalensis*. Wilson (1952) described the B Zone ammonoid *Beyrichoceratoides redesdalensis* from the Cove Lower Marine Band, but this bed cannot be correlated with certainty with the Humbie Marine Band at the base of the Gullane Formation. The Granton 'shrimp-bed' within the formation on the shore north of Edinburgh is the locality where the soft structures of a conodont animal were first described (Briggs et al., 1983).

Formal subdivisions
See also Appendix 1. Members of the West Lothian Oil-Shale Formation in stratigraphical order include:

4.3.13.1 CALDERS MEMBER (CDE)

Name
The name was proposed by Chisholm et al. (1989), the main outcrop area and the thickest development of the member being around West Calder, Midcalder and East Calder.

Lithology
The Calders Member comprises a succession of black to grey mudstones, grey siltstones and white, grey and pink sandstones with thin beds of grey argillaceous, limestone and dolostone ('cementstone'), and algal-rich black to grey oil shales with some lapilli-tuff beds. The strata are not disposed in readily recognisable sedimentary cycles. The member includes the Dalmahoy Oil-Shale, Hailes Sandstone (which was much worked in the past for dimension stone), Pumpherston Shell Bed (a bed of fossiliferous mudstone with a marine fauna), and the overlying Pumpherston Oil-Shale. A regionally persistent but thin (less than 1 m) algal dolostone has been recognised at Hopetoun and Queensferry.

Genetic interpretation
The strata are almost all of lacustrine and fluvial origins, with sporadic marine incursions.

Stratotype
The type section is the shore at Queensferry between Longcraig Pier [NT 144 786] and just east of the Forth Railway Bridge [NT 138 784] (Carruthers et al., 1927 p. 80; McAdam and Clarkson, 1986, map 24). Reference sections include the shore and coastal section at Hopetoun [NT 088 793 to 094 791] (Carruthers et al., 1927), and the river section in the Water of Leith near Redhall in Edinburgh [NT 217 702 to 214 697] (Chisholm and Brand, 1994, p. 100), which exposes the Redhall Marine Band and overlying mudstones with oil-shales, up to the base of the Hailes Sandstone.

Lower and upper boundaries
The lower boundary is defined by the Redhall (Humbie) Marine Band. This is the lowest of the Macgregor Marine Bands in the area, up to 0.3 m thick, and in Edinburgh is contained within at least 13.8 m of generally tough, black and dark grey mudstones. The lowest 9 m of these mudstones form the top of the underlying Gullane Formation (Chisholm and Brand, 1994, p. 100) which are assigned to the currently undefined Wardie Shales Member.

The top of the Calders Member is defined at the base of the Burdiehouse Limestone (BULS) (Mitchell and Mykura, 1962, p. 67) (Figure 6, Column 4D).

Thickness
The member is on average about 290 m thick (Cameron and McAdam, 1978, fig. 2) but estimated at 350 m in west Edinburgh. The Hailes Sandstone has a maximum thickness of about 57 m.

Distribution and regional correlation
West Lothian and part of Midlothian. The unit is no longer mapped as Calders Member in Fife, where it is now mapped as the Sandy Craig Formation (Figure 6, Column 4C).

Age and biostratigraphical characterisation
Asbian. Currie (1954) listed ammonoids from the Pumpherston Shell Bed including *Beyrichoceratoides* aff. *fournieri*, *B*. cf. *fournieri* or *B*. cf. *redesdalensis*, *B*. cf. *truncatus* and *?Dimorphoceras* sp. On the evidence available Currie (1954) and George et al. (1976) assigned the Pumpherston Shell Bed to the middle Visean (Asbian).

4.3.13.2 HOPETOUN MEMBER (HON)

Name
The name was proposed by Chisholm et al. (1989) to replace the Upper Oil Shale Group of Carruthers et al. (1927) and Mitchell and Mykura (1962). It originates from the best natural sections, which are on the coast near Hopetoun House.

Lithology
The Hopetoun Member consists of a sequence of black to grey mudstone, grey siltstone, white, grey and pink sandstone and white to pale greenish grey calcareous mudstone with thin beds of black to grey oil shale, coals (Hurlet, Two Foot and Houston seams); together with grey to white, pure to argillaceous limestone and dolostone that comprise the upper part of the West Lothian Oil-Shale Formation. Some lapilli-tuff beds are present and thin coal seams. The strata are not generally disposed in readily recognisable sedimentary cycles. The member includes the Camps, Under Dunnet, Dunnet, Broxburn, Fells, Grey, Mungle, Raeburn and Fraser shales (oil shales), and the Dunnet and Binny sandstones that were worked in the past for dimension stone. The limited number of thin marine beds include the Dunnet, Raeburn and Fraser shell beds (fossiliferous mudstone beds with a marine fauna) and the Under or Gilmerton Bone Bed Limestone. Lacustrine limestones are present

such as the Barracks Limestone with the regionally important and thick Burdiehouse Limestone at the base of the member. The Bathgate Hills Volcanic Formation (Bathgate Group) basaltic lavas and tuffs are interbedded near the top in the West Lothian and Falkirk areas. The Hurlet Coal is the topmost named bed in the member in West Lothian.

Genetic interpretation
The strata are almost all of lacustrine and fluvial origins with a limited number of marine incursions.

Stratotype
The shore at Abercorn [NT 061 794 to 088 793] provides a partial type section of limited exposure and modest quality. It includes from the Raeburn Shale downwards. Reference sections occur on the shore at Queensferry [NT 127 784] to Port Edgar [NT 138 784] (basal part of the member) and in the River Almond valley at Mid Calder, West Lothian [NT 079 671 to 086 685] (from the Broxburn Shale downwards).

Lower and upper boundaries
The lower boundary is defined at the base of the Burdiehouse Limestone (BULS) (Mitchell and Mykura, 1962, p. 67) (Figure 6, Column 4D) resting on strata of the Calders Member. This distinctive limestone is a lacustrine deposit, commonly 6–9 m thick, containing abundant fossilised ostracod, plant and fish remains, and rarely algal oncoids.

The top of the generally noncyclic Hopetoun Member is defined at the base of the Hurlet Limestone (Figure 6, Column 4D). This marine limestone forms the base of the marine-dominated cyclic successions of the overlying Lower Limestone Formation (Clackmannan Group).

Thickness
The member is on average about 830 m thick in the Lothians (Cameron and McAdam, 1978, fig. 2).

Distribution and regional correlation
West Lothian and part of Midlothian.

Age
Asbian to Brigantian

EAST LOTHIAN (Figure 6, Column 4E)

4.3.14 Garleton Hills Volcanic Formation (GHV)

Name
From the Garleton Hills, East Lothian. The formation name was established by Chisholm et al. (1989).

Lithology
The Garleton Hills Volcanic Formation consists of lavas, tuffs and subordinate volcaniclastic sedimentary rocks. The lavas are transitional to mildly alkaline and show a limited range of composition. The basic rocks are hypersthene-normative. They are macroporhyritic in the range olivine-pyroxene-phyric basalt and basanite–olivine-clinopyroxene-plagioclase-phyric basalt–plagioclase-phyric hawaiite–mugearite–trachyte.

Genetic interpretation
The formation was produced by a single episode of volcanic activity. The depositional environment was terrestrial, probably on a coastal plain.

Stratotype
The type area is the Garleton Hills [NT 54 85], where there are many natural exposures. A reference section of thinner development occurs from 287.27 to 554.19 m depth in the Spilmersford Borehole, south-west of Haddington (BGS Registration Number NT46NE/73) [NT 4570 6902].

Lower and upper boundaries
The base of the formation is taken at the lithological change from underlying clastic sedimentary rocks of the Ballagan Formation (Inverclyde Group) to lavas, tuffs or volcaniclastic sedimentary rocks. This is gradational, and drawn where volcanic rocks predominate over sedimentary as in the Spilmersford Borehole (see above).

The top of the formation, at the base of the overlying Gullane Formation (Figure 6, Column 4E), is also gradational (as in the Spilmersford Borehole).

Thickness
The maximum thickness of the formation may be about 380 m (McAdam and Tulloch, 1985, fig. 18).

Distribution and regional correlation
Lothians. The rocks crop out in a belt from North Berwick to Dirleton on the coast to the Dunbar–Gifford Fault east of Haddington with their main outcrop in the Garleton Hills. A further outcrop occurs east of Gifford between the Dunbar–Gifford Fault and the Lammermuir Fault. The formation has been proved under younger rocks as far south-west as Spilmersford. Volcanic rocks encountered in a confidential borehole at D'Arcy in the Midlothian Coalfield are now referred to the Garleton Hills Volcanic Formation rather than an eastward extension of the Arthur's Seat Volcanic Formation (M A E Browne, verbal communication, 01 March 2007).

Age
Chadian to Arundian.

Formal subdivisions
See also Appendix 1. Members of the Garleton Hills Volcanic Formation in ascending stratigraphical order include:

4.3.14.1 North Berwick Pyroclastic Member (NBPY)

Name
Previously named the North Berwick Member (see McAdam and Tulloch, 1985).

Lithology
The North Berwick Pyroclastic Member consists of green (lower part in the north) and red (all in the south) tuffs, lapilli-tuffs and agglomerate locally with sedimentary intercalation of a lacustrine limestone, the Sunnyside Limestone, up to 2.9 m thick. These are commonly well bedded and waterlain and interbedded with volcaniclastic sedimentary rocks including thin dolostones and siliciclastic mudstones with sandstones showing ripple marks.

Stratotype
The type area is East Lothian [NT 4500 6900 to 6300 8500] around North Berwick, East Linton, the Garleton Hills, and Stenton (see Davies et al., 1986, fig. 10; McAdam and Tulloch, 1985, fig. 17). Complete reference sections are provided by the IGS East Linton 2 Borehole (BGS Registration Number NT57NE/2) [NT 59664 77091] from about 48.8 to 104.2 m depth, and the Spilmersford Borehole (BGS Registration Number NT46NE/73) [NT 4570 6902] from about 476 to 544 m depth.

Lower and upper boundaries
The base is conformable on the underlying Ballagan Formation (Inverclyde Group). The change is transitional by interbedding of tuff and lapilli-tuff into the underlying siliciclastic and carbonate rocks.

The member is overlain by the basaltic lavas of the East Linton Lava Member to the south of the Dunbar–Gifford Fault where the somewhat younger siliciclastic Gullane Formation rests directly on it. The contact is conformable and locally unconformable.

Thickness
Between 0 and 220 m

Distribution and regional correlation
East Lothian, outcrop of the Garleton Hills Volcanic Formation around North Berwick, East Linton, Garleton Hills, Stenton and in the subcrop farther west in the BGS Spilmersford Borehole (see above) near Pencaitland, and south to the Lammermuir Fault.

Age
Early Visean (Chadian to Arundian

4.3.14.2 East Linton Lava Member (ELLA)

Name
Previously named the East Linton Member (see McAdam and Tulloch, 1985).

Lithology
The East Linton Lava Member consists characteristically of macroporphyritic basalt and basanite ('Craiglockhart' type) and hawaiite ('Dunsapie' type), both with olivine and clinopyroxene (large augite) phenocrysts and the latter, also with plagioclase. Non-porphyric basaltic trachyandesites and a single leucite-bearing analcime trachybasalt ('kulaite') are also present. Beds of tuff and lapilli-tuff also occur in the succession. Flows are usually 5–15 m thick, the upper half of each being 'slaggy' and vesicular.

Stratotype
The type area is East Lothian [NT4600 6900 to 6000 8300] around North Berwick, East Linton, the Garleton Hills, and Stenton (see Davies et al., 1986, fig. 10; McAdam and Tulloch, 1985, fig. 17). Reference sections are provided by the IGS East Linton 2 Borehole (BGS Registration Number NT57NE/2) [NT 59664 77091] which provides a partial section through the member from 0 to about 48.8 m depth, and the Spilmersford Borehole (BGS Registration Number NT46NE/73) [NT 4570 6902], which provides a complete section from about 372 to 476 m depth.

Lower and upper boundaries
The base is conformable or locally unconformable on the North Berwick Pyroclastic Member. The change is from basaltic pyroclastic rocks to basic lavas.

The member is overlain by the Hailes Lava Member. The contact is conformable and locally unconformable. The change is from basalt and basanite and hawaiite to olivine basalt and mugearite.

Thickness
Between 0 and 90 m.

Distribution and regional correlation
East Lothian, outcrop of the Garleton Hills Volcanic Formation around North Berwick, East Linton, Garleton Hills, Stenton and in the subcrop farther west in the BGS Spilmersford Borehole (see above) near Pencaitland, but absent adjacent to the Lammermuir Fault.

Age
Early Visean (Chadian to Arundian).

4.3.14.3 Hailes Lava Member (HSLA)

Name
Previously named the Hailes Member (see McAdam and Tulloch, 1985).

Lithology
The Hailes Lava Member consists of dark grey, feldspar-phyric olivine basalts ('Markle' type) with sparse to abundant, large or small feldspar phenocrysts, aphyric basalts and pale purple-grey, platy-jointed mugearites. Thicknesses of flows are up to 17 m. The feldsar-phyric basalts characterise this unit of about six flows.

Stratotype
The type area is East Lothian [NT 4500 6900 to 6000 8300] around North Berwick, East Linton, the Garleton Hills, and Hailes (see Davies et al., 1986, fig. 10; McAdam and Tulloch, 1985, fig. 17), and in the Spilmersford Borehole (BGS Registration Number NT46NE/73) [NT 4570 6902], which provides a complete section from about 348 to 372 m depth.

Lower and upper boundaries
The base is conformable or locally unconformable on the East Linton Lava Member (olivine-, clinopyroxene- and sometimes plagioclase-phyric basaltic lavas; basalt and basanite and hawaiite) or locally unconformable on the North Berwick Pyroclastic Member.

The member is overlain by the Bangley Trachytic Member. The contact is conformable and locally unconformable. The change is from olivine basalt and mugearite lavas up into trachytic lavas with trachytic tuff and lapilli-tuff.

Thickness
Between 0 and 70 m.

Distribution and regional correlation
East Lothian, outcrop of the Garleton Hills Volcanic Formation around North Berwick, East Linton, Garleton Hills, Hailes and in the subcrop farther west in the BGS Spilmersford Borehole (see above) near Pencaitland, but absent south of Hailes adjacent to the Dunbar–Gifford Fault.

Age
Early Visean (Chadian to Arundian).

4.3.14.4 Bangley Trachytic Member (BYTRC)

Name
Previously named the Bangley Member (see McAdam and Tulloch, 1985).

Lithology
The Bangley Trachytic Member consists of purple and blue-grey trachytic lavas with both feldspar-phyric (sodic plagioclase to sanidine) and aphyric types. Individual flows are known to be over 20 m thick. Quartz-trachytes are also present. Red, brown and purple trachytic tuff and lapilli-tuff with agglomerate and some volcaniclastic sedimentary rocks also are interbedded in units known to be at least 8 m thick.

Stratotype
The type area is East Lothian [NT 4500 6900 to 6000 7300] around North Berwick, East Linton, the Garleton Hills, and Stenton (see Davies et al., 1986, fig. 10; McAdam and Tulloch, 1985, fig. 17), and in the Spilmersford Borehole (BGS Registration Number NT46NE/73) [NT 4570 6902], which provides a complete section from about 286 to 348 m depth.

Lower and upper boundaries
The base is apparently conformable on the Hailes Lava Member, which consists of basaltic lavas and volcaniclastic rocks.

The member is overlain by the siliciclastic sedimentary rocks of the Gullane Formation (Strathclyde Group). The contact is considered unconformable with volcaniclastic conglomerate recorded locally at the base of the overlying formation.

Thickness
Between 0 and 160 m.

Distribution and regional correlation
East Lothian, outcrop of the Garleton Hills Volcanic Formation around North Berwick, East Linton, the Garleton Hills, and Stenton, and in the subcrop farther west in the BGS Spilmersford Borehole (see above) near Pencaitland, but absent adjacent to the Lammermuir Fault.

Age
Early Visean (Chadian to Arundian).

4.3.15 Gullane Formation (GUL)

See Section 4.3.12 for definition.

4.3.16 Aberlady Formation (ABY)

Name
From Aberlady, East Lothian. The formation name was established by Chisholm et al. (1989).

Lithology
The Aberlady Formation consists of a cyclical sequence predominantly of pale sandstone interbedded with grey siltstone and grey mudstone. Subordinate but common lithologies are coal, seatrock, ostracod-rich limestone/dolostone and sideritic ironstone, and marine bands or bioclastic limestones with relatively rich and diverse faunas. The last-named feature distinguishes the unit from the Gullane Formation.

Genetic interpretation
The depositional environment was fluviodeltaic into lakes and marine embayments.

Stratotype
The type section is from 21.64 to 155.44 m depth in the Spilmersford Borehole (BGS Registration Number NT46NE/73) [NT 4570 6902] (see Browne et al., 1999, fig. 2, col. 11). Other reference sections occur from 28.88 to 168.10 m depth in the Skateraw Borehole (BGS Registration Number NT77NW/47) [NT 7373 7456] and (partially) on the coast at Cove [NT 78 71] in the Oldhamstocks Basin (see Browne et al., 1999, fig. 2, col. 12) and at Kilspindie [NT 46 80] by Aberlady Bay.

Lower and upper boundaries
The base lies in a transitional sequence and is taken at the base of the lowest of the Macgregor Marine Bands, lying above the predominantly sandstone, mudstone and siltstone of the Gullane Formation (Figure 6, Column 4E). The formation is laterally equivalent to and has a laterally transitional boundary with the West Lothian Oil-Shale Formation to the west, being distinguished from it chiefly by the rarity of oil shales.

The top of the formation is drawn at the base of the Hurlet Limestone, located at the base of the Lower Limestone Formation (Clackmannan Group).

Thickness
The maximum thickness of the formation is about 140 m (Chisholm et al., 1989, section 4.4).

Distribution and regional correlation
Lothians.

Age and biostratigraphical characterisation
Visean (Asbian to Brigantian). Mainly NM Miospore Zone of Neves et al. (1973) though the VF and TC zones are also represented. The Macgregor Marine bands at the base of the formation have a rich and distinctive fauna including *Punctospirifer scabricosta, Pteronites angustatus* and *Streblopteria redesdalensis*, which may be diagnostic. Wilson (1952) described the B Zone ammonoid *Beyrichoceratoides redesdalensis* from the Cove Lower Marine Band, the lowest of the Macgregor Marine bands at Cockburnspath.

4.4 BATHGATE GROUP (BATH)

The name was first applied by Browne et al. (1999) and derives from the town of Bathgate. The sequence comprises:

> At *Salsburgh, Lanarkshire*, the Salsburgh Volcanic Formation;
> In *Fife*, the Kinghorn Volcanic Formation;
> In *West Lothian*, the Bathgate Hills Volcanic Formation.

These formations are generally characterised by olivine-microphyric basalts and basanites of 'Dalmeny' and 'Hillhouse' types with some olivine-macrophyric basalts of 'Craiglockhart' and 'Dunsapie' types. Bedded tuffites and tuffaceous sedimentary rocks also occur. However, unlike the petrologically wide ranging volcanic rocks of the Clyde Plateau Volcanic Formation (Strathclyde Group) of the western Midland Valley of Scotland, these formations are not readily subdivided into members.

The base of the group is taken at an upward transition from sedimentary rocks in most areas, but is drawn at the top of the Clyde Plateau Volcanic Formation in the Rashiehill Borehole (BGS Registration Number NS87SW/22) [NS 8386 7301], west of Slammanan, and at a supposed unconformity in the Salsburgh 1A oil well (BGS Registration Number NS86SW/89) [NS 8166 6487]. The top is taken at the top of the highest known pyroclastic rock interdigitated in the Passage Formation (Clackmannan Group) (*fluviodeltaic* (*'Millstone Grit'*) *facies*) in the Central Coalfield area (see Cameron et al. 1998, p. 50).

The type area of the Bathgate Group (not shown on Figure 5) is limited in geographical extent to Falkirk, Fife, Lanarkshire and West Lothian, but it interdigitates with a large thickness of sedimentary formations, including the upper part of the Strathclyde Group and the larger part of the Clackmannan Group. Asbian to Arnsbergian in age, it is very variable in thickness, locally occurring in excess of 450 m.

4.4.1 Salsburgh Volcanic Formation (Salv)

Name
From the type section. The term was first applied by Browne et al. (1999).

Lithology
The Salsburgh Volcanic Formation consists of highly altered basaltic lavas with sporadic interbeds of limestone, mudstone, tuff and tuffaceous mudstone and tuffaceous sandstone.

Stratotype
The type section is from 1114.65 to 1216.15 m depth in the Salsburgh 1A oil well (BGS Registration Number NS86SW/89) [NS 8166 6487] north-west of Shotts (see Browne et al., 1999, fig. 2, col. 6).

Lower and upper boundaries
The Early Devonian trachytic rocks at the base of the Salsburgh 1A oil well (see above) have been interpreted as intrusive feldspar-macrophyric microgranodiorite (or rhyodacite). The contact between the latter and the overlying Salsburgh Volcanic Formation had previously been accepted as an unconformity, but now could be reinterpreted as intrusive (Phillips and Browne, 2000).

The top of the formation is a conformable transition to the cyclical sequence of mainly sandstones with siltstones and mudstones of the West Lothian Oil-Shale Formation, Strathclyde Group. In the type section, a limestone correlated with the Burdiehouse Limestone rests directly on the Salsburgh Volcanic Formation.

Thickness
The maximum known thickness of the formation is 102 m in its type section, where the base was apparently not reached (Phillips and Browne, 2000).

Distribution and regional correlation
The formation is only known in its type section (see above).

Age
Visean (Asbian?)

4.4.2 Bathgate Hills Volcanic Formation (BHV)

Name
From the Bathgate Hills, West Lothian. The name was first used by Smith et al. (1994) to replace earlier terms such as 'Bathgate lavas'. It was formally defined by Browne et al. (1999).

Lithology
The Bathgate Hills Volcanic Formation consists of lavas, tuffs and volcaniclastic sedimentary rocks. The lavas are mostly relatively primitive, silica-undersaturated rocks with a restricted range of composition. The 'basic' rocks are commonly nepheline-normative basanites. The lavas are mostly basalt and basanite and olivine-clinopyroxene-microphyric basalt with rare microporphyritic hawaiite. Weathered ferruginous palaeosols (red boles) are developed. The volcanic rocks interdigitate and interact with clastic sedimentary rocks of various formations.

Genetic interpretation
The formation was produced by long-lived series of episodes of volcanic activity. The depositional environment was mainly terrestrial, at times into water, at times into hot springs.

Stratotype
The type area comprises natural exposures in the Bathgate Hills [NS 98 75]. A reference section, in which twenty-six lavas interdigitate with clastic sedimentary rocks, is in the Rashiehill Borehole (BGS Registration Number NS87SW/22) [NS 8386 7301] from 791.6 to 1110.4 m depth.

Lower and upper boundaries
The base of the formation is taken at the lithological change from underlying clastic sedimentary rocks, to lavas, tuffs or volcaniclastic sedimentary rocks or at an upward change from the petrologically wider range of volcanic rocks that form the Clyde Plateau Volcanic Formation, as in the Rashiehill Borehole (see above). In the former case the boundary is gradational and is taken where volcanic rocks predominate over sedimentary rocks. The top is likewise gradational.

The formation is laterally equivalent to, and interdigitates with, the West Lothian Oil-Shale (Strathclyde Group), and Lower Limestone, Limestone Coal, Upper Limestone and Passage formations (Clackmannan Group).

Thickness
Up to 319 m maximum in the Rashiehill Borehole (see above).

Distribution and regional correlation
The main outcrop is in the Bathgate Hills, West Lothian where the rocks crop out in a belt from Bathgate to Bo'ness on the coast. The formation has been proved under younger rocks as far west as Rashiehill.

Age
Visean to Namurian (Asbian to Arnsbergian)

4.4.3 Kinghorn Volcanic Formation (KNV)

Name
From the town of Kinghorn, Fife. The term was introduced by Browne et al. (1999) to replace earlier informal names such as 'Burntisland lavas'.

Lithology
The Kinghorn Volcanic Formation consists of basaltic lavas, locally with pillows and hyaloclastic textures. Volcaniclastic sedimentary rocks with subordinate tuffs also occur. The lavas are dominantly olivine- and olivine-clinopyroxene-phyric with rare olivine-clinopyroxene-plagioclase-phyric basalts. They are mostly microporphyritic but some macroporphyritic varieties also occur. The limited analyses available suggest that the lavas are mostly hypersthene-normative.

Genetic interpretation
The formation is mainly of subaerial origin but locally subaqueous.

Stratotype
The type section is on the Fife coast between Kinghorn and Kirkcaldy [NT 254 863 to 278 882] where about 460 m of mainly green, olivine-rich, basalt lava can be seen in flows interbedded with tuff, sandstone, mudstone and marine limestone. The lavas are variably vesicular and amygdaloidal, include ophitic textures and pillow structures, and may be scoriaceous (see Geikie, 1900, pp. 53–76; MacGregor, 1968, pp. 248–253; Browne et al., 1999, fig. 2, col. 18).

Lower and upper boundaries
The base and top of the formation are usually transitional to sedimentary units belonging to the Strathclyde Group and possibly the basal part of the Clackmannan Group. In the type area (see above) the formation is known to interdigitate with sedimentary strata of the Sandy Craig and Pathhead formations (Figure 6, Column 4C).

Thickness
Over 422 m in the Seafield No. 1 Shaft (BGS Registration Number NT28NE/35) [NT 2769 8953] just south of Kirkcaldy. The depth range is from about 134 m to the bottom of the hole at about 556 m. The full thickness of the formation is therefore not proved.

Distribution and regional correlation
Fife.

Age and biostratigraphical characterisation
Visean (Asbian–Brigantian). Wilson (1989) favoured equation of the 2nd Abden Limestone within the type section (see above) with the Hurlet Limestone at the base of the Lower Limestone Formation, Clackmannan Group and also suggested that both Abden limestones may be part of a single marine episode that was interrupted by the volcanic activity. The associated shales and limestones themselves are richly fossiliferous yeilding brachiopods, bivalves, gastropods, ostracods, foraminifers, corals and bryozoa. The Hurlet Limestone is distinguished by the faunal sequence (the Macnair Fauna) in the underlying mudstone (Wilson, 1989) and contains typical P_2 ammonoids (Currie, 1954).

4.5 CLACKMANNAN GROUP (CKN)

The term 'Clackmannan Group' (Figure 5) was first used in the Airdrie district by I H S Hall (BGS, 1992) and Forsyth et al. (1996). The succession comprises the Lower Limestone, Limestone Coal, Upper Limestone and Passage formations, which represent a variable section of *mixed shelf carbonate and deltaic ('Yoredale') facies, fluviodeltaic ('Millstone Grit') facies* and *fluviodeltaic ('Coal Measures') facies*. The formations are characterised by strongly cyclical, upward-coarsening units of limestone, mudstone, siltstone and sandstone capped by coal and seatearth, the proportions differing in each of the formations. Thus, beds of laterally extensive limestone, with diverse marine faunas, are more conspicuous in the Lower and Upper Limestone formations than elsewhere; coals are most common in the Limestone Coal Formation; and sandstones and seatearths (including some economically important high-alumina seatclay, fireclay and bauxitic clay) are the most prominent constituents of the Passage Formation. Depositional environments, likewise, show an underlying similarity, being related to the repeated advance and retreat of fluviodeltaic systems into embayments of varying salinity. The Lower and Upper Limestone formations contain the highest proportion of marine deposits *(mixed shelf carbonate and deltaic ('Yoredale') facies)*, whilst the Passage Formation is dominated by alluvial deposits *(fluviodeltaic ('Millstone Grit') facies)*. The Limestone Coal Formation occupies an intermediate position *(fluviodeltaic ('Coal Measures') facies)*.

The base of the group is taken at the base of the Lower Limestone Formation, where a cyclical sequence of marine limestone-bearing strata normally rests conformably on various formations of the Strathclyde Group. The base of the Scottish Coal Measures Group *(fluvio-deltaic ('Coal Measures') facies)* defines the top of the group.

The type area of the Clackmannan Group is the Clackmannan Syncline. It extends across the Midland Valley of Scotland and includes Machrihanish and Arran. Up to 1800 m thick in the Clackmannan area, the group is mostly Namurian in age, but ranges from Brigantian to early Langsettian.

The Clackmannan Group also occurs in the Southern Uplands of Scotland at Sanquhar and Thornhill. In the eastern part of the Sanquhar Basin the Clackmannan Group (undivided) comprises an older, highly variable sequence of mainly arenaceous and argillaceous strata, which were probably deposited in semi-isolated sub-basins during the period of maximum marine transgression. In the west of the basin, younger sandstones, siltstones and carbonaceous mudstones with marine bands probably represent marginal deltaic conditions. The base of the group is unconformable on the mainly greywacke sandstones of the Ordovician Tappins and Barrhill groups, and the top is taken at the base of Tait's Marine Band, of possible Westphalian age (Wilson in Davies, 1970, p. 52), at the base of the cyclical sandstones, siltstones, mudstones, seatrocks and coals of the Scottish Lower Coal Measures Formation. In the Sanquhar Basin the Clackmannan Group is about 40 m thick in total and falls within the age range of late Visean to Langsettian.

In the Thornhill Basin the Clackmannan Group (see Section 5.3) comprises the marine–intertidal Enterkin Mudstone Formation of *'mixed shelf carbonate and deltaic ('Yoredale') facies',* and the Passage Formation of *'fluviodeltaic ('Millstone Grit') facies'*. The base of the group is unconformable on the mainly sandstone-dominated turbidites of the Ordovician Glenlee Formation, Leadhills Supergroup, and the top is taken at the conformable base of the Scottish Lower Coal Measures Formation of *fluviodeltaic ('Coal Measures') facies*. In the Thornhill Basin the Clackmannan Group is up to 55 m thick in total and falls within the age range of late Visean to pre-Westphalian.

4.5.1 Lower Limestone Formation (LLGS)

Name
Forsyth et al. (1996) changed the name Lower Limestone Group to Lower Limestone Formation, without changes to the boundary definitions.

Lithology
The Lower Limestone Formation (see Browne et al., 1999, fig. 3) comprises repeated upward-coarsening cycles of limestone, mudstone, siltstone and sandstone. The cycles may be capped by thin beds of seatearth and coal. The limestones, which are almost all marine and fossiliferous, are pale to dark grey. The mudstones (many of which also contain marine fossils) and siltstones are predominantly grey to black. Nodular clayband ironstones and limestones are well developed in the mudstones. The sandstones, which are usually fine- to medium-grained, are generally off-white to grey. Except locally, coal seams are thin (0.3 m) and few in number. Other minor lithologies include cannel and blackband ironstone. A few nonmarine fossiliferous beds are known. Upward-fining parts of the succession, dominated by fine- to medium-grained sandstone but lacking limestone, also occur. In the western part of the Midland Valley the sequence is condensed, with the intervals between limestones dominated by mudstone.

Genetic interpretation
The formation comprises *mixed shelf carbonate and deltaic ('Yoredale') facies*. The lower parts of the cycles,

including almost all limestones and many mudstones, were deposited in marine environments. The upper parts of the cycles, including sandstones and coals, were deposited as progradational lobate deltas.

Stratotype
The type section is from 81.98 to 292.51 m depth in the Wester Gartshore Colliery Underground Borehole (BGS Registration Number NS67SE/99) [NS 6824 7239] at Kirkintilloch, north-west of Airdrie (see Browne et al., 1999, fig. 3, col. 4).

Lower and upper boundaries
The conformable base of the formation is taken at the base of the Hurlet Limestone, which is underlain by sedimentary rocks of the Lawmuir, Pathhead, West Lothian Oil-Shale or Aberlady formations (Figure 6, Columns 1, 4A–E).

The top of the formation is drawn at the top of the Top Hosie Limestone (TOHO), which is overlain by cyclic sedimentary rocks of the Limestone Coal Formation.

Thickness
The maximum thickness of the formation is about 240 m in the Lathallan–Radernie area of east Fife (Forsyth and Chisholm, 1977, p. 60). In the western part of the Midland Valley it is condensed to less than 50 m (Browne et al., 1985). Generalised thickness were given of 45 m on Arran (BGS, 1987a) and 8.75 m in the main coalfield area at Machrihanish (BGS, 1996).

Distribution and regional correlation
Throughout the Midland Valley, the Isle of Arran and at Machrihanish. Browne et al. (1999, table 4) proposed a rationalisation of the principal named horizons across the Midland Valley of Scotland, using the Glasgow nomenclature as the standard.

Age and biostratigraphical characterisation
Visean to Namurian (late Brigantian to early Pendleian/early Serpukhovian). Ammonoids of zonal significance include *Paradimorphoceras marioni, Metadimorphoceras varians, Girtyoceras multicameratum* and *Beyrichoceratoides truncatus* Var. M all of P_2 age found in the Neilson Shell Bed, and '*Cravenoceras' scoticum* of E_1 age found below the Top Hosie Limestone (Currie, 1954). The Hurlet Limestone is distinguished by the macrofauna in the underlying mudstone. Known as the Macnair Fauna, its upward sequence includes layers with inarticulate brachiopods, bivalves and finally articulate brachiopods (see Wilson, 1989, p. 104). The mudstones of the Neilson Shell Bed immediately above the Blackhall Limestone have a well-preserved fauna including the brachiopod *Tornquistia youngi* (abundant), the gastropods *Borestus wrighti* and *Tropidocyclus oldhami* and the bivalves *Euchondria neilsoni*, *Pernopecten fragilis* and *Posidonia corrugata gigantea*, all of which are confined to the Neilson Shell Bed (Wilson, 1989). The faunas of the Hosie Limestones are rich, though corals are relatively scarce and bryozoa are common only in the lower two limestones. The bivalve *Caneyella membranacea* (a very common fossil in the higher beds of P_2 age in the Pennines area of England) is all but confined to the Hosie Limestones. It is more common in the lower two limestones (Wilson, 1989) perhaps corroborating Cozar et al. (2008) recognition on foraminiferal evidence that the Second and Top Hosie Limestones are both E_1 (Pendleian or early Serpukhovian) in age. *Curvirimula* is the predominant nonmarine bivalve genus in the formation.

4.5.2 Limestone Coal Formation (LSC)

Name
Forsyth et al. (1996) changed the name Limestone Coal Group to Limestone Coal Formation, but without changes to the boundaries.

Lithology
The Limestone Coal Formation (see Browne et al., 1999, fig. 4) comprises sandstone, siltstone and mudstone, mostly in repeated upward-coarsening cycles, though some fine-upwards. The cycles are usually capped by seatearth and coal. The siltstone and mudstone are usually grey to black, while the sandstone is usually fine- to medium-grained and off-white to grey. Locally named coal seams are common and many exceed 0.3 m in thickness. Minor lithologies include cannel, and blackband and clayband ironstone, the latter nodular as well as bedded. Nonmarine limestone is rare and marine limestones are present only locally towards the bottom of the formation. Upward-fining parts of the succession, dominated by fine-grained to locally coarse-grained sandstone, are widely developed, and thick multistorey sandstones are present. Locally, successions may be particularly sandy or argillaceous. Unlike the Johnstone Shell Bed and 'Black Metals Marine Bands' that can be correlated widely, the coal seams are not so easily correlated and retain their local names.

Genetic interpretation
Fluviodeltaic ('Millstone Grit') facies. The cycles indicate periodic delta progradation, with the 'marine bands' resulting from marine transgression.

Stratotype
Type sections are represented by two boreholes in north-east Glasgow; the upper part of the formation from 316.0 to 539.5 m depth in the Cardowan No. 2 Borehole (BGS Registration Number NS66NE/66) [NS 6706 6752] and the lower part from 0 to 106.7 m depth in the Cardowan No. 13 Borehole (BGS Registration Number NS66NE/104) [NS 6706 6875].

Lower and upper boundaries
The base of the formation is taken at the top of the Top Hosie Limestone (TOHO) of the Lower Limestone Formation, and the top is drawn at the base of the Index Limestone (ILS) of the Upper Limestone Formation (Figure 6, Column 4). The Lower and Upper limestone formations include conspicuous beds of laterally extensive limestone, with diverse marine faunas, whilst the Limestone Coal Formation, in contrast, has prominent beds of coal.

Thickness
The maximum thickness of the formation is greater than 550 m in the Clackmannan area of the Central Coalfield (Browne et al., 1985, p. 11). In Ayrshire the sequence is condensed and less than 100 m thick. Generalised thicknesses were given of 110 m for the formation on Arran (BGS, 1987a) and 25–105 m in the main coalfield area at Machrihanish (BGS, 1996).

Distribution and regional correlation
Throughout the Midland Valley of Scotland, the Isle of Arran and at Machrihanish.

Age and biostratigraphical characterisation
Namurian (Pendleian). Beds containing large numbers of shells (coquinas) of *Lingula*, or of the nonmarine bivalves

Naiadites and *Curvirimula*, occur in the fine-grained rocks (including ironstones and cannel). Because of the form of preservation, these shells usually do not form conspicuous 'musselbands' like those of the Scottish Coal Measures Group. Marine shells are present in some fine-grained strata, and the Johnstone Shell Bed and 'Black Metals Marine Bands' can be correlated throughout the Midland Valley.

The formation has yeilded no goniatites (Currie, 1954). The Johnstone Shell Bed is normally developed in two beds, the lower carrying the richer faunal assemblage dominated by the annelid *Serpuloides carbonarius*, the brachiopods *Pleuropugnoides* cf. *pleurodon*, *Lingula squamiformis* and *Productus* spp., the gastropods *Euphemites* spp. and *Retispira* spp., and the bivalves *Anthraconeilo luciniformis*, *A. mansoni* and *Streblopteria ornata* (Wilson, 1967). The 'Black Metals Marine Bands' yield macrofossils including annelids, brachiopods and bivalves (see below) in most parts of central Scotland, although in some areas only *Lingula* sp. is present. Note that amongst the productoid brachiopod genera *Productus* is dominant in the Johnstone Shell Bed and rare in the 'Black Metals Marine Bands', whilst *Buxtonia* dominates in the 'Black Metals Marine Bands' and is rare in the Johnstone Shell Bed. Non-marine bivalves are represented in the Limestone Coal Formation by species of *Curvirimula, Naiadites* and *Paracarbonicola*.

Formal subdivisions
See also Appendix 1. Members of the Limestone Coal Formation in stratigraphical order include:

4.5.2.1 Kilbirnie Mudstone Member (KLMD)

Name
The member was previously known as the Kilbirnie Mudstone Formation. The present definition is that of Monro (1999; see also Browne et al., 1999; Paterson et al., 1990).

Lithology
The Kilbirnie Mudstone Member comprises mostly dark grey mudstone with ironstone, sporadic shelly marine bands and siltstone, medium-grained rooted grey sandstone and coal. The strata occur in upward-coarsening cycles, some capped by thin coal beds. The member includes the Dalry Clayband Ironstone, a grey argillaceous ironstone, and the Johnstone Shell Bed mudstone, with a marine fauna.

Genetic interpretation
The cyclical nature of the member indicates periodic delta progradation, with the mudstone of the Johnstone Shell Bed being the result of a marine transgression.

Stratotype
The type section is in Paduff Burn, starting 200 m north of Place [NS 3028 5483] to the centre of Kilbirnie [NS 3148 5450] (Monro, 1999). Here can be seen some 30 m of mudstones overlying the Top Hosie Limestone. They include the Dalry Clayband Ironstone (0.5 m thick) and the Johnstone Shell Bed (at least 2.2 m thick) with a marine fauna of brachiopods and bivalves. Above this bed are upward coarsening sedimentary cycles including sandstones (commonly over 4 m thick) and thin coals. The sequence is partly intruded by dolerite dykes (Monro, 1999, pp. 50–51).

Lower and upper boundaries
The base of the member is taken at the top of the Top Hosie Limestone (TOHO), the highest of a number of thin limestones at the top of the Lower Limestone Formation (Figure 6, Column 4).

The top of the member is taken at the lithological change from mudstone of the Kilbirnie Mudstone Member, to the overlying dominantly sandstone-bearing cyclical sequences of the parent Limestone Coal Formation. The upper boundary is diachronous.

Thickness
Between 0 and 45 m.

Distribution and regional correlation
North Ayrshire. Not present south of the Inchgotrick Fault.

Age
Pendleian

4.5.2.2 Black Metals Member (BKME)

Name
Clough et al. (1916) previously named the member the Black Metals. It should not to be confused with the locally named Black Metals (Haughton) Marine Band of the Cumberland Coalfield which is Duckmantian (Westphalian B) in age.

Lithology
The Black Metals Member is a thick, laterally persistent dark grey mudstone (Read, 1965) distinguished by one or more beds, termed 'Black Metals Marine Bands'. Read (1965) described a sequence within the member of mudstone with *Lingula* at the base; overlain by mudstone with nonmarine bivalves or unfossiliferous mudstone, overlain by mudstone with a varied marine fauna that comprises the middle part of the member; which in turn is overlain by mudstone with nonmarine bivalves. The characteristic lithologies of the member vary laterally within the Midland Valley of Scotland. On the western side of the Central Coalfield in the Glasgow district strata that comprise the member are described and illustrated by Hall et al. (1998, fig. 11) as black and dark grey, carbonaceous mudstones and silty mudstones with characteristic development of brownish-grey clayband ironstone nodules (California Clayband Ironstone). Sandstones are restricted to thin beds, collectively 2 or 3 m thick in a total thickness interval of about 32 m. Eastwards from the Central Coalfield the member includes siltstone and sandstone beds that increase progressively in number and thickness to become the predominant lithology; seatearth and coal also appear (Read, 1965). In the western coastal Irvine district, the Logan's Bands, comprising thin beds of ironstone in a laterally persistent mudstone sequence, have been correlated with the Black Metals Member of the Glasgow district (Richey et al., 1930).

Genetic interpretation
Beds containing shelly marine faunas indicate a marine depositional environment (Wilson, 1967). However, beds with shells including *Naiadites* sp., indicate nonmarine depositional conditions.

Stratotype
The type section is north of Glasgow in the Cardowan No. 2 Bore (BGS Registration Number NS66NE/66) [NS 6706 6752] from 470 to 502.3 m depth. Reference sections are provided in Fife, at the Dora Opencast Coal Site, Area G (BGS Registration Number NT19SE/550) [NT 1830 9100 to 1860 9130], and in Midlothian, in the Monkton House Borehole (BGS Registration Number NT37SW/43) [NT 3325 7044] from about 888 to 907 m depth (see Tulloch and Walton, 1958, plate 3). Both reference sections include

interbedded sandstone and coal-bearing strata within the member.

Lower and upper boundaries
In the Central Coalfield the base of the mudstone comprising the member is picked at the top of the Black Metals Basal Coal (Forsyth and Read, 1962). Eastwards the base is picked at the top of a laterally equivalent seatearth and correlated to a thin coal above the Torrance Four-inch Coal farther east in Fife (Read, 1965, fig. 2). Westwards, in the Glasgow district, marine fossils are recorded just above the base of the Black Metals Member, the boundary being picked at the roof of the Upper Garscadden Coal which here may be developed as a blackband ironstone (Upper Garscadden Ironstone) (Hall et al., 1998, fig. 11; Forsyth and Read, 1962).

At its upper boundary in the Central Coalfield, mudstone of the Black Metals Member is interbedded with sandstone of the overlying Limestone Coal Formation (Figure 6, Column 4). The boundary is picked at the base of the lowermost bed of coarse siltstone or sandstone (Read, 1965). In the Bo'ness area of the Livingson district (Read, 1965), the erosive base of the sandstone has cut down into the member, or it is abruptly overlain by lavas of the Bathgate Hills Volcanic Formation. In the Glasgow district the upper boundary of the Black Metals Member is just below (within about 5 m of) the Knott Coal horizon (Hall et al., 1998, fig. 11).

Thickness
Read (1965) described the thickness of the member as exceeding that of typical fining-upwards cycles of the Limestone Coal Formation, which are usually about 3–10 m thick. North of Glasgow on the western side of the Central Coalfield in the Cardowan No. 2 Bore (see above) the member is 32.3 m thick (from 470 to 502.3 m depth) (Hall et al., 1998, fig. 11). The thickness is similar in the Kincardine and Fife–Midlothian basins. However, in the Kincardine Basin in west Fife the thickness of the member increases eastwards from 33 m to a maximum of 66 m, associated with the lateral change to an increasingly sandstone-bearing succession (Francis et al., 1970, p. 190, and plate 8).

Distribution and regional correlation
Central Scotland, but not identified in southern and central Ayrshire by Simpson and MacGregor (1932) or Eyles et al. (1949).

Age and biostratigraphical characterisation
Pendleian. The 'Black Metals Marine Bands' yield macrofossils in most parts of central Scotland although in some areas only *Lingula* is present. The annelid *Serpuloides carbonarius*, the brachiopods *Buxtonia* spp., *Pleuropugnoides* cf. *pleurodon* and *Lingula* spp. and the bivalve *Streblopteria ornata* are the main forms. The bivalve *Aviculopinna mutica* is commonly present in Midlothian and Fife, but has not been found elsewhere (Wilson, 1967). The member also includes beds with a nonmarine shelly fauna including *Naiadites* sp. The Logans Bands in the western coastal Irvine district contain *Lingula* and *Naiadites* or nonmarine bivalves (Monro, 1999).

4.5.3 Upper Limestone Formation (ULGS)

Name
Forsyth et al. (1996) changed the name Upper Limestone Group to Upper Limestone Formation. The boundary definitions were unaffected.

Lithology
The Upper Limestone Formation (see Browne et al., 1999, fig. 5) is characterised by repeated upward-coarsening cycles comprising grey limestone overlain by grey to black mudstones and calcareous mudstones, siltstones and paler sandstones capped by seatrocks and coal. The limestones contain marine faunas and are usually argillaceous. These limestones are laterally extensive and have standard names that can be used throughout the Midland Valley. The proportion of limestone increases to the west. The sandstones are generally off-white and fine- to medium-grained. The coals are usually less than 0.6 m thick. Minor lithologies include ironstone and cannel, and there are some volcanic rocks. Upward-fining sequences of coarse- to fine-grained sandstones passing up into finer-grained rocks are also present.

Genetic interpretation
The formation comprises *mixed shelf carbonate and deltaic ('Yoredale') facies*. The lower parts of the cycles, including almost all limestones and many mudstones, were deposited in marine environments. The upper parts of the cycles, including sandstones and coals, were deposited as progradational lobate deltas. The increase in the proportion of limestone to the west, indicates increasingly marine conditions in that direction (Francis, 1991).

Stratotype
The type section of the Upper Limestone Formation is the Mossneuk Borehole (BGS Registration Number NS88NE/204) [NS 8723 8609], south of Alloa, between 335.0 and 770.3 m depth (see Browne et al., 1999, fig. 5, col. 6).

Lower and upper boundaries
The base of the formation is taken at the base of the Index Limestone (ILS) or, locally, at a plane of disconformity, in both cases underlain by cyclic sedimentary rocks of the Limestone Coal Formation (Figure 6, Column 4).

Where the Upper Limestone Formation is fully developed, the top is drawn at the top of the Castlecary Limestone (CAS), overlain by cyclic sedimentary rocks of the Passage Formation.

Thickness
The maximum thickness of the formation is over 600 m in the Clackmannan area of the Central Coalfield (Browne et al., 1985, p. 11). It is less than 100 m thick in Ayrshire. Generalised thickness were given of 90–140 m on Arran (BGS, 1987a) and 87.5 m in the main coalfield area at Machrihanish (BGS, 1996).

Distribution and regional correlation
Throughout the Midland Valley of Scotland, the Isle of Arran and at Machrihanish.

Age and biostratigraphical characterisation
Namurian (Pendleian to Arnsbergian). Ammonoids including *Tumulites pseudobilinguis* recovered from the Index Limestone, *Eumorphoceras bisulcatum grassingtonense* from the Orchard Limestone, *E. B. ferrimontanum* and *'Cravenoceras' gairense* from the Calmy Limestone, and *Cravenoceratoides nitidus* from the Castlecary Limestone provide evidence for the $E_{1b}2$ to $E_{2b}2$ age of the formation (see Ramsbottom, 1977b). According to Wilson (1967) the brachiopod *Antiquatonia costata* is only found in the Orchard Limestone, whilst *Pugnax* cf. *pugnus* and *Sinuatella* cf. *sinuata* (with the bivalve *Actinopteria regularis*) are only associated with the

Calmy Limestone. The gastropods *Meekospira* sp. in the Index Limestone, *Straparollus (Euomphallus) carbonarius* in the Orchard Limestone and *Euphemites ardenensis* with the bivalve *Edmondia punctatella* in the Calmy Limestone fauna have short vertical ranges with their acme at the level mentioned. The bivalve *Streblopteria ornata* disappears after ranging up to the Lyoncross Limestone, whilst the nautiloid *Tylonautilus nodiferus* has not been found below the Calmy Limestone. The nonmarine bivalve genera in the formation are *Curvirimula* and *Naiadites*.

4.5.4 Passage Formation (PGP)

Name
Forsyth et al. (1996) changed the name Passage Group to Passage Formation. The boundary definitions were unaffected.

Lithology
The Passage Formation (see Browne et al., 1999, fig. 6) is characterised by an alternation of fine- to coarse-grained sandstones (with some conglomerates) and structureless clayrocks (including some high-alumina seatclay, fireclay and bauxitic clay). The clayrocks are commonly mottled reddish brown and greenish grey. Upward-fining cycles predominate over upward-coarsening cycles. Bedded grey and black siltstones and mudstones are also present, and beds of limestone, ironstone, cannel and coal. Marine faunas, diverse and closely spaced at the base, become progressively impoverished upwards. Volcanic rocks also occur.

Genetic interpretation
Fuviodeltaic ('Millstone Grit') facies.

Stratotype
The type section of the Passage Formation occurs between 48.95 and 368.15 m depth in the Saltgreen No. 1 Borehole (BGS Registration Number NS98NW/197) [NS 9196 8608], south of Clackmannan (see Browne et al., 1999, fig. 6, col. 6).

Lower and upper boundaries
The base is taken at the top of the Castlecary Limestone (CAS) or at a plane of disconformity where the base is erosive, both underlain by cyclic sedimentary rocks of the Upper Limestone Formation (Figure 6, Column 4). The top is drawn at the base of the Lowstone Marine Band (LOMB) or a correlative, marking the base of the Scottish Coal Measures Group. It has been suggested (see Read, 1981, Read et al., 2002, pp. 281–282) that, in the area of greatest thickness, the formation includes up to three major disconformities. These apparently cut out strata of mid Arnsbergian, late Arnsbergian to late Alportian, and Kinderscoutian to Marsdenian age and may include the mid Carboniferous break. In some areas, such as Douglas, two unconformities have been proved.

The Passage Formation also occurs in the Thornhill Basin, where the sandstone facies (including grey, white and pink pebbly sandstone with beds of conglomerate) lie conformably or disconformably on the carbonate and siliciclastic rocks of the late Asbian to Brigantian Closeburn Limestone Formation (Yoredale Group) (Figure 6, Column 6), or unconformably on the mainly sandstone turbidites of the Ordovician Glenlee Formation or Silurian Gala Group. They are overlain by the *fluviodeltaic ('Coal Measures') facies* of the Scottish Lower Coal Measures Formation.

Thickness
The maximum thickness of the formation is about 380 m in the Clackmannan area of the Central Coalfield (Browne et al., 1985, p. 10). Generalised thicknesses were given of 0–50 m on Arran (BGS, 1987a) and 152.5 m in the main coalfield area at Machrihanish (BGS, 1996).

Distribution and regional correlation
Throughout the Midland Valley of Scotland, on the Isle of Arran, at Machrihanish, and in the Thornhill Basin and the western part of the Sanquhar Basin.

Age and biostratigraphical characterisation
Namurian to Westphalian (Arnsbergian to Langsettian), lower SO to lower SS Miospore zones. Ammonoids are rare. *Anthracoceras glabrum* and *A. paucilobum* of Arnsbergian (E_2) age have been recovered from shortly above the Castlecary Limestone (see Currie, 1954), and *Homoceratoides* sp. of apparently Kinderscoutian (R_1) age has been found probably within the No.3 Marine Band group (Neves et al., 1965). Neves et al. (1965) located spore assemblages of lower Kinderscoutian (R_1), uppermost Marsdenian (R_2), by implication Yeadonian (G_1), and lower Langsettian (G_2) age in the Scottish Namurian and Westphalian, but found no evidence of the Chokierian (H_1) or Alportian (H_2) stages. The No.2 Marine Band, which is developed in places as a thin, impure limestone (the Roman Cement Limestone) is largely composed of crushed brachiopod valves. The mudstone and ironstone marine bands in the formation have dominantly brachiopods including orthotetoids, *Productus* cf. *carbonarius* and *Schizophoria* cf. *resupinata* and the bivalve *Schizodus taiti* (Wilson, 1967). The nonmarine bivalve genus *Curvirimula* is abundant in the immediate roof mudstone of the Castlecary Limestone, which forms the uppermost bed of the Upper Limestone Formation (see above).

Formal subdivisions
See also Appendix 1. Members of the Passage Formation in ascending stratigraphical order include:

4.5.4.1 Troon Volcanic Member (TVL)

Name
Named after the town of Troon and previously known as the 'Troon Volcanic Formation' and 'Passage Group Lavas'. The present member was defined by Monro (1999); see also Browne et al. (1999).

Lithology
The Troon Volcanic Member comprises olivine-microphyric basalt ('Dalmeny' type).

Stratotype
Type sections occur in the Lugton Water [NS 332 447] where a full sequence through the lavas is exposed, but the total thickness is only about 10 m and the lavas are highly decomposed. Additionally, the member was encountered in the BGS Gailes Farm Borehole (BGS Registration Number NS33SW/1) [NS 32788 34867] from about 32.84 to 207.68 m depth.

Lower and upper boundaries
The lower boundary of the member is taken at the lithological change from sandy clastic strata of the underlying parent Passage Formation to basaltic lava.

The upper boundary of the member is taken at the base of the Ayrshire Bauxitic Clay Member and is defined as the lithological change from olivine-microphyric basalt to bauxitic clay. This boundary is described as normally gradational.

Thickness
Some 10 m thick at Lugton Water and about 175 m in the BGS Gailes Farm Borehole (see above).

Distribution and regional correlation
North and central Ayrshire

Age
Namurian

4.5.4.2 Ayrshire Bauxitic Clay Member (ABC)

Name
Formerly known as the Ayrshire Bauxitic Clay Formation (Monro, 1982). See also Monro (1999); Browne et al. (1999).

Lithology
Pale grey to buff clayrock, of massive habit with conchoidal fracture, hard and compact. Texture ranges from fine-grained to oolitic, pisolitic and coarsely clastic. Mineralogically, 'bauxitic in the chemical sense of containing more Al_2O_3 than can be accommodated with SiO_2 to give kaolinite'. The bauxitic clay may be considered a flint clay. The member may also contain sphaerosiderite, fossil plant fragments and tree trunks and include beds of seatrock, coal and mudstone.

Stratotype
The type section is the Saltcoats shore [NS 2401 4150]. Here the section into the bauxitic clay is about 1.2–1.5 m thick and consists of a massive, pale grey, to buff clayrock with steep joints. Dark grey plant scraps are common and ooliths and pisoliths are present. Sphaerosiderite is common and varies in abundance through the bed. There is a gradational passage into an underlying clayrock, which further grades into basaltic lavas of the Troon Volcanic Member (Monro, 1999, p. 65).

Lower and upper boundaries
The base is taken at the lithological change from olivine-microphyric basalt of the underlying Troon Volcanic Member and is gradational from basalt through clayrock rich in sphaerosiderite to bauxitic clay. The base is considered to be stratiform, although it may be obscured by later lateritic weathering or diagenesis and some in-situ alteration of basalt to bauxitic clay may have occurred.

The top of the member is taken at the base of the Scottish Lower Coal Measures. In Ayrshire this is marked by the Raise Coal seam that lies immediately above the Ayrshire Bauxitic Clay.

Thickness
Up to about 20 m

Distribution and regional correlation
Limited to north Ayrshire and parts of central Ayrshire.

Age
Namurian to Westphalian (Langsettian)

4.6 SCOTTISH COAL MEASURES GROUP (CMSC)

The 'Coal Measures' were regarded as a lithostratigraphical group by Forsyth et al. (1996). The epithet 'Scottish' was proposed by Waters et al. (2007) to distinguish the 'Coal Measures' of Scotland from those of England and Wales to account for the different definitions of the base of the Upper Coal Measures and the base of the groups.

The Scottish Coal Measures Group (Figure 5; Browne et al., 1999, fig. 7) *(fluviodeltaic ('Coal Measures') facies)* is divided, in ascending sequence, into Scottish Lower, Middle and Upper Coal Measures formations. Lithologically the group comprises repeated cycles of sandstone and mudstone with coal and seatearth, arranged in both upward-fining and upward-coarsening units. The strata are generally grey in colour but are extensively reddened towards the top. A wide range of alluvial and lacustrine environments of deposition is represented. These include wetland forest and soils (coal and seatrock), floodplain (planty or rooted siltstone and mudstone), river and delta distributary channel (thick sandstones), prograding deltas (upward-coarsening sequences) and shallow lakes (mudstones with nonmarine faunas). Marine bands are rare but provide important stratigraphical markers. Economically important coal seams are common in the Lower and Middle Coal Measures, some of which can be correlated between coalfields.

The base of the group in the Midland Valley of Scotland is now taken at the base of the Lowstone Marine Band, its local correlative, or at a plane of disconformity. This is at a slightly higher stratigraphical level than in England and Wales, where the lower boundary lies at the base of the Subcrenatum Marine Band at the base of the Langsettian (Westphalian A) Stage. This horizon has not been recognised in Scotland though it may correlate with one of the higher marine bands of the Passage Formation (No. 6) and with the Porteous Marine Band of the Douglas Coalfield. An unconformity of regional extent beneath Permian strata marks the top of the Scottish Coal Measures Group in the Midland Valley of Scotland.

The Scottish Coal Measures Group occurs in the Midland Valley of Scotland and adjacent areas including Sanquhar, Thornhill, Machrihanish, Arran, Stranraer and Morvern. Probably exceeding 1790 m in the Midland Valley of Scotland, it is Langsettian to Asturian (Westphalian D) in age. It is considered that no Stephanian rocks have been identified in the Midland Valley of Scotland. However, see Wagner (1983), details provided below.

4.6.1 Scottish Lower Coal Measures Formation (LCMS)

Name
The epithet 'Scottish' is applied to the Lower Coal Measures to distinguish them from the formation in England and Wales on account of the different definition of the base of the formation (and group) (Waters et al., 2007).

Lithology
The Scottish Lower Coal Measures comprise sandstone, siltstone and mudstone in repeated cycles, which most commonly coarsen-upwards, but also fine-upwards, with seatearth and coal at the top. The mudstones and siltstones are usually grey to black, while the sandstone is fine- to medium-grained and off-white to grey. Coal seams are common and many exceed 0.3 m in thickness. Minor lithologies include cannel and blackband and clayband ironstone, the latter nodular as well as bedded. Bands composed mainly of nonmarine bivalves, the characteristic 'musselbands', usually occur in mudstone or ironstone. Upward-fining parts of the succession, dominated by fine- to coarse-grained sandstone, are widely developed and thick multistorey sandstones are a feature.

Genetic interpretation
Fluviodeltaic ('Coal Measures) facies. The depositional environments include prograding deltas (upward-coarsening sequences), floodplain (planty or rooted siltstone and mudstone), shallow lakes (mudstones with nonmarine faunas), river and delta distributary channel (thick sandstones) and wetland forest and soils (coal and seatrock). Marine bands will have resulted from marine transgressions.

Stratotype
The type section of the formation is between 187.50 and 301.19 m depth in the Clyde Bridge, Motherwell Borehole (BGS Registration Number NS75NW/68) [NS 7380 5622] in the west Central Coalfield (see Browne et al., 1999, fig. 7, col. 4).

Lower and upper boundaries
The base of the Scottish Lower Coal Measures is taken at the base of the Lowstone Marine Band (LOMB), its local correlative, or at a plane of disconformity. It is underlain by cyclical sedimentary rocks of the Passage Formation (Figure 6, Column 4). This is at a slightly higher stratigraphical level than in England and Wales (see Section 4.6 above).

The top of the formation lies at the base of the Vanderbeckei (Queenslie) Marine Band (VDMB), or its local equivalent, at the base of the Scottish Middle Coal Measures.

Thickness
The maximum thickness of the formation is between 220 and 240 m in the Sealab No. 2 Borehole (BGS Registration Number NT38SW/1) [NT 3272 8449] in the Firth of Forth from about 220 to 500 m depth. The variation in thickness is a function of correction for stratal dip (see Browne et al., 1999, p. 18). Generalised thickness were given of about 65 m on Arran (BGS, 1987a) and 67.5 m in the main coalfield area at Machrihanish (BGS, 1996).

Distribution and regional correlation
The Midland Valley of Scotland, on the Isle of Arran, at Machrihanish, and in the small basins of the Southern Uplands (excluding Solway).

Age and biostratigraphical characterisation
Westphalian A (Langsettian). SS to RA Miospore zones of Clayton et al. (1977). The most abundant fauna of the formation is the nonmarine bivalves of the upper Lenisulcata, Communis and lower Modiolaris chronozones (see Trueman and Weir, 1946; Calver, 1969). Genus *Carbonicola* dominates and includes, for example, in the upper Lenisulcata Chronozone *C. extenuata*, in the Communis Chronozone *C. polmontensis, C. pseudorobusta* and *C. oslansis*, and in the lower Modiolaris Chronozone *C. venusta* (see Cameron and Stephenson, 1985, fig. 29). The Lowstone Marine Band at the base of the formation is commonly developed as a *Lingula* band as too is the small group of up to three marine bands present near the top of the Lenisulcata Chronozone.

4.6.2 Scottish Middle Coal Measures Formation (MCMS)

Name
The epithet 'Scottish' is applied to the Middle Coal Measures to distinguish them from the formation in England and Wales (Waters et al., 2007).

Lithology
The Scottish Middle Coal Measures comprise similar lithologies to the Scottish Lower Coal Measures (see Section 4.6.1 above).

Genetic interpretation
Fluviodeltaic ('Coal Measures') facies. The depositional environments include prograding deltas (upward-coarsening sequences), floodplain (planty or rooted siltstone and mudstone), shallow lakes (mudstones with non-marine faunas), river and delta distributary channel (thick sandstones) and wetland forest and soils (coal and seatrock). Marine bands resulted from marine transgressions.

Stratotype
The type section of the upper part of the Scottish Middle Coal Measures (from the base of 'Skipsey's Marine Band' marking the top of the formation, to the Drumpark Marine Band) is from 9.5 to 26.0 m depth in the Dalzell Works, Motherwell Bore No. 4 (BGS Registration Number NS75NE/316) [NS 7571 5672]. For the lower part of the formation (from the Drumpark Marine Band to the 'Queenslie Marine Band' at the base) the type section is from 18.29 to 187.50 m depth in the Clyde Bridge, Motherwell Borehole (BGS Registration Number NS75NW/68) [NS 7380 5622]. A section containing a full development of the Vanderbeckei (Queenslie) Marine Band (VDMB) is present from 15.24 to 37.49 m depth in the Moffat Mills Water Bore (BGS Registration Number NS76SE/77A) [NS 7898 6499] east of Airdrie. All three of these sections are in the west Central Coalfield (see Browne et al., 1999, fig. 7, col. 4).

Lower and upper boundaries
The base of the Scottish Middle Coal Measures is taken at the base of the Vanderbeckei (Queenslie) Marine Band (VDMB) or its local equivalent, overlying cyclical sedimentary rocks of the Scottish Lower Coal Measures (Figure 6, Column 4). Where this horizon cannot be established, the closest approximation based on nonmarine bivalve faunas is taken. In North Ayrshire this is the top of the Shale Coal.

The top of the Scottish Middle Coal Measures is drawn at the base of the Aegiranum (Skipsey's) Marine Band (AGMB), forming the base of the Scottish Upper Coal Measures.

Thickness
The maximum thickness of the formation is about 350 m based on the dip corrected section of the Sealab No. 1A Borehole (BGS Registration Number NT38NW/31) [NT 3230 8568] in the Firth of Forth from about 32 to 340 m depth, and exposures on the Fife Coast between West Wemyss [NT 321 947] and Buckhaven [NT 351 976]. Generalised thicknesses were given of about 50 m on Arran (BGS, 1987a) and 95 m in the main coalfield area at Machrihanish (BGS, 1996).

Distribution and regional correlation
The Midland Valley of Scotland, on the Isle of Arran, at Machrihanish, and in the small basins of the Southern Uplands (excluding the Solway).

Age and biostratigraphical characterisation
Westphalian B (Duckmantian). NJ Miospore Zone of Clayton et al. (1977). The most abundant fauna of the formation is the non-marine bivalves of the upper Modiolaris and Lower Similis-Pulchra chronozones

(see Trueman and Weir, 1946; Calver, 1969). Genus *Anthracosia* dominates and includes, for example, in the upper Modiolaris Chronozone *A. ovum* and *A. phrygiana*, and in the Lower Similis-Pulchra Chronozone *A. caledonica* and *A. atra* (see Cameron and Stephenson, 1985, fig. 29). The Vanderbeckei Marine Band at the base of the formation attains 'goniatite-pectenoid', 'productoid' and *Lingula* facies. Its varied fauna may include in places the ammonoid *Anthracoceras* sp. with the bivalve *Dunbarella* sp., brachiopods (including productoids), or just *Lingula* (see Calver, 1969). A group of up to four marine bands occurs in the Lower Similis-Pulchra Chronozone, usually only with *Lingula*, but with bivalves present in a few areas.

4.6.3 Scottish Upper Coal Measures Formation (UCMS)

Name
The epithet 'Scottish' is applied to the Upper Coal Measures to distinguish them from the formation in England and Wales on account of the different definition of the base of the formation (Waters et al., 2007).

Lithology
The Scottish Upper Coal Measures comprise sandstone, siltstone and mudstone in repeated cycles, which most commonly fine-upwards. The mudstone occurs most commonly as structureless beds and seatearth. The sequences are usually reddish brown and purplish grey. Coal seams are not common, are normally less than 0.3 m thick and may be replaced, totally or in part, by red (haemetitic) and dark grey carbonaceous diagenetic limestone. Brecciation textures may occur and nodular pedogenic carbonate is present in some clay/silt grade rocks in Fife.

Genetic interpretation
Fluviodeltaic ('Coal Measures) facies. The reddish brown and purplish grey colours are due to oxidation of originally grey strata beneath the Permian unconformity, but some reddening may be primary, related to periods of lowered water table during deposition.

Stratotype
The partial type section of the Scottish Upper Coal Measures is from surface to 285 m depth in the Hallside Borehole (BGS Registration Number NS65NE/66) [NS 6693 5974] south-east of Glasgow in the west Central Coalfield (see Browne et al., 1999, fig. 7, col. 4). Reference sections are provided by the Killoch No. 1 Bore (BGS Registration Number NS42SE/7) [NS 4756 2023] from the sub-Permian unconformity at 39.9 m depth to an 'ashy conglomerate' at 123.6 m depth (the strata at 63.9 m depth including *Anthraconaia pruvosti* of the undifferentiated Phillipsii and Tenuis chronozones), and the Killoch No. 1A Bore (BGS Registration Number NS42SE/8) [NS 4758 2024] which continues the section from 123.6 m depth at the 'ashy conglomerate' mentioned above, to the Aegiranum (Skipsey's) Marine Band at 481.3 depth.

Lower and upper boundaries
The base of the formation is drawn at the base of the Aegiranum (Skipsey's) Marine Band (AGMB) (Forsyth et al., 1996; Browne et al., 1999, p.19), which is underlain by cyclical sedimentary rocks of the Scottish Middle Coal Measures (Figure 6, Column 4). In Fife and Lothian this bed has been tentatively recorrelated with the 'Buckhaven *Planolites* Band' and the Montague Bridge Marine Band (see Browne et al., 1999, and references therein). The Aegiranum Marine Band is at a lower stratigraphical level than the Cambriense Marine Band, the top of which marks the base of the Pennine Upper Coal Measures.

The top of the Scottish Upper Coal Measures is marked by an erosional unconformity of regional extent beneath Permian strata.

Thickness
Based on the interpretation of commercial seismic data the maximum thickness of the formation probably exceeds 1200 m under the Firth of Forth. Up to 460 m in central Ayrshire. A generalised thickness of 280 m in the main coalfield area at Machrihanish was given by BGS (1996).

Distribution and regional correlation
The Midland Valley of Scotland, Machrihanish and the small basins of the Southern Uplands (excluding Solway).

Age and biostratigraphical characterisation
Westphalian C–D (Bolsovian–Asturian). The fauna of the formation includes, in its lower parts, nonmarine bivalves of the Upper Similis-Pulchra and the combined Phillipsii and Tenuis chronozones. *Anthraconaia adamsi, A. spathulata* and *Naiadites hindi* may, for example, occur in the Upper Similis-Pulchra Chronozone, and *A. pruvosti, Anthraconauta phillipsii* and *An. tenuis* in Phillipsii/ Tenuis strata (see Trueman and Weir, 1946; Mykura, 1967; Calver, 1969; Cameron and Stephenson, 1985, fig. 29). The Aegiranum Marine Band at the base of the formation has a rich and varied 'benthonic and cephalopod' fauna with calcareous brachiopods, ammonoids and nautiloids (see Calver, 1969). There is no evidence of marine conditions above the Upper Similis-Pulcra Chronozone. In the upper part of the Upper Coal Measures only scarce plant remains and the annelid *Spirorbis* sp. are found (Cameron and Stephenson, 1985). Floras indicative of the Bolsovian and Asturian stages have been identified (Scott, 1976).

Plant impressions from a sedimentary intercalation in the Mauchline Volcanic Formation exposed in the River Ayr near Stairhill [NS 4521 2423] were formerly regarded as being characteristic of an Asturian (Westphalian D) or more likely late Stephanian age (see Wagner, 1966; Mykura, 1967, pp. 25, 27, 80; Ramsbottom et al., 1978, fig. 14:4, p. 62). However, with further evidence, including the presence of *Lobatopteris geinitzii* (von Gutbier, emend. Sterzel) comb. nov., Wagner (1983; see also Brand, 1983, p. 175 and references therein) was able to compare the assemblage with lower Rotliegend floras of central Europe and give it a probable early Permian (early Autunian; Asselian) age, which is still accepted (see Cleal and Thomas, 1995, pp. 229–233). However, biostratigraphical problems associated with geologically long-lived plant genera, phylogenic variation, climate change and the potential of mixed diachronous and refugial floral assemblages at the Carboniferous–Permian boundary make desirable an independent reinterpretation of the fossil flora and palynology at the Stairhill site (Hilton in Dean, 2002).

5 Carboniferous rocks of the Southern Uplands of Scotland

5.1 THE SANQUHAR AND THORNHILL BASINS

The Sanquhar and Thornhill basins (Figure 6, Columns 5, 6) occupy much of the valley of the River Nith. At Sanquhar the beds mostly belong to the Scottish Coal Measures (the Scottish Lower, Middle and Upper Coal Measures formations all being present), but small thicknesses of the Clackmannan Group (undivided) and the Passage Formation are present below an unconformity. At Thornhill, rocks of the Yoredale Group (Closeburn Limestone Formation), Clackmannan Group (Enterkin Mudstone and Passage formations) and Scottish Coal Measures Group (including the Scottish Lower, Middle and Upper Coal Measures formations) are recognised.

5.2 YOREDALE GROUP (YORE)

The Yoredale Group, as defined in full in Section 6.7, is restricted to the Thornhill Basin, with a single formation, the Closeburn Limestone Formation.

5.2.1 Closeburn Limestone Formation (CLO)

Name
From Closeburn, south of Thornhill, Dumfries and Galloway. Defined as a formation by McMillan (2002; see also Menteath, 1845; Pringle and Richey, 1931; Jones, 1994).

Lithology
The formation consists dominantly of limestone and dolomitic limestone with interbedded sandstone, siltstone and mudstone.

Genetic interpretation
The fauna (see below) of the limestone indicates that it is marine.

Stratotype
A partial type section occurs in Upper Closeburn Quarry (Croalchapel Quarry) [NX 9100 9170 to 9120 9130]. This section is in the upper part of the formation lying above the upper of two limestones separated by 5.5 m of strata. These limestone beds were noted by Geikie (1877) but are not visible today. Pringle and Richey (1931) indicated that about 12 m of sandstone, shale and fireclay lie above the upper limestone. McMillan (1991, and references therein) provided logs of sections recorded in Croalchapel Quarry in 1962 at [NX 9109 9159] with siltstone (2.4 m), limestone (0.5 m) and sandstone (7.2 m) and at [NX 9109 9150] with siltstone (0.7 m), mudstone (0.1 m) and sandstone (1.8 m). A good section in the Closeburn Limestone Formation was cored in the BGS Closeburn Borehole (BGS Registration Number NX99SW/2) [NX 9021 9145] between about 6.5 and 29.7 m depth, but the presence of unconformities at both the top and bottom of this section suggest the full thickness of the formation is not represented.

Lower and upper boundaries
The unconformable base of the formation is taken where the greywacke sandstone of the underlying Silurian Gala Group passes upward into dominantly limestone strata.

The top of the formation is apparently conformable or disconformable with the base of the overlying grey, white and pink pebbly sandstone with beds of conglomerate of the Passage Formation (Figure 6, Column 6).

Thickness
The maximum thickness of the formation is about 25 m.

Distribution and regional correlation
The formation is limited to the Thornhill Basin. The fauna of the limestones suggests correlation with strata in the upper part of the Tyne Limestone Formation or Alston Formation (Yoredale Group) of the Solway Basin.

Age and biostratigraphical characterisation
Late Visean (late Asbian to Brigantian). The formation has corals, brachiopods (incuding productoids, gigantoproductoids and orthotetoids), gastropods, bivalves (including nuculids and various species of *Edmondia* and *Leiopteria*), orthocone and coiled nautiloids (including large specimens of the former) and fish. The overall aspect of the fauna suggests a late Visean (late Asbian, B_2 to Brigantian, P_2) age (see McMillan, 2002; Table 2).

5.3 CLACKMANNAN GROUP (CKN)

The Clackmannan Group, as defined in full in Section 4.5, is present in both the Sanquhar and Thornhill basins.

SANQUHAR BASIN

In the Sanquhar Basin the Clackmannan Group has not been formally divided into constituent formations. However, lower and upper sequences within the group are recognised.

5.3.1 Clackmannan Group (CKN) (undivided)

Name
See Section 4.5 for definition. Details relevant to the Sanquhar Basin are provided below:

Lithology
The lower sequence, formerly called the 'Carboniferous Limestone Series', comprises basal conglomerate or breccia that passes up into sandstone, which in turn is overlain by fossiliferous, grey, calcareous mudstone and siltstone with local impure limestone beds and thin coals and seatclays. The unit shows marked lateral variations in lithology. The upper sequence, formerly called the 'Millstone Grit Series', comprises coarse-grained, greenish sandstone at the base, superseded by greyish-white, cross-bedded sandstones, grey, brown and purple siltstones, and carbonaceous mudstones with marine bands overlain by kaolinitic beds. The unit shows lateral variations in lithology, and local unconformities are present.

Genetic interpretation
The marked lateral variations in lithology in the lower sequence, suggest deposition probably occurred in semi-isolated sub-basins during the period of maximum marine transgression. The lateral variations in lithology and the presence of local unconformities and marine bands in the upper unit, suggest local deposition of condensed sequences in marginal deltaic conditions.

Stratotype
Reference sections are exposed for the lower sequence in Howat's Burn [NS 828 097] near Sanquhar with conglomerate, sandstone, calcareous mudstone and shelly fossiliferous limestone, and for the upper sequence in Barr Burn [NS 759 089] with sandstones, siltstones and mudstones (including a probable equivalent of the Polhote Marine Band), Polbroc Burn [NS 7293 1029] with conglomerate and sandstone including the Polhote Marine Band, and Kello Water [NS 730 104] with prominent kaolinitic beds.

Lower and upper boundaries
The base of the Clackmannan Group (undivided) is unconformable on the mainly greywacke sandstones of the Ordovician Tappins and Barrhill groups. The top of the lower sequence is unconformably overlain by the cyclical sandstone, siltstone, mudstone, seatearth and coal of the basal Scottish Coal Measures Group (Figure 6, Column 5), whilst the top of the upper sequence is taken at the base of Tait's Marine Band (TMB) (Davies, 1970) at the base of the Scottish Lower Coal Measures Formation.

Thickness
The lower sequence is up to 10 m thick, whilst the upper sequence is up to 30 m thick.

Distribution and regional correlation
The lower sequence has been proved in the eastern part of the Sanquhar Basin. It has not been encountered in boreholes in the centre and west of the basin. It possibly correlates with Visean strata in the north of the Thornhill Basin namely the Enterkin Mudstone Formation (McMillan, 2002) or the Lower Limestone Formation of the Midland Valley (Browne et al., 1999). Locally, the upper succession is limited to the western part of the Sanquhar Basin. Equivalents extend from the Midland Valley of Scotland into the Thornhill Basin (McMillan and Brand, 1995; Smith, 1999; McMillan, 2002). Davies (1970) concluded that the bulk of the strata could be correlated with the upper part of the Upper Limestone Formation or the lower part of the Passage Formation of the Midland Valley of Scotland. Subsequently, local erosion occurred and then deposition continued up into the Langsettian, when Tait's Marine Band was deposited.

Age and biostratigraphical characterisation
The lower sequence is late Visean, P_1–P_2 ammonoid biozones (Wilson in Davies, 1970) or P_2 (Greig, 1971). The upper sequence is Arnsbergian to Kinderscoutian, E_2–R_1 ammonoid biozones, on macrofaunal evidence, and Pendleian (E_1) to Langsettian, on microfloral evidence (Davies, 1970).

THORNHILL BASIN

In the Thornhill Basin the Clackmannan Group comprises the Enterkin Mudstone and Passage formations:

5.3.2 Enterkin Mudstone Formation (ENT)

Name
From Enterkin Burn, north of Carronbridge, Dumfries and Galloway. Defined as a formation by McMillan (2002; see also Simpson and Richey, 1936).

Lithology
The formation consists dominantly of purple-grey mudstone and siltstone with interbedded sandstone.

Genetic interpretation
This *mixed shelf carbonate and deltaic ('Yoredale') facies* unit formed in a marine–intertidal environment. The mudstones contain a marine fauna.

Stratotype
The type section is in the Enterkin Burn [NS 8706 0526] where up to 15 m of interbedded red-brown and purple mudstone and siltstone, and purplish red sandstone and seatearth are exposed (McMillan, 2002; Simpson and Richey, 1936, table 3).

Lower and upper boundaries
The base of the formation is unconformable on the mainly sandstone-dominated turbidites of the Ordovician Glenlee Formation, Leadhills Supergroup.

The top of the formation is conformable with the base of the Scottish Lower Coal Measures Formation (Figure 6, Column 6) comprising sandstones, siltstones and mudstones, with seatearths.

Thickness
Up to 15 m of the formation are exposed at the type section in the Enterkin Burn [NS 8706 0526] (McMillan, 2002; Simpson and Richey, 1936, table 3).

Distribution and regional correlation
The formation is restricted to the Thornhill Basin. The mudstones contain a fauna, that suggests possible correlation with the Clackmannan Group (undivided) Visean strata of the Sanquhar Basin.

Age and biostratigraphical characterisation
Visean to Namurian (Brigantian to early Pendleian). The mudstones contain a brachiopod, bivalve and nautiloid fauna, which may be of similar age to the fauna of the Closeburn Limestone Formation.

5.3.3 Passage Formation (PGP)

Name
From the Passage Formation of the Midland Valley of Scotland (see Section 4.5.4 for full definition). Details relevant to the Thornhill Basin are provided below.

Lithology
The sandstone facies includes grey, white and pink pebbly sandstone with beds of conglomerate.

Stratotype
Partial type sections are defined at Towburn Wood, Closeburn [NX 915 939] and in the BGS boreholes at Crichope Linn (BGS Registration Number NX99NW/1) [NX 9093 9551] and Carronbank (BGS Registration Number NS80SE/1) [NS 8816 0127].

Lower and upper boundaries
The base of the formation is apparently conformable, or disconformable, on the limestone and dolomitic limestone with interbedded sandstone, siltstone and mudstone of the Closeburn Limestone Formation (Figure 6, Column 6), or unconformable on the mainly sandstone turbidites of the Lower Palaeozoic Glenlee Formation (Ordovician) and Gala Group (Silurian).

The base of the nonmarine fossiliferous Scottish Lower Coal Measures Formation conformably overlies the Passage Formation, which lacks fossils.

Thickness
The maximum proved thickness is 43.9 m from 147.7 to 191.6 m depth (based on McMillan and Brand, 1995; McMillan, 2002) in the BGS Crichope Linn Borehole (see above).

Distribution and regional correlation
The Thornhill Basin. Equivalents occur in the Midland Valley of Scotland and the western part of the Sanquhar Basin.

Age and biostratigraphical characterisation
Pre-Westphalian. Whilst there is no known fauna in the Thornhill Basin to provide a biostratigraphical age, the Passage Formation in the Midland Valley of Scotland is Namurian to Westphalian (Arnsbergian to Langsettian).

Formal subdivisions
See also Appendix 1. Member of the Passage Formation:

5.3.3.1 Townburn Sandstone Member (TWN)

Name
The Townburn Sandstone Member derives its name from its reference section (see *Stratotype* below). Previous names include the Crichope Sandstone Member and Passage Group (undivided).

Lithology
Mainly medium- to coarse-grained sandstone with subsidiary conglomerate and pebbly sandstone.

Genetic interpretation
The member comprises fluvial-channel sands deposited in low sinuousity braided channels. (McMillan, 2002, p. 74; Jones, 1994).

Stratotype
The type section is between 161.39 and 202.94 m depth in the Crichope Linn Borehole (BGS Registration Number NX99NW/1) [NX 9093 9551]. A reference section is the Town Burn, Townburn Wood, Closeburn, 650 m north-east of Barraby Farm [NX 9146 9390]. McMillan (2002, p. 71) described this exposure as one of several localities in the Thornhill district where sequences up to 15 m thick of pebbly sandstone and beds of conglomerate can be seen (see also Simpson and Richey, 1936).

Lower and upper boundaries
The lower boundary is unconformable on the mainly sandstone turbidites of the Lower Palaeozoic Glenlee Formation (Ordovician) and Gala Group (Silurian), though it rests locally on the Lower Carboniferous limestone and dolomitic limestone with interbedded sandstone, siltstone and mudstone of the Closeburn Limestone Formation, or the mudstone and siltstone with interbedded sandstone of the Enterkin Mudstone Formation.

The base of the nonmarine fossiliferous Scottish Lower Coal Measures Formation conformably overlies the fossil-free Townburn Sandstone Member.

Thickness
Some 41.55 m in the Crichhope Linn Borehole (see above).

Distribution and regional correlation
Thornhill Basin at Closeburn, Keir, Eccles, River Nith (Drumlanrig), Hapland, Fellend, Townhead and Morton Wood.

Age
Namurian to Westphalian.

5.4 SCOTTISH COAL MEASURES GROUP (CMSC)

The Scottish Coal Measures Group, as defined in full in Section 4.6 is present in both the Sanquhar and Thornhill basins, where it is again divided into Lower, Middle and Upper formations.

Lithologically the group comprises a cyclical alternation of sandstone, siltstone and mudstone with coal seams well developed in the middle of the sequence. The rocks are typically grey, but they redden towards the top of the group as they approach the Permian (Variscan) unconformity. The lithofacies reflect steady basin subsidence in a generally deltaic environment with periodic marine incursions. Rare marine bands, *Planolites* bands and especially non-marine bivalve 'musselbands' are important for correlation.

There is no formally defined Lowstone Marine Band equivalent at the base of the Scottish Coal Measures Group in these basins. In the western part of the Sanquhar Basin the base is taken at the base of Tait's Marine Band (TMB), whilst in the east it occurs at an unconformity above the mainly sandstone, calcareous mudstone and siltstone of the older sequence of the Clackmannan Group (undivided). Generally in the Thornhill Basin the nonmarine fossiliferous Scottish Coal Measures Group overlies the nonfossiliferous sandstone facies of the Passage Formation. The top of the group in both basins is the Variscan Unconformity. At Sanquhar this is partially overlain by the olivine basalts of the Lower Permian Carron Basalt Formation, whilst in the Thornhill Basin the Carron Basalt Formation and red sandstones of the Lower Permian Thornhill Sandstone Formation occur immediately above it.

The maximum thicknesses of the Scottish Coal Measures Group in the Southern Uplands region are about 555 m in the Sanquhar Basin and about 141 m in the Thornhill Basin. Based on the presence of nonmarine bivalve 'musselbands', both areas include strata of Langsettian (Westphalian A) to Bolsovian (Westphalian C) age.

The Scottish Coal Measures Group is also present in the Stranraer Basin, and outcrops on the eastern side of the northern Rhins peninsula between Jamieson's Point [NX 032 711] and Lochans [NX 060 572]. The sequence, formerly referred to the now obsolete Leswalt Formation, comprises about 30 m of grey, red, and mottled yellow-brown sandstone, interbedded with purplish grey shale, rare seatclay, and a single pervasively weathered olivine-basalt sheet. The strata lie unconformably on steeply inclined Lower Palaeozoic greywackes, and become more arenaceous upwards. A flora from thin interbedded siltstones seems most likely to be of Westphalian age, and the strata belong to either the Scottish Lower or Middle Coal Measures formations. The Scottish Upper Coal Measures Formation appears to be missing here, so the upper boundary of the Scottish Coal Measures Group is considered unconformable beneath beds of red sandstone and breccia of Permian age (see Stone, 1995, and references therein).

5.4.1 Scottish Lower Coal Measures Formation (LCMS)

Name
From the Lower Coal Measures of the Midland Valley of Scotland (see Browne et al., 1999; Davies, 1970; Forsyth et al., 1996; McMillan, 2002; McMillan and Brand, 1995; Simpson and Richey, 1936; Smith, 1999; Waters et al., 2007).

Lithology
In general, the formation comprises cyclical successions of sandstone, siltstone, mudstone, seatrock and coal. At Sanquhar the lower parts of the formation are mainly arenaceous whilst the upper parts contain coals.

Genetic interpretation
Generally fluviodeltaic

Stratotype
Reference sections of the formation in the Thornhill Basin are provided by the BGS Crichope Linn Borehole (BGS Registration Number NX99NW/1) [NX 9093 9551] from 98.0 to 147.7 m depth, and the BGS Carronbank Borehole (BGS Registration Number NS80SE/1) [NS 8816 0127] from about 63 to 122 m depth. In the Sanquhar Basin a reference section is at Kello Water [NS 734 106].

Lower and upper boundaries
In the Thornhill Basin, the base of the nonmarine fossiliferous Scottish Lower Coal Measures conformably overlies the nonfossiliferous sandstone facies of the Passage Formation (Figure 6, Column 6). There is no formally defined Lowstone Marine Band equivalent, but in the BGS Crichope Linn Borehole (see above) the base of the Scottish Lower Coal Measures is taken below beds with *Planolites* sp., below the lowest nonmarine 'musselband'.

In the western part of the Sanquhar Basin, where the formation overlies the Clackmannan Group (undivided) (Figure 6, Column 5), the local base of the Scottish Lower Coal Measures is taken at the Tait's Marine Band (TMB) recognised by Davies (1970), as here, again, there is no formally defined Lowstone Marine Band.

Where the Scottish Lower Coal Measures overlie the former 'Carboniferous Limestone Series' (Clackmannan Group, undivided) in the eastern part of the Sanquhar Basin, the boundary is unconformable. The irregular base, thickness and development of coals towards the base of the formation at Sanquhar suggests that initial deposition of coal measures overstepped on to the northern margins of the Southern Upland Massif.

The top of the formation in both basins is conformable with the base of the Scottish Middle Coal Measures and taken at the base of the Vanderbeckei Marine Band (VDMB).

Thickness
The maximum proved thickness of the formation is 50 m in the BGS Crichope Linn Borehole (see above). At Sanquhar, the succession is about 120 m thick. The thickness and development of coals within the formation at Sanquhar is less than in the adjacent Midland Valley but greater than that around Thornhill.

Distribution and regional correlation
The formation is present in the Thornhill and Sanquhar basins, where correlation with the Midland Valley of Scotland and Solway Basin is on the basis of nonmarine 'musselbands'.

Age and biostratigraphical characterisation
Langsettian (Westphalian A) based on the presence of nonmarine 'musselbands' of the upper *lenisulcata*, *communis* and lower *modiolaris* biozones. While there is a lithological similarity with the successions elsewhere, the local bases of the formation are not strictly equivalent as the same basal marine band cannot be identified across the area.

5.4.2 Scottish Middle Coal Measures Formation (MCMS)

Name
From the Middle Coal Measures of the Midland Valley of Scotland (see Browne et al., 1999; Davies, 1970; Forsyth et al., 1996; McMillan, 2002; McMillan and Brand, 1995; Smith, 1999; Simpson and Richey, 1936; Waters et al., 2007).

Lithology
In general, the formation consists of a cyclical sequence of sandstone, siltstone, mudstone, seatrock and coal.

Genetic interpretation
Generally fluviodeltaic. The widespread development of regular, well-developed coal seams suggests steady basin subsidence in a deltaic environment.

Stratotype
Type sections of the formation in the Thornhill Basin are defined in the BGS boreholes at Crichope Linn (BGS Registration Number NX99NW/1) [NX 9093 9551] from 22.5 to 98.0 m depth, and Carronbank (BGS Registration Number NS80SE/1) [NS 8816 0127] where the lower 45 m of the Scottish Middle Coal Measures Formation are seen between about 18 and 63 m depth. A reference section in the Sanquhar Basin is Lagrae Burn [NS 703 148], where sandstones and mudstones with seatearths and coals are seen. Davies (1970) referred to former workings in the Calmstone and Creepie coals, mudstones with nonmarine bivalves and *Estheria* sp., and the Bankhead, Eastside and Skipsey's (Vanderbeckei) marine bands, the last mentioned including a fauna of brachiopods, molluscs and conodont elements.

Lower and upper boundaries
In both basins, the base of the Scottish Middle Coal Measures conformably overlies the Scottish Lower Coal Measures and is taken at the base of the Vanderbeckei Marine Band (VDMB) (Figure 6, Columns 5, 6).

The top of the formation is conformable with the base of the Scottish Upper Coal Measures and the boundary is taken at the base of the Aegiranum Marine Band (AGMB).

Thickness
In the Thornhill Basin, the maximum proved thickness of the formation is 75.5 m in the BGS Crichope Linn Borehole (see above). In the Sanquhar Basin the formation is about 135 m thick.

Distribution and regional correlation
The formation is present in the Thornhill and Sanquhar basins, where correlation with the Midland Valley of Scotland and Solway Basin is on the basis of nonmarine 'musselbands'.

Age and biostratigraphical characterisation
Duckmantian (Westphalian B) based on the presence of nonmarine 'musselbands' of the upper part of the *modiolaris* and Lower *similis-pulchra* biozones.

5.4.3 Scottish Upper Coal Measures Formation (UCMS)

Name
From the Upper Coal Measures of the Midland Valley of Scotland (see Browne et al., 1999; Davies, 1970; Forsyth et al., 1996; McMillan, 2002; McMillan and Brand, 1995; Simpson and Richey, 1936; Smith, 1999; Waters et al., 2007).

Lithology
In the Thornhill Basin the formation consists dominantly of purple and red siltstone and mudstone with thin sandstone and seatearth. In the Sanquhar Basin the formation is fairly well developed and comprises mainly typical grey Coal Measures beds with mudstones, siltstones and sandstones and subordinate thin coals in a succession that tends to be reddish towards the top.

Stratotype
The type section of the formation in the Thornhill Basin is defined in the BGS Borehole at Crichope Linn (BGS Registration Number NX99NW/1) [NX 9093 9551] between 7.2 and 22.5 m depth. Reference sections in the Sanquhar Basin are provided by Lagrae Burn [NS 707 141] and Tower Burn [NS 754 122]. Lagrae Burn shows mudstones, siltstones, sandstones, seatearths and thin coals, with faunas notably including nonmarine bivalves and *Planolites ophthalmoides*. The Lagrae Marine Band has foraminifers, *Lingula mytilloides, Curvirimula* sp. and *Planolites ophthalmoides*, and Davies (1970, p. 77) suggested it may correlate with the standard Edmondia Marine Band of the Pennine region. Tower Burn has sandstones, mudstones, and seatclays with thin coals. The *phillipsi* Biozone is represented there (Simpson and Richey, 1936).

Lower and upper boundaries
The base of the Scottish Upper Coal Measures in both basins conformably overlies the Scottish Middle Coal Measures and is taken at the base of the Aegiranum Marine Band (AGMB) (Figure 6, Columns 5, 6).

The top of the formation in both basins is the Variscan unconformity. At Sanquhar this is partially overlain by the olivine basalts of the typically much weathered Lower Permian Carron Basalt Formation, whilst in the Thornhill Basin the Carron Basalt Formation and red sandstones of the Lower Permian Thornhill Sandstone Formation occur immediately above it. The reddening towards the top of the formation here may be due to oxidation below the pre-Permian erosion surface or staining by waters percolating from the subsequent Permian overburden.

Thickness
In the Thornhill Basin the maximum proved thickness of the formation is 15.3 m in the BGS Crichope Linn Borehole (see above). The remaining thickness of the formation in the Sanquhar Basin is estimated to be up to 300 m.

Distribution and regional correlation
The formation is present in the Thornhill and Sanquhar basins. In the Thornhill Basin, correlation with the Midland Valley of Scotland and Solway Basin is based on the presence of mudstone with *Planolites ophthalmoides* and abundant foraminifers, or *Lingula mytilloides*, which is taken to represent the Aegiranum Marine Band. At Sanquhar, the formation lies within the core of the basin and was cut out by later movement on the Southern Upland Fault. It too correlates with similar strata in the Midland Valley of Scotland (and southwards to Thornhill and beyond) based on the presence of *Planolites opthalmoides* and non-marine bivalves of the Upper *similis-pulchra* Biozone.

Age and biostratigraphical characterisation
Bolsovian (Westphalian C). In the Thornhill Basin, the Aegiranum Marine Band (AGMB) is taken to be represented by mudstone with *Planolites ophthalmoides* and abundant foraminifers, or *Lingula mytilloides*. The trace fossil *Planolites ophthalmoides* and nonmarine bivalves of the Upper *similis-pulchra* Biozone are present at Sanquhar.

6 Carboniferous rocks of the Northern England Province

6.1 INTRODUCTION

The Northern England Province encompasses the area between the Southern Uplands and the Craven Fault System (Figure 3); it includes the Northumberland and Stainmore troughs, the Tweed and Solway basins, the Alston and Askrigg blocks and the Manx–Lake District Block (Figures 7–15). During Westphalian times this area formed the northern part of the Pennine Basin.

The Northumberland Trough has a Tournaisian succession distinct from the rest of the province. Along the southern margin of the Southern Uplands Massif, the earliest Carboniferous strata are of *continental and peritidal facies*, very similar to the Inverclyde Group of the Midland Valley of Scotland. This group name and some component formations have been extended into the northern part of the Northumberland Trough. Within the Northumberland Trough the Inverclyde Group is overlain by the Border Group of early Visean age.

Elsewhere, the *continental and peritidal facies* 'cornstone' subfacies is preserved only in local basins in the deformed Lower Palaeozoic rocks that formed the Devonian continental landmass. The distribution, adjacent to the Pennine–Dent and Lake District boundary faults suggests that they were preserved in half-grabens that formed during the initial stages of extension in the Late Devonian–early Carboniferous. Local formation names are used for each isolated basin. The *continental and peritidal facies* 'cementstone' subfacies is associated with deposition in epicontinental basins with a limited marine influence. The evaporite-bearing succession marks the initial marine transgression with deposition in sabkha environments along arid shorelines. An increasing marine influence and transgression is denoted by the deposition of peritidal carbonates. Only within the Stainmore Trough has sufficient lithostratigraphical variation been identified to warrant *continental and peritidal facies* strata being assigned to a group, namely the Ravenstonedale Group.

South of the Northumberland Trough, the remainder of the province comprised basins and highs both of which formed largely distinct and isolated areas of deposition until Asbian times, each with different formational nomenclature. However, each structural entity showed a consistent development in facies in time from *open marine, platform and ramp carbonates facies* to cyclical *mixed shelf carbonate and deltaic ('Yoredale') facies*. Strata of the former are assigned to the Great Scar Limestone Group and strata of the latter to the Yoredale Group. During Namurian times, the Millstone Grit Group *(fluviodeltaic ('Millstone Grit') facies)* extended over the Askrigg Block, and subsequently, during Westphalian times the Pennine Coal Measures Group *(fluviodeltaic ('Coal Measures') facies)* extended across the entire province. 'Barren Measures' *(alluvial ('Barren Measures') facies*) of late Westphalian age, have been assigned formation names within the Warwickshire Group.

6.2 UNGROUPED FORMATIONS OF CONTINENTAL AND PERITIDAL FACIES IN THE CRAVEN BASIN

The Late Devonian to Visean *continental and peritidal facies* is restricted to localised areas of deposition at the northern margin of the Craven Basin. The deposits have been attributed a stand-alone formational name, with a geographical range limited to the known extent of the sub-basin. The SFC Committee did not consider these isolated deposits warranted group status.

6.2.1 Stockdale Farm Formation (STFA)

Name
The formation is named after Stockdale Farm, Stockdale, east of Settle. It was first proposed by Arthurton et al. (1988) for a succession proved in the Halsteads (Cominco S2) Borehole (BGS Registration Number SD86SW/6) [SD 8491 6345] and the Stockdale Farm (Cominco S7) Borehole (BGS Registration Number SD86SE/6) [SD 8541 6378], both of which are located on the Settle Sheet.

Lithology
The formation comprises an informal lower member of thinly interbedded laminated dolostone, dolomitic–siliciclastic siltstone, mudstone and laminated anhydrite, which is overlain by an informal middle member of interbedded sandstone, siltstone, mudstone and thin limestone. The sandstones are arkosic pale grey, fine-grained, micaceous and carbonaceous, and the limestones are dark grey micrites with subordinate packstones and wackestones. An upper informal member comprises interbedded limestone, siltstone and mudstone, lithologically similar to the middle member, but lacking sandstones.

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

Stratotype
The type section of the formation is the Halsteads (Cominco S2) Borehole (see above) from about 389.35 m to the base of the bore at 426.35 m depth. A reference section, proving the upper and middle parts of the formation, is the Stockdale Farm (Cominco S7) Borehole (see above) from about 169.9 m to the base of the bore at 309.9 m depth.

Lower and upper boundaries
The base of the formation is not seen, but it is possibly an angular unconformity above Lower Palaeozoic sandstone, siltstone and mudstone.

The top of the formation is a deeply fissured surface marking a significant non-sequence. It is overlain by conglomerates of the Chapel House Limestone Formation and underlain by limestone, siltstone and mudstone of the Stockdale Farm Formation (Figure 15, Column 6).

Thickness
Known only in boreholes (see above), the formation is greater than 165 m thick.

Distribution and regional correlation
The formation occurs in the Askrigg Block–Craven Basin 'Transition Zone'. It is possibly equivalent to the Roddlesworth Formation of the Central Lancashire High (see Waters et al., 2009).

Age and biostratigraphical characterisation
Tournaisian to Chadian. The macrofauna is generally poor except in the top 12 m where it includes *Delepinea* sp. and *Michelinia megastoma* (see Arthurton et al., 1988). The topmost 11 m of the formation include the typical early Chadian (Tournaisian) foraminifers *Palaeospiroplectammina mellina, Endothyra danica, Lugtonia monilis* and *Spinoendothyra mitchelli* (Arthurton et al., 1988).

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.

6.3 INVERCLYDE GROUP (INV)

The Inverclyde Group (Paterson and Hall, 1986) (Figure 7) of *continental and peritidal facies* comprises strata directly equivalent to the group of the same name present in the Midland Valley of Scotland (see Section 4.2 above), where the type area occurs at Greenock in the Inverclyde District (see Paterson and Hall, 1986). The Kinnesswood and Ballagan formations also equate to their namesakes in the Midland Valley of Scotland, but in the Berwick area and Solway Basin they are separated by the Kelso and Birrenswark Volcanic formations respectively (see Greig, 1988 and Lumsden et al., 1967). There is no equivalent to the Clyde Sandstone Formation of the Midland Valley of Scotland in the Northern England Province.

The base of the group is taken where Silurian strata (greywackes with interbedded mudstones) of the Riccarton Group are succeeded unconformably by red sandstones, siltstones and conglomerates of the Kinnesswood Formation. The base of the Border Group *(heterolithic clastic and nonmarine carbonate facies* and *fluviodeltaic ('Millstone Grit') facies)* defines the top of the group (see Section 6.5).

Tournaisian (Courceyan to Chadian) in age, the Inverclyde Group is up to 900 m thick in the Tweed Valley, Northumberland, and up to 640 m thick in the Solway Firth area.

6.3.1 Kinnesswood Formation (KNW)

Name
From the Kinnesswood Formation of the Midland Valley of Scotland. See Section 4.2.1 for definition. The following description is specific to the Northern England Province.

Lithology
The Kinnesswood Formation comprises red sandstones, siltstones and conglomerates.

Genetic interpretation
The original sediments were laid down in calcrete-rich ('cornstone') alluvial fans that were deposited in a series of small, linked basins with internal drainage that developed during early stages of crustal extension (Chadwick et al., 1995). The beds are dominantly fluvial with a palaeocurrent towards the north-east.

Stratotype
The type section is defined in the Midland Valley of Scotland (see Section 4.2.1).

Lower and upper boundaries
The base of the formation is unconformable upon Silurian strata (grewackes and interbedded mudstones) of the Riccarton Group.

In the Berwick area and Solway Basin, the mainly basalts of the Kelso and Birrenswark volcanic formations overlie the formation conformably and irregularly respectively (Figure 8, Column 12; Figure 6, Column 7).

Thickness
Up to 200 m.

Distribution and regional correlation
The formation extends across and south of the Southern Uplands from Eyemouth to Dalbeattie, where it crops out narrowly along the northern margin of the Northumberland Trough in the Langholm area (Lumsden et al., 1967) and west of the Cheviot Hills.

Age
Late Devonian (Famennian) to early Tournaisian (Courceyan). Lumsden et al. (1967) and George et al. (1976) postulated an early Carboniferous age for the upper part of the formation.

6.3.2 Kelso Volcanic Formation (KT)

Name
Named after the town of Kelso, with early references to the 'Kelso traps' (see Eckford and Ritchie, 1939) and Kelso Lavas (McRobert, 1925).

Lithology
The Kelso Volcanic Formation comprises olivine basalts and subordinate tuffs and sedimentary strata (volcaniclastic sandstone).

Genetic interpretation
The formation formed during the main initial phase of extensional faulting associated with development of the Northumberland Trough.

Stratotype
Partial type sections occur in the Blackadder Water at Lintmill [NT 7338 4636] (which includes the lowest lava), Lintmill Railway Cutting [NT 727 463 to 736 466] east of Greenlaw (see Williamson in Stephenson et al., 2003), the Eden Water below Girrick [NT 6676 3724], and the River Tweed south of Makerstoun House [NT 6736 3154]. See Eckford and Ritchie (1939) for further reference to these local sequences in the formation.

Lower and upper boundaries
The base of the formation conformably overlies the red sandstones, siltstones and conglomerates of the Kinneswood Formation in Berwickshire (Figure 8, Column 12).

The top of the formation is conformable with the base of the 'cementstone'-bearing strata of the Ballagan Formation.

Thickness
Up to 150 m.

Distribution and regional correlation
Berwickshire. Correlated with the Birrenswark Volcanic Formation of the Solway Basin.

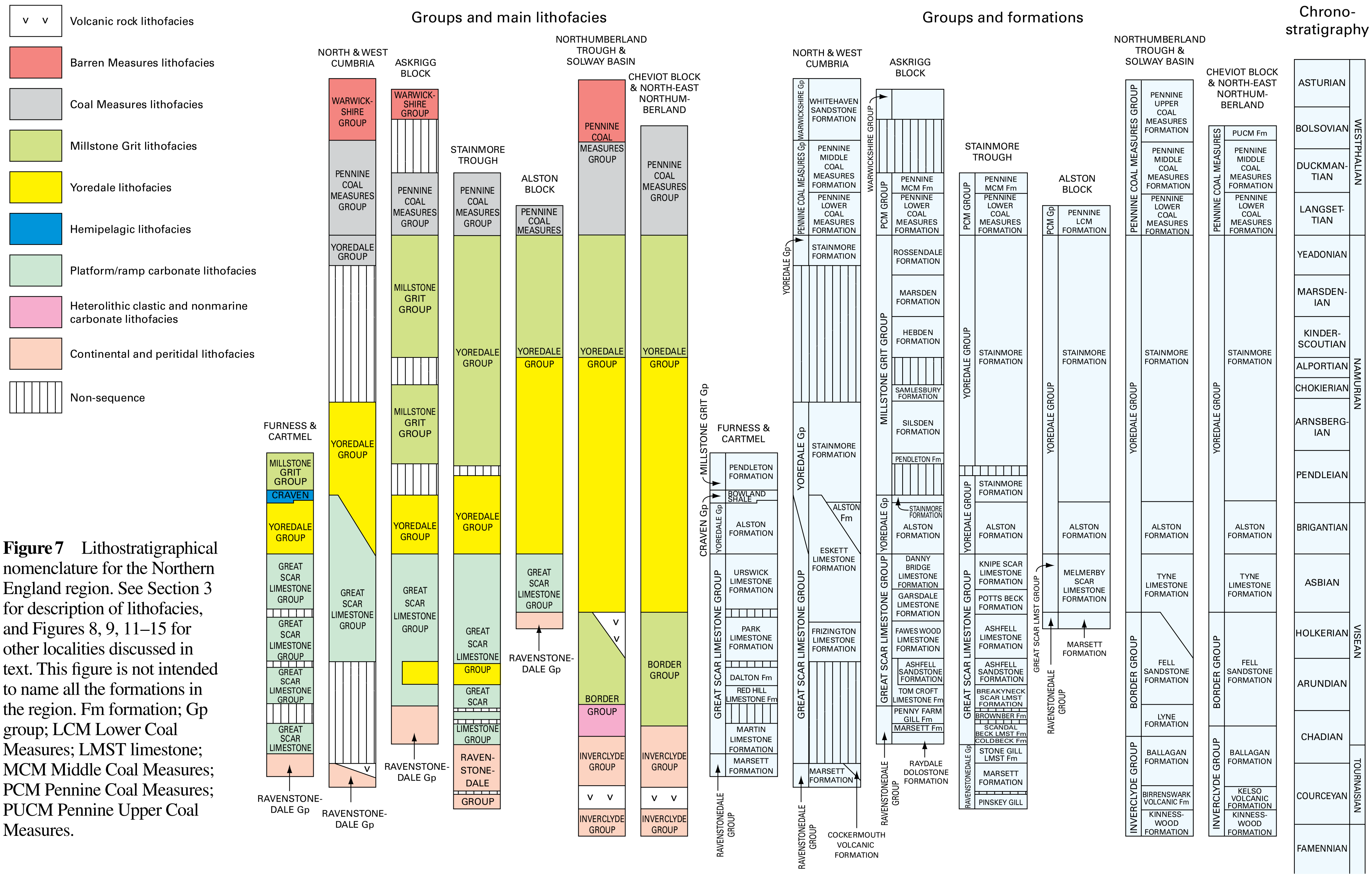


Figure 7 Lithostratigraphical nomenclature for the Northern England region. See Section 3 for description of lithofacies, and Figures 8, 9, 11–15 for other localities discussed in text. This figure is not intended to name all the formations in the region. Fm formation; Gp group; LCM Lower Coal Measures; LMST limestone; MCM Middle Coal Measures; PCM Pennine Coal Measures; PUCM Pennine Upper Coal Measures.

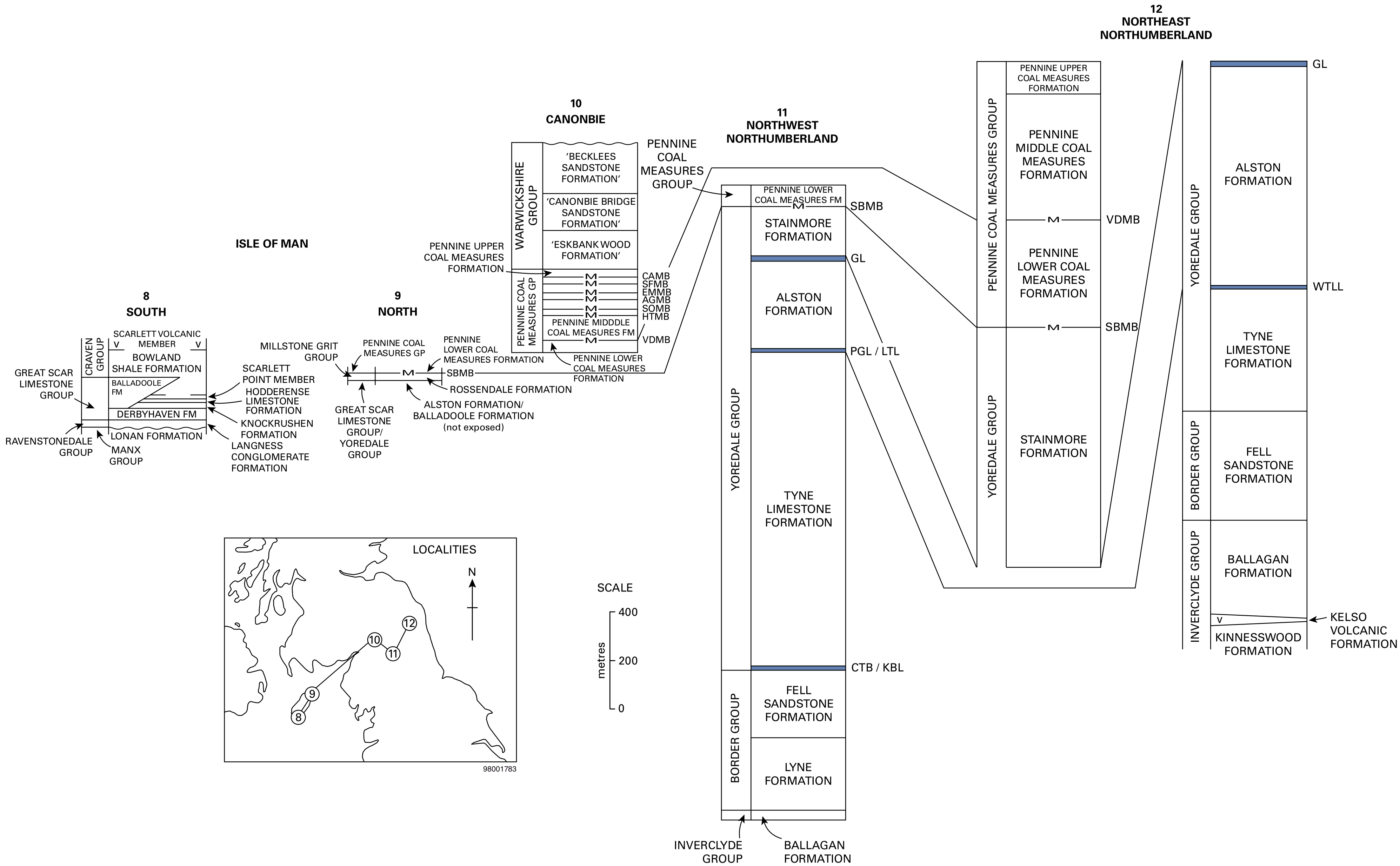


Figure 8 Generalised vertical sections and correlation for Carboniferous strata in the Isle of Man, Canonbie and Northumberland. Based on Ramsbottom et al. (1978) and Chadwick et al. (2001). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band; v indicates named volcanic rock units; blue colour indicates named limestone beds; wavy lines indicate unconformity surfaces.

Age
Mid Tournaisian (Courceyan)

6.3.3 Birrenswark Volcanic Formation (BIRV)

Name
Named from Birrenswark (Burnswark) Hill. Described in detail by Pallister (1952). See also Lumsden et al. (1967); Lintern and Floyd (2000).

Lithology
The Birrenswark Volcanic Formation comprises olivine basalt lavas intercalated with subordinate tuffs and impersistent sedimentary strata including sandstone, mudstone and dolostone ('cementstone').

Genetic interpretation
The formation formed during the main initial phase of extensional faulting associated with development of the Northumberland Trough.

Stratotype
Partial type sections occur near Langholm at White Cove [NY 4060 9176] where almost the total sequence about 15 m thick is seen, Warb Law [NY 359 831] where at least five flows about 60 m thick in total occur, and Hartsgarth Fell at the head of the Tarras Water [NY 446 935] where the base of the sequence and upwards through about 29 m is seen (see Lumsden et al., 1967, pp. 73–76).

Lower and upper boundaries
The irregular base of the formation overlies the 'cornstone'-bearing Kinnesswood Formation in the Solway Basin (Figure 6, Column 7; Figure 10, Columns 2, 3).

The top of the formation is the faulted or irregularly conformable base of the 'cementstone'-bearing strata of the Ballagan Formation.

Thickness
Between 15 and 60 m. Best developed between Dinely and Langholm, the lavas thin westwards towards Birrenswark Hill.

Distribution and regional correlation
Solway Basin. From between Dinely and Langholm westward to Kirkbean Glen, southern Kirkcudbrightshire. Correlated with the Kelso Volcanic Formation.

Age
Mid Tournaisian (Courceyan).

6.3.4 Cottonshope Volcanic Formation (COVO)

Name
Previously known as the Cottonshope Lavas (Taylor et al., 1971).

Lithology
Basalt lavas, olivine-phyric, tholeiitic; several sheets of intensely fractured, dark blue-grey basalt, each passing up into highly amygdaloidal, scoriaceous and pillow-like tops which contain infills of overlying sedimentary rock. The upper part of formation is intercalated with dark grey and greenish grey sandstone and argillaceous dolostone ('cementstone') of the overlying Ballagan Formation.

Stratotype
The type section is Cottonshope Head Quarry and adjacent Cottonshope Burn, Upper Redesdale, Northumberland [NT 803 058] (see Millward in Stephenson, et al., 2003; Miller, 1887; Tomkeieff, 1931; Taylor et al., 1971). Here the volcanic succession comprises three sheets of basalt. The lowest one is 12 m thick and has an undulating pillow-like to 'slaggy', scoriaceous top with sedimentary infills. This is overlain by a 6 m-thick vesicular basalt. The uppermost basalt, also 6 m thick, is separated from the underlying ones by 6 m of bedded mudstones, flaggy sandstones and 'cementstones' (Millward in Stephenson, et al. (2003, p. 136).

Lower and upper boundaries
The lower boundary is taken at the broadly conformable base of the lowest basalt sheet that sharply overlies a sequence of red and grey flaggy sandstones with ochreous brown spots, interbedded with purple, red, lilac and green mudstone containing ochreous concretions, and thin concretionary carbonate ('cornstone') beds (the Lower Freestone Beds of Taylor et al., 1971). This is possibly part of the Kinnesswood Formation.

The upper boundary of the formation is taken at the base of the overlying interbedded sandstone, mudstone and argillaceous dolostone sequence of the Ballagan Formation (formerly the Cementstone Group). The upper contact is intercalated.

Thickness
Up to 24 m.

Distribution and regional correlation
South-west flanks of the Cheviot Block: exposed in Cottonshope Burn, Spithope Burn, Hungry Law, and between the Bareinghope Burn and the Chattlehope Burn, Northumberland.

Age
Tournaisian.

6.3.5 Roddam Dene Conglomerate Formation (RDCO)

Name
Named after the type section (see *Stratotype* below) (Cossey et al., 2004).

Lithology
Conglomerate, in thick and very thick beds; reddish coloured; subangular to subrounded clasts of pebble- to boulder-grade set in a clay-rich sandstone matrix; matrix supported to clast supported. Clasts predominantly of andesite, derived from the Cheviot Volcanic Formation, but also rare clasts of Silurian mudstone and greywacke sandstone and Cheviot granite. There are minor intercalations of mudstone, sandstone and siltstone at the top.

Stratotype
The type section is Roddam Dene, south of Wooler, Northumberland [NU 018 207 to 025 207] where about 170 m of dominantly conglomerate, with interbedded sandstone, mudstone, and calcareous mudstone are seen in three fault-bounded units (see Cossey et al., 2004, pp. 149–151).

Lower and upper boundaries
The lower boundary is not seen, but it is thought to overlie the Cheviot Volcanic Formation unconformably.

The upper boundary of the formation is not seen, but it is believed to be overlain conformably by rocks of the Ballagan Formation (formerly the Cementstone Group of Northumberland).

Thickness
About 170 m seen.

Distribution and regional correlation
Limited to the eastern flanks of the Cheviot Block, Northumberland.

Age
Tournaisian.

6.3.6 Ballagan Formation (BGN)

Name
From the Ballagan Formation of the Midland Valley of Scotland. See Section 4.2.2 for definition. The formation now encompasses part of the Cementstone Group of previous literature in Northern England, the Tweed Basin, and the Solway Basin (see Peach and Horne, 1903; Craig, 1956; Craig and Nairn, 1956; Nairn, 1956, 1958), and part of the Lower Border Group of Lumsden et al. (1967). The following description is specific to the Northern England Province.

Lithology
The Ballagan Formation comprises interbedded sandstone, mudstone, limestone ('cementstone') and anhydrite, the latter present in the subsurface only. There are also pseudomorphs after evaporite minerals, some rootlet beds and thin coals. In the Langholm and Annandale districts, the Kirkbean Cementstone Member includes the Whita and Annandale Sandstone beds respectively. The former comprises medium- to thickly bedded, fine- to coarse-grained, white, grey and pink sandstones with a few thin siltstones and sandy 'cementstones', and the latter, dark red, fine- to coarse-grained sandstone and locally derived conglomerate.

Genetic interpretation
Deposition of the formation was dominated by the influx of alluvial fans, and fluvial and fluviodeltaic sediments from the Southern Uplands, intercalated with lacustrine and arid coastal plain deposits (Deegan, 1973; Leeder, 1974). Hypersaline lacustrine and floodplain facies include pseudomorphs after evaporite minerals, some rootlet beds and thin coals. The Whita and Annandale sandstone beds are fluviodeltaic sedimentary rocks locally derived from the north to north-west in the Southern Uplands Massif (Leeder, 1974).

Stratotype
The type section is defined in the Midland Valley of Scotland. Partial type sections include: the Whita Sandstone Beds of Langholm in disused quarries on Whita Hill [NY 381 848], and in the River Esk from Longwood [NY 3710 8290] to Broomholm [NY 3730 8150]; the Annandale Sandstone Beds on the River Annan from Rochell [NY 1300 7450] to Hoddom Castle [NY 1500 7300]; the Kirkbean Cementstone Member in the Tarras Water [NY 3811 8119] and at Kirkbean Glen [NX 9745 5914]; and the Orroland Member in the coastal section from Port Mary [NY 7520 4540] to Castle Muir [NY 7980 4700]. A reference section for the Kirkbean Cementstone Member is the BGS Hoddom No.2 Borehole (BGS Registration Number NY17SE/3) [NY1641 7285] between 139.84 and 199.74 m depth (end of borehole).

Lower and upper boundaries
The base of the formation is faulted or irregularly conformable upon the Birrenswark Volcanic Formation in the Solway Basin (Figure 6, Column 7; Figure 10, Columns 2, 3), conformable on the Kelso Volcanic Formation in the Berwick area (Figure 8, Column 12), and elsewhere unconformable upon Devonian and older strata.

The top of the formation is at least presumed conformable beneath the cyclical sequences of sandstone, siltstone, mudstone and thin-bedded limestone of the Lyne Formation (Border Group) of the Northumberland Trough and Solway Basin (Figure 6, Column 7; Figure 10, Columns 2, 3), but is unconformable beneath the sandstone of the Fell Sandstone Formation in the north-east part of the Northumberland Trough (Figure 8, Column 12; Figure 11, Column 1; Figure 12, Columns 1, 2; Figure 13, Column 3).

Thickness
The 'cementstone' facies is up to 250 m thick in the Northern England Province. The Whita Sandstone in the Langholm district is about 300 m thick (Lumsden et al., 1967, p. 78). The Annandale Sandstone Beds in the Dalton area of Dumfriesshire are 180 m thick.

Distribution and regional correlation
The formation crops out in the north-eastern margins of the Northumberland Trough and at Kirkbean in the Solway Firth area. In the central part of the Northumberland Trough a lateral facies change sees the Ballagan Formation pass into the Lyne Formation of the Border Group.

Age and biostratigraphical characterisation
Tournaisian (Courceyan to Chadian) (Armstrong and Purnell, 1987). Characterised by bivalves (including a modiolid fauna) and *Serpula* sp.

Formal subdivisions
See also Appendix 1. Members of the Ballagan Formation in ascending stratigraphical order include:

6.3.6.1 Kirkbean Cementstone Member (KICM)

Name
Previously named the 'Basal Cementstones' by Craig (1956), and the Kirkbean Cementstone Formation by Lintern and Floyd (2000), the status is here changed to a member.

Lithology
The Kirkbean Cementstone Member comprises mainly thinly interbedded greenish grey carbonaceous siltstone and argillaceous limestone ('cementstone'). In the Langholm and Annandale districts, it includes the Whita and Annandale Sandstone beds respectively. The former comprise medium- to thickly bedded, fine- to coarse-grained, white, grey and pink sandstones with a few thin siltstones and sandy 'cementstones', and the latter comprise dark red, fine- to coarse-grained sandstone and locally derived conglomerate.

Stratotype
The partial type section is Kirkbean Glen [NX 9745 5914] where fragmentary plant remains, but no shelly fauna, have been found in a 20 m sequence of carbonaceous siltstones and mudstones with thin 'cementstone' stringers, that is faulted against basalt (Lintern and Floyd, 2000, p. 77).

Lower and upper boundaries
The base rests unconformably on basalt lavas of the Birrenswark Volcanic Formation (Figure 10, Column 2).

The top of the member is not exposed, but is probably gradational with the Southerness Limestone Member.

Thickness
The 'cementstone' facies is greater than 100 m thick. The Whita Sandstone in the Langholm district is about 300 m thick (Lumsden et al., 1967, p. 78), and the Annandale Sandstone Beds in the Dalton area of Dumfriesshire are 180 m thick.

Distribution and regional correlation
Kirkbean area, Southerness, Kirkcudbrightshire, Dumfries and Galloway.

Age
Tournaisian (Courceyan to Chadian).

6.3.6.2 WALL HILL MEMBER (WLH)

Name
Previously named the Wall Hill Sandstone Group by Deegan (1973), and the Wall Hill Sandstone Formation by Lintern and Floyd (2000). The status is here changed to a member and the 'Sandstone' epithet dropped.

Lithology
The member comprises fining-upwards cycles of pale grey to white conglomerates and sandstones with thin purple siltstones, 'marls' and shales.

Stratotype
The type section is the coastal outcrop between White Port Bay [NX 7234 4336] and Port Mary [NX 7550 4540] where the sequence comprises (base upwards) of about 210 m of conglomeratic sandstones, siltstones, 'marls' and shales with isolated dolostone nodules; 120 m of sandstones (sometimes conglomeratic), siltstone and shale; and more than 40 m of coarse conglomerates, interbedded with conglomeratic sandstones and a few thin red 'marls' (Deegan, 1973; see also Lintern and Floyd, 2000, p. 83–85).

Lower and upper boundaries
The base is unconformable on turbidites of the Silurian Raeberry Castle Formation, Riccarton Group.

The top of the member is faulted against the coarse conglomeratic red bed facies of the Orroland Member (Figure 10, Column 1).

Thickness
About 370 m

Distribution and regional correlation
Coastal outcrop between White Port [NX 7234 4336] and Port Mary [NX 7550 4540], south-west Scotland (Solway Firth).

Age
Tournaisian.

6.3.6.3 ORROLAND MEMBER (ORR)

Name
Previously known as the Orroland Limestone Beds by Craig and Nairn (1956), the Orroland Group by Deegan (1973), and the Orroland Formation by Lintern and Floyd (2000). The status is here changed to a member.

Lithology
Conglomerates, conglomeratic sandstones, sandstones, red siltstones, 'marls' and pedogenic dolostones ('cornstones').

Stratotype
The type section is the coastal section from Port Mary to Castle Muir [NX 7445 4537 to 7980 4720] where the sequence comprises (base upwards) of about 90 m of conglomerates and sandstones; 18 m of conglomeratic sandstones, siltstones, 'marls' and dolostones; 25 m of conglomeratic sandstones, and silty and sandy 'marls' with dolostone nodules; about 10 m of calcareous sandstones, mudstones, 'marls' and impure marine limestones; about 9 m of burrowed marine sandstone; 28 m of conglomeratic sandstones and 'marls' with dolostone nodules; and 90–100 m of conglomeratic sandstones and sandstones (Deegan, 1973; see also Lintern and Floyd, 2000, p. 85).

Lower and upper boundaries
The base of the member is faulted against the sandstones and conglomerates of the Wall Hill Member (Figure 10, Column 1).

The top of the member is faulted against the conglomeratic sandstone and thin interbeds of calcareous mudstone and siltstone of the Rascarrel Member (Fell Sandstone Formation).

Thickness
About 280 m.

Distribution and regional correlation
Coastal section from Port Mary [NX 7445 4537] to Castle Muir [NX 7980 4720], south-west Scotland (Solway Firth).

Age
Chadian.

6.4 RAVENSTONEDALE GROUP (RVS)

The Ravenstonedale Group, named after the Ravenstonedale area of Cumbria, is of *continental and peritidal facies*. It comprises a typically thin succession, with geographically isolated outcrops present across parts of Cumbria.

Lithologically, the group includes green to green-grey and/or variably reddened pebble conglomerate (locally calcite cemented), lithic sandstone, sandstone and mudstone. Evaporitic deposits have been recorded in boreholes. Pedogenic carbonates occur within the sandstones, though they are less common than within the Kinnesswood Formation of the Inverclyde Group. Conglomerates have a local provenance, and basaltic lava flows occur locally within the alluvial fan facies. The most diverse lithological development is in the western part of the Stainmore Trough and northern part of the Askrigg Block.

Within the *Stainmore Trough* the group comprises the Pinskey Gill, Marsett, Cockermouth Volcanic, Stone Gill Limestone and Shap Village Limestone formations (the last mentioned also occurring on the Alston Block and in east Cumbria).

On the *Askrigg Block* the group comprises the Raydale Dolostone, Marsett and Penny Farm Gill formations.

In north, south and west Cumbria the group comprises the Marsett Formation. In the Kendal area it is here suggested that what is presently assigned to the lower part of a local equivalent of the Martin Limestone Formation, Great Scar Limestone Group of *open marine*, *platform and ramp carbonates facies*, is more typical of the Ravenstonedale Group (see Section 6.6.19).

On the *Isle of Man*, the Langness Conglomerate Formation (formerly the 'Basement Conglomerate') is tentatively referred to the Ravenstonedale Group.

The on-lapping succession of the group was deposited within an epicontinental basin as alluvial fan, fluviodeltaic, marginal marine and peritidal deposits (Holliday et al., 1979).

Deposition on the Askrigg Block occurred following early Visean sea-level rise, with the succession located marginal to the more open marine conditions present in the Stainmore Trough at the time. Outside of the Stainmore Trough and northern part of the Askrigg Block the group is dominated by alluvial fan subfacies deposited within linked basins.

The group rests unconformably upon rocks ranging from Ordovician to Devonian in age, including the Wensleydale Granite beneath the Askrigg Block at Raydale. Limestone formations at the base of the Great Scar Limestone Group *(open marine, platform and ramp carbonates facies)* define the top of the Ravenstonedale Group – though locally, a nodular dolostone bed with rhizoliths, indicative of emergence, marks the top of the group on the Askrigg Block (Burgess, 1986).

Occurring across Cumbria and north Yorkshire, the Ravenstonedale Group is thickest in the western part of the Stainmore Trough (about 380 m) and northern part of the Askrigg Block (about 150 m). In south Cumbria, in the Duddon Estuary, it attains a maximum thickness of 240 m thinning appreciably towards the south and east. In north and east Cumbria the group is typically less than 35 m thick. Within the Stainmore Trough it is Tournaisian in age. Whilst on the northern margin of the Askrigg Block it is Chadian to early Holkerian.

STAINMORE TROUGH (Figure 9, Column 16):

6.4.1 Pinskey Gill Formation (PNKG)

Name
Derived from Pinskey Gill, by Newbiggin on Lune, Cumbria. The formation was originally named the Pinskey Gill Beds by Garwood (1913, p. 496).

Lithology
The Pinskey Gill Formation comprises grey, vuggy, dolomitic limestone and dolostone interbedded with grey to dark grey calcareous mudstone and thin-bedded, calcareous, silty sandstone.

Genetic interpretation
The strata were deposited in a peritidal marine and fluvial environment.

Stratotype
The type section is in Pinskey Gill [NY 698 040] where the formation is about 20 m thick and comprises beds of sandstone, calcareous mudstone with sporadic pebbles, sandy shale, interbedded mudstone and shale, and dolomite, (see Garwood, 1913, pp. 496– 499).

Lower and upper boundaries
The formation rests unconformably upon a smooth planation surface cut into Lower Palaeozoic strata. Conglomerate beds of the Marsett Formation overlie it unconformably (Figure 9, Column 16).

Thickness
Up to 50 m.

Distribution and regional correlation
The formation is found only at Ravenstonedale in the Stainmore Trough.

Age and biostratigraphical characterisation
Miospores including *Schopfites claviger* and *S. delicatus* of the CM and possibly PC zones (Johnson and Marshall, 1971; Holliday et al., 1979) and conodonts dominated by *Bispathodus aculeatus aculeatus, B. stabilis* and *Clydagnathus unicornis* of the *Pseudopolygnathus multistriatus* Zone (Varker and Higgins, 1979; Varker and Sevastopulo, 1985) indicate a Tournaisian (mid Courceyan) age for the formation (Table 2).

6.4.2 Marsett Formation (MASA)

Name
The formation, locally referred to as the 'basement beds', feldspathic conglomerate, quartz conglomerate, greywacke sandstone, etc., in previous work (see for example Garwood, 1913; Rose and Dunham, 1977; Mitchell, 1978; Pattison, 1990) is named after the hamlet of Marsett in Raydale.

Lithology
The Marsett Formation comprises laterally variable beds of conglomerate, lithic sandstone and mudstone. The sandstone beds are generally cross-bedded and may be in shades of brown, red, grey, green or buff. Over much of the Stainmore Trough, the Marsett Formation comprises red sandstone, green shale and conglomerate. On the Askrigg Block the formation consists of reddish brown and greenish grey sandstone and conglomerate with rare dolostone beds. In north Cumbria, basaltic lavas of the Cockermouth Volcanic Formation occur within the alluvial fan facies of the formation.

Genetic interpretation
In most instances the beds are fluvial in origin, though reworking in shallow marginal marine conditions may have occurred locally.

Stratotype
The type section is from about 406 to 463 m depth in the BGS Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9026 8474] on the Askrigg Block. Localities in the Appleby district include Shap Abbey [NY 5482 1533] where about 9 m of shaly sandstone and conglomerate occur in a cliff on the River Lowther (see Garwood, 1913), and Holghyll [NY 4290 2730] where a thick succession is accessible in the ravine (see McCormac, 2001, p. 12).

Lower and upper boundaries
The Marsett Formation rests unconformably upon the limestones, mudstones and sandstones of the Pinskey Gill Formation in the Stainmore Trough (Figure 9, Column 16) and on the siltstones and sandstones with thin-bedded and nodular dolostones of the Raydale Dolostone Formation on the Askrigg Block (Figure 9, Column 17; Figure 15, Column 3). In the Furness area the formation is underlain unconformably by unspecified Lower Palaeozoic strata (see Section 6.4.2.1). The formation is contiguous with the overlying marine Tournaisian/Visean succession. This comprises in the Stainmore Trough and on the Askrigg Block the limestones, sandstones and mudstones of the Stone Gill Limestone and Penny Farm Gill formations respectively.

North of the River Lowther in Westmorland the formation is overlain by the dolostones of the Shap Village Limestone Formation (the base of which is marked by beds with algal mats and nodules) (Figure 14, Column 3). Near Orton, east of Shap, in a gully section next to the M6 Motorway [NY 600 075] black marine mudstone beds of the Marsett Formation lie beneath calcareous limestone and siltstone beds of the Stone Gill Limestone Formation (see Pattison, 1990, p. 9; Day, 1992, p. 15; McCormac, 2001, p. 12) (Figure 9, Column 16). On the Alston Block and in north and

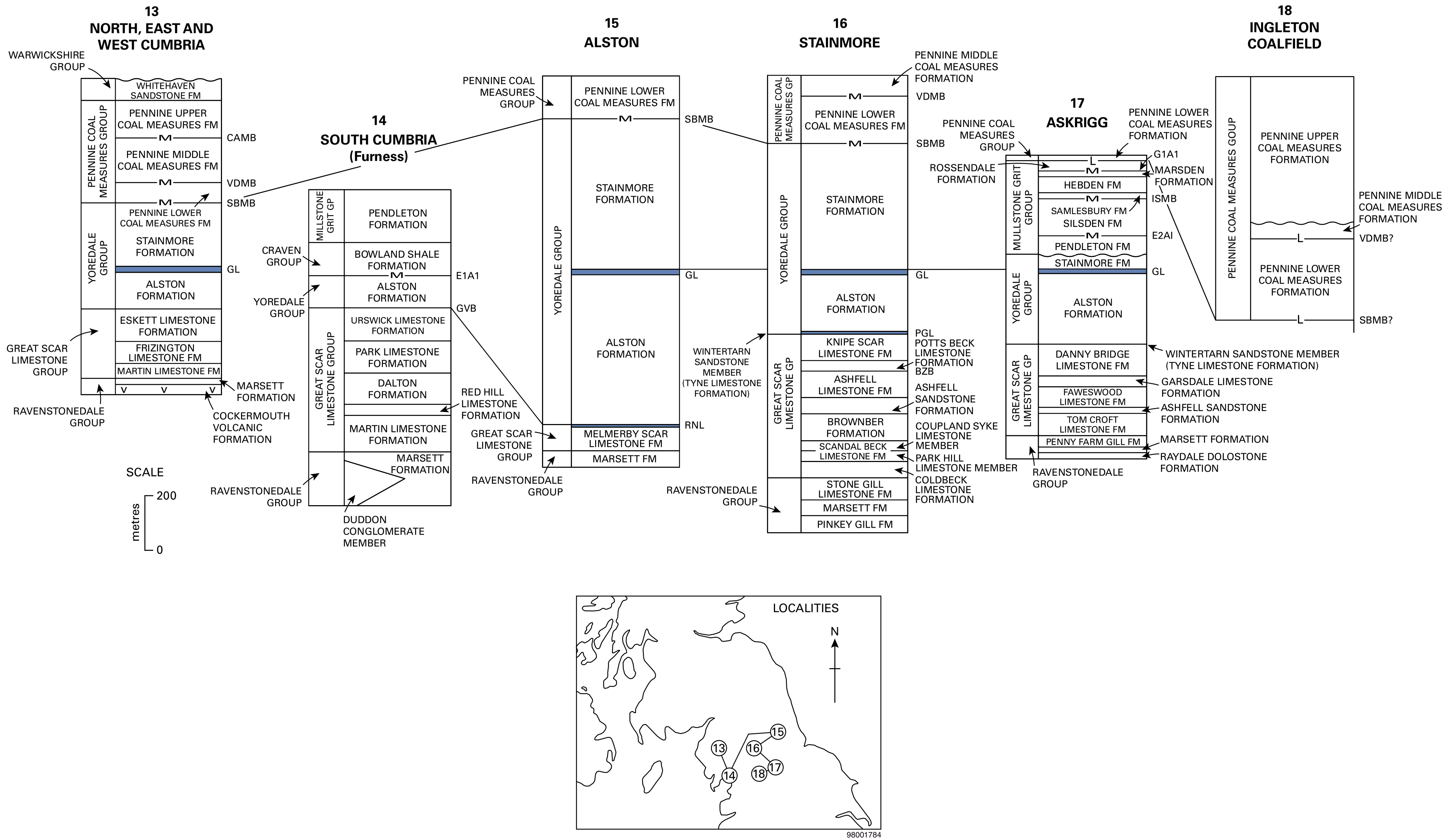


Figure 9 Generalised vertical sections and correlation for Carboniferous strata in Cumbria, Alston, Stainmore, Askrigg and the Ingleton Coalfield. Based on Ford (1954), IGS (1973), George et al. (1976), Mitchell (1978), Ramsbotton (1978), Ramsbottom et al. (1978), Dunham and Wilson (1985), Arthurton et al. (1988), Pattison (1990) and Millward et al. (2003). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band; L *Lingula* band. v indicates named volcanic rock units; blue colour indicates named limestone beds. Wavy lines indicate unconformity surfaces.

west Cumbria the conglomerates of the Marsett Formation are, respectively, unconformably and disconformably overlain by the carbonates of the Melmerby Scar Limestone and Frizington Limestone formations, Great Scar Limestone Group (Figure 9, Column 15; Figure 14, Columns 1, 2), though at the northern margin of the Lake District the top of the Marsett Formation conformably underlies the basalt lavas of the Cockermouth Volcanic Formation (Figure 14, Column 2). In the Furness area the formation passes conformably up to grey, red and green marine mudstone and limestone of the Martin Limestone Formation (Figure 9, Column 14) (see Sections 6.4.2.1 and 6.6.19).

Thickness
In most areas the formation is thin. In the Appleby district it is 2–20 m thick. In north and east Cumbria it is typically less than 35 m thick. On the Askrigg Block it is 60 m thick. However, on the northern margin of the Stainmore Trough, at Roman Fell [NY 760 200], beds up to 200 m thick are present. The formation is up to 240 m thick in the Furness area.

Distribution and regional correlation
Present in north, east and west and south Cumbria and throughout north Yorkshire, including the Stainmore Trough and Askrigg Block. In the Kendal area it is suggested that what is presently assigned to the lower part of a local equivalent of the Martin Limestone Formation, Great Scar Limestone Group of *open marine, platform and ramp carbonates facies*, is more typical of the Ravenstonedale Group (see Section 6.6.19).

Age and biostratigraphical characterisation
Miospore assemblages from a number of sites including Cockermouth, Ravenstonedale and Furness (Mitchell, 1978; Holliday et al., 1979; Rose and Dunham, 1977) all indicate a CM Zone, Tournaisian age for the formation. However, the beds pass upwards in unbroken succession into limestone, which may be as young as Holkerian. Biostratigraphy of the Raydale Borehole (see above) suggests a possible late Chadian age for the formation at this locality on the Askrigg Block (see Dunham and Wilson, 1985). The full age range of the formation is therefore currently undetermined.

Formal subdivisions
See also Appendix 1. The Marsett Formation includes one formal member:

6.4.2.1 DUDDON CONGLOMERATE MEMBER (DUCO)

Name
See Johnson et al. (2001); Rose and Dunham (1977).

Lithology
Conglomerate, sandstone and mudstone, mainly red-brown with pale green and mottled layers, with traces of evaporite. Large clasts (pebbles up to 15 cm) are well rounded, commonly with ferruginous skins. Clast lithologies all occur locally and include Borrowdale Volcanic Group andesite, tuff and rhyolite, Silurian 'grit' and 'greywacke' and Eskdale Granite and Ennerdale Granophyre.

Stratotype
The type section is a borehole (BGS Registration Number SD27NW/323) [SD 2113 7991] between 88.52 and 255.50 m depth (see Rose and Dunham, 1977).

Lower and upper boundaries
The base is unconformable on the top of the Lower Palaeozoic basement (Figure 9, Column 14).

The top of the member occurs at upward change from conglomerate beds to grey, red and green marine mudstone and limestone with subordinate thin conglomerate beds of the Martin Limestone Formation. The junction may be sharply gradational or possibly an onlap surface.

Thickness
Maximum recorded 240 m in Dunnerholme (Rose and Dunham, 1977).

Distribution and regional correlation
Furness, Cumbria confined to the area of the Duddon Estuary.

Age
Courceyan.

6.4.3 Cockermouth Volcanic Formation (CKML)

Name
Originally named the Cockermouth Lavas (Eastwood, 1928). See also Millward in Stephenson et al. (2003); Macdonald and Walker (1985).

Lithology
Basalt, olivine-phyric and andesite, tholeiitic. Up to four sheets of massive to intensely amygdaloidal and scoriaceous rock, dark blue-grey to grey. Interpreted to be lavas. No intercalated pyroclastic or sedimentary rocks are present.

Stratotype
The partial type section is Gill Beck, immediately south of Blindcrake, about 4.5 km north-east of Cockermouth, Cumbria [NY 149 341 to 149 344] where a sequence of at least four tholeiitic olivine-phyric basalt lavas about 67 m thick can be seen, though the base and top of the succession is not exposed (see Millward in Stephenson et al., 2003, pp. 116–120). A reference section is Bothel Craggs Quarry, on the west side of the A591 road, about 1.5 km south-south-east of Bothel, Cumbria [NY 186 371] where apparently one, sparsely amygdaloidal tholeiitic andesite about 4 m thick is seen, though the base and top of the succession are not exposed (see Millward in Stephenson et al., 2003, pp. 120–122).

Lower and upper boundaries
In north Cumbria the base is conformable on the conglomerates and sandstones of the Marsett Formation, and the top lies beneath bedded mudstone, limestone and sandstone at the base of the Great Scar Limestone Group (specifically beneath a conglomerate developed locally at the base of the Frizington Limestone Formation) (Figure 14, Column 2).

Thickness
Some 105 m in the Cockermouth area; 67 m thick in the type section.

Distribution and regional correlation
Northern margin of the Lake District Lower Palaeozoic massif, from just west of Cockermouth to Bothel. Intrusions of dolerite and deposits of lapilli-tuff on Little Mell Fell, in the Appleby district, may include intrusive equivalents to the Cockermouth Volcanic Formation (Macdonald and Walker, 1985).

Age
Courceyan.

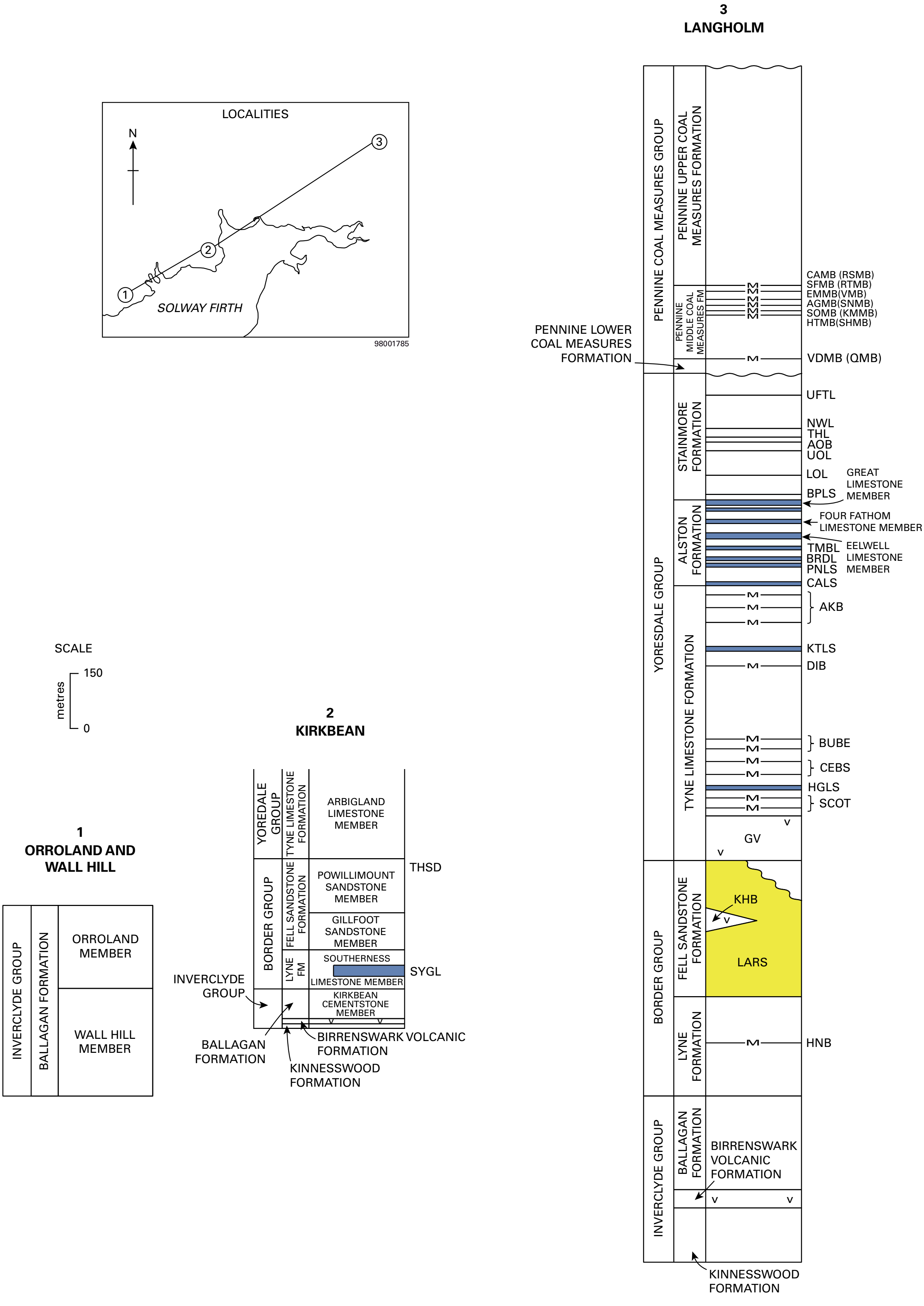


Figure 10 Solway Basin. Representative sections for Carboniferous strata at Orroland and Wall Hill, Kirkbean and Langholm. Based on Lumsden et al. (1967) and Lintern and Floyd (2000). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band; v indicates named volcanic rock units; blue colour indicates named limestone beds; green colour indicates significant developments of named sandstone units. Wavy lines indicate unconformity surfaces.

6.4.4 Stone Gill Limestone Formation (STE)

Name
The name comes from that proposed by Garwood (1907) and defined in the type section at Stone Gill by Ramsbottom (1973).

Lithology
The Stone Gill Limestone Formation comprises grey, porcellanous limestone and thin dolostone, with beds of argillaceous limestone, sandstone and mudstone common above the base. Calcretes, desiccation structures and pseudomorphs after evaporites are also present.

Genetic interpretation
The presence of calcretes, desiccation structures and evaporite pseudomorphs (Holliday et al., 1979) indicate deposition in a quiet, nearshore to peritidal restricted marine environment.

Stratotype
The type section is in Stone Gill [NY 718 040] as defined by Ramsbottom (1973). A locality in the Appleby district is Shap Abbey [NY 5478 1550] where about 18 m of dolostone and 'magnesian' limestone is exposed in a cliff on the east bank of the River Lowther (see Garwood, 1913). See also the Wyegarth Gill No. 1 Borehole (BGS Registration Number NY70SW/1) [NY 7201 0354] and the gully section next to the M6 Motorway [NY 600 075] mentioned below with regard to the lower boundary of the formation.

Lower and upper boundaries
The base of the formation is conformable. Defined at a depth of 49.73 m in the Wyegarth Gill No. 1 Borehole (see above) where there is a gradational change in rock type from the underlying sandstones and siltstones of the Marsett Formation to a sequence of limestones, sandstones and mudstones of the Stone Gill Limestone Formation. However, the base can be precisely located in a gully section next to the M6 Motorway [NY 600 075], where calcareous siltstone and limestone beds rest on black marine mudstone beds marking the top of the Marsett Formation (see Pattison, 1990, p. 9; Day, 1992, p. 15; McCormac, 2001, p. 12; Figure 9, Column 16).

The formation is conformably overlain by the Coldbeck Limestone Formation of the Great Scar Limestone Group south of the Anne's Well Fault (Figure 9, Column 16), and by the Shap Village Limestone Formation, Ravenstonedale Group, north of it.

Thickness
Up to 100 m thick in the Ravenstonedale area. 20–40 m thick in the Appleby district.

Distribution and regional correlation
Stainmore Trough. In the Kendal area, strata presently assigned to the lower part of a local equivalent of the Martin Limestone Formation, Great Scar Limestone Group of *open marine, platform and ramp carbonates facies*, is suggested to be more typical of the Ravenstonedale Group. This appears to be further supported by the striking similarity noted in field characteristics between this succession and the Stone Gill Limestone Formation (see Section 6.6.19).

Age and biostratigraphical characterisation
The formation has a restricted marine biota of algae (including *Solenopora* sp.), foraminifers (including *Brunsia* sp. and *Dainella* sp.), *Syringopora* sp., *'Camarotoechia' proava, Cleiothyridina glabistria,* vermetid gastropods, and ostracods. It was considered to be early Chadian (Tournaisian) in age by Holliday et al. (1979). However, the upper part has a Pu Zone miospore assemblage, and *'Camarotoechia' proava* and *Cleiothyridina glabistria* are late Chadian chronozonal brachiopods (see Garwood, 1913). The succession apparently includes the early–late Chadian (Tournaisian–Visean) boundary but its position is uncertain. It may exist near the top of the formation.

6.4.5 Shap Village Limestone Formation (SHVI)

Name
The name is derived from the Village of Shap, Cumbria. The name Shap Village Limestone Formation was introduced by McCormac (2001) and the unit is equivalent to the Shap Limestone of Dakyns et al. (1897; see Millward et al. 2003, p. 13).

Lithology
The Shap Village Limestone Formation is composed, in its lower part, of well-bedded dolostone with interbeds of siltstone and calcareous sandstone. In its middle part it consists of cross-bedded, dark grey, sandy packstone/ grainstone with the coral genus *Dorlodotia*. In its upper part it comprises finely cross-laminated oolites, thick-bedded calcareous, rippled sandstone, pebbly sandstone, and cross-bedded calcarenite.

Genetic interpretation
The depositional environments include fluvial and marginal marine.

Stratotype
The partial type section is in Force Beck [NY 5684 1384 to 5772 1354] where the basal algal beds are overlain by a mudstone seatearth, dolostone (20–40 m thick) with thin interbeds of siltstone or fine-grained sandstone, of packstone/grainstone (also 20–40 m thick and with thin interbeds of siltstone or fine-grained sandstone), oolitic limestone, and a mixed succession of calcareous sandstone, pebbly sandstone, and oolites. The section is incomplete due to faulting (see McCormac, 2001, pp. 12–13). Another locality in the Appleby district is Loudon Hill [NY 4650 2725], Dacre, where workings in the upper sandstones can be seen (see McCormac, 2001, p. 13).

Lower and upper boundaries
Beds with algal mats and nodules mark the base of the Shap Village Limestone Formation. North of Anne's Well Fault in the Shap area the formation overlies the limestones with sandstones and mudstones of the Stone Gill Limestone Formation, and north of the River Lowther in Westmorland it overlies the sandstone and conglomerate dominated Marsett Formation.

The top of the Shap Village Limestone Formation is marked by distinctive pebble beds and is overlain conformably by the Ashfell Sandstone Formation (Great Scar Limestone Group) (Figure 14, Column 3).

Thickness
The formation is 40–120 m thick, and 70–100 m thick in the Appleby district.

Distribution and regional correlation
The Shap–Penrith area, east Cumbria (McCormac, 2001), extended to include equivalent rocks assigned to the

'Ravenstonedale Limestone' in the Alston and Brough areas (Arthurton and Wadge, 1981; Burgess and Holliday, 1979).

Age and biostratigraphical characterisation
The coral genus *Dorlodotia*, described from several localities in the Shap and Askham area (Dean, 2001), indicates a late Chadian age for the bulk of the formation. Garwood (1913) described a coral/brachiopod fauna typical of his *Camarophoria isorycha* subzone at the top of the succession at Shap. In the correlation of George et al. (1976), this would place the upper part of the formation in the Arundian. However, more recently, Riley (1993) has argued that all the rocks found at this level in the Ravenstonedale area are Chadian in age, and this cannot be refuted in the apparent absence of of data concerning the presence of archaediscid foraminifers, the first entry of primitive forms defining the base of the Arundian.

ASKRIGG BLOCK (Figure 9, Column 17):

6.4.6 Raydale Dolostone Formation (RDO)

Name
The name is derived from the Raydale Dolomite Formation as described in the Raydale Borehole (see below). See Dunham and Wilson (1985, p. 26, fig. 5, and references therein).

Lithology
The Raydale Dolostone Formation comprises thinly bedded and nodular dolostones ('cementstones') interbedded with siltstone and sandstone. The strata are similar to those present in the Ballagan Formation of the Midland Valley of Scotland and Northumberland Trough.

Genetic interpretation
Marginal marine

Stratotype
The formation occurs in the BGS Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9026 8474] between about 463 and 495 m depth where it comprises thinly bedded and nodular dolostones with much interbedded siltstone and fine-grained sandstone (Dunham and Wilson, 1985, p. 26).

Lower and upper boundaries
The formation occurs immediately above the Wensleydale Granite, which was reached in the Raydale Borehole (see above) at 495.05 m depth.

The top of the formation occurs at the base of the conglomeratic Marsett Formation (Figure 9, Column 17; Figure 15, Column 3).

Thickness
About 30 m.

Distribution and regional correlation
Askrigg Block.

Age and biostratigraphical characterisation
Miospores indicate a Chadian (post-Tournaisian) age for the formation (Owens, pers. comm. reported in Waters et al. 2007).

6.4.7 Marsett Formation (MASA)

See Section 6.4.2 for definition.

6.4.8 Penny Farm Gill Formation (PFD)

Name
The name is derived from Penny Farm Gill, Askrigg Block. The original name 'Penny Farm Gill Dolomite Formation' was proposed by Burgess (1986, p. 6).

Lithology
The Penny Farm Gill Formation comprises interbedded limestone, dolostone, sandstone and siltstone, commonly rhythmically bedded.

Genetic interpretation
The strata were deposited within a shallow marine, intertidal and supratidal environment, marginal to the more open marine conditions in the Stainmore Trough at the time.

Stratotype
Partial type sections include the lowest 17 m of the formation seen in Nor Gill [SD 698 933] in a sequence that comprises mainly sandstones, silty limestones and siltstones; and the succeeding 35 m of beds, which are well seen in the inlier at Penny Farm Gill [SD 698 932], where the sequence comprises sandy and micritic dolostones, siltstone with dolostone beds (not exposed, but suggested by debris), and sandy limestones with interbedded dolostones (Burgess, 1986, pp. 6–7; see also Dunham and Wilson, 1985, p. 26). The formation also occurs in the Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9026 8474] from about 350 to 406 m depth (see Dunham and Wilson, 1985, and references therein).

Lower and upper boundaries
The formation overlies contiguously the conglomeratic Marsett Formation.

The top of the Penny Farm Gill Formation is marked locally by a nodular dolostone bed with rhizoliths that is indicative of emergence (Burgess, 1986). The biosparites of the Tom Croft Limestone Formation (Great Scar Limestone Group) disconformably overlie the formation (Figure 9, Column 17; Figure 15, Column 3).

Thickness
According to Dunham and Wilson (1985) the formation is 50.6 m thick in the Penny Farm Gill inlier, and about 56 m thick in the Raydale Borehole (see above).

Distriution and regional correlation
Askrigg Block.

Age and biostratigraphical characterisation
The formation has a limited fauna of bivalves, gastropods, the brachiopod *Rhynchonella fawcettensis*, and ostracods. However, a miospore assemblage from the formation has been assigned to the (Chadian to Arundian) Pu Zone, although the presence of *Knoxisporites stephanephorus* suggests an Arundian to early Holkerian age TS Zone (Burgess, 1986).

ISLE OF MAN (Figure 8, Column 8):

6.4.9 Langness Conglomerate Formation (LNCO)

Name
The name is derived from Langness, south Isle of Man, and was given by Dickson et al. (1987).

Lithology
The formation comprises reddish brown, generally poorly sorted, typically clast-supported conglomerate with subordinate interbedded sandstone. Sedimentary structures include crude stratification and rare cross-bedding. See Chadwick et al. (2001).

Genetic interpretation
The formation is an alluvial fan deposit, transported by debris flow and streamflow processes.

Stratotype
A partial type section includes foreshore exposures along the Langness Peninsula [SC 2819 6604 to 2854 6661] where an estimated 30 m of coarse clastic sedimentary rocks are present (see Dickson et al., 1987, p. 205).

Lower and upper boundaries
The formation is unconformable on the underlying, steeper-dipping, Ordovician Lonan Formation (see Chadwick et al., 2001).

The limestones of the Turkeyland Member, Derbyhaven Formation, Great Scar Limestone Group (Figure 8, Column 8) overlie the apparently partly reworked sandstone top to the Langness Conglomerate Formation.

Thickness
The formation is about 30 m thick.

Distribution and regional correlation
The formation occurs in the south Isle of Man.

Age
?Devonian to Courceyan (Chadwick et al., 2001, p. 59)

6.5 BORDER GROUP (BDR)

The Border Group (Lumsden et al. 1967; Day, 1970) consists of two sedimentary formations corresponding to some extent to the geographically extended, former Lower and Middle Border groups of Day (1970; see also Waters et al., 2007). The lower, the Lyne Formation (which equates with the 'Cementstones' of older terminology in Northumberland) comprises strata of *heterolithic clastic* and *nonmarine carbonate facies*. The Fell Sandstone Formation, of *fluviodeltaic ('Millstone Grit') facies*, diachronously overlies the Lyne Formation. Thin olivine basalt lavas occur as the Kershopefoot basalts (Williamson in Stephenson et al., 2003).

The base of the group is conformable where the interbedded sandstones, limestones, anhydrites, rootlet beds and thin coals of the Ballagan Formation (Inverclyde Group) pass upward into the cyclical sequences of sandstone, mudstone and thin limestone of the Lyne Formation. This is the presumption at Bewcastle and Kirkbean, and it has been proved in a borehole at Annandale. The base is also conformable at Brampton where the Ballagan Formation passes upwards into the sandstone-dominated Fell Sandstone Formation. However, in the north-east part of the Northumberland Trough the same boundary is unconformable; and within the central part of the trough, the base of the group has not been proved. The base of the Yoredale Group *(mixed shelf carbonate and deltaic ('Yoredale') facies)* defines the top of the Border Group.

The Border Group is restricted in geographical extent to the Northumberland Trough and Solway Basin, and is greater than 1350 m thick in the central part of the former. It is late Tournaisian to Holkerian in age.

6.5.1 Lyne Formation (LYNE)

Name
The Lyne Formation is synonymous with the Cementstone Series of the Bewcastle district as defined by Garwood (1913). It equates with the Lower Border Group of Lumsden et al. (1967) and Day (1970), and is named after the River White Lyne at Bewcastle (Day, 1970). See also Lintern and Floyd (2000).

Lithology
In the Northumberland Trough, the Lyne Formation comprises cyclical sequences of fine-grained subarkosic sandstone, siltstone, mudstone, and thin limestone in which thin oolitic pellet beds are characteristic components. In the Solway Basin, in the Easton 1 borehole (BGS Registration Number NY47SW/15) [NY 44124 71694] the formation is represented by the Easton Anhydrite Member, of grey or white anhydrite interbedded with limestone, shale, siltstone and sandstone.

Genetic interpretation
The Lyne Formation limestones are typically peritidal, with the first incoming of marine limestones occurring later towards the north-east of the Northumberland Trough, north-east of Bewcastle. The sandstones were deposited from lobate deltas that migrated periodically along the basin axis from north-east to south-west (Leeder, 1974). In the Solway Basin, the Easton Anhydrite Member is predominantly of shallow water origin. The sediments were deposited in a rapidly subsiding basin, with restricted marine circulation, in which sedimentation and rapid burial is inferred to have kept pace with subsidence. Most of the anhydrite is likely to have had a subaqueous rather than a sabkha origin, the purer and thicker beds probably precipitating as gypsum in regionally extensive salinas.

Stratotype
Type sections of the constituent members include for the Easton Anhydrite Member, the Easton 1 borehole (see above) from 1054 to 2260 m depth (this is a partial type section since the base of the member is not proved); for the Southerness Limestone Member, the shore section at Southerness [NX 9690 5420 to 9740 5420]; for the Lynebank Member, Ellery Sike [NY 5433 7584] to Nixontown [NY 5482 7550] on the River White Lyne; for the Cambeck Member, the River White Lyne [NY 5116 7300 to 5109 7322] at Bewcastle; for the Main Algal Member, Birky Cleuch [NY 5885 7540 to 5932 7538], Kirk Beck, Bewcastle; and for the Bewcastle Member, Ashy Cleuch [NY 5648 7698 to 5808 7665] upstream from Stockastead Quarry.

Lower and upper boundaries
The formation in the central part of the Northumberland Trough passes northward, by lateral facies change, into strata of the Ballagan Formation, Inverclyde Group (Figure 8, Column 11). In Annandale, the Hoddom No. 2 Borehole (BGS Registration Number NY17SE/3) [NY 1641 7285] showed the Lyne Formation conformably overlying the Ballagan Formation at 139.84 m depth. The base of the Lyne Formation is not seen at Bewcastle (Figure 11, Column 2) or Kirkbean (Figure 10, Column 2) but it is presumed to rest conformably on the Ballagan Formation in these places. The base of the Easton Anhydrite Member is not seen, but seismic interpretation indicates the presence of 'several thousands of feet' of conformable strata below the succession in some parts of the Solway Basin (see Ward, 1997, p. 283).

The upper boundary of the formation is locally unconformable and diachronous with the Fell Sandstone Formation in the central parts of the Northumberland Trough. At Bewcastle, the base of the latter is locally defined as the base of the Whitberry Band (WBB) (Figure 11, Column 2).

The top of the Easton Anhydrite Member is taken where numerous beds of anhydrite interbedded with limestones, shales, siltstones and sandstones give way to strata with variously algal, oolitic, peloidal, shelly, crinoidal and serpulid limestones, which may represent the Main Algal Member of the Lyne Formation. However, this has not been positively identified.

Thickness
In the Bewcastle area, in the central part of the Northumberland Trough, the formation is at least 890 m thick. However, in Annandale, the Hoddom No. 2 Borehole (see above) showed the Lyne Formation to be 37.22 m thick. In the Easton 1 borehole (see above) the Easton Anhydrite Member is more than 1153 m thick (base not seen).

Distribution and regional correlation
Northumberland Trough and Solway Basin: Langholm–Bewcastle, and Southerness. Seismic reflectors suggest that the top of the Easton Anhydrite Member extends at depth from west Cumbria eastwards to the flanks of the Bewcastle Anticline and beyond (see Ward, 1997, fig. 11).

Age and biostratigraphical characterisation
Late Tournaisian to Chadian (Waters et al., 2007, p. 18). The limestones commonly contain stromatolites and vermetid gastropod bioherms and biostromes. In the west quasimarine shelly faunas contain abundant brachiopods (including *Antiquatonia teres*). Based on limited palynology, the Easton Anhydrite Member is considered to be early Visean in age.

Formal subdivisions
See also Appendix 1. Members of the Lyne Formation in ascending stratigraphical order include:

6.5.1.1 Easton Anhydrite Member

Name
Originally named the 'Easton Anhydrite Facies of the Lower Border Group' by Ward (1997) the unit is here formally renamed the Easton Anhydrite Member. It is derived from the Easton 1 borehole, which was drilled near the hamlet of Easton 16 km north of Carlisle, and includes the type section.

Lithology
Grey or white anhydrite interbedded with limestones, shales, siltstones and sandstones.

Genetic interpretation
The sedimentary rocks are predominantly of shallow water origin. They were deposited in a rapidly subsiding basin, with restricted marine circulation, in which sedimentation and rapid burial is inferred to have kept pace with subsidence. Most of the anhydrite is likely to have had a subaqueous rather than a sabkha origin, the purer and thicker beds probably precipitating as gypsum in regionally extensive salinas.

Stratotype
The partial type section is the Easton 1 borehole (BGS Registration Number NY47SW/15) [NY 44124 71694] from 1054 to 2260 m depth (the base of member not being proved). An upper unit, 126 m thick, includes successions of generally upward-thinning beds of anhydrite, interbedded with limestone, some dolostone, sandstone and shale. A middle unit, 639 m thick, includes nine large cyclical sequences of limestones, shales, sandstones and anhydrite. A lower unit, at least 440 m thick, includes composite limestone-anhydrite beds, 2.4–6.1 m thick, separated by shales or claystones that thicken downwards. Sandstones in this unit are numerous but thin.

Lower and upper boundaries
The base of the member is not seen, but seismic interpretation indicates the presence of 'several thousands of feet' of conformable strata below the succession in some parts of the Solway Basin (see Ward, 1997, p. 283).

The top of the member is taken where numerous beds of anhydrite interbedded with limestones, shales, siltstones and sandstones give way to strata with variously algal, oolitic, peloidal, shelly, crinoidal and serpulid limestones, which may represent the Main Algal Member of the Lyne Formation. However, this has not been positively identified.

Thickness
More than 1153 m (base not seen).

Distribution and regional correlation
Solway Basin, proved in the Easton 1 borehole (see above). The member is not exposed at the surface (breccias present suggest it was removed by solution), but seismic reflectors suggest that the top of the member extends at depth from west Cumbria eastwards to the flanks of the Bewcastle Anticline and beyond (see Ward, 1997, fig. 11). A total area well in excess of 1000 km^2 is inferred.

Age
Early Visean, determined by limited palynology (Ward, 1997).

6.5.1.2 Southerness Limestone Member (SOLM)

Name
Previously known as the Southerness Beds (Craig, 1956; Deegan, 1970) and the Southerness Limestone Formation (Lintern and Floyd, 2000). The status is changed to that of a member.

Lithology
Interbedded fossiliferous marine limestone, mudstone and minor siltstone, with thick beds of bioturbated sandstone and prominant algal horizons. See Craig (1956); Deegan (1970).

Stratotype
The partial type section of the Southerness Limestone Member occupies a 0.5 km stretch of coast about 400 m west of the lighthouse at Southerness [NX 968 543 to 973 541]. The strata are deformed by a gently north-east plunging anticline within the eastern limb of which are exposed some 135 m of fossiliferous, thin-bedded, calcareous mudstones, siltstones and limestones, with four thin beds of calcareous sandstone (Lintern and Floyd, 2000, p. 78).

Lower and upper boundaries
The base is not exposed, but the boundary is probably gradational with the thinly interbedded siltstones and argillaceous limestones ('cementstones') of the Kirkbean Cementstone Member of the Ballagan Formation (Inverclyde Group).

The top of the member has a gradational contact with strata of the Gillfoot Sandstone Member of the Fell Sandstone Formation (Figure 10, Column 2).

Thickness
More than 135 m.

Distribution and regional correlation
Southerness shore, Southerness, Kirkcudbrightshire, south-western Scotland (Southern Uplands).

Age
Courceyan to Arundian

6.5.1.3 Lynebank Member (LYN)

Name
Previously known as the Lynebank Beds (Day, 1970). See also Leeder (1974).

Lithology
Alternations of thin limestones, dolomitic limestones ('cementstones') and mudstones, with sandstone beds towards the top of the sequence.

Stratotype
A partial type section including the lower part of the Lynebank Member occurs in the River White Lyne between Ellery Sike [NY 5433 7584] and Nixontown [NY 5482 7550]. The upper part of the Lynebank Member occurs in the River Black Lyne [NY 5431 7828 to 5411 7821] south-east of Holmehead Farm (Day, 1970).

Lower and upper boundaries
Base not seen. The upper boundary is conformable at the base of the Bogside Limestone (BGSL) at the base of the Bewcastle Member (Figure 11, Column 2) with cyclical sequences of sandstone, siltstone, mudstone and thin limestones and 'cementstones'.

Thickness
About 430 m at Bewcastle.

Distribution and regional correlation
The Northumberland–Solway Basin, but described only in the Bewcastle region (Day, 1970).

Age
Chadian

6.5.1.4 Bewcastle Member (BWCB)

Name
Previously known as the Bewcastle Beds (Day, 1970).

Lithology
Cyclical sequences of sandstone, siltstone, mudstone and thin limestones, locally dolomitic ('cementstones'); locally thin seatearths, nodular algal limestone and traces of coal (see Day, 1970; Leeder, 1974).

Stratotype
A partial type section that includes nearly all of the Bewcastle Member, from the Bogside Limestone to just above a probable equivalent of the Junction Limestone, is exposed in Ashy Cleuch [NY 5648 7698 to 5808 7665] (Day, 1970).

Lower and upper boundaries
At Bewcastle, the lower boundary is defined at the base of the Bogside Limestone (BGSL), and is conformable on the alternating thin limestones, 'cementstones' and mudstones of the Lynebank Member (Figure 11, Column 2).

The upper boundary is conformable with the base of the lowermost algal bed (M.A.1 of Day, 1970) of the rhythmically alternating limestone and mudstone with nodular algal beds of the Main Algal Member.

Thickness
About 180 m at Bewcastle.

Distribution and regional correlation
The Northumberland–Solway Basin, but described only in the Bewcastle region (Day, 1970).

Age
Chadian to Arundian.

6.5.1.5 Main Algal Member (MAN)

Name
Previously known as the Main Algal Limestone Beds (Day, 1970). See also Leeder (1974).

Lithology
Rhythmic alternations of limestone and mudstone with 14 well developed nodular algal beds and subsidiary sandstone and siltstone.

Stratotype
The type section is in Birky Cleuch from [NY 5885 7540 to 5932 7538] a tributary of the Kirk Beck at Bewcastle. Here, a complete sequence from M.A.1 to M.A.14, about 87 m thick is exposed (Day, 1970).

Lower and upper boundaries
At Bewcastle, the lowermost algal bed (M.A.1 of Day, 1970) of the Main Algal Member lies conformably on the Bewcastle Member (Figure 11, Column 2), which comprises cyclical sequences of sandstone, siltstone, and mudstone, with thin limestones and 'cementstones'.

At the top of the Main Algal Member, the top of the uppermost algal bed (M.A.14 of Day, 1970) is conformable with the overlying Lower *Antiquatonia* Bed (LAQB) of the Cambeck Member, which comprises rhythmic cycles of mainly sandstones, thin limestones and mudstones.

Thickness
Some 87 m at Bewcastle.

Distribution and regional correlation
The Northumberland–Solway Basin, but described only in the Bewcastle region (Day, 1970).

Age
Arundian.

6.5.1.6 Cambeck Member (CMBB)

Name
Previously known as the Cambeck Beds (Day, 1970). See also Leeder (1974).

Lithology
Rhythmic cycles of mainly sandstones, thin limestones and mudstones (the beds being abundantly shelly), and some algal beds and subsidiary siltstone. See Day (1970); Leeder (1974).

Stratotype
Partial type sections at Bewcastle include the River White Lyne [NY 5116 7300 to 5109 7322] with strata from the

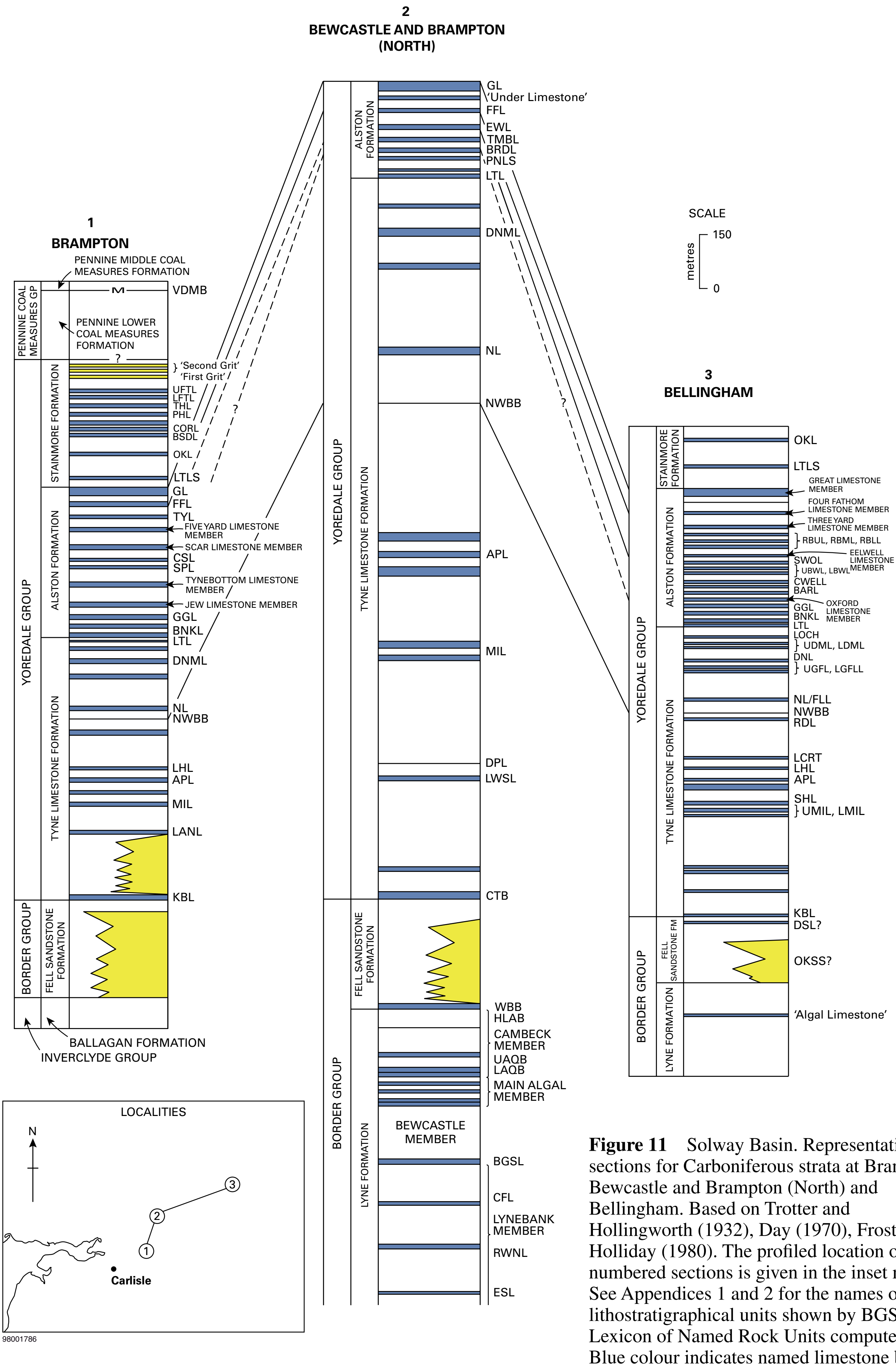


Figure 11 Solway Basin. Representative sections for Carboniferous strata at Brampton, Bewcastle and Brampton (North) and Bellingham. Based on Trotter and Hollingworth (1932), Day (1970), Frost and Holliday (1980). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. Blue colour indicates named limestone beds; green colour indicates significant developments of named sandstone units. Dashed lines indicate conjecture.

Lower *Antiquatonia* Band to the base of the Whitberry Band, and Whitberry Burn [NY 5220 7404 to 5203 7408] with strata from the Barrow's Pike Sandstone to the base of the Whitberry Band (Day, 1970).

Lower and upper boundaries
At Bewcastle, the base is conformable on the uppermost algal bed (M.A.14 of Day, 1970) of the Main Algal Member (Figure 11, Column 2), which comprises rhythmic alternations of limestone and mudstone with nodular algal beds.

There is a conformable upper boundary with the base of the locally developed Whitberry Band (WBB) of the sandstone-dominated Fell Sandstone Formation.

Thickness
Some 204 m at Bewcastle

Distribution and regional correlation
The Northumberland–Solway Basin, but described only in the Bewcastle region (Day, 1970).

Age
Arundian to Holkerian.

6.5.2 Fell Sandstone Formation (FELL)

Name
The name is derived from the Larriston Fells (Peach and Horne, 1903).

Lithology
The Fell Sandstone Formation in the north-east Northumberland Trough comprises fine- to medium-grained, mica-poor, subarkosic sandstone with sparse interbeds of red mudstone (Smith, 1967). This passes towards the central part of the trough into a continuation of the cyclical successions of fine-grained subarkosic sandstone, siltstone, mudstone and thin limestone present in the underlying Lyne Formation, although in the Fell Sandstone the sandstones are thicker and the limestones thinner (Day, 1970). Seatearths are common in the formation, but only in the upper part. Thin olivine basalt lavas occur as the Kershopefoot basalts (Williamson in Stephenson et al., 2003). At Southerness, members of the formation include the Gillfoot Sandstone and Powillimount Sandstone members. In the Colvend and Rerrick outliers the formation includes the Rascarrel Member.

Genetic interpretation
The sandstone is interpreted as having been deposited from both low-gradient meandering rivers and high-gradient braided perennial rivers, which occupied channel belts several kilometres wide along the axial part of the Northumberland Trough (Hodgson, 1978). The Fell Sandstone succession in the central part of the trough represents deposition in a mixed fluviodeltaic and shallow marine environment.

Stratotype
The Fell Sandstone Formation reaches its most characteristic development in the Simonside Hills in the Rothbury area of Northumberland (B. Young, written communication, 24 June 2004). Type sections occur at Murton High Crags, south-west of Berwick-upon-Tweed [NT 9620 4950], on the foreshore at Burnmouth [NT 9580 6110], and on the River White Lyne [NY 5110 7320]. Further sections occur south-west of Berwick-upon-Tweed [NT 9300 4500]. In Annandale, the Hoddom No.2 Borehole (BGS Registration Number NY17SE/3) [NY 1641 7285] included the Fell Sandstone Formation from 41.60 to 102.62 m depth. The type section of the Kershopefoot basalts is at Kershopefoot Quarry [NY 5005 8339], but neither the top nor bottom of the sequence is seen.

Lower and upper boundaries
The base of the Fell Sandstone Formation is locally unconformable and diachronous on a range of Lower Carboniferous strata, including the Lyne Formation in the central parts of the Northumberland Trough (Figure 8, Column 11). Locally, it is defined as the base of the Whitberry Band (WBB) (Figure 11, Column 2). At Brampton, the base of the Fell Sandstone Formation rests conformably on the Ballagan Formation, Inverclyde Group (Figure 11, Column 1), but in the north-east part of the Northumberland Trough the same boundary is unconformable (Figure 8, Column 12).

The top of the formation is locally unconformable and diachronous at the base of the Clattering Band (CTB) of north-west Northumberland (Figure 8, Column 11), its correlative the Kingsbridge Limestone (KBL), or in the Langholm area, the Glencartholm Volcanic Beds (GV), of the Tyne Limestone Formation (Yoredale Group) (Figure 10, Column 3).

Thickness
The formation ranges from 130–300 m thick in the north-east of the Northumberland Trough. It is 350–450 m thick in the central part of the trough measured between the bases of the Whitberry and Clattering bands. At Annandale, in the Hoddom No. 2 Borehole (see above) the Fell Sandstone Formation is about 61 m thick. The Kershopefoot basalts attain a maximum thickness of about 36.5 m (Williamson in Stephenson et al., 2003).

Distribution and regional correlation
Tweed Basin and the northern and central parts of the Northumberland Trough–Solway Basin, from Burnmouth, Berwickshire in the north-east to Southerness, Kirkcudbrightshire in the south-west. The Kershopefoot basalts occur in scattered outcrops south-east of Langholm between [NY 40 83 and 50 83].

Age
Deposition of the formation occurred earliest in the north-east of the Northumberland Trough (Chadian to Holkerian). In the central part of the trough, the equivalent strata are of Arundian to Holkerian age.

Formal subdivisions
See also Appendix 1. Members of the Fell Sandstone Formation in ascending stratigraphical order include:

6.5.2.1 Gillfoot Sandstone Member (GISD)

Name
Originally named the Gillfoot Beds by Craig (1956), and the Gillfoot Sandstone Formation by Lintern and Floyd (2000).

Lithology
See Craig (1956); Deegan (1970). The member comprises interbedded medium- to coarse-grained sandstone and subsidiary conglomerate with limestone and siltstone.

Stratotype
The type section is Gillfoot Bay, Southerness, Kirkcudbrightshire [NX 9780 5430 to 9870 5610] where

between 120 and 150 m of strata, comprised dominantly of sandstones and conglomerates with subordinate shales and fossiliferous marine beds, are exposed on the shore (Craig, 1956; Lintern and Floyd, 2000).

Lower and upper boundaries
The base has a gradational contact with strata of the Southerness Limestone Member (Figure 10, Column 2).

The upper boundary is taken as the top of the uppermost conglomerate associated with reddened strata, and is gradational with the interbedded mainly sandstone, sandy limestone and mudstone of the Powillimount Sandstone Member.

Thickness
Between 120 and 150 m.

Distribution and regional correlation
Gillfoot Bay, Southerness, Kirkudbrightshire, south-western Scotland (Southern Uplands).

Age and biostratigraphical characterisation
Arundian. Near the top of the member a shelly 'rib' yielded a fauna (possibly derived) including the coral *Siphonodendron* cf. *scoticum* and the brachiopod *Punctospirifer scabricosta*. *S. scoticum* occurs in Arundian to Asbian strata in Britain and the faunal evidence suggests that the Gillfoot Sandstone Member is Arundian in age (Lintern and Floyd, 2000 and references therein).

6.5.2.2 Powillimount Sandstone Member (POSD)

Name
Originally named the Powillimount Beds and Thirlstane Sandstone by Craig (1956), and the Powillimount Sandstone Formation by Lintern and Floyd (2000).

Lithology
See Craig (1956) and Deegan (1970). Interbedded bioturbated sandstone, sandy limestone (with some oncolite beds), and sparsely fossiliferous mudstone. There is subsidiary siltstone and a trace of coal.

Stratotype
The type section is the coast between Powillimount Bay [NX 9880 5610] and Thirl Stane [NX 9925 5690] with about 160 m of sandstone, limestone, and mudstone. The top 25 m of the member comprise the thick-bedded Thirlstane Sandstone Beds (Lintern and Floyd, 2000).

Lower and upper boundaries
The base is gradational and taken where mainly interbedded medium- to coarse-grained sandstone and subsidiary conglomerate of the Gillfoot Sandstone Member gives way to mainly interbedded bioturbated sandstone, sandy limestone and mudstone of the Powillimount Sandstone Member (Figure 10, Column 2).

The top of the member is taken at the top of the Thirlstane Sandstone, which lies conformably beneath the interbedded marine limestone, mudstone and subsidiary siltstone, with thick cross-bedded, bioturbated, medium-grained sandstone of the Arbigland Limestone Member, Tyne Limestone Formation.

Thickness
Some 135 m

Distribution and regional correlation
Powillimount shore, Southerness, Kirkcudbrightshire, south-western Scotland (Southern Uplands).

Age
Arundian to Holkerian.

6.5.2.3 Rascarrel Member (RASC)

Name
Previously known as the Rascarrel Sandstones and Conglomerates by Craig and Nairn (1956), and the Rascarrel Group by Deegan (1973), the status has been changed from a formation to a member and the "Sandstone" epithet removed.

Lithology
Conglomeratic sandstone interbedded with thin beds of 'marl' and siltstone, and subsidiary coal and mudstone.

Stratotype
Partial type sections include coastal sections between Castle Muir Point [NX 7980 4710] and Rascarrel Burnfoot [NX 8030 4800] where there are more than 360 m of sandstone, 'marl', and siltstone with thin mudstones and coals; and between Castlehill Point [NX 8545 5240] and Gutcher's Isle [NX 8635 5265] where the sequence includes a basal breccia, conglomerate, sandstone and shale, perhaps 21 m thick (see Craig and Nairn, 1956; Deegan, 1973; Lintern and Floyd, 2000).

Lower and upper boundaries
The base has faulted and unconformable contacts with the calcareous greywackes and silty mudstones (hornfelsed where they occur within the aureole of the Criffel Granodiorite) of the Ross Formation (Hawick Group). In the Rerrick Outlier the member is faulted against the conglomerates, conglomeratic sandstones, sandstones, red siltstones, 'marls' and pedogenic dolostones ('cornstones') of the Orroland Member (Ballagan Formation).

The top of the member is not seen, and Lintern and Floyd (2000, p. 86) indicate that no rocks of Namurian or Westphalian age are present on the Kirkudbright–Dalbeatie coast.

Thickness
More than 360 m.

Distribution and regional correlation
Rascarrel Bay (Rerrick Outlier); Castlehill Point to Gutcher's Isle and Portling to Portowarren shores (Colvend Outlier), Kirkcudbrightshire, south-western Scotland (Southern Uplands).

Age
Arundian to Holkerian.

6.6 GREAT SCAR LIMESTONE GROUP (GSCL)

The Great Scar Limestone Group (George et al., 1976; see also Waters et al., 2007) (Figure 7) of *open marine, platform and ramp carbonates facies* is widespread across Northern England. It comprises many formations with distinct formation nomenclature for the isolated horst and tilt-block highs.

The *Alston Block* includes the Melmerby Scar Limestone Formation (see Dunham, 1990).

The *Stainmore Trough* has the Coldbeck Limestone, Scandal Beck Limestone, Brownber, Breakyneck Scar Limestone, Ashfell Sandstone, Ashfell Limestone, Potts Beck Limestone and Knipe Scar Limestone formations (see Dunham and Wilson, 1985).

The *Askrigg Block* includes the Tom Croft Limestone, Ashfell Sandstone, Fawes Wood Limestone, Garsdale Limestone and Danny Bridge Limestone formations (see Dunham and Wilson, 1985).

The *Askrigg Block–Craven Basin Transition Zone* includes the Kilnsey, Chapel House Limestone, Malham and Cracoe Limestone formations (see Arthurton et al., 1988).

South Cumbria has the Martin Limestone, Red Hill Limestone, Dalton, Park Limestone and Urswick Limestone formations (see Rose and Dunham, 1977; Johnson et al., 2001).

North and west Cumbria includes the Frizington Limestone and Eskett Limestone formations (see Akhurst et al., 1997). It therefore includes the lower part of the now obsolete Chief Limestone Group.

The south *Isle of Man* includes the Derbyhaven, Knockrushen and Balladoole formations (see Chadwick et al., 2001).

The north *Isle of Man* includes undifferentiated strata assigned to either the Great Scar Limestone Group or the Yoredale Group (see Chadwick et al., 2001).

The succession comprises limestone, typically well washed, bioclastic, highly bioturbated with crinoid banks, shelly or coral biostromes and algal (*Girvanella*) bands. The group, common to other Visean platform areas in the British Isles, shows a trend from dark grey Arundian to Holkerian carbonates to pale grey Asbian to Brigantian limestones with eight major palaeokarstic bedding surfaces overlain by thin mudstones (Waltham, 1971). Apron knoll reefs are developed along the southern margin of the Askrigg Block. In the Stainmore Trough the limestone succession locally includes numerous intercalated sandstone beds, presumably derived from upstanding areas of lower Palaeozoic rocks. The lower part of the group, present in the Stainmore Trough (Coldbeck Limestone Formation) and South Cumbria (Martin Limestone Formation), was deposited in a carbonate dominated, nearshore to peritidal, restricted marine environment with common stromatolites and oncolites. Younger strata, dominated by thick bioclastic limestones, were deposited in an open, shallow marine environment. Palaeokarst surfaces indicate periodic emergence. The alluvial Brownber and fluviodeltaic Ashfell Sandstone formations represent brief incursions of siliciclastic deposits into the Stainmore Trough that encroached from the north. They may have been a distal extension of the Fell Sandstone Formation of the Border Group. In the north of the Isle of Man undifferentiated strata assigned to either the Great Scar Limestone Group or the Yoredale Group comprise massive, stylolitised, fractured and sucrosic dolomite (see Chadwick et al. 2001).

In the Stainmore Trough the base of the group is taken at the base of the Coldbeck Limestone Formation where the Algal Nodular Beds of the underlying Ravenstonedale Group are conformably overlain by carbonate-dominated strata.

On the Askrigg Block the base of the group is taken at the base of the Tom Croft Limestone Formation where a nodular dolostone bed with rhizoliths, indicative of emergence (Burgess, 1986), is locally developed at the top of the underlying Penny Farm Gill Formation (Ravenstonedale Group). This boundary is disconformable and marks a low sea-level stand.

On the Alston Block the base of the group is taken at the base of the Melmerby Scar Limestone Formation where the conglomerates of the underlying Marsett Formation (Ravenstonedale Group) are unconformably overlain by the onset of platform carbonate strata.

In north and west Cumbria the base of the group is taken at the base of the Frizington Limestone Formation where the conglomerates of the Marsett Formation (Ravenstonedale Group) are disconformably overlain by bioturbated peritidal limestones with rhizoliths, lime muds and sandstones. This disconformity represents nondeposition during Chadian to Arundian times.

In south Cumbria the base of the group is not exposed, but it is taken to be at the base of the Martin Limestone Formation where limestone becomes dominant over shale in the conglomeratic Marsett Formation (Ravenstonedale Group).

In the south Isle of Man the base of the group is taken at the base of the Derbyhaven Formation where the conglomerates (some of which are apparently reworked) of the Langness Conglomerate Formation (Ravenstonedale Group) are directly overlain by limestones.

In most places, the base of the Yoredale Group *(mixed shelf carbonate and deltaic ('Yoredale') facies)* defines the top of the Great Scar Limestone Group. The exceptions include the north Isle of Man where the Millstone Grit Group *(fluviodeltaic ('Millstone Grit') facies)* defines the top of what may be either the Great Scar Limestone Group or the Yoredale Group, and the south Isle of Man where the Craven Group defines the top of the Balladoole Formation.

The type area of the Great Scar Limestone Group is the Askrigg Block, where it was first formalised as a group by George et al. (1976). Subsequently the name was expanded to unify all equivalent, locally named, thick carbonate platform successions of the Tournaisian to early Namurian (Pendleian) of Northern England (see Waters et al., 2007, for further details).

The group is about 107 m thick on the Alston Block and Asbian in age. It gains a maximum thickness of about 800 m in the Stainmore Trough where it is Chadian to Asbian in age. On the Askrigg Block it is about 400 m thick and Arundian to Asbian in age. In Cumbria, up to about 740 m of Tournaisian to Pendleian strata are present, and in the south Isle of Man the group is up to about 157 m thick and Arundian to Asbian in age. In the north Isle of Man the approximately 7.3 m of what may be either Great Scar Limestone Group or Yoredale Group strata at the base of the Ballavaarkish (Shellag North) Borehole (see below) are possibly early Namurian or Visean in age, but diagenesis of the sedimentary rocks has completely ruled out obtaining a biostratigraphical age (Chadwick et al., 2001).

ALSTON BLOCK (Figure 9, Column 15):

6.6.1 Melmerby Scar Limestone Formation (MEL)

Name

The name is derived from the Melmerby Scar on the Alston Block.

Lithology

See Dunham (1990). The formation comprises distinctive lower and upper parts. The lower part, the Melmerby Scar Limestone, comprises grey, thick bedded limestone with generally thin calcareous mudstone partings. These apparently pass northward into two or three rhythmic units including clastics as well as limestone in the Brampton district and Northumberland Trough. The upper part of the formation comprises the Robinson Limestone, which consists of alternations of shale, sandstone and limestone.

Genetic interpretation
Marine platform

Stratotype
The type area is the Pennine escarpment above Melmerby. Natural sections in the formation occur along the Melmerby Scar escarpment at, for example, Longfell, Scoredale, Dufton Fell and Blencarn Beck (see Dunham, 1990), and also in boreholes as at Roddymoor and Emma Pit (BGS Registration Number NZ13NE/146) [NZ 1513 3635] and Rookhope (BGS Registration Number NY94SW/1) [NY 9375 4278], the depth range in the latter being from about 344 to 379 m.

Lower and upper boundaries
The base of the formation is unconformable on the conglomerates of the Marsett Formation, Ravenstonedale Group (Figure 9, Column 15; Figure 15, Column 1).

At the top of the formation there is evidence of pene-contemporaneous erosion and pot-holing at the top of the Robinson Limestone (RNL). This surface is overlain unconformably by siltstone or sandstone of the Tyne Limestone Formation, Yoredale Group.

Thickness
The Melmerby Scar Limestone ranges in thickness from 35–107 m. The Robinson Limestone is normally 4–6 m thick, but in Augill Beck (approaching the Stainmore Trough) it is 25 m thick.

Distribution and regional correlation
Alston Block.

Age and biostratigraphical characterisation
Asbian. The equivalent of Garwood's (1913) 'Bryozoa Band', encountered in the Garsdale Limestone Formation of the Askrigg Block, also occurs near the base of the Melmerby Scar Limestone Formation (Turner, 1927). The late Asbian Cf6γ Subzone foraminifers *Bradyina rotula* and *Endothyranopsis crassa*, and alga *Ungdarella uralica*, are examples of those recovered from the Melmerby Scar Limestone Formation in the Rookhope Borehole (see above) (Cozar and Somerville, 2004).

STAINMORE TROUGH AND RAVENSTONEDALE (Figure 9, Column 16):

6.6.2 Coldbeck Limestone Formation (CLK)

Name
The name is derived from Coldbeck, Ravenstonedale, Westmorland.

Lithology
See Mitchell (1978); Dunham and Wilson (1985). The formation comprises dark grey, fine-grained, well bedded limestones with mudstone partings, and flaggy dolostones characterised by an abundance of algal macrostructures including stromatolites and oncolites.

Genetic interpretation
The formation was deposited in a carbonate-dominated, nearshore to peritidal, restricted marine environment.

Stratotype
The type area is Ravenstonedale (see Taylor et al., 1971; Mitchell, 1978). 52 m of strata are visible in a continuous section in Stone Gill [NY 71 03].

Lower and upper boundaries
The lower boundary is at the base of the 'Spongiostroma Band' of Turner (1950), which overlies the thick-bedded, porcellanous limestones and thin-bedded dolostones in the upper part of the Stone Gill Limestone Formation, Ravenstonedale Group (Figure 9, Column 16).

The upper boundary of the Coldbeck Limestone Formation is at the top of the Algal Nodular Beds. These conformably underlie the dark grey limestone of the Scandal Beck Limestone Formation.

Thickness
Some 52 m of strata are visible in a continuous section in Stone Gill, Ravenstonedale, but Turner (1950, p. 30) estimated that a further 31 m are cut out by faulting. The formation is about 50 m thick at Gaisgill, but thins westward from here.

Distribution and regional correlation
Ravenstonedale, Cumbria and the Stainmore Trough.

Age and biostratigraphical characterisation
Early Chadian. There are at least three algal bands within the formation.

6.6.3 Scandal Beck Limestone Formation (SCBL)

Name
The name was first proposed by Mitchell (1972) and given formation status by Pattison (1990).

Lithology
The Scandal Beck Limestone Formation largely comprises dark grey, fine- to medium-grained, variable but commonly quite thin-bedded, packstone. Interbeds of sandstone, siltstone or mudstone between these fossiliferous limestones are common.

Genetic interpretation
Millward et al. (2003) considered the depositional environment to be a deep water carbonate ramp.

Stratotype
The type area is Scandal Beck [NY 718 040], in the Ravenstonedale area.

Lower and upper and boundaries
The base of the formation is conformable on the the Algal Nodular Beds at the top of Coldbeck Limestone Formation, the latter comprising well bedded limestones with mudstone partings, and flaggy dolostones with algal macrostructures.

A succession of sandstones, oolitic limestones and layers of quartz pebbles, the Brownber Formation (BNBF), conformably overlies the Scandal Beck Limestone Formation in Ravenstonedale (Figure 9, Column 16).

Thickness
The formation is about 120 m thick at Ravenstonedale, thinning to the north-east and south-west. It is about 50 m thick in the Appleby district.

Distribution and regional correlation
The Ravenstonedale area.

Age and biostratigraphical characterisation
Chadian to early Arundian? (see Mitchell, 1978, fig. 60, col. D after Taylor et al., 1971; Ramsbottom in Dunham and Wilson, 1985, p. 28; George et al., 1976, p. 39, fig. 11:4;

Millward et al., 2003, fig. 7). Stratigraphically significant fossils within the formation include the coral *Dorlodotia pseudovermiculare*.

Formal subdivisions
See also Appendix 1. Members of the Scandal Beck Limestone Formation, in ascending stratigraphical order, include:

6.6.3.1 PARK HILL LIMESTONE MEMBER (PAL)

Name
The name was given by Pattison (1990) for the lower part of the Scandal Beck Limestone Formation.

Lithology
Limestone and dolostone, fine-grained grainstone and packstone, dark grey to buff, wavy-bedded, interbedded with sandstone, siltstone and mudstone. The limestone lacks the common occurrence of corals, typical of the overlying Coupland Syke Limestone Member.

Stratotype
Partial type section is the course of the Rais Beck [NY 6393 0681 to 6428 0693], north of Fawcett Mill, by the village of Orton, Cumbria where about 20 m of limestone with thin beds of dolostone, sandstone and siltstone near the top of the member are patchily exposed (see Pattison, 1990).

Lower and upper boundaries
In the Ravenstonedale area, the base of the member coincides with the top of the Algal Nodular Beds at the top of Coldbeck Limestone Formation, the latter comprising well bedded limestones with mudstone partings, and flaggy dolostones with algal macrostructures.

The top of the member occurs beneath the more regularly bedded and fossiliferous packstones with thin mudstone and siltstone interbeds of the overlying Coupland Syke Limestone Member (COSL) (Figure 9, Column 16). The junction is taken at the top of a 5 m-thick sandstone and mudstone unit that forms a topographical depression.

Thickness
Between 50 and 75 m

Distribution and regional correlation
Ravenstonedale, Cumbria between the M6 road and the Dent Fault Zone, south of Kirkby Stephen.

Age
Chadian

6.6.3.2 COUPLAND SYKE LIMESTONE MEMBER (COSL)

Name
The name was proposed by Pattison (1990) for the limestones that occur between the Park Hill Limestone Member and the Brownber Formation.

Lithology
Packstone, dark grey, regularly bedded, blocky, partly dolomitised and bituminous. Cyclically interbedded with thin mudstone and siltstone beds. There are traces of chert. The limestone beds are a fairly constant 0.75 m thickness.

Stratotype
A partial type section is in a stone quarry (working in 2005) on the B6261 road west of the village of Orton, Cumbria [NY 5975 0920]. It occurs as a thick-bedded, bituminous limestone (wackestone) (see McCormac, 2001). This differs from similar thick-bedded rocks in disused quarries to the west [NY 5984 0924 and 5924 0968] where the blocky limestones are commonly or extensively dolomitised (possibly in association with minor faults) and geodic (see Pattison, 1990; McCormac, 2001). A reference section is Stapestones Quarry (disused), Raisbeck, Cumbria [NY 6496 0692] where 11 m of limestone (with some dolomitisation) are exposed (see Pattison, 1990).

Lower and upper boundaries
The base of the member is taken at the top of a 5 m unit of interbedded sandstone and mudstone, which forms a topographical depression at the top of the underlying Park Hill Limestone Member. The junction is nowhere exposed, but the interbedded unit was formerly seen in a road cutting at [NY 7248 0448] during the construction of the Ravenstonedale By-pass, and the junction was recorded in M6 Site Investigation Boreholes at [NY 5885 0998].

The top of the member is taken at the base of the overlying Brownber Formation (Figure 9, Column 16) where there is a change from dark grey cyclically bedded limestone to pale grey ooidal limestone and calcarenite.

Thickness
Between 40 and 50 m.

Distribution and regional correlation
Ravenstonedale, Cumbria between the M6 road and the Dent Fault Zone, south of Kirkby Stephen.

Age and biostratigraphical characterisation
Chadian. Colonial corals (notably genus *Dorlodotia*) are common within the member.

6.6.4 Brownber Formation (BNBF)

Name
The name is derived from Brownber, near Newbiggin-on-Lune, Westmorland; see Tiddeman (in Aveline and Hughes, 1888); Mitchell (1978); Pattison (1990); Millward et al. (2003).

Lithology
The sedimentary rocks of the Brownber Formation comprise interbedded sandstone (fine-grained, pale brown, laminated in part), limestone (calcarenites, grainstones, oolitic in part) and dolostone (yellow and flaggy) containing abundant quartz pebbles in distinctive and laterally discontinuous beds near the top.

Genetic interpretation
Interpretations include a shoreline (beach) deposit (Barraclough, 1983; Leeder, 1988) and deposition in a tidal, high and low energy environment (Millward et al., 2003).

Stratotype
Reference sections occur in old quarries north of Bousfield, Park and Dawns [NY 6102 0922 to 6107 0924] including beds of limestone and sandstone (with gaps), at or near the top of the formation, 4.8 m thick; and in a stream section north of Orton Village Green from [NY 6241 0844 to 6243 0851] which includes sandstone and limestone (with gaps) 6.7 m thick (see Pattison, 1990).

Lower and upper boundaries
The sandstones of the Brownber Formation overlie limestones of the Coupland Sike Limestone Member (Scandal Beck

Limestone Formation) (Figure 9, Column 16), but the boundary is poorly known in the Ravenstonedale area (see Pattison, 1990; McCormac, 2001).

Within the Stainmore Trough, an unconformity is present at the base of the overlying dark grey limestone of the Breakyneck Scar Limestone Formation which comprises packstone or grainstone with mudstone/siltstone interbeds.

Thickness
About 15–80 m thickness is recorded in the Orton area with 10–40 m in the Appleby district.

Distribution and regional correlation
The Ravenstonedale, Shap and Appleby area.

Age
Chadian (Millward et al., 2003) or Arundian (George et al., 1976, pp. 38–39, fig. 11, col. D; Mitchell, 1978, pp. 172–173, fig. 60, col. D after Taylor et al., 1971).

6.6.5 Breakyneck Scar Limestone Formation (BRE)

Name
The name is derived from Breakyneck Scar, Scandal Beck, Ravenstonedale and was proposed by Pattison (1990). It replaces such terms as the Blea Tarn and Tarn Sike limestones of Garwood (1913), and the '*Michelinia grandis* Beds' of George et al. (1976). Similar in lithology and identical in age range to the Tom Croft Limestone Formation of the Askrigg Block (see below), it may be argued that either one or the other of these formation names be deemed redundant. However, whilst BGS is not actively working on these successions rationalisation must be deferred.

Lithology
The Breakyneck Scar Limestone Formation comprises dark grey, unevenly (commonly rubbly) bedded, fine- to coarse-grained fossiliferous packstone or grainstone with dark grey mudstone/siltstone interbeds.

Genetic interpretation
Shallow marine–transgressive carbonates.

Stratotype
The type section is exposed in the valley of Scandal Beck, Ravenstonedale, Cumbria, where there is an estimated 150 m thickness of mainly limestones with interbedded mudstones (see Pattison, 1990). The contact with the underlying Brownber Formation is exposed near Orton [NY 6103 0923 to 6125 0925]. A locality in the Appleby district is Ravensworth Fell [NY 597 098] where calcarenites of the Brownber Formation are overlain by coarse-grained fossiliferous limestone (see McCormac, 2001).

Lower and upper boundaries
The formation unconformably overlies the interbedded sandstone, limestone and dolostone of the Brownber Formation within the Stainmore Trough.

The top of the formation, beneath the overlying Ashfell Sandstone Formation cannot be described precisely due to poor exposure (see Pattison, 1990).

Thickness
Up to 150 m thick in the east of Ravenstonedale the formation thins westwards, pinching out along the line of the Anne's Well Fault at [NY 584 115] (McCormac, 2001). It is about 75 m thick north of Newbiggin-on-Lune, and about 25 m thick near Howe Nook, Orton.

Distribution and regional correlation
Ravenstonedale, Stainmore Trough.

Age and biostratigraphical characterisation
Early Arundian (George et al., 1976; Mitchell, 1978; Millward et al., 2003). The limestones contain a rich fauna including the corals *Siphonodendron martini, Palaeosmilia murchisoni* and *Syringopora* sp., the productoid *Linoprotonia* sp. and costate spiriferoids.

6.6.6 Ashfell Sandstone Formation (AFS)

Name
The name is derived from Ashfell in Ravenstonedale; see Garwood (1913); Turner (1950; 1959); Ramsbottom (1973); Mitchell (1978); Dunham and Wilson (1985); Millward et al. (2003).

Lithology
The Ashfell Sandstone Formation comprises thick-bedded, fine-grained sandstone with current ripple laminations, rare cross-bedding, and convolute bedding. Interdigitating are beds of marine mudstone and thin limestone with shelly faunas.

Genetic interpretation
The fluviodeltaic, marine-regressive, Ashfell Sandstone Formation represents an incursion of siliciclastic deposits into the Stainmore Trough encroaching from the north-east. It may be a southern and western, distal extension of the Fell Sandstone Formation, Border Group.

Stratotype
The longest and most complete section through the formation is along the Scandal Beck in the Ravenstonedale area, where up to 160 m of sandstone with four limestone interbeds occurs (see Pattison, 1990; Dunham and Wilson, 1985).

Lower and upper boundaries
The base of the formation overlying the Breakyneck Scar Limestone Formation cannot be defined precisely due to poor exposure.

The top of the formation conformably underlies the mainly packstone, shelly grainstone or lime mudstone of the Ashfell Limestone Formation in the Stainmore Trough (Figure 9, Column 16) and Shap, east Cumbria (Figure 14, Column 3), and the mainly biomicrosparites and biomicrites of the Fawes Wood Limestone Formation on the Askrigg Block (Figure 9, Column 17; Figure 15, Column 3).

Thickness
The formation is 152 m thick in the Ravenstonedale area, thinning northwards. In the Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9026 8474] it is 38.40 m thick. In the Appleby district it is 20–40 m thick.

Distribution and regional correlation
The formation extends from the edge of the Lake District to the Alston Block, including the Eden Valley and northern margin of the Stainmore Trough.

Age and biostratigraphical characterisation
Late Arundian. Fossils of the thin limestone beds include the corals *Diphyphyllum smithi* and *Siphonodendron martini*.

6.6.7 Ashfell Limestone Formation (AFL)

Name
The name is derived from Ashfell in Ravenstonedale, Cumbria; see Ramsbottom (1973); George et al. (1976); Mitchell (1978); Dunham and Wilson (1985); Pattison (1990).

Lithology
The distinctive Ashfell Limestone Formation is characteristically dark grey to dark blue-grey and mainly a packstone, shelly grainstone or lime mudstone. Strongly cross-bedded units, with thin interlaminae of siltstone and fine-grained sandstone occur at the base of the formation. Convolute beds and nodules of dark grey chert occur locally, and partial dolomitisation is common. The top of the formation is marked by the presence of dark grey, cross-bedded, coarse-grained crinoidal grainstone, grey mudstone with bivalves, and vuggy porcellanous limestone (the 'Bryozoa Band' of Garwood, 1913).

Genetic interpretation
Shallow marine, perhaps slightly restricted carbonate environment.

Stratotype
Partial type sections occur in Potts Valley [NY 6988 0827], [NY 6981 0820] and [NY 6972 0805 to 6969 0813] where more than 48 m of limestones in the upper and middle parts of the formation are exposed, and at Ewe Fell [NY 6971 0702 to 6999 0711] where 60 m of the lowest part of the formation, comprising limestone and 7 m of sandstone, are exposed (see Pattison, 1990).

Lower and upper boundaries
The mainly packstone, shelly grainstone or lime mudstone of the Ashfell Limestone Formation conformably overlies the sandstones, mudstones and thin limestones of the Ashfell Sandstone Formation.

On the northern margin of the Stainmore Trough, the 'Bryozoa Band' (BZB) at the top of the Ashfell Limestone Formation is overlain either conformably by the mainly sparry packstone of the Potts Beck Limestone Formation (Figure 9, Column 16), or disconformably by the rhythmically bedded limestone (mainly wackestone and packstone) of the Knipe Scar Limestone Formation (Figure 14, Column 3).

Thickness
The formation is 40–50 m thick at Penrith and Brough, but thickens to 100 m in the Stainmore Trough.

Distribution and regional correlation
Penrith, Brough and the Stainmore Trough.

Age and biostratigraphical characterisation
Holkerian. Shelly beds contain stromatolite colonies, coral fragments (including *Lithostrotion minus*), bryozoa, brachiopods (including rhynchonellids, spiriferoids and *Davidsonina carbonaria*), gastropods, crinoid ossicles, fish scales and burrows. The characteristic Holkerian brachiopod *Davidsonina carbonaria* is found in the Orton and Ravenstonedale area (Pattison, 1990). The 'Bryozoa Band' of Garwood (1913) occurs at the top of the formation.

6.6.8 Potts Beck Limestone Formation (PBK)

Name
The name is derived from Potts Beck near Ravenstonedale, Cumbria (see George et al., 1976).

Lithology
See Mitchell (1978); Dunham and Wilson (1985); Millward et al., (2003). The Potts Beck Limestone Formation is composed largely of pale grey, thick-bedded, strongly jointed, sparry packstone. Rubbly weathered calcrete horizons are present, as are subordinate sandstones and mudstones.

Genetic interpretation
Marine.

Stratotype
The type section is at Great Kinmond [NY 6728 0892 to 6728 0927] where some 39 m of mostly fossiliferous limestone is exposed. The type area is at Little Asby Scar [NY 6988 0827] on the north side of Potts Valley, near Newbiggin-on-Lune, Cumbria where the base of the formation is exposed.

Lower and upper boundaries
The base of the formation is conformable, and taken at the change from dark grey, cross-bedded, coarse-grained, crinoidal grainstone with mudstone interbeds (the 'Bryozoa Band' of Garwood, 1913) at the top of the underlying Ashfell Limestone Formation (Figure 9, Column 16), to grey, coralline packstone.

The upper boundary of the formation is overlain by the grey, scar-forming, rhythmically bedded, limestone (mainly wackestone and packstone) of the Knipe Scar Limestone Formation.

Thickness
The formation is up to 45 m thick in the Stainmore Trough, but thins rapidly towards the surrounding block areas. It is, for example, absent north of Shap village.

Distribution and regional correlation
Stainmore Trough.

Age and biostratigraphical characterisation
Latest Holkerian to early Asbian. Fossils, which can be abundant, include the corals *Axophyllum* sp., *Dibunophyllum bourtonense*, *Palaeosmilia murchisoni*, *Siphonodendron junceum* and *S. martini*, and the brachiopods *Daviesiella llangollensis* and *Gigantoproductus* sp. The Stainmore Trough includes the basal Asbian Stratotype at Little Asby Scar [NY 6988 0827] (George et al., 1976). Faunal analysis of this section places the Holkerian/Asbian boundary above the base of the formation (Ramsbottom, 1981).

6.6.9 Knipe Scar Limestone Formation (KNL)

Name
The name is derived from Knipe Scar, Bampton, Cumbria. See Mitchell (1978).

Lithology
The Knipe Scar Limestone Formation is wholly dominated by rhythmically bedded limestone, comprising mostly thick-bedded, pale to mid grey, wackestone and packstone, with some grainstone. Palaeokarst horizons and conspicuous stratiform mottled calcrete textures in beds up to 1 m thick are present. Significant beds of fine-grained sandstone, siltstone and mudstone punctuate the upper part of the succession, but are rarely seen at outcrop. The formation is the equivalent of the Melmerby Scar Limestone Formation of the Alston Block and the Danny Bridge Limestone Formation of the Askrigg Block and forms spectacular scenery of terraced topography and limestone pavements.

Genetic interpretation
Shallow marine. The palaeokarst horizons and stratiform mottled calcrete textures indicate emergence of the unconsolidated carbonate substrate.

Stratotype
The formation is exposed in its entirety on the pavements of Great Asby Scar [NY 650 100] and Knipe Scar [NY 528 193]. The type area is Great Asby Scar [NY 6592 0917 to 6630 0969] where some 50 m of largely thick-bedded and mostly bioclastic limestone is exposed. Major new exposures are available in quarries at Hardendale [NY 587 138] and Shap Beck [NY 550 183], where continuous sections show thin sandstone and mudstone interbeds in the limestone sequence (see Pattison, 1990).

Lower and upper boundaries
In Ravenstonedale and the Stainmore Trough the formation conformably overlies the packstones of the Potts Beck Limestone Formation (Figure 9, Column 16). It disconformably overlies the 'Bryozoa Band' at the top of the Ashfell Limestone Formation on the northern Stainmore Trough margin.

The top of the formation is disconformably overlain by a variable sandstone and mudstone unit known locally as the Wintertarn Sandstone Member (WTRS) at the base of the Tyne Limestone Formation, Yoredale Group (Figure 9, Column 16; Figure 14, Column 3).

Thickness
The formation is up to 50 m thick at Knipe Scar, but thickens to 100 m at Ravenstonedale.

Distribution and regional correlation
Ravenstonedale and the Stainmore Trough.

Age and biostratigraphical characterisation
Late Asbian. The formation is not abundantly fossiliferous in the Stainmore Trough, but includes *Siphonodendron pauciradiale, Davidsonina septosa* and *Delepinea* sp. In the Eamont Valley [NY 490 260] it is conspicuously fossiliferous containing large broken stromatolite colonies, *Hexaphyllia* sp., *Lithostrotion* sp. and *Siphonodendron* sp. and *Gigantoproductus* sp.

ASKRIGG BLOCK (Figure 9, Column 17; Figure 15, Column 3):

6.6.10 Tom Croft Limestone Formation (TCL)

Name
The formation was first proposed by Burgess (1986). The name is derived from Tom Croft Wheel [SD 6948 9147], Garsdale, Yorkshire. Similar in lithology and identical in age range to the Breakyneck Scar Limestone Formation (see above) of the Ravenstonedale area, it may be argued that either one or the other of these formation names be deemed redundant. However, whilst BGS is not actively working on these successions rationalisation must be deferred.

Lithology
The Tom Croft Limestone Formation comprises mid to dark grey, poorly bedded biosparites (grainstone containing peloids, shelly debris, crinoid fragments and variable quantities of dolomite grains). The formation includes a macrofauna comparable with that of the 'Dalton Beds' of south Cumbria (see Rose and Dunham 1977) and may include a thin basal unit of limestone breccia with siltstone and quartz pebbles.

Genetic interpretation
Shallow marine carbonate.

Stratotype
Reference sections in the formation include: the River Clough [SD 6954 9143 to 6947 9147], Garsdale, where the lowest beds are cut out by faults (Burgess, 1986, p. 7) but there is an 80 m-thick run (possibly including some repetition) of dominantly dark grey limestone virtually free of mudstone partings (Burgess, 1986, p. 8; see Dunham and Wilson, 1985, p. 28); the Beckermonds Scar Borehole (BGS Registration Number SD88SE/1) [SD 8636 8016] from 209.15 to 267.88 m depth including dominantly dark grey limestone with some mid grey runs (see Wilson and Cornwell, 1982); and the BGS Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9626 8474] from about 273 to 350 m depth (see Dunham and Wilson, 1985, fig. 5, cols. 5 and 7).

Lower and upper boundaries
The base of the formation is disconformable on the limestone, dolostone, sandstone and siltstone of the Penny Farm Gill Formation, Ravenstonedale Group (Figure 9, Column 17).

The top of the formation underlies the diachronous Ashfell Sandstone Formation in the Stainmore Trough and the same formation and the Fawes Wood Limestone Formation on the Askrigg Block (Figure 15, Column 3).

Thickness
The formation is 60–80 m thick.

Distribution and regional correlation
Askrigg Block.

Age and biostratigraphical characterisation
Arundian. The macrofauna includes the corals *Koninckophyllum* sp. and *Michelinia megastoma*, and the brachiopod *Delepinea carinata*.

6.6.11 Ashfell Sandstone Formation (AFS)

See Section 6.6.6 for definition.

6.6.12 Fawes Wood Limestone Formation (FWL)

Name
The name is derived from Fawes Wood [SD 6955 9145], on the River Clough, Garsdale, Yorkshire (see Dunham and Wilson, 1985 and references therein). The formation was first proposed by Burgess (1986).

Lithology
The Fawes Wood Limestone Formation comprises mid to dark grey biomicrosparites and biomicrites (calcarenite, mainly grainstone and packstone) with silty or stylolitic partings and some porcellaneous micrites.

Genetic interpretation
Shallow marine carbonate

Stratotype
Reference sections in the formation include: the River Clough, Garsdale [SD 6967 9129 to 6961 9134] where the formation comprises biomicrites and medium-grained limestones 80.77 m thick (Burgess, 1986, p. 11; Dunham and Wilson, 1985, p. 28); part of the Beckermonds Scar Borehole (BGS Registration Number SD88SE/1) [SD 8636

8016] from about 143 to 200 m depth, where it comprises mid–dark grey limestone, chiefly medium-grain calcarenite (Wilson and Cornwell, 1982, p. 64); and the BGS Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9626 8474] from about 158 to 235 m depth. Dunham and Wilson (1985, p. 28, see also fig. 5, cols. 5 and 7) summarised the formation as comprising about 56–81 m of dominantly dark grey and grey fine-grained grainstones and packstones with a few mudstone and siltstone beds.

Lower and upper boundaries
The formation conformably overlies the sandstones of the Ashfell Sandstone and biosparites of the Tom Croft Limestone formations (Figure 9, Column 17; Figure 15, Column 3).

The formation is conformably overlain by the limestones with interbedded sandstones, siltstones and numerous thin beds of mudstone of the Garsdale Limestone Formation.

Thickness
The formation ranges in thickness from 80.77 m in the River Clough to 55.80 m in the Beckermonds Scar Borehole (Dunham and Wilson, 1985).

Distribution and regional correlation
Askrigg Block.

Age and biostratigraphical characterisation
Holkerian. Fossils include *Siphonodendron martini, Linoprotonia* sp., and ?*Macrochilina* sp. The lower part of the formation contains distinctive Holkerian assemblages with *Lithostrotion minus, Siphonodendron sociale* and *Davidsonina carbonaria*. Although it is lithologically similar to the Ashfell Limestone Formation, the upper limit of the Fawes Wood Limestone Formation is taken at a lower stratigraphical level.

6.6.13 Garsdale Limestone Formation (GAL)

Name
The name is derived from Garsdale [SD 73 90], Yorkshire (see Dunham and Wilson, 1985 and references therein).

Lithology
The Garsdale Limestone Formation comprises dark grey biomicrosparites to porcellanous micrites (wackestone with bands of porcellaneous calcilutite) with interbedded sandstone and siltstone, numerous thin mudstone beds and rare thin coals. Three coal seams, up to 0.07 m thick, occur in the Beckermonds Scar Borehole (see below). Minor fenestral and palaeokarst surfaces occur. The formation contains the equivalent of Garwood's (1913) 'Bryozoa Band'.

Genetic interpretation
Shallow marine carbonates (with some intertidal deposits).

Stratotype
The type section is the River Clough [SD 6977 9128 to 6967 9129] in Garsdale, comprising a variety of limestones with interbedded sandstones and siltstones, and a thin coal (see Burgess, 1986, pp. 11–12). Reference sections include the Beckermonds Scar Borehole (BGS Registration Number SD88SE/1) [SD 8636 8016] from about 101 to 143 m depth, including dark grey wackestones with beds of calcilutite, three thin coal seams, and beds of mudstone concentrated near the top of the unit (see Wilson and Cornwell, 1982), and the BGS Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9626 8474] from about 103 to 158 m depth. Dunham and Wilson (1985, p. 28, see also fig. 5 cols. 5 and 7) described the formation as comprising dominantly dark grey, fine-grained wackestone with many interbeds of siltstone and mudstone, and one to four thin coal seams and seven to ten beds of calcilutite up to 1.22 m thick.

Lower and upper boundaries
The conformable base of the formation overlies the mid to dark grey limestones of the Fawes Wood Limestone Formation (Figure 9, Column 17; Figure 15, Column 3).

The top of the formation is conformable beneath the pale to mid grey limestone of the Danny Bridge Limestone Formation.

Thickness
The formation is 41–58 m thick (Dunham and Wilson, 1985).

Distribution and regional correlation
Askrigg Block and Wharfedale.

Age and biostratigraphical characterisation
Late Holkerian to early Asbian. The equivalent of Garwood's (1913) 'Bryozoa Band' includes *Pleuropugnoides pleurodon, Productus garwoodi, Punctospirifer scabricosta, Leiopteria lunulata* and ostracods. Dunham and Wilson (1985) considered that the Holkerian–Asbian boundary should occur within the Garsdale Limestone Formation as defined at Little Asby Scar (see George et al., 1976). As such it has no direct lithological, or time equivalent, correlative within the nearby Holkerian/Asbian succession of Ravenstonedale.

6.6.14 Danny Bridge Limestone Formation (DBL)

Name
The name is derived from Danny Bridge [SD 6982 9128], Garsdale, Yorkshire (see Dunham and Wilson, 1985, and references therein). The formation was proposed by Burgess (1986).

Lithology
The Danny Bridge Limestone Formation consists of pale to mid grey biosparites and biopelsparites (mainly wackestone, with packstone and minor grainstone), and subordinate mudstone in 10 regularly spaced interbeds. Palaeokarst surfaces overlain by bentonitic clays, palaeosols and calcareous laminated crusts are common and the formation displays a characteristically stepped landscape.

Genetic interpretation
Shallow marine carbonates (emergent at times).

Stratotype
The type section of the formation is the River Clough at Garsdale [SD 7000 9118 to 6977 9128], which consists mainly of marine limestone (biomicrite, biomicrosparite, biosparite) and mudstone (see Burgess, 1986, pp. 13–14). Reference sections include the Beckermonds Scar Borehole (BGS Registration Number SD88SE/1) [SD 8636 8016] from about 8.0 to 101 m depth with mainly pale grey (and subordinate mid grey) limestone, thin mudstone or siltstone beds, and a section of mineralised flats (see Wilson and Cornwell, 1982, pp. 61–63; Dunham and Wilson, 1985, fig. 5, col. 5), and the BGS Raydale Borehole (BGS Registration Number SD98SW/1) [SD 9626 8474] from about 5 to 103 m depth. Dunham and Wilson (1985, fig. 5,

col. 7) summarised the Raydale Borehole and surface exposures as a largely complete sequence about 127 m thick with mainly pale grey limestone and thin mudstone or siltstone beds.

Lower and upper boundaries
The base of the formation is conformable on the dark grey limestone of the Garsdale Limestone Formation (Figure 9, Column 17).

The cross-bedded, regressive sandstones of the Wintertarn Sandstone Member (WTRS), marking the base of the Tyne Limestone Formation, Yoredale Group, overlie the top of the Danny Bridge Limestone Formation (Figure 15, Column 3).

Thickness
The formation is 102–168 m thick, the greatest thickness being on the southern margin of the Askrigg Block (see Dunham and Wilson, 1985).

Distribution and regional correlation
Askrigg Block, Wensleydale and Wharfedale. The formation is the direct equivalent of the Knipe Scar and Urswick limestone formations of the Stainmore Trough and south Cumbria respectively.

Age and biostratigraphical characterisation
Late Asbian. Amongst the general shelly debris, fossils include *Davidsonina septosa* and typically, *Siphonodendron martini*. The formation also yields a diagnostic late Asbian assemblage of foraminifers (see Dunham and Wilson, 1985, p. 22).

ASKRIGG BLOCK–CRAVEN BASIN TRANSITION ZONE (Figure 15, Column 6)

6.6.15 Chapel House Limestone Formation (CHPL)

Name
See Arthurton et al. (1988); Murray (1983).

Lithology
The lower part of the succession is dominated by mid to mid–pale grey, medium- and coarse-grained calcarenite, oolitic grainstones interbedded with conglomerates, 'mixed laminites' (interbedded siltstone with sandstone and mudstone laminae), dolomicrites and fenestral or algal lime-mudstones. Argillaceous wackestones occur locally in the upper part of the formation.

Genetic interpretation
Shallow marine (see Murray, 1983).

Stratotype
The type section is the Chapel House Borehole (BGS Registration Number SD96NE/1) [SD 9726 6647], near Kilnsey, Yorkshire, which records the entire thickness of the formation (33.8 m) from 56.3 to 90.1 m depth (see Arthurton et al., 1988).

Lower and upper boundaries
The base is drawn at the base of the conglomerate of the Chapel House Limestone Formation where it rests with significant non-sequence on the deeply fissured limestone top surface of the Stockdale Farm Formation (Figure 15, Column 6), which comprises limestone, siltstone and mudstone. It lies directly on Lower Palaeozoic rocks elsewhere.

The top of the formation is drawn at the sharp conformable upward passage from grainstone of the Chapel House Limestone Formation to darker limestones of the Scaleber Force Limestone Member (Kilnsey Formation).

Thickness
Maximum of about 56 m adjacent to the Middle Craven Fault, and 33.8 m thick in the type section (see above).

Distribution and regional correlation
A series of inliers in the southern part of the Askrigg Block, North Yorkshire, including Gordale Beck [SD 91 65], Stainforth Force, River Ribble [SD 82 67], and Barrel Sykes, north of Settle [SD 82 64]. The formation is proved elsewhere in the subsurface of the Settle area in boreholes.

Age and biostratigraphical characterisation
Arundian. Arthurton et al. (1988) record the presence of the corals *Michelinea megastoma* and *Palaeosmilia murchisoni* from the top and base of the formation respectively, and the foraminifers *Ammarchaediscus bucullentus, Eoparastaffella simplex, Glomodiscus miloni, Latiendothyranopsis menneri solida* and *Rectodiscus* sp., which confirm its Arundian age.

6.6.16 Kilnsey Limestone Formation (KLSL)

Name
See Mundy and Arthurton (1980) and Arthurton et al. (1988). Kilnsey Crag occurs in north Yorkshire near the Hamlet of Kilnsey, north of Skipton.

Lithology
The formation comprises dark to mid–pale grey, thick to thin-bedded, bioclastic limestone with mudstone beds and partings.

Genetic interpretation
Marine.

Stratotype
See Arthurton et al. (1988). The partial type section is at Kilnsey Crag [SD 9735 6846] near Malham, North Yorkshire, with 8 m of the upper part of the Scaleber Force Limestone Member and 29 m of the overlying Scaleber Quarry Limestone Member. A reference section is in the Stockdale Farm (Cominco S7) Borehole (BGS Registration Number SD86SE/6) [SD 8541 6378] near Settle, North Yorkshire with the formation present from 15.2 to 120.1 m depth, which includes 61.6 m thickness of the Scaleber Force Limestone Member and 43.2 m in the Scaleber Quarry Limestone Member.

Lower and upper boundaries
The lower boundary of the formation is drawn at the base of the dark grey limestones with mudstone partings of the Scaleber Force Limestone Member where it rests sharply and conformably on paler grainstone of the Chapel House Limestone Formation (Figure 15, Column 6).

The upper boundary of the formation is drawn at the conformable upward passage from mid–dark grey limestone of the Scaleber Quarry Limestone Member to pale grey limestone of the Cove Limestone Member, Malham Formation.

Thickness
The maximum thickness is about 224 m in boreholes south of the Middle Craven Fault. The formation thins rapidly northwards to 53 m in the Kilnsey area.

Distribution and regional correlation
Limited to a series of inliers in the southern part of the Askrigg Block, North Yorkshire including Kilnsey [SD 97 68], Langcliffe [SD 82 65], and Austwick [SD 77 68].

Age and biostratigraphical characterisation
Arundian to Holkerian. Biostratigraphically important fossils recorded within the formation include foraminifers (diagnostic of both stages), *Delepinea carinata* (which is characteristic of the Arundian), and *Lithostrotion sensu stricto* (cerioid), which is not recorded below the base of the Holkerian (Mitchell, 1989).

Formal subdivisions
See also Appendix 1. Members of the Kilnsey Formation in ascending stratigraphical order include:

6.6.16.1 Scaleber Force Limestone Member (SFLM)

Name
The name is derived from Scaleber Force [SD 8407 6256]. It was previously known as the Kilnsey Limestone-with-mudstone Member and originally defined by Hudson (1930). Arthurton et al. (1988) is the principal reference.

Lithology
Bioturbated, well-bedded, fine- to coarse-grained dark limestones (packstones and subordinate wackestones), generally argillaceous with common detrital quartz, and with common mudstone partings and interbeds up to 1.8 m thick.

Stratotype
The type locality is Scaleber Force [SD 8407 6256] where a 22 m section is exposed. A reference section is the Cominco S7 Borehole (BGS Registration Number SD86SE/6) [SD 8541 6378] near Settle, North Yorkshire, which includes the full thickness of the member from 58.5 to 120.1 m depth.

Lower and upper boundaries
The base of the Scaleber Force Limestone Member is drawn where the dark limestones rest sharply and conformably on paler grainstone of the Chapel House Limestone Formation (Figure 15, Column 6).

The top of the member is taken where the dark grey limestones of the Scaleber Force Limestone Member are overlain by mid–dark grey limestone of the Scaleber Quarry Limestone Member.

Thickness
North of the Middle Craven Fault the member is 22–58 m thick. South of the fault it is 61.6 m thick at the type locality (see *Stratotype* above).

Distribution and regional correlation
The member occurs in a series of inliers in the southern part of the Askrigg Block, North Yorkshire, including Kilnsey [SD 97 68], Langcliffe [SD 82 65], and Austwick [SD 77 68].

Age
Arundian.

6.6.16.2 Scaleber Quarry Limestone Member (SQLM))

Name
The name is derived from Scaleber Quarry [SD 9225 5328]. It was previously known as the Kilnsey Limestone and originally defined by Hudson (1930). Arthurton et al. (1988) is the principal reference.

Lithology
Well-bedded, thin and thick beds of mid and mid–dark grey, fine- to coarse-grained limestone, with minor mudstone beds. Bioclastic packstones characterise the lower part of the member, passing up to packstones and grainstones. Bands and nodules of black chert occur locally in the lower part of the member.

Stratotype
The type locality is Scaleber Quarry [SD 8407 6263] where a 12 m section 18 m above the base of the member is exposed. Reference sections are provided by the Cominco S2 Borehole (BGS Registration Number SD86SW/6) [SD 8491 6345] at Low Barn, Stockdale Beck, from 224.2? to 363.9? m depth, and Kilnsey Crag [SD 9735 6846] where 29 m are exposed at outcrop in a cliff section. Both reference sections include the top and base, and full thickness, of the member.

Lower and upper boundaries
The base is taken where the mid grey limestone of the Scaleber Quarry Limestone Member overlies the dark grey limestone and mudstones of the Scaleber Force Limestone Member (Figure 15, Column 6). This boundary is typically gradational and for convenience the base is taken at the top of the highest prominent mudstone.

The top of the member is drawn at the conformable, gradational and slightly diachronous upward passage from mid–dark grey limestone of the Scaleber Quarry Limestone Member to the pale grey limestone of the Cove Limestone Member (Malham Formation).

Thickness
Up to 134 m thick in the Cominco Borehole S2, decreasing to 29 m at Kilnsey Crag (see above).

Distribution and regional correlation
The member occurs in a series of inliers in the southern part of the Askrigg Block, North Yorkshire, including Kilnsey [SD 97 68], Langcliffe [SD 82 65] and Austwick [SD 77 68].

Age and biostratigraphical characterisation
Holkerian. The member contains an abundant macrofauna characterised by cerioid and fasciculate lithostrotionid corals.

6.6.17 Malham Formation (MALM)

Name
See Arthurton et al. (1988) and Mundy and Arthurton (1980). Malham Cove [SD 8975 6411] occurs in Yorkshire near the village of Malham, east of Settle.

Lithology
The formation includes massive- to weakly bedded, pale grey to very pale grey, medium- to coarse-grained calcarenite packstones and grainstones, and well bedded, thick- to very thick-bedded, mid–pale to very pale grey, calcarenite packstones, wackestones and subordinate grainstones.

Genetic interpretation
Limestone deposition on a rimmed marine shelf. The Cove Limestone Member in shallow water well within fair-weather wave-base, and the Goredale Limestone Member in cyclical shallow water with emergent episodes (see Cossey and Adams, fig. 5.21 in Cossey et al., 2004).

Stratotype
Partial type sections occur at Malham Cove [SD 8975 6411], North Yorkshire, where 72 m of the upper part of the Cove Limestone Member, including the top, is present, and at Gordale Scar [SD 913 640] where the complete thickness (94 m) of the Gordale Limestone Member, including its top and base, is seen. See Arthurton et al. (1988).

Lower and upper boundaries
The lower boundary of the formation is drawn at the base of the pale grey limestone of the Cove Limestone Member where it rests conformably (but gradationally and slightly diachronously) on the mid–dark grey limestone of the Scaleber Quarry Limestone Member, Kilnsey Formation (Figure 15, Column 6), or locally, unconformably on Lower Palaeozoic strata.

The conformable upper boundary of the formation is drawn at the upward passage from pale grey limestone of the Gordale Limestone Member to darker grey limestone of the Lower Hawes Limestone at the base of the Alston Formation, Yoredale Group. However, in the Cominco S11 Borehole (BGS Registration Number SD86SE/5) [SD 8590 6340] the upper boundary of what is probably the Malham Formation is unconformable beneath the Bowland Shale Formation, Craven Group.

Thickness
The thickness of the formation ranges from about 220 m south of the Middle Craven Fault, to about 140 m north of the North Craven Fault.

Distribution
Southern part of the Askrigg Block, north of Settle [SD 77 to 97].

Age
Holkerian to Asbian

Formal subdivisions
See also Appendix 1. Members of the Malham Formation in ascending stratigraphical order include:

6.6.17.1 Cove Limestone Member (CVLS)

Name
See Arthurton et al. (1988); Mundy and Arthurton (1980). Malham Cove [SD 8975 6411] occurs in Yorkshire near the village of Malham, east of Settle.

Lithology
Pale grey to very pale grey limestone, mainly medium- and coarse-grained calcarenite, bioclastic and peloidal packstones and grainstones, massive to weakly bedded. Subordinate micrites (‘Porcellaneous Bed’), variably fenestral, and clay beds occur locally, the latter occurring in places above palaeokarstic surfaces. The member generally produces a topography characterised by steep grassy slopes, although the uppermost 6 m forms a continuous scar, commonly with an overhang.

Stratotype
Partial type section occurs at Malham Cove [SD 8975 6411] where 72 m of the upper part of the Cove Limestone Member, including the top, is present (see Arthurton et al., 1988).

Lower and upper boundaries
The lower boundary is drawn at the base of the pale grey limestone of the Cove Limestone Member where it rests conformably (but gradationally and slightly diachronously) on the mid–dark grey limestone of the Scaleber Quarry Limestone Member, Kilnsey Formation (Figure 15, Column 6), or locally, unconformably on Lower Palaeozoic strata, for example, at Crummack Dale [SD 781 707 to 767 710].

The upper boundary of the member is taken at a conspicuous bedding plane at the base of the scar-forming, pale grey limestones of the Gordale Limestone Member.

Thickness
Some 72 m thick in its type section at Malham Cove [SD 8975 6411], and 114 m thick in the Cominco Borehole S2 (BGS Registration Number SD86SW/6) [SD 8491 6345], south of the Middle Craven Fault.

Distribution
Southern part of the Askrigg Block, north of Settle [SD 77 to 97].

Age and biostratigraphical characterisation
Holkerian. The macrofauna of the Cove Limestone Member is poor, though diagnostic Holkerian foraminifers occur.

6.6.17.2 Gordale Limestone Member (GDLL)

Name
The member is named from the limestone at Gordale Scar [SD 913 640] (see Arthurton et al., 1988; Mundy and Arthurton, 1980).

Lithology
Scar-forming, mid–pale to very pale grey limestone, well bedded, varying from thick- to very thick-bedded. Variations include fine- and medium-grained (more rarely coarse-grained) bioclastic calcarenite packstones, wackestones and subordinate grainstones, with thin conglomerates adjacent to the Middle Craven Fault. The wackestones and packstones commonly show pseudobrecciation and the grainstones are cross-bedded. Undulating palaeokarstic surfaces are present, commonly overlain by thin clays (bentonites). Topographically, the member forms conspicuous stepped scar-features and prominent limestone pavements.

Stratotype
The type section is at Gordale Scar [SD 913 640] where the complete thickness (94 m) of the Gordale Limestone Member, including top and base is seen (see Arthurton et al., 1988).

Lower and upper boundaries
The lower boundary is taken at a conspicuous bedding plane at the base of the scar-forming pale grey, well-bedded limestone of the Gordale Limestone Member above the pale grey massive limestone of the Cove Limestone Member.

The conformable upper boundary is drawn at the upward passage from pale grey limestone of the Gordale Limestone Member to darker grey limestone of the Lower Hawes Limestone at the base of the Alston Formation, Yoredale Group (Figure 15, Column 6).

Thickness
Some 94 m in its type section at Gordale Scar [SD 913 640]. Elsewhere a thickness of 70–75 m is typical.

Distribution
Southern part of the Askrigg Block, north of Settle [SD 77 to SD 97].

Age and biostratigraphical characterisation
Asbian. Typical Asbian fossils in the Gordale Limestone Member include *Dibunophyllum bourtonense*, *Davidsonina septosa* and *Delepinea comoides*. Diagnostic foraminifers also occur.

6.6.18 Cracoe Limestone Formation (CCOE)

Name
Cracoe Village, after which the formation is named, is situated 5.5 miles north-north-west of Skipton. The formation was previously known as the 'Marginal Reef Limestones' (see Arthurton et al., 1988, and references therein).

Lithology
The formation includes mid and mid–pale grey limestones ranging from organic boundstones to packstones and wackestones with a variable grainsize depending on the bioclastic components. Zones of megabrecciation and neptunian dykes (crinoid- and mudstone-filled) are present within the formation at its partial type section at Swinden Quarry (see below).

Genetic interpretation
Apron reef.

Stratotype
A partial type section is at Swinden Quarry [SD 975 611 to 982 619], near Cracoe, North Yorkshire, where a large carbonate bank ('reef') of pale grey and very pale grey wackestones is exposed, faulted against 'pre-reef' and 'post-reef' limestones. Zones of megabrecciation and neptunian dykes are also present in the quarry (Arthurton et al., 1988; see also Mundy, 2000).

Distribution and regional correlation
South of the Middle Craven Fault, occurring in a roughly west–east tract extending 20 km east from Settle [SD 83 63] to Burnsall [SE 01 61]. The apron reef has become dislocated into fault-slices along the Craven Fault System. The formation passes northwards into the Cove Limestone and Gordale Limestone members and probably also into the Lower Hawes Limestone (Alston Formation, Yoredale Group).

Lower and upper boundaries
The lower boundary has not been proved, but is likely to comprise reef limestones of the Cracoe Limestone Formation resting upon the bedded, mid to mid–dark grey limestone of the Scaleber Quarry Limestone Member.

The upper boundary is a marked unconformity, with the reef limestones of the Cracoe Limestone Formation overlain by dark grey mudstones of the Bowland Shale Formation. Pre-reef and post-reef limestones are present in the partial type section at Swinden Quarry (see above), but the contacts with the reef limestones of the Cracoe Limestone Formation are faulted.

Thickness
The total thickness has not been proved, but is in excess of 100 m at the type locality.

Age and biostratigraphical characterisation
?Holkerian to Brigantian. The biota is diverse with biostratigraphically significant ammonoids including *Goniatites hudsoni*, *G. wedberensis*, *Bollandites castletonensis* and *G. moorei* of B_2 age (Arthurton et al., 1988), and foraminifers of P_{1a} age including stellate archaediscids and *Howchinia bradyana* (Strank in Arthurton et al., 1988).

SOUTH CUMBRIA (Figure 9, Column 14)

6.6.19 Martin Limestone Formation (MTL)

Name
The name is derived from Martin Quarry, Dalton-in-Furness. The Martin Limestone of Rose and Dunham (1977) was given formational status by Johnson et al. (2001).

Lithology
The Martin Limestone Formation comprises grey or greenish grey carbonate mudstones (commonly with fenestrae), pelletoid and bioclastic grainstones (locally with small oncoliths) and ooidal limestones. The limestone is extensively dolomitised locally, and there is a calcareous or dolomitic nodular band with algal structures at the base (Johnson et al., 2001; Rose and Dunham, 1977).

Genetic interpretation
The formation was deposited in a carbonate-dominated, nearshore to peritidal, restricted marine environment, with barrier beach complexes, tidal flats and restricted lagoons (Johnson et al., 2001). A more open marine platform carbonate facies developed in the upper part of the succession (Rose and Dunham, 1977).

Stratotype
The type section is at the partly filled in Martin (now Marton) Quarry [SD 2434 7688] near Dalton-in-Furness. Leviston (1979, p. 12, fig. 2) referred to 14 m of bioclastic calcite mudstone with common micaceous shales and a well-developed oncolitic limestone being present 5 m above the base. A reference section is at Meathop Quarry [SD 4316 7928], Grange-over-Sands. Leviston (1979, p. 8–10, fig. 2) referred to about 4.5 m of dolomitised bioclastic limestone with interbedded grey micaceous shale and common algal beds, being overlain by 21.7 m of slightly dolomitised pelletic bioclastic limestone with common beds of black micaceous shale and common dolomitised stromatolitic limestone, beneath 19.5 m of bioclastic limestone (a higher proportion being highly dolomitised) without shale beds. A further reference section occurs in the Kendal Quarry Borehole (BGS Registration Number SD59SW/25) [SD 5022 9250] at Kendal from 84.8 to 159.75 m depth. Here, 29.14 m of limestone with sporadic corals overlie 27.51 m of dolomitised limestone and 12.3 m of dolostone with interbedded siltstone. 6 m of siltstone with beds of dolostone occur at the base.

Lower and upper boundaries
The base of the formation in Furness (South Cumbria) is not exposed, but it is taken to overlie the Marsett Formation (Ravenstonedale Group) (Figure 9, Column 14) where limestone becomes dominant over shale (Rose and Dunham, 1977, p. 28). In practice, the base is taken in boreholes at the first significant shale parting.

The upper boundary of the formation is a non-sequence below the grainstones of the Red Hill Limestone Formation, the base of which may be marked by the 'Algal Band' of Rose and Dunham (1977).

Thickness
The formation is 25–135 m thick in Furness. The variable thickness is attributed to onlap on to irregular ridges in the early Palaeozoic basement topography (see Johnson et al., 2001, p. 58).

Distribution and regional correlation
South Cumbria and north Lancashire, including the Furness and Cartmel, Kendal, Arnside, Carnforth and Kirkby Lonsdale areas, separated from the Stainmore Trough by the Howgills 'axis'. In west Cumbria a 6–12 m thick shallow marine succession proved in boreholes at Sellafield was assigned to the Martin Limestone Formation by Barclay et al. (1994) and Akhurst et al. (1997). This may prove unwarranted if the succession is later considered to be part of the Marsett Formation. In the Kendal area, there is a transitional passage from conglomerate and shale of the Marsett Formation (which in the Stainmore Trough is of a mostly fluvial but locally reworked shallow marginal marine facies), to the lower part of what is considered to be a local equivalent of the Martin Limestone Formation (of carbonate-dominated, near shore to peritidal, restricted marine facies). The inclusion of interbedded fluvial facies in the lower part of the Martin Limestone Formation, suggests that the formation is more typical of the Ravenstonedale Group of *continental and peritidal facies*, and this appears to be further supported by the striking similarity noted in field characteristics between the lower part of the Martin Limestone Formation and the Stone Gill Limestone Formation. However, the upper part of the Martin Limestone Formation, at Kendal and elsewhere, contains a more *open marine platform and ramp carbonates facies*, typical of the Great Scar Limestone Group.

Age and biostratigraphical characterisation
Tournaisian to late Chadian. Fossils, which are more numerous in the upper part of the formation, include the coral *Dorlodotia pseudovermiculare* and foraminifer *Eoparastaffella* sp. (*Eoparastaffella* Cf4 Zone).

6.6.20 Red Hill Limestone Formation (RHO)

Name
The name is derived from Red Hills Quarry, Millom, south-west Cumbria. The Red Hill Oolite of Rose and Dunham (1977) was given formational status by Johnson et al. (2001).

Lithology
The Red Hill Limestone Formation comprises pale grey, closely jointed, coarse-grained, intraclastic peloidal grainstone, which is cross-bedded in part. Rubbly textured limestone with probable nodular calcrete (the 'Algal Band' of Rose and Dunham, 1977) marks the base of this unit.

Genetic interpretation
Transgressive shallow marine carbonate.

Stratotype
The original type section at Red Hills Quarry [SD 178 793], Millom includes 20 m of massive or poorly bedded, bioclastic limestone but the section is now largely obscured (see Rose and Dunham, 1977, p. 40). Reference sections exist at Dunnerholme [SD 2128 7963] where 21 m of the base and lower parts of the formation are present as pale grey, 'oolitic' and fragmental limestones with some beds being secondarily dolomitised (Rose and Dunham, 1977, p. 41; Johnson et al., 2001, p. 59), and Meathop Quarry [SD 4316 7928], Grange-over-Sands where the base of the formation is taken at a sharp, erosional contact with the subjacent Martin Limestone Formation (Johnson et al., 2001, p. 59).

Lower and upper boundaries
The base of the formation is a non-sequence. The lower boundary is taken at the base of the 'Algal Band' of Rose and Dunham (1977) in the type locality and elsewhere, or at upward change from the carbonate mudstones, grainstones and fine oolites of the Martin Limestone Formation to coarse grainstone (Figure 9, Column 14).

The conformable upper boundary of the formation is the base of the overlying dark grey crinoidal packstones with conspicuous thin siltstone interbeds of the Dalton Formation.

Thickness
The formation is up to about 60 m thick.

Distribution and regional correlation
South Cumbria.

Age and biostratigraphical characterisation
Early Arundian. Fossils are not common, but include the corals *Koninckophyllum* sp., *Michelinia megastoma* and *Palaeosmilia murchisoni*. The base of the formation is coincident with the Arundian/Chadian boundary. The formation corresponds to the *'Camarophoria isorhyncha'* subzone of Garwood (1913).

6.6.21 Dalton Formation (DLB)

Name
The formation is named after Dalton-in-Furness, Cumbria. The Dalton Beds of Rose and Dunham (1977) were given formational status by Johnson et al. (2001). Three informal divisions correspond approximately to Garwood's (1913) '*Chonetes carinata* Subzone', '*Clisiophyllum multiseptatum* Band', and 'Gastropod Beds', in ascending order.

Lithology
The Dalton Formation comprises dark grey, well-bedded, bituminous, crinoidal packstone with conspicuous thin siltstone interbeds. Three informal divisions are recognised: a lower division with small 'reefs'; a middle division with many marine mudstone and siltstone interbeds; and an upper division comprising pale grey packstone and grainstone.

Genetic interpretation
The middle division of the formation was deposited in deeper water than the lower and upper divisions. A siltstone bed occurring at the base of the type section marks the abrupt change from shallow to relatively deeper water limestone deposition.

Stratotype
The type section of the formation is the Dalton-in-Furness bypass (A590) road cutting from [SD 2245 7489] (base) to [SD 2175 7466] where a dark grey siltstone with thin limestone interbeds at its base is overlain by three informal divisions comprising mid to dark grey planar-bedded packstone with thin siltstone partings and reefs (lowest), limestone with conspicuous siltstone partings (middle), and bioclastic packstones and grainstones (upper). A thinner reference section is available in the Plumpton Quarries from [SD 3079 7856] (base) to [SD 3106 7814]. See Johnson et al. (2001, pp. 59–60).

Lower and upper boundaries
The base of the formation is defined at the type section (and inferred to be the same over a wide area) at the base of a 1.5 m thick dark grey siltstone with limestone interbeds, conformably overlying bioturbated crinoidal grainstones of the Red Hill Limestone Formation. In general, however, the base of the formation is taken at the first appearance

of dark grey limestone above the pale grey fragmental limestones of the Red Hill Limestone Formation (Figure 9, Column 14).

At the upper boundary of the formation, a non-sequence preceded deposition of the overlying pale grey limestones of the Park Limestone Formation.

Thickness
The formation is about 240 m thick in Low Furness, but it is believed to thin rapidly south and east of Ulverston.

Distribution and regional correlation
South Cumbria, north Lancashire

Age and biostratigraphical characterisation
Arundian. Fossils are relatively common within the formation and include *Haplolasma subibicinum, Clisiophyllum multiseptatum* and *Michelinia megastoma.* The characteristic Arundian brachiopod *Delepinea carinata* occurs at the base, whilst the upper part of the formation has the first appearance of *Siphonodendron martini*.

6.6.22 Park Limestone Formation (PKL)

Name
The name is derived from Park Sop (hematite mine) [SD 213 754] in Low Furness. The Park Limestone of Rose and Dunham (1977) was given formational status by Johnson et al. (2001). It is equivalent to Garwood's (1913) '*Nematophyllum (Lithostrotion) minus* Subzone'.

Lithology
The Park Limestone Formation consists of pale grey or cream, weakly bedded, closely jointed, poorly sorted and bioturbated, packstone and grainstone.

Genetic interpretation
Shallow marine carbonate.

Stratotype
The type area is the south Cumbria– Furness area. Reference sections are at Barker Scar [SD 3330 7827] to Capes Head [SD 334 778] (including the crag forming the western boundary of Old Park Wood), and a disused quarry at Ravensbarrow Point [SD 3380 7749]. At Barker Scar, the basal 45 m of the formation, and the contact with the underlying Dalton Formation are exposed. At Crown Quarry at about [SD 246 728] and Devonshire Quarry [SD 249 728] more than 150 m of limestone is exposed, comprising approximately the upper half of the Park Limestone and much of the Urswick Limestone formations (see Rose and Dunham, 1977, pp. 35, 48–49).

Lower and upper boundaries
The base of the formation conformably overlies the Dalton Formation (Figure 9, Column 14), and the absence of Garwood's (1913) '*Cyrtina carbonaria* Subzone' suggests basal onlap. The upward change from dark grey, bedded packstones of the Dalton Formation to pale grey, unbedded grainstones of the Park Limestone Formation can extend over 1 or 2 m but more generally it is even sharper.

The top of the Park Limestone Formation is a well-developed palaeokarstic surface, locally with clay-filled potholes. This upper boundary shows change from typical Park Limestone to pale grey, thickly bedded, 'pseudobrecciated' limestone of the overlying Urswick Limestone Formation.

Thickness
The formation maintains a nearly constant thickness of about 125 m throughout its outcrop.

Distribution and regional correlation
South Cumbria. The formation extends from around Dalton-in-Furness in the west, to near Carnforth in the east.

Age and biostratigraphical characterisation
Fossils are uncommon, but include *Diphyphyllum smithi, Lithostrotion minus, Linoprotonia ashfellensis* and *L. corrugatohemispherica*, all of which are restricted to the unit in the south Cumbria area. The formation almost equates to the Holkerian Stage. The lower lithostratigraphical boundary seen in the Holkerian Stratotype at Barker Scar [SD 3330 7827] (George et al., 1976) is 4.2 m lower than the Holkerian/Arundian stage boundary (see Johnson et al., 2001, pp. 60–61). It should be noted that Riley (1993) stated that it seems likely that a considerable non-sequence is developed at Barker Scar and that the stratotype will require relocation.

6.6.23 Urswick Limestone Formation (UL)

Name
The name was derived from outcrops around the villages of Great and Little Urswick, Low Furness. The Urswick Limestone of Rose and Dunham (1977) was given formational status by Johnson et al. (2001).

Lithology
The Urswick Limestone Formation is wholly dominated by rhythmically bedded, pale grey, commonly 'pseudobrecciated', biocalcarenite with stylolitic partings and palaeokarstic surfaces at cycle tops overlain by thin, bentonitic mudstone beds. It creates typical stepped karst scenery with griked surfaces throughout the south Cumbria district. A 4 m-thick bed of black mudstone with thin limestone interbeds, called the Woodbine Shale, occurs about 30 m above the base and splits the formation into informal lower and upper divisions (Horbury, 1987).

Genetic interpretation
Shallow marine carbonate (emergent at times).

Stratotype
A nearly complete type section through the formation is preserved at Trowbarrow Quarry [SD 481 758]. Other reference sections include those at the Stainton Quarry complex (now partly obscured) from about [SD 245 728 to 249 728], Headhouse Quarry [SD 3990 8185], Ravensbarrow Point Quarry [SD 3380 7749], Allithwaite Quarry [SD 391 767], and Humphrey Head Point [SD 3927 7334 to 3929 3746] (see Rose and Dunham, 1977; Johnson et al., 2001).

Lower and upper boundaries
The base of the formation is conformable, except in west Cumbria where it is disconformable. The lower boundary is at the point where the poorly bedded limestones of the Park Limestone Formation pass upwards into well-bedded 'pseudobrecciated' limestones of the Urswick Limestone Formation (Figure 9, Column 14).

The upper boundary of the formation is taken where the predominantly pale grey, thickly bedded Urswick Limestone Formation passes upward into the predominantly dark grey, thinner-bedded limestones of the Alston Formation, Yoredale Group.

Thickness
The formation is 120–160 m thick in Furness, and 40–180 m thick in west Cumbria.

Distribution and regional correlation
South and west Cumbria to north Lancashire, from the Duddon Estuary to the Carnforth area.

Age and biostratigraphical characterisation
Asbian. The formation corresponds almost exactly to the '*Lower Dibunophyllum* Subzone' (uppermost Holkerian to lowest Brigantian) of Garwood (1913). Fossils are relatively prolific and include *Dibunophyllum bourtonense, Lithostrotion* spp., *Palaeosmilia murchisoni, Siphonodendron* spp., *Gigantoproductus maximus*, and, towards the top of the unit, *Davidsonina septosa*.

NORTH AND WEST CUMBRIA (Figure 9, Column 13; Figure 14, Columns 1, 2):

6.6.24 Frizington Limestone Formation (FRLI)

Name
The name is derived from Frizington Parks Quarry, west Cumbria. Barclay et al. (1994) proposed the name Frizington Limestone for the exposed correlative, the Seventh Limestone (Eastwood et al., 1931; Arthurton and Wadge, 1981). Akhurst et al. (1997) treated the Frizington Limestone with formational status.

Lithology
In west Cumbria the Frizington Limestone Formation consists of thin- to thick-bedded tabular limestones with thin shale interbeds (Barclay et al., 1994). The lower part of the formation displays intensely bioturbated, mainly thin- to medium-bedded, sandy and silty limestone with rhizoliths, fenestral lime mudstones and tabular to hummocky cross-bedded sandstones. This is overlain by a foraminiferal-rich, mainly medium- to thick-bedded, bioclastic packstone and grainstone with abundant micritised peloids, common lithostrotionoid sheets, and thin shale and sandy limestone beds. Palaeokarst surfaces and calcrete and mudstone palaeosols are present within the upper part of the formation.

Genetic interpretation
The lower part of the formation was deposited within a peritidal environment; the overlying beds were deposited in a shallow marine setting with periodic emergence.

Stratotype
The Sellafield 3 Borehole (BGS Registration Number NY00SW/35) [NY 02596 02646] between 1515.75 and 1615.45 m depth below the rotary table provides a partial type section (including the base) comprising mostly bioclastic packstones, with lesser grainstones, sandy limestones at some levels and some thin sandstones. A few fenestral lime mudstones occur, mostly towards the base of the formation (see Barclay et al., 1994). A reference section is at Frizington Parks Quarry (disused), west Cumbria [NY 0405 1560] where about 26 m of the lower part of the formation are seen, though not the base, which is thought to be within 10 m of the lowest beds seen. The simplified sequence comprises a lower part about 9 m thick of bioclastic sandy limestones interbedded with packstones and grainstones, a middle portion about 12 m thick of mainly grainstones with brachiopod 'hashes' and coral horizons, and an upper part, poorly exposed, about 5 m thick of sandstones and thin shales (see Barclay et al., 1994).

Lower and upper boundaries
In north and west Cumbria the base of the formation, which is marked locally by conglomeratic sandstone, rests either disconformably on the Martin Limestone Formation (with Arundian strata missing), or directly on the conglomerates of the Courceyan Marsett Formation and lavas of the Cockermouth Volcanic Formation (Figure 9, Column 13; Figure 14, Columns 1, 2). Locally, the formation may directly overlie Lower Palaeozoic rocks.

In north Cumbria the top of the formation is taken immediately beneath the 'Sixth Shale', which comprises the base of the Sixth Limestone unit, Eskett Limestone Formation. In the Uldale area [NY 2560 3700] the top is a palaeosol containing a thin coal seam (Eastwood et al., 1968). In west Cumbria, calcretes, palaeokarst surfaces and terrigenous deposits are evidence of emergence and subaerial exposure at the top of the formation beneath the Urswick Limestone Formation. Here, early Asbian strata are missing.

Thickness
The formation is 50–100 m thick in west Cumbria.

Distribution and regional correlation
The formation occurs in west and north Cumbria between Whitehaven and Penrith. The western limit is truncated below the Permo–Triassic basal unconformity. The eastern limit is taken at the Kirk Rigg Fault, along the line of the A66 highway, west of Penrith (McCormac, 2001).

Age and biostratigraphical characterisation
Holkerian. The presence of foraminifer *Pojarkovella nibelis* in the Sellafield boreholes (Barclay et al., 1994) is indicative of the Cf5 Zone. The palaeokarst surfaces and calcrete and mudstone palaeosols present within the upper part of the formation indicate that periodic emergence preceded a period of nondeposition during late Holkerian and early Asbian times.

6.6.25 Eskett Limestone Formation (ESKT)

Name
The name is newly erected for individually named units, or sets of units in north and west Cumbria (see Akhurst et al., 1997), that represent minor transgression/regression carbonate cyclothems (see Stabbins, 1969) separated by emersion surfaces and palaeosols.

Lithology
The Eskett Limestone Formation is dominated by pale to dark grey limestones with subordinate, commonly bentonitic, and pale grey to buff, fine- to medium-grained micaceous and cross-bedded sandstone. There is also interbedded limestone and mudstone, black shale, siltstone, and seatearth that can include crinoidal and shelly fossils or plant remains. Historically, the lithostratigraphical succession has been divided into individually named units, or sets of units (see Eastwood et al., 1931; Eastwood et al., 1968; Akhurst et al., 1997) that represent minor transgression–regression carbonate cyclothems (see Stabbins, 1969) separated by emersion surfaces and palaeosols. The names of these local units, in ascending stratigraphical order, are: 'Sixth Limestone' (including the 'Sixth Shale'); 'Fifth Shale'; 'Fifth Limestone'; 'Fourth Shale'; 'Fourth Limestone'; 'Third Shale'; 'Third Limestone'; 'Orebank Sandstone' (or 'Second Shale'); 'Second Limestone'; 'First Shale'; 'First Limestone'. The middle part of the succession, the 'Fourth Limestone', includes limestones with prominent palaeokarst surfaces and distinctive fossils, which can characterise

various fossil-rich beds (for example the *Girvanella* and *Orionastrea* beds and the Junceum Limestone).

Genetic interpretation
A platform carbonate facies with minor marine transgression–regression and emergence.

Stratotype
The type section is Eskett Quarry [NY 0534 1673], Frizington, Cumbria which exposes from the Rough to the Junceum limestones and includes the Orionastrea Band, and the *Ethrospongia* Band at the base of the Junceum Limestone (Eastwood et al., 1931, pp. 88–89). Reference sections include: Stockhow Hall Quarry [NY 0665 1755] (Sixth Limestone and Fifth Shale); Clints Quarry [NY 0080 1240] (Fourth Shale and Fourth Limestone); and a quarry at Tendley Hill [NY 088 286] (First Limestone).

Lower and upper boundaries
The base of the formation is taken at the base of the Sixth Limestone unit (Figure 14, Columns 1, 2). This is at a level, which may only be defined in borehole logs, as there are no known surface exposures. Barclay et al. (1994) located the top of the underlying Frizington Limestone Formation in a borehole at Sellafield on the perceived late Holkerian/ Asbian boundary. However, they were unable to draw a correlation with the west Cumbria outcrop.

The top of the formation, in the Egremont–Whitehaven–Maryport–Cockermouth area, is marked by the cessation of continuous limestone deposition at the top of the First Limestone, which is conformably overlain by the mostly clastic marine and deltaic facies of the Stainmore Formation (Yoredale Group). Here, at outcrop, this overlying formation is generally represented by the coarse-grained, fluvial Hensingham Grit, with a basal mudstone. Immediately west of the Bothel Fault, the upper boundary of the Eskett Limestone Formation occurs at the top of the limestones with palaeokarst surfaces and distinctive fossils, the Fourth Limestone, which is overlain by the Alston Formation (Yoredale Group) (Figure 9, Column 13) with cyclical sequences of coarsening upwards sedimentary rocks including relatively thick and common limestones. East of the Bothel Fault, however, the top of the Eskett Limestone Formation is close below the Asbian–Brigantian boundary, at the top of the White Limestone unit, which is included at the base of the Fourth Limestone. Here again, the Alston Formation, just described, overlies the boundary. It should be stressed that division east and west of the Bothel Fault is purely for ease of description. The Bothel Fault is not implied to have exerted any penecontemporaneous effects on deposition.

Thickness
In west Cumbria the formation is about 85 m thick.

Distribution and regional correlation
North and west Cumbria. The uppermost unit, the First Limestone, is the lateral equivalent of the Great Limestone Member (Alston Formation, Yoredale Group) of the Alston Block, and the 'Main' (now Great) Limestone Member of the Askrigg Block.

Age and biostratigraphical characterisation
Holkerian to Pendleian. The presence of *Productus garwoodi* in the lower part of the Sixth Limestone at Rowrah (Ramsbottom, 1955) indicates that the Holkerian/ Asbian boundary occurs within, and not at the base of the formation. In west Cumbria the platform carbonate facies continued to dominate until the early Pendleian. The distinctive fossils of the Fourth Limestone include *Girvanella* sp., *Saccamminopsis* sp., *Orionastrea* sp. *Siphonodendron junceum* and *Spirorbis* sp.

ISLE OF MAN (Figure 8, Column 8)

6.6.26 Derbyhaven Formation (DBH)

Name
The name is derived from Derbyhaven, south Isle of Man. See Chadwick et al. (2001); Lewis (1930); Dickson et al. (1987).

Lithology
The formation comprises limestone, with interbedded, subordinate claystone and siltstone. The limestones vary from packstone, to wackestone and grainstone. They are typically grey, bioclastic (including crinoids and corals) and bioturbated. Sedimentary structures vary but include cross-bedding, wave ripples and hummocky cross-bedding. The claystones and siltstones are grey, bioclastic, and form thin, discontinuous beds. The formation includes three members, the Turkeyland, Sandwick (Isle of Man), and Skillicore members.

Genetic interpretation
The sequence is interpreted as representing a carbonate ramp facies.

Stratotype
Dickson et al. (1987; see also Chadwick et al., 2001) compiled the type section from the constituent members along the eastern coastline of the Isle of Man. They referred to exposures of the Turkeyland Member 16.7 m thick at Derbyhaven [SC 289 678], where dolomitisation has destroyed much of the primary rock fabric; exposures of the Sandwick (Isle of Man) Member, apparently 46 m thick at Sandwick Bay [SC 282 671], and on the foreshore east of Ronaldsway Airport [SC 294 684], where there are limestones with shale partings; and exposures of the Skillicore Member, 21 m thick on the foreshore north-east of the airport [SC 292 682] comprising mainly argillaceous limestones with abundant shale intercalations.

Lower and upper boundaries
The base of the formation (taken at the base of the typically ooidal and bioclastic grainstones of the Turkeyland Member) is poorly defined. It rests directly on conglomerates of the Langness Conglomerate Formation, Ravenstonedale Group, on the foreshore at Derbyhaven [SC 2820 6607] (Figure 8, Column 8), although outcrops are discontinuous and poorly exposed. It was formerly exposed at the now infilled Turkeyland Quarry [SC 2950 6940], where it rests directly on conglomerates of the Langness Conglomerate Formation.

The top of the formation is poorly defined. It is overlain by the limestones with interbedded subordinate claystone of the Knockrushen Formation, with the boundary taken immediately above a byozoan bed, which is exposed to the north-east of the airport light gantry at Ronaldsway at about [SC 28 68], at Port St Mary at about [SC 21 67], and at Ballasalla at about [SC 28 70] (see Dickson et al., 1987 who quoted no grid references for these localities).

Thickness
The formation is more than 90 m thick (Chadwick et al., 2001).

Distribution and regional correlation
The southern part of the Isle of Man, in the Castletown area.

Age and biostratigraphical characterisation
Arundian. The Skillicore Member includes the coral *Michelinia megastoma*.

Formal subdivisions
See also Appendix 1. Members of the Derbyhaven Formation in ascending stratigraphical order include:

6.6.26.1 Turkeyland Member (TURK)

Name
The Turkeyland Member was named and defined by Dickson et al. (1987). See also Lamplugh (1903).

Lithology
Limestone, typically an ooidal and bioclastic grainstone, dolomitic, grey, stylolitic, well-sorted, fossiliferous, with relict cross-bedding, wave ripples and hummocky cross-bedding and rare claystone partings.

Genetic interpretation
The unit is interpreted as a transgressive, high energy, shallow marine facies deposited on a carbonate ramp.

Stratotype
A partial type section occurs in natural foreshore exposures between Derbyhaven and Langness Point [SC 2804 6595 to 2849 6672]: specifically 1 km north-east of Langness Point, at a point marked on the 1:50 000 scale Ordnance Survey Map as Creg Inneen Thalleyr [SC 281 659]. These represent discontinuous exposures through the entire thickness of the member (see Chadwick et al., 2001).

Lower and upper boundaries
The base of the Turkeyland Member is poorly defined. It rests directly on sandstones of the Langness Conglomerate Formation on the foreshore of the Langness Peninsula [SC 2820 6607], although exposures are discontinuous and poorly exposed. It was formerly exposed at the now infilled Turkeyland Quarry [SC 2950 6940], where Dickson et al. (1987) recorded it resting directly on conglomerates of the Langness Conglomerate Formation.

The top of the Turkeyland Member is poorly exposed on the foreshore at Derbyhaven [SC 2835 6653] where it is overlain by the Sandwick (Isle of Man) Member of the Derbyhaven Formation. The boundary is gradational, taken at the change from limestone to limestone with interbedded claystones.

Thickness
Between 18 and 25 m.

Distribution and regional correlation
The member occurs in the southern part of the Isle of Man, to the south-east of Castletown, from Derbyhaven [SC 2907 6806] to Creg Inneen Thalleyr [SC 2804 6595]. Visean rocks in the northern part of the island are entirely concealed and it is not known whether it is present there.

Age
Arundian.

6.6.26.2 Sandwick (Isle of Man) Member (SWIK)

Name
Dickson et al. (1987) divided the singular Sandwick Member (as defined by Chadwick et al., 2001) into a lower unit, the 'Sandwick Member', and an upper unit, the 'Ronaldsway Member'. See also Lamplugh (1903). The epithet (Isle of Man) is added to distinguish the Sandwick (Isle of Man) Member from the Sandwick Fish Bed Member (Orkney).

Lithology
Limestone, with interbedded subordinate claystone and siltstone. The limestones are packstone and wackestone, grey, bioclastic (including crinoids and corals), bioturbated, sharp based, graded beds with hummocky cross-bedding. The grey, bioclastic claystones and siltstones form thin, discontinuous beds.

Genetic interpretation
The member is interpreted as a mid-ramp carbonate facies with storm deposit limestones, and quiet water mudstones. It represents a period of maximum flooding.

Stratotype
A partial type section occurs in natural foreshore exposures 700 m to the south-south-east of Derbyhaven [SC 2827 6699]. Discontinuous poorly exposed outcrops are present through the lower half of the member [SC 2831 6718 to 2825 6669] (see Dickson et al., 1987). A reference section is provided on the foreshore east of Ronaldsway Farm [SC 2924 6822 to 2941 6859]. Here about 24 m of discontinuous exposures in the lower part of the Sandwick (Isle of Man) Member are present (see Dickson et al., 1987).

Lower and upper boundaries
The base of the Sandwick (Isle of Man) Member is poorly defined. It is poorly exposed on the foreshore at Derbyhaven [SC 2835 6653] where it overlies the Turkeyland Member. The boundary is gradational, taken at the change from limestone to limestone with interbedded claystones.

The top of the member is also poorly defined as it is overlain by limestones, sandstones and siltstones of the Skillicore Member, with a gradational contact. It is taken at the appearance and increasing occurrence of fine-grained sandstone, together with an increase in siltstone and a more tabular bedding style in the Skillicore Member.

Thickness
Some 46 m.

Distribution and regional correlation
The member occurs in the southern part of the Isle of Man, in the area east of Castletown [SC 2970 6913 to 2822 6677]. Visean rocks in the northern part of the island are entirely concealed and hence it is unknown whether it is present in the north.

Age
Arundian.

6.6.26.3 Skillicore Member (SKIL)

Name
Derived from Lough Skillicore and defined by Chadwick et al. (2001), the member was formerly named the Upper *Michelinia* Beds by Lewis (1930).

Lithology
Argillaceous limestone, with common interbedded claystone and siltstone and subordinate sandstone. The limestones are packstone, grey, bioclastic, bioturbated and pyritic, with wave ripple cross-lamination. The claystones and siltstones are grey, forming beds up to 1 m thick. They are generally

unfossiliferous, though some are burrowed. The sandstones are fine-grained, cross-laminated and wave rippled.

Genetic interpretation
The unit is interpreted as an upper-ramp, shallow-water carbonate facies.

Stratotype
A partial type section, exposing the lower part of the member, occurs at Lough Skillicore [SC 2914 6831 to 2921 6838] in an embayment of the sea on the foreshore east of Ronaldsway Airport (see Dickson et al., 1987).

Lower and upper boundaries
The base of the member is poorly defined. It overlies the limestones of the Sandwick (Isle of Man) Member with a gradational contact, taken at the appearance and increasing occurrence of fine-grained sandstone, together with an increase in siltstone and a more tabular bedding style.

The top of the member is also poorly defined. It is overlain by the Knockrushen Formation, with the boundary taken as immediately above a bryozoan-bearing limestone bed, which is exposed at Port St Mary [SC 212 672] and Ballasalla [SC 276 700] (Dickson et al., 1987). No thickness is given by Dickson et al. (1987) for this bed, but the top surface is figured in their publication (see Dickson et al., 1987, fig. 7).

Thickness
Between 21 and 46 m.

Distribution and regional correlation
The member occurs in the southern part of the Isle of Man, in the Castletown area, from Ballasalla [SC 2857 7017] to Derbyhaven [SC 2798 6754]. Visean rocks in the northern part of the island are entirely concealed and hence it is unknown whether it is present in the north.

Age and biostratigraphical characterisation
Arundian. The limestones have crinoids and corals (including *Michelinia megastoma*), the claystones and siltstones have some *Chondrites* burrows.

6.6.27 Knockrushen Formation (KNRN)

Name
The name is derived from Knockrushen House, south Isle of Man. See Chadwick et al. (2001); Lewis (1930); Dickson et al. (1987).

Lithology
The formation comprises limestone, with interbedded subordinate claystone and siltstone at the top. Limestones vary from wackestone to fine-grained packstone; they are commonly nodular in form and argillaceous. Thin beds of black fissile claystone are also present. Siltstone is common near the base of the formation.

Genetic interpretation
The succession apparently represents an onshore marine ramp with evidence of deposition above storm wave-base (see Dickson et al., 1987; Chadwick et al., 2001).

Stratotype
A partial type section is a foreshore exposure east of Knockrushen House [SC 2584 6627 to 2653 6727] where 21 m of irregularly bedded to nodular, dark-grey, argillaceous spicular limestones (wackestones) are interbedded with black, fissile shales. There is a reference section on the foreshore by the lime kilns at Scarlett [SC 2300 6860] where the top 6 m of the formation are exposed. See Dickson et al. (1987).

Lower and upper boundaries
The formation overlies the Skillicore Member of the Derbyhaven Formation (Figure 8, Column 8). The basal boundary is taken immediately above a bryozoan bed, which is exposed to the north-east of the airport light gantry at Ronaldsway at about [SC 28 68], at Port St Mary at about [SC 21 67], and at Ballasalla at about [SC 28 70] (see Dickson et al., 1987 who quoted no grid references for these localities, so the boundary can be regarded as not well defined).

The top of the formation is also poorly defined. The wackestones and packstones of the Knockrushen Formation are overlain by the massive lime mudstones of the Hodderense Limestone Formation, Craven Group. Dickson et al. (1987) described the base of the Hodderense Limestone Formation as occurring close [SC 2580 6620] to the Visitor Centre at Scarlett south of the old lime kilns, where its base is taken at the lowest mottled horizon. This mottling is a result of the presence of blue or grey micrite nodules up to 3 cm in size.

Thickness
The formation is 21 m thick.

Distribution and regional correlation
The south Isle of Man, in the Castletown area.

Age and biostratigraphical characterisation
Holkerian. The formation contains the large caninioid coral *Siphonophyllia benburbensis* and the brachipod *Megachonetes papilionensis*. *Zoophycos* burrows are common near the base.

6.6.28 Balladoole Formation (BOOL)

Name
The name is derived from Balladoole, south Isle of Man. See Chadwick et al. (2001); Lewis (1930); Dickson et al. (1987).

Lithology
The formation comprises limestone, with interbedded subordinate claystone and siltstone at the top. The limestones are typically grey, contain crinoids, brachiopods and corals, and are locally dolomitic. They vary from grainstone to packstone, with bioherms of wackestone. Large bioherms have been described, up to 5 m in height and 10 m in width.

Genetic interpretation
The formation represents carbonate platform edge deposits.

Stratotype
A partial type section is poorly exposed along the foreshore adjacent to Balladoole Quarry from Poyll Ritchie [SC 2400 6810] to Salt Spring Cottage [SC 2440 6790]. Due to faulting the base of the formation is not exposed at Balladoole, but the top of the formation is seen below Salt Spring Cottage where it comprises unbedded lime-mud mounds overlain by a series of well-bedded skeletal limestones, intercalated with soft, fissile shales (see Dickson et al., 1987).

Lower and upper boundaries
See Figure 8, Column 8. The base of the formation is

poorly defined and thought to be diachronous. It is partly coeval with the Bowland Shale Formation, Craven Group and was subsequently overstepped by it (Chadwick et al. 2001). At Sea Mount [SC 2590 6990] in Castletown Bay the Balladoole Formation rests directly on the nodular, cherty wackestone with scattered thin claystone layers of the Hodderense Limestone Formation (Craven Group).

The top of the formation is poorly defined. The Bowland Shale Formation oversteps the Balladoole Formation at outcrop in a foreshore exposure north-east of Spring Cottage [SC 2440 6790]. Here the Balladoole Formation comprises unbedded lime mud mounds, and the overlying Bowland Shale Formation comprises detrital carbonates, with interbedded grey mudstones and debris beds, including erosively based, graded packstone beds.

Thickness
The formation is about 90 m thick.

Distribution and regional correlation
The southern part of the Isle of Man, in the Castletown area.

Age
Asbian.

6.7 YOREDALE GROUP (YORE)

There is long established usage of the term Yoredale facies, based upon the description of Yoredale cycles as early as Phillips (1836). The name Yoredale Group now replaces the Wensleydale Group of the Askrigg Block; the Alston Group of the Alston Block; and the Upper Border Group, and Lower and Upper Liddesdale groups of the Northumberland Trough (Waters et al., 2007).

The Yoredale Group *(mixed shelf carbonate and deltaic ('Yoredale') facies* and *fluviodeltaic ('Millstone Grit') facies)* (Figure 7) extends across the entire Northern England province and comprises:

In the *Northumberland Trough and Solway Basin*, the Tyne Limestone, Alston and Stainmore formations;

In the *Alston Block, Stainmore Trough and Askrigg Block*, the Alston and Stainmore formations;

In *north Cumbria*, the Alston Formation;

In *south Cumbria (and north Lancashire)*, the Alston Formation;

In *west Cumbria*, the Stainmore Formation;

In the north Isle of Man, a sequence similar to the Alston Formation, and another apparently assigned to either the Great Scar Limestone Group or Yoredale Group. These are known only in boreholes (see Chadwick et al., 2001).

The Yoredale Group comprises repeated, typically upward-coarsening cycles of basal, laterally extensive marine limestone, marine shale (commonly bioturbated), thin sandstone commonly topped with seatearth or ganister and an overlying coal. The limestones are typically mid to dark grey, thin-bedded and biomicritic, with a restricted benthic fauna and rare ammonoids. The sandstones are typically pale grey, fine- to medium-grained and quartzitic to subarkosic. The clastic component was deposited by progradation of high-constructive lobate deltas, though there is evidence to suggest that there has been extensive shallow marine reworking of clastic sediments following delta abandonment (Elliott, 1975). Large fluvial channels were incised into underlying cyclothems on the Alston Block during the Brigantian and Pendleian (Dunham, 1990), and in Northumberland an element of tectonic control on this process can be demonstrated (Young and Lawrence, 2002). The marine limestones were deposited during sea-level rises and when delta lobes were switched or abandoned. The cycles, which range from 5–90 m thick, are named after the limestone present at the base of the cyclothem (Leeder et al., 1989). Limestones have bed status unless there are good reasons for them to have member status. Minor limestones and sandstones remain informal beds. Dunham and Wilson (1985) provided details of limestone nomenclature and correlations, and cyclothem thicknesses for the Askrigg Block and Stainmore Trough, and Dunham (1990) provided similar information for the Alston Block. On the north Isle of Man undifferentiated strata assigned to either the Great Scar Limestone Group or the Yoredale Group occurs in the Ballavaarkish (Shellag North) Borehole [NX 4625 0070] between 172.34 and 179.60 m depth. They comprise massive, stylolitised, fractured and sucrosic dolostone, which may be of early Namurian or Visean age, but diagenesis has destroyed any biostratigraphical evidence (see Chadwick et al. 2001).

The conformable but diachronous base of the Yoredale Group is typically taken at the base of marine limestone marker bands. In the Solway Basin, Northumberland Trough, Cheviot Block and north-east Northumberland, the sandstones of the Fell Sandstone Formation, Border Group pass upward, locally unconformably and diachronously, into the Tyne Limestone Formation, Yoredale Group; the lower boundary of which is variably represented as the base of the Clattering Band or its correlative the Kingsbridge Limestone, or in the Langholm area, the Glencartholm Volcanic Beds.

In the Brough-under-Stainmore and Penrith districts the Robinson Limestone of the Melmerby Scar Limestone Formation, Great Scar Limestone Group, is overlain by siltstone or sandstone of the Tyne Limestone Formation, Yoredale Group. There is evidence of penecontemporaneous erosion and potholing on the top surface of the Robinson Limestone.

In east Cumbria and the Stainmore Trough, the lower boundary of the Yoredale Group occurs where the top of the mostly thick-bedded, pale to mid grey limestone of the Knipe Scar Limestone Formation, Great Scar Limestone Group, is disconformably overlain by the variable sandstone and mudstone Wintertarn Sandstone Member of the Tyne Limestone Formation.

On the northern Askrigg Block, the pale to mid grey limestones (with palaeokarst surfaces) and subordinate mudstones of the Danny Bridge Limestone Formation, Great Scar Limestone Group pass upward into the cross-bedded, regressive sandstones of the Wintertarn Sandstone Member, Tyne Limestone Formation.

In the Settle area, the lower boundary of the Yoredale Group is generally taken where the paler grey, thick- to very thick-bedded limestone with palaeokarst surfaces of the Malham Formation, Great Scar Limestone Group pass upward into the darker grey Lower Hawes Limestone (Alston Formation) at the base of the Yoredale facies sequence.

In west Cumbria, in the Egremont–Whitehaven–Maryport–Cockermouth area, the lower boundary of the Yoredale Group occurs where the shelf carbonate sequence of the First Limestone, Eskett Limestone Formation is terminated and conformably overlain by the mostly clastic marine and deltaic facies of the Stainmore Formation. However, at outcrop the basal part of the Stainmore Formation generally comprises the coarse-grained, fluvial, Hensingham Grit, with a basal mudstone.

In north Cumbria, east of the Bothel Fault, the lower boundary of the Yoredale Group occurs above the pale to dark grey limestones of the Eskett Limestone Formation, Great Scar Limestone Group, at the top of the White Limestone unit, which forms the base of the Fourth Limestone. Immediately west of the Bothel Fault, however, the same boundary occurs at the top of the Fourth Limestone, which is distinguished by the inclusion of palaeokarst surfaces and distinctive fossils. It should be stressed that division east and west of the Bothel Fault is purely for ease of description. The Bothel Fault is not implied to have exerted any penecontemporaneous effects on deposition.

In south Cumbria, the lower boundary of the Yoredale Group is at the point where the predominantly pale grey, thickly bedded limestones of the Urswick Formation, Great Scar Limestone Group, pass up into the predominantly dark grey, thinner bedded limestones and mudstones of the Alston Formation.

On the northern part of the Isle of Man, platform carbonates of the Balladoole Formation, Great Scar Limestone Group are thought to be overlain by a cyclothemic mixed carbonate clastic sequence, similar to the Alston Formation, Yoredale Group of south Cumbria.

The top of the Yoredale Group is defined in north, west and east Cumbria, the Solway Basin, the Stainmore and Northumberland troughs, on the Alston Block and in north-east Northumberland by the base of the Pennine Coal Measures Group *(fluviodeltaic ('Coal Measures') facies).* To the north of Wensleydale on the Askrigg Block and in the Settle area, it is defined by the base of the Millstone Grit Group (*fluviodeltaic* ('*Millstone Grit*') *facies*). On the northern part of the Isle of Man the top of what may be either the Great Scar Limestone Group or the Yoredale Group is also defined by the base of the Millstone Grit Group. In south Cumbria the base of the Craven Group (*hemipelagic facies*) defines the top of the Yoredale Group.

The type area of the Yoredale Group is the valley of the River Ure, Wensleydale on the Askrigg Block (see Phillips, 1836; George et al., 1976; Dunham and Wilson, 1985), and it extends across the entire Northern England Province. Thickness varies greatly since the group, formations and individual sandstones tend to thicken into troughs and half-grabens, and conversely all the elements of any rhythm may be reduced or absent. The range in thickness is from 50 m in the Lamplugh area of west Cumbria (Young and Bolland, 1992) to a proved maximum of 1219 m in the Seal Sands Borehole (BGS Registration Number NZ52SW/457) [NZ 538 238] in the eastern part of the Stainmore Trough (Dunham and Wilson, 1985). In south Cumbria the group is 80–180 m thick, and over 500 m of strata are present in the Solway Basin in boreholes north of Maryport. On the Askrigg Block, generalised vertical sections on BGS maps suggest a range of thickness in the order of about 200–900 m, and there are marked thickness variations across the Stublick–Ninety Fathom Fault, separating the Northumberland Trough from the Alston Block, to the south.

The age of the Yoredale Group is Holkerian or Asbian to Yeadonian. The base is diachronous, and ranges from Holkerian in the Kirkbean Outlier and early Asbian in the Northumberland Trough and Solway Basin, to early Brigantian on the Alston and Askrigg blocks, in the Stainmore Trough and in south Cumbria, to Pendleian in north and west Cumbria where there is also a large non-sequence within the group in which strata of Chokierian to Marsdenian age are absent (Akhurst et al., 1997). In south Cumbria, only the Visean part of the succession is present.

The top of the group is latest Yeadonian nearly everywhere, the exceptions being on the Askrigg Block where it is late Pendleian and south Cumbria where it is late Brigantian. In the north Isle of Man the top of the sequence, which is similar to the Alston Formation, is at least early Namurian, but the age of the top of what may be either Great Scar Limestone Group or Yoredale Group strata at the base of the Ballavaarkish (Shellag North) Borehole (see above) remains uncertain (see Chadwick et al., 2001). The base of the Namurian Series is defined as the base of the *Cravenoceras leion* Marine Band. The position of this marine band is taken to be near the base of the Great Limestone Member (see Johnson et al. 1962).

6.7.1 Tyne Limestone Formation (TYLS)

Name
The name is derived from the River Tyne, Northumberland.

Lithology
In the Solway Basin, the Tyne Limestone Formation comprises a heterogeneous Yoredale Group cyclicity, with limestone and sandstone components absent from parts of the succession. The sandstones tend to thicken into troughs and half-grabens. The formation includes the Glencartholm Volcanic Beds at the base, which comprises a succession of tuffs, volcaniclastic sedimentary rocks and subordinate basalt lavas, 150–180 m thick (Lumsden et al., 1967; Williamson in Stephenson et al., 2003). In the Northumberland Trough, the 'Scremerston Coal Member' comprises up to 300 m of shales and limestones, sandstones and thick coals (Smith, 1967; Leeder et al., 1989), and passes transitionally south-west into typical cyclicity. The Tyne Limestone Formation is distinguished from the Alston Formation by the common presence of thick, commonly bioclastic limestones in the latter.

Genetic interpretation
Shallow water marine and deltaic.

Stratotype
The partial type section is the Archerbeck Borehole (BGS Registration Number NY47NW/14) [NY 4160 7820] from the base of the Cornet Limestone at 504.7 m depth to within the Glencartholm Volcanic Beds at the bottom of the borehole at 1403.3 m depth (see Lumsden and Wilson, 1961). Reference sections include the Stonehaugh Borehole (BGS Registration Number NY77NE/2) [NY 7899 7619] from rockhead at about 4 m depth to the possible Kingbridge Limestone at about 211 m depth; the Ridsdale Borehole (BGS Registration Number NY88SE/1) [NY 8946 8288] from the Redesdale Limestone at 0.91 m depth to strata below the Lower Millerhill Limestone at 305.41 m depth; the Ferneyrigg Borehole (BGS Registration Number NY98SE/13) [NY 9579 8364] from the base of the Low Tipalt Limestone at 77.32 m depth to strata below the Furnace Coal at 457.50 m depth; the River Black Lyne, north of Dappleymoor Fault, from between Dodgsonstown Ford [NY 5009 7452] and the bend [NY 4987 7511] south-west of Cumcrook, Bewcastle; the Cairing Croft Borehole (BGS Registration Number NY66NE/2) [NY 6626 6700] from the base of the Low Tipalt Limestone at about 85 m depth to strata below the Thirlwall Coal at about 413 m depth; and the Hoddom No. 2 Borehole (BGS Registration

Number NY17NE/3) [NY 1641 7280] between 3.2 and 41.6 m depth.

Lower and upper boundaries
In the Solway Basin, Northumberland Trough, Cheviot Block and north-east Northumberland, the sandstones of the Fell Sandstone Formation, Border Group pass upward, locally unconformably and diachronously, into the Tyne Limestone Formation, the lower boundary of which is variably represented as the base of the Clattering Band or its correlative the Kingsbridge Limestone (Figure 8, Column 11; Figure 11, Columns 1–3), or in the Langholm area, the Glencartholm Volcanic Beds (Figure 10, Column 3).

The upper boundary of the formation is conformable with the base of the Alston Formation, normally at the base of the Low Tipalt or Callant Limestone (Figure 6, Column 7; Figure 8, Column 11; Figure 10, Column 3; Figure 11, Columns 1–3). However, in districts where the formally defined upper boundary of the Tyne Limestone Formation has not or cannot be mapped, at the base of the limestone that marks the base of the Brigantian Stage, the upper boundary is taken at the top of the next, widely mapped limestone below it. This means that in the Rothbury district, for example, the top of the Tyne Limestone Formation is taken at the top of the Dun Limestone (Figure 13, Column 3).

Thickness
The formation tends to thicken into troughs and half-grabens. The Glencartholm Volcanic Beds are 150–180 m thick (150 m proved in the Archerbeck Borehole — see above; Lumsden et al., 1967). The 'Scremerston Coal Member' is up to 300 m thick at Berwick (Smith, 1967).

Distribution and regional correlation
Solway Basin, Northumberland Trough, Cheviot Block north-east Northumberland, and north-west England.

Age and biostratigraphical characterisation
Holkerian to Asbian. The brachiopod *Linoprotonia corrugatohemisphaerica* is diagnostic of the Holkerian. Others that also occur include *Punctospirifer scabricosta* and *Composita ambigua*. Corals, including *Dibunophyllum* sp., *Lithostrotion portlocki* and *Siphonodendron martini*, and gigantoproductoid brachiopods are common in the Asbian.

Formal subdivisions
See also Appendix 1. Members of the Tyne Limestone Formation include:

6.7.1.1 ARBIGLAND LIMESTONE MEMBER (ARLM)

Name
Previously known as Arbigland Group (Craig, 1956) and Arbigland Beds (Deegan, 1970). The status was changed from the Arbigland Limestone Formation (Lintern and Floyd, 2000) to a member of the Tyne Limestone Formation.

Lithology
The member comprises interbedded marine limestone, mudstone and subsidiary siltstone, with thick cross-bedded, bioturbated, medium-grained sandstone.

Stratotype
The type section is the Arbigland coast, Kirkcudbrightshire, from Arbigland [NX 9940 5720] to Hogus Point [NX 9970 5880], where mudstones, siltstones, sandstones, and limestones constitute a section probably more than 300 m thick (Craig, 1956; Deegan, 1970; but see Lintern and Floyd, 2000, p. 82).

Lower and upper boundaries
The base of the Arbigland Limestone Member is probably conformable on the Thirlstane Sandstone (Powillimount Sandstone Member, Fell Sandstone Formation) (Figure 10; Column 2). It is stratigraphically the highest unit in the Kirkbean Outlier, and its top is not exposed.

Thickness
More than 300 m.

Distribution and regional correlation
The Kirkbean Outlier of the Kirkcudbright — Dalbeattie district.

Age and biostratigraphical characterisation
Asbian. The limestones and mudstones have an abundant and diverse fauna of corals (including *Lithostrotion clavicatum, Siphonodendron scotica* and *Siphonophyllia benburbensis*), brachiopods (including *Actinopteria persulcata, Linoprotonia* cf. *ashfellensis*, *Productus* cf. *garwoodi, Punctospirifer scabricosta redesdalensis* and *Stenoscisma* cf. *isorhyncha*), bivalves (including *Prothyris* cf. *oblonga* and *Pteronites* cf. *angustatus*) and other molluscs, crinoids and bryozoa. *Siphonophyllia benburbensis* is unknown in strata earlier than the Asbian.

6.7.1.2 DUN LIMESTONE MEMBER (DNL)

Name
Previously referred to as the Ladies Wood Limestone (obsolete) in the Bellingham district, and the Lamberton Limestone (obsolete) in the Eyemouth district. See Frost and Holliday (1980); Greig (1988); Gunn (1900).

Lithology
A dark grey, argillaceous, crinoidal, shelly limestone with algal nodules, weathering to a rusty ochreous colour.

Genetic interpretation
Of marine origin

Stratotype
The type area is the north side of Huds Head, Spittal, near Berwick-upon-Tweed, Northumberland [NU 010 510 to 015 506] (see Scrutton, 1995).

Lower and upper boundaries
At the lower boundary, the Dun Limestone is generally underlain conformably by a thin marine mudstone that overlies a thin coal or seatearth of the Tyne Limestone Formation (Figure 12, Columns 1–4).

The upper boundary of the member is generally a conformable change from limestone to overlying marine mudstone that passes up into deltaic arenaceous deposits of the Tyne Limestone Formation (or Alston Formation, where the normal boundary at the base of the limestone that marks the base of the Brigantian Stage has not or cannot be mapped).

Thickness
Between 1.2 and 1.6 m in the Eyemouth and north Berwickshire districts. 5–8 m in Northumberland (Frost and Holliday 1980).

Distribution and regional correlation
Confined to Berwickshire and north Northumberland in the Tyne Limestone Formation, Yoredale Group, the Dun Limestone is widely correlatable throughout the Northumberland Trough (Frost and Holliday, 1980). The contained fauna and flora is equivalent to the MacGregor

Marine Bands of the Midland Valley of Scotland (Wilson, 1974; Neves et al., 1973).

Age and biostratigraphical characterisation
Asbian. An NM Zone miospore assemblage was reported by Neves et al. (1973) in the Dun Limestone Member in the Marshall Meadows Borehole (BGS Registration Number NT95NE/5) [NT 9797 5685], and an Asbian age is supported by the presence of the coral *Siphonodendron junceum* (see Fowler, 1926).

6.7.1.3 Wintertarn Sandstone Member (WTRS)

Name
The member was previously known as the Thorney Force Sandstone (BGS, 1997). See Arthurton and Wadge (1981); Burgess and Holliday (1979); McCormac (2001), Rowley (1969).

Lithology
Sandstone, with subsidiary siltstone, mudstone and limestone.

Stratotype
The type section is a borehole at Flusco Limeworks (BGS Registration Number NY42NE/1) [NY 4587 2905] from 54.73 to 59.84 m depth with sandstone and a thin bed of mudstone (Arthurton and Wadge, 1981, p. 153).

Lower and upper boundaries
The base is the top of the uppermost thick-bedded limestone of the Great Scar Limestone Group (Figure 9, Columns 16, 17; Figure 14, Column 3; Figure 15, Column 3). It may be locally erosive.

The top of the member is at the base of the overlying wackestones and packstones of the Askham Limestone Member, Alston Formation.

Thickness
Between 3 and 7 m.

Distribution and regional correlation
North-west England.

Age
Asbian.

6.7.2 Alston Formation (AG)

Name
The name is derived from the former Alston Group of the Alston Block and Stainmore Trough, which formerly included platform carbonates as well as 'Yoredale' facies (George et al., 1976). In south Cumbria the Alston Formation now replaces the Gleaston Formation of Rose and Dunham (1977). In north Cumbria it includes the upper part of the now obsolete Chief Limestone Group.

Lithology
The Alston Formation normally (but see below) extends stratigraphically from the base of the Peghorn Limestone (or correlatives) to the top of the Great Limestone (or correlatives). The formation is distinguished from the Tyne Limestone and Stainmore formations by the common presence of thick, commonly bioclastic limestones. Distinctive facies variations within the formation are recommended to be given member status. Numerous local names exist for the major limestones but their lateral persistence allows a single nomenclature to be applied across most of north and north-east England. This has been standardised in the Stainmore region and includes, in ascending stratigraphical order, the Peghorn Limestone, Smiddy Limestone, Lower Little Limestone, Jew Limestone, Tynebottom Limestone, Single Post Limestone, Scar Limestone, Five Yard Limestone, Three Yard Limestone, Four Fathom Limestone, Iron Post Limestone, and Great Limestone.

In a few areas closely spaced, and individually named, limestone beds may merge to give a differently named unit. For example, the Peghorn and Smiddy limestones of the Edenside and north Cumbria districts, when combined, are known as the Askham Limestone Member. The Great Limestone Member includes the uppermost limestone of the formation. This was formerly known as the Main Limestone on the Askrigg Block. Throughout most of the region it comprises an uncharacteristically thick, bioclastic, locally biostromal, limestone. It has been correlated with the Top Hosie Limestone of the Midland Valley of Scotland, and the First Limestone in Cumbria.

In south Cumbria (see Rose and Dunham, 1977; Johnson et al., 2001) the formation comprises a variable succession of thinly interbedded dark grey to black limestone, shaley mudstone and subordinate (and impersistent) sandstone. The limestones are richly fossiliferous in places with a coral–brachiopod fauna, and some beds have been linked with name equivalents in the Askrigg Block area suggesting depositional continuity. The *Girvanella* Nodular Band of Garwood (1913) occurs at or near the base of the formation in south Cumbria. Carboniferous rocks in the northern part of the Isle of Man are entirely concealed and poorly known, but a cyclothemic, mixed carbonate (grey argillaceous limestone)–clastic sequence similar to the Alston Formation of south Cumbria has been proved in boreholes (see Chadwick et al., 2001).

Genetic interpretation
The Alston Formation typically represents cycles of marine to fluvio-deltaic sedimentation. East of Morecambe Bay it is poorly exposed, shows considerable structural complexity, and displays characteristics of deposition on a deeper shelf. West of Morecambe Bay the cycles pass laterally into the hemi-pelagic succession of the Bowland Shale Formation.

Stratotype
The type area of the formation is the Alston Block. It is proposed that the original type section in Augill Beck, Cumbria (see Burgess and Holliday, 1979) is replaced by the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] Weardale, from rockhead in the upper part of the Great Limestone at 6.86 m depth to the base of the Peghorn Limestone at 331.7 m depth (see Johnson and Nudds, 1996; Cozar and Somerville, 2004). In south Cumbria the formation occurs in boreholes at Harbarrow No. 1 (BGS Registration Number SD27SE/37) [SD 2531 7197] from 39.01 to 135.94 m depth and Gleaston Castle Farm (BGS Registration Number SD27SE/51) [SD 2549 7185] from 124.27 to 165.36 m depth (the bottom of the borehole). Natural sections in south Cumbria occur at Gleaston and on the East Shore [SD 3906 7469] of Humphrey Head; the Kirkhead Railway Cutting [SD 3949 7524]; and, most extensively, in Holker Park at about [SD 350 774] in a succession, mostly exposed, of limestones and sandstones with sporadic siltstone and coal some 140 m thick (see Johnson et al., 2001; Rose and Dunham, 1977). On the north Isle of Man in the Ballaghenny Borehole of Lamplugh (1903, pp. 286–288), cyclothemic 'Yoredale' facies of mixed carbonate–clastic lithologies have been attributed to the Yoredale Group (see Chadwick et al., 2001).

Lower and upper boundaries
In the Northumberland Trough and Solway Basin, the base of the Alston Formation, defined at the base of the Peghorn Limestone (or its correlatives), lies conformably on the Tyne Limestone Formation (Figure 6, Column 7; Figure 8, Columns 11,12). In the Brough-under-Stainmore and Penrith districts the Peghorn Limestone is underlain by siltstone or sandstone of the Wintertarn Sandstone Member, Tyne Limestone Formation (Figure 9, Column 16).

In east Cumbria and the Stainmore Trough, the lower boundary occurs sharply at the base of the Askham (Peghorn) Limestone on the mainly sandstones of the Wintertarn Sandstone Member (Figure 9, Column 16; Figure 14, Column 3). On the northern Askrigg Block, the Hawes (Peghorn) Limestone occurs above the cross-bedded, regressive sandstones of the Wintertarn Sandstone Member, Tyne Limestone Formation (Figure 15, Column 3).

In north Cumbria, east of the Bothel Fault, the lower boundary of the Alston Formation occurs at the top of the White Limestone unit at the base of the Fourth Limestone, Eskett Limestone Formation (Great Scar Limestone Group) (Figure 14, Column 2), which comprises pale to dark grey limestones. Immediately west of the Bothel Fault, the lower boundary of the Alston Formation is at the top of the limestones with palaeokarst surfaces and distinctive fossils, the Fourth Limestone (Great Scar Limestone Group). It must be stressed that this division at the Bothel Fault is purely for ease of description. The fault is not implied to have exerted any penecontemporaneous effects on deposition.

In south Cumbria the lower boundary is at the point where the thickly bedded pale grey limestones of the Urswick Limestone Formation, Great Scar Limestone Group, pass up into the predominantly dark grey, thinner-bedded limestone and mudstone of the Alston Formation (Figure 9, Column 14). The *Girvanella* Nodular Band of Garwood (1913) may mark the base of the formation.

In districts where the formally defined lower boundary to the Alston Formation has not or cannot be mapped at the base of the limestone that marks the base of the Brigantian Stage, that boundary is taken at the top of the next, widely mapped limestone below it. This means that in the Rothbury district, Northumberland Trough, for example, the base of the Alston Formation is taken at the base of the Asbian strata that overlie the Dun Limestone, Tyne Limestone Formation (Figure 13, Column 3).

On the north Isle of Man, the platform carbonates of the Balladoole Formation, Great Scar Limestone Group, are thought to be overlain by a cyclothemic mixed carbonate–clastic sequence similar to the Alston Formation of south Cumbria.

The top of the formation is generally defined by the base of the Stainmore Formation with its cyclical succession of mudstones, siltstones, sandstones and thin limestones and thin coals. However, in south Cumbria the upper boundary is taken at the base of the *Cravenoceras leion* Marine Band where the thinly interbedded limestones, mudstones and subordinate sandstones of the Alston Formation pass upward into the thick mudstones and fine-grained siltstones of the overlying Bowland Shale Formation, Craven Group (Figure 9, Column 14).

Thickness
The formation tends to thicken into troughs and half-grabens. It is 80–180 m thick in south Cumbria, 200–250 m thick in the Appleby district, up to 300 m thick in Edenside and about 337 m thick in the Rookhope Borehole (see above) on the Alston Block, and 600 m thick in the Stainmore Trough. Offshore, in the Keys Embayment, between the Isle of Man and the west Cumbria coast, a well proved 108 m of strata equated with the probable onshore Alston Formation.

Distribution and regional correlation
South Cumbria and north Lancashire from the Duddon Estuary to the Carnforth area, the Askrigg and Alston blocks, the Stainmore and Northumberland troughs, and the Solway Basin. The formation also occurs in north Cumbria, east and immediately west of the Bothel Fault (though it is not implied that the fault exerted any penecontemporaneous effects on deposition), and apparently, on borehole evidence, on the north Isle of Man.

Age and biostratigraphical characterisation
Asbian in places, but generally Brigantian to Pendleian. In the River Eden [NY 7832 0375] at Janny Wood on the Alston Block, the Peghorn (Lower Smiddy) Limestone is defined as the Brigantian Stage Basal Stratotype (George et al., 1976). Microfaunal dating in the Rookhope Borehole suggests mostly Brigantian (Cf6γ Subzone age), but early Serpukhovian (Pendleian) for the Great Limestone Member (Cozar and Sommerville, 2004). The base of the Namurian, defined as the base of the *Cravenoceras leion* Marine Band, is taken as near the base of the Great Limestone. In south Cumbria the richly fossiliferous limestones commonly have various species of *Lithostrotion* and *Siphonodendron*, and the following corals and brachiopods are, according to Rose and Dunham (1977), restricted to the formation here: *Actinocyathus floriformis, Aulophyllum pachyendothecum, Dibunophyllum bipartitum, Diphyphyllum lateseptatum, Eomarginifera cambriensis, Productus hispidus*, and *Pugilis pugilis*. The unit in south Cumbria equates with the 'Upper *Dibunophyllum* Subzone' of Garwood (1913) and is Visean (Brigantian) in age. Onshore, on the north Isle of Man the Yoredale facies attributed to the Alston Formation in the Ballaghenny Borehole may be Namurian (or Visean) in age (see Chadwick et al., 2001).

Formal subdivisions
See also Appendix 1. Members of the Alston Formation in ascending stratigraphical order include:

6.7.2.1 Askham Limestone Member (ASKL)

Name
Named after the village of Askham, east Cumbria. See Rowley (1969), and Burgess and Holliday (1979); Dunham (1990); Arthurton and Wadge (1981); McCormac (2001).

Lithology
Limestone, dark grey, well-bedded, wackestone and packstone, porcellanous in parts. Prominent layers with algal oncoliths and coral colonies. The member is split into 2 leaves by a thin layer of red-brown mudstone.

Stratotype
The type section is an abandoned roadside (east side of minor road) quarry [NY 583 171] beside Wintertarn Farm, by Shap, Cumbria (Rowley, 1969) where the limestone, a mid grey biomicrite, is divided into two parts by an algal horizon, most likely the equivalent of the *Girvanella* Bed of Garwood (1913). A reference section is the Flusco Lodge disused quarry [NY 474 282], 3.8 km west of the M6 Penrith interchange, where a full section of the limestone is preserved, along with the top part of the underlying Wintertarn Sandstone Member, Tyne Limestone Formation (McCormac, 2001).

Lower and upper boundaries
The base of the member is sharp, occurring at the base of a limestone bed overlying the mainly sandstone of the

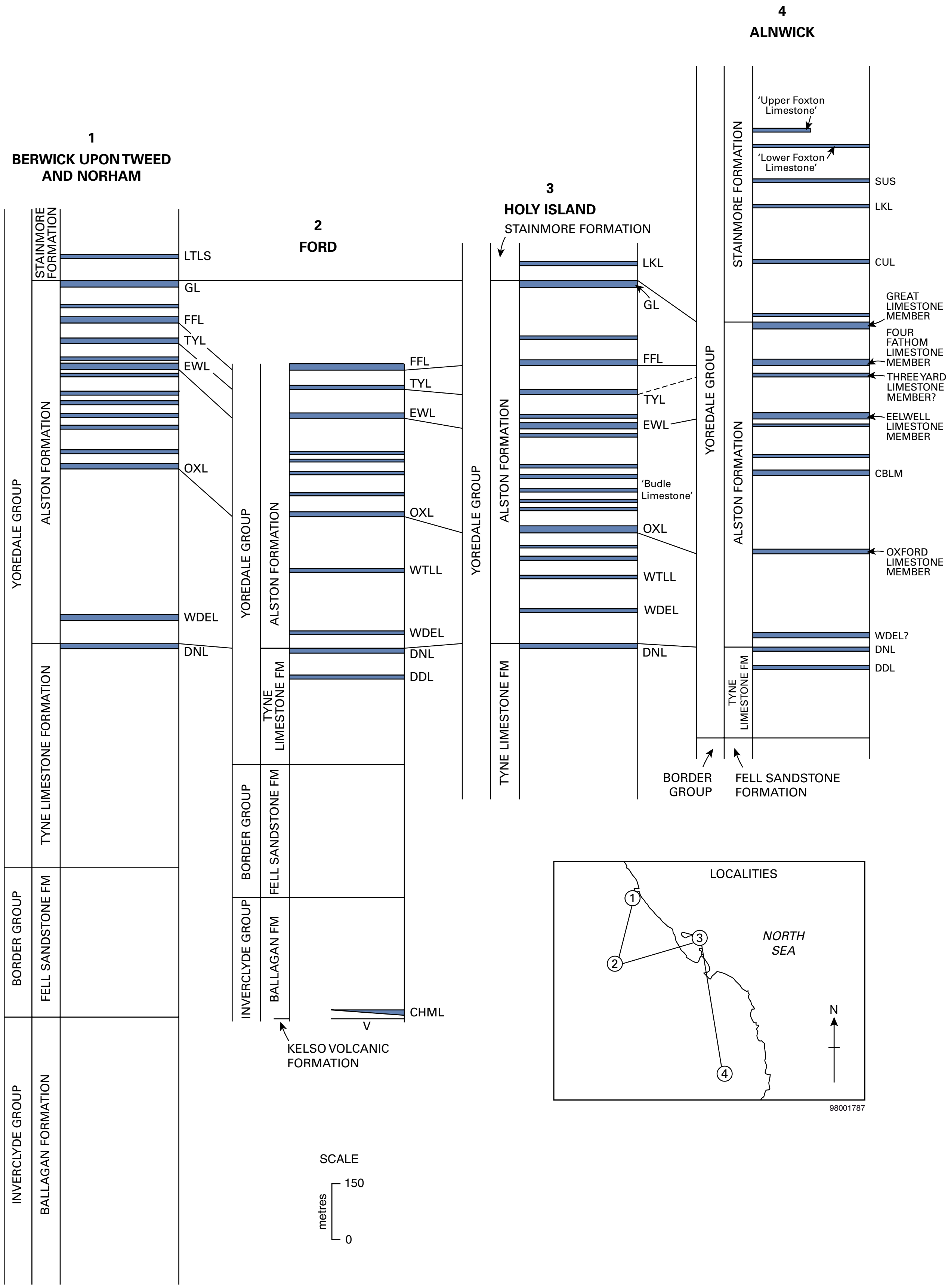


Figure 12 Northumberland Trough. Generalised vertical sections for Carboniferous strata at Berwick-upon-Tweed, Ford, Holy Island and Alnwick. Based on IGS (1972, 1974, 1976, and 1977). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. v indicates named volcanic units; blue colour indicates named limestone beds. Dashed lines indicate conjecture.

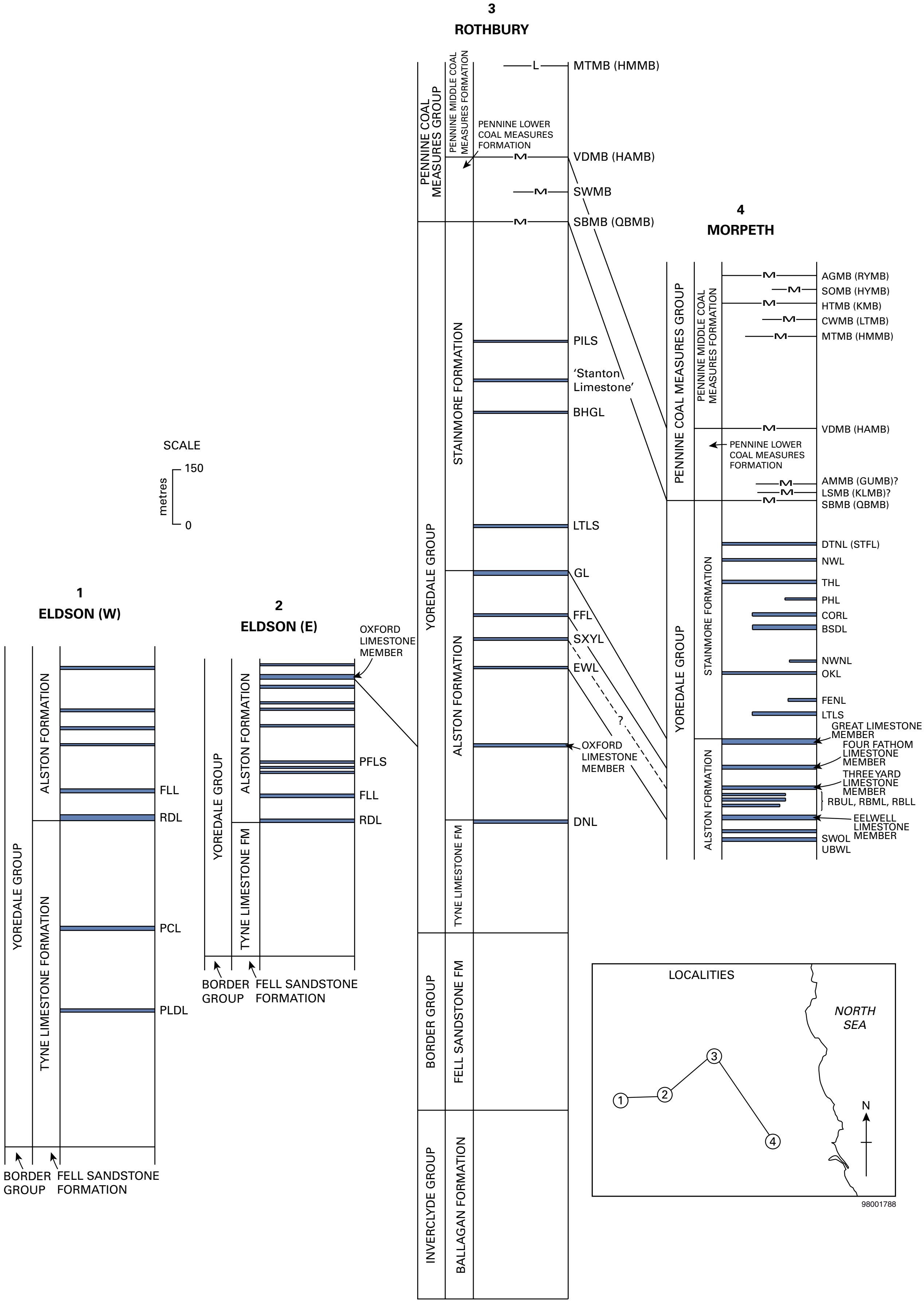


Figure 13 Northumberland Trough. Generalised vertical sections for Carboniferous strata at Elsdon, Rothbury and Morpeth. Based on GSGB (1951), IGS (1966), Mills and Holliday (1998), Young (1998), Young and Lawrence (1998) and Dean (2001). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band; L *Lingula* band. Blue colour indicates named limestone beds. Dashed lines indicate conjecture.

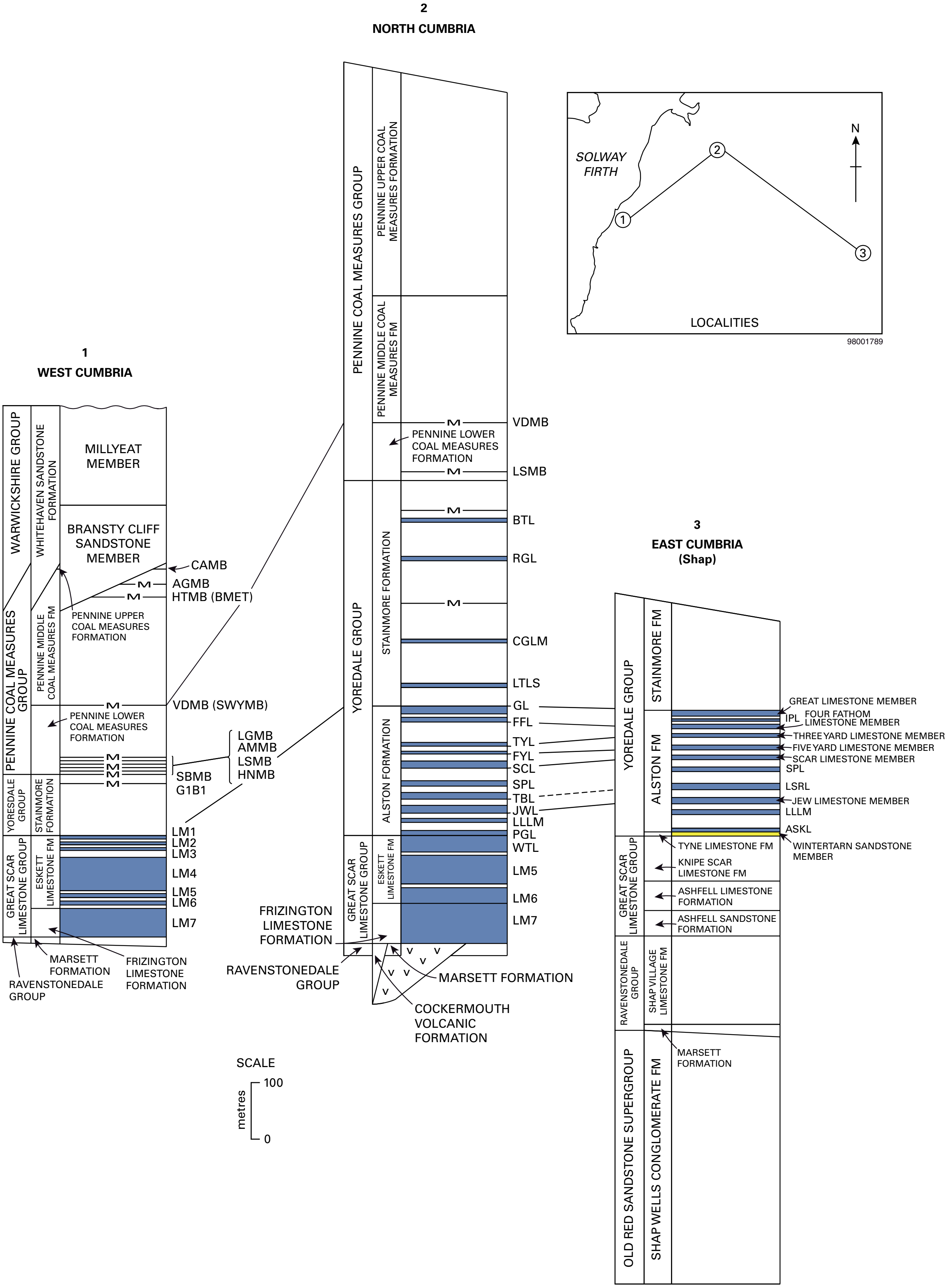


Figure 14 Cumbria. Representative sections for Carboniferous strata in West, North and East Cumbria. Based on George et al. (1976), Mitchell (1978), Ramsbottom (1978), and Ramsbottom et al. (1978). The profiled location of the numbered sections is given in the inset map. See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band, Blue colour indicates named limestone beds; green colour indicates significant developments of named sandstone units. Dashed lines indicate conjecture; wavy lines indicate unconformity surfaces.

Wintertarn Sandstone Member, Tyne Limestone Formation (Figure 14, Column 3).

The upper boundary of the member is taken at the base of the overlying shelly marine mudstone within the Alston Formation Yoredale facies depositional cycle.

Thickness
Between 12 and 14.7 m.

Distribution and regional correlation
North Cumbria and Edenside, west of Pennine–Dent Fault zone.

Age
Asbian to Brigantian.

6.7.2.2 Jew Limestone Member (JWL)

Name
No longer bed status, now a member of the Alston Formation. See Johnson and Dunham (1963); Dunham (1990); Burgess and Holliday (1979); Trotter and Hollingworth (1932); Eastwood et al. (1968); Johnson and Nudds (1996).

Lithology
Limestone, bioclastic, dark grey, thick wavy beds with fissile mudstone partings, and usually with abundant fossils. At many localities it contains a *Saccaminopsis* band about two-thirds of the thickness above the base (Burgess and Holliday, 1979). In Cumbria, the member is composed of pale porcellaneous limestone with dark irregular spots (pseudobreccias) at the base, overlain by well-bedded grey and grey-blue limestone crowded with *Saccamminopsis fusulinaformis*, and in some beds with abundant '*Lithostrotion*' (Eastwood et al., 1968).

Stratotype
The type section is Force Burn, about 1.2 km upstream from its confluence with the River Tees just above the Cow Green Reservoir, Teesdale, Cumbria [NY 771 306] where the limestone is fossiliferous and contains many colonial corals (Johnson and Dunham, 1963, p. 46). A reference section is a roadside quarry 730 m E25°N of the church in Uldale, Cumbria [NY 2576 3734], with about 6.5 m of dark grey, mostly well-bedded, fossiliferous limestone (including a '*Lithostrotion* band') beneath about 2 m of grey-white fossiliferous limestone with red spots (see Eastwood et al., 1968, p. 171).

Lower and upper boundaries
The lower boundary is taken at the sharp base of limestone beds overlying a generally conformable ganister sandstone of the Alston Formation (Figure 11, Column 1; Figure 14, Column 3; Figure 15, Column 1), or north of the Lake District resting on a few metres of siltstone, mudstone and sandstone (Figure 14, Column 2).

The upper boundary of the member is overlain, generally conformably, by siltstone and mudstone of the Alston Formation.

Thickness
Between 5 and 9.5 m on the Alston Block and 9.1–12.2 m north of the Lake District massif.

Distribution and regional correlation
A member within the Alston Formation of the Alston and Lake District blocks, and questionably the equivalent of the Oxford Limestone in north Northumberland. It is exposed along the North Pennine escarpment, on the northern flanks of the Lake District massif and in the Vale of Eden, and in Teesdale, Cumbria; also in Weardale, Durham, in the Cowgreen–Maizebeck area and was formerly seen on the site of the Burnhope reservoir in Weardale. Proved at depth in many boreholes and shafts in the northern Pennines of Northumberland and to the east in Durham, including the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] (Johnson and Nudds, 1996), the Roddymoor and Emma Pit (BGS Registration Number NZ13NE/146) [NZ 1513 3435] (Woolacott 1923) and the Seal Sands Borehole (BGS Registration Number NZ52SW/308) [NZ 538 239]. The Jew Limestone is apparently absent in the Allenhead's No 1 Borehole (BGS Registration Number NY84NE/4) [NY 8604 4539].

Age
Brigantian.

6.7.2.3 Oxford Limestone Member (OXL)

Name
Known alternatively as the Greenses Limestone. See Frost and Holliday (1980); Burgess and Holliday (1979); Day (1970); Fowler (1926); George and Black (1971); Gunn (1900); Gunn and Clough (1895).

Lithology
Limestone, thick bedded at base, becoming thin bedded at top; grey to dark grey with numerous red-weathered *Osagia* (an alga) haloes; particularly rich in corals and brachiopods.

Stratotype
The type section is near Broomlee Lough, Northumberland [NY 7903 6990 and 7960 7041]. Frost and Holliday (1980, p. 32) noted this locality in the grey to dark grey fossiliferous limestone with *Osagia* ('*Girvanella*') haloes, which is 5–6 m thick in the Bellingham district (Figure 11, Column 3).

Lower and upper boundaries
The lower boundary is taken at the generally conformable, sharp base of the first bed of limestone that overlies measures of the Alston Formation. This typically displays a coal or seatearth immediately below the limestone.

The upper boundary of the member is taken at the top of the uppermost limestone bed that is overlain by a coarsening upwards sequence of dark grey mudstones, siltstone and sandstone, the first containing ironstone nodules.

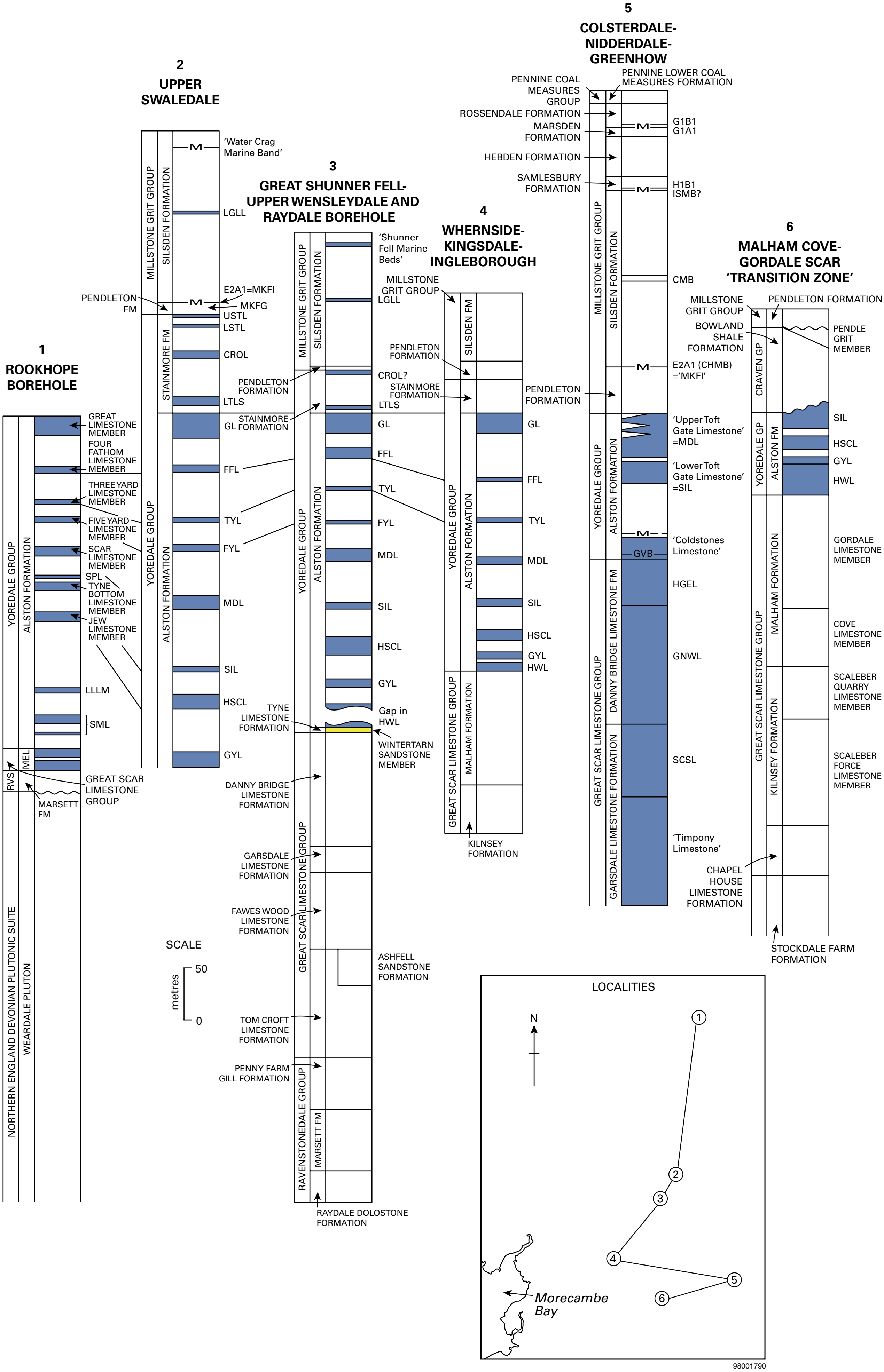
Thickness
Between 5 and 6 m.

Distribution and regional correlation
Widespread limestone member occurring throughout the Northumberland Trough in northern England and the Scottish Borders within the Alston Formation, stratigraphically lying below the Eelwell Limestone (Figure 12, Column 1–4; Figure 13, Column 3). Some authors correlate the Oxford Limestone with the Jew Limestone of the Alston Block and north of the Lake District (George and Black, 1971) and with the Bridge Limestone in the Bewcastle and Langholm area (Day, 1970) (Figure 10, Column 3; Figure 11, Column 2).

Age
Brigantian.

6.7.2.4 Tynebottom Limestone Member (TBL)

Name
The member is so-called because it crops out in, or is closely underlying, the bed of the River South Tyne



1
ROOKHOPE BOREHOLE
2
UPPER SWALEDALE
3
GREAT SHUNNER FELL-UPPER WENSLEYDALE AND RAYDALE BOREHOLE
4
WHERNSIDE-KINGSDALE-INGLEBOROUGH
5
COLSTERDALE-NIDDERDALE-GREENHOW
6
MALHAM COVE-GORDALE SCAR 'TRANSITION ZONE'
GREAT LIMESTONE MEMBER
FOUR FATHOM LIMESTONE MEMBER
THREE YARD LIMESTONE MEMBER
FIVE YARD LIMESTONE MEMBER
SCAR LIMESTONE MEMBER
SPL
TYNE BOTTOM LIMESTONE MEMBER
JEW LIMESTONE MEMBER
LLLM
SML
GREAT SCAR LIMESTONE GROUP
MARSETT FM
YOREDALE GROUP
ALSTON FORMATION
MEL
RVS
NORTHERN ENGLAND DEVONIAN PLUTONIC SUITE
WEARDALE PLUTON
'Water Crag Marine Band'
LGLL
E2A1=MKFI
MKFG
USTL
LSTL
CROL
LTLS
PENDLETON FM
MILLSTONE GRIT GROUP
SILSDEN FORMATION
STAINMORE FM
FFL
TYL
FYL
MDL
SIL
HSCL
GYL
GL
SCALE
50
0
metres
'Shunner Fell Marine Beds'
PENDLETON FORMATION
STAINMORE FORMATION
TYNE LIMESTONE FORMATION
DANNY BRIDGE LIMESTONE FORMATION
GARSDALE LIMESTONE FORMATION
FAWES WOOD LIMESTONE FORMATION
TOM CROFT LIMESTONE FORMATION
PENNY FARM GILL FORMATION
RAVENSTONEDALE GROUP
MARSETT FM
RAYDALE DOLOSTONE FORMATION
ASHFELL SANDSTONE FORMATION
Gap in HWL
WINTERTARN SANDSTONE MEMBER
MILLSTONE GRIT GROUP
LGLL
CROL?
LTLS
SILSDEN FM
MALHAM FORMATION
HWL
KILNSEY FORMATION
PENNINE COAL MEASURES GROUP
PENNINE LOWER COAL MEASURES FORMATION
ROSSENDALE FORMATION
MARSDEN FORMATION
HEBDEN FORMATION
SAMLESBURY FORMATION
G1B1
G1A1
H1B1
ISMB?
CMB
E2A1 (CHMB) ='MKFI'
'Upper Toft Gate Limestone' =MDL
'Lower Toft Gate Limestone' =SIL
'Coldstones Limestone'
GVB
HGEL
GNWL
SCSL
'Timpony Limestone'
CHAPEL HOUSE LIMESTONE FORMATION
DANNY BRIDGE LIMESTONE FM
GARSDALE LIMESTONE FORMATION
GREAT SCAR LIMESTONE GROUP
MILLSTONE GRIT GROUP
BOWLAND SHALE FORMATION
PENDLE GRIT MEMBER
CRAVEN GP
YOREDALE GP
ALSTON FM
GORDALE LIMESTONE MEMBER
COVE LIMESTONE MEMBER
SCALEBER QUARRY LIMESTONE MEMBER
SCALEBER FORCE LIMESTONE MEMBER
KILNSEY FORMATION
STOCKDALE FARM FORMATION
LOCALITIES
N
Morecambe Bay
98001790

Figure 15 *(opposite)* Askrigg Block. Representative sections for Carboniferous strata various localities including at upper Swaledale, Great Shunner Fell–upper Wensleydale and the Raydale Borehole, Whernside–Kingsdale–Ingleborough, Colsterdale–Nidderdale–Greenhow, and the Malham Cove–Gordale Scar 'Transition Zone', together with a summary log of the Rookhope Borehole, Alston Block to provide correlation of members and individual limestones within the Alston Formation between the Askrigg and Alston blocks. Based on Dunham et al. (1965), Dunham and Wilson (1985) and Arthurton et al. (1988). See Appendices 1 and 2 for the names of the lithostratigraphical units shown by BGS Lexicon of Named Rock Units computer codes. M marine band; Blue colour indicates named limestone beds: green colour indicates significant developments of named sandstone units. Dashed lines indicate conjecture; wavy lines indicate unconformity surfaces.

between Alston and Tynehead. It no longer has bed status (i.e. the Tyne Bottom Limestone of, for example, Trotter and Hollingworth, 1932), but is now a member of the Alston Formation. See Johnson and Dunham (1963); Dunham (1990); Burgess and Holliday (1979); Eastwood et al. (1968); Johnson and Nudds (1996); Arthurton and Wadge (1981).

Lithology
Limestone, blue-grey, thick-bedded, planar to wavy-bedded, stylolitic, in part fissile with intercalated thin mudstone beds. Fossiliferous, particularly with abundant corals, brachiopods and crinoid debris. It commonly has a *Saccamminopsis* band 1.5 to 2 m from the top. A bed near the top is characteristically argillaceous and 'slaggy' (Johnson and Dunham 1963).

Stratotype
The type area is High Cup Gill, Dufton Fell, Cumbria [NY 730 250 to 752 274] where about 8 m of limestone are exposed (see Burgess and Holliday, 1979, fig. 26, col. 6). A reference section is the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] from 175.62 to 184.94 m depth (Johnson and Nudds, 1996).

Lower and upper boundaries
The lower boundary is taken at the sharp base of limestone overlying measures within the Alston Formation, in places comprising sandstone, elsewhere mudstone.

The upper boundary of the member is taken at the base of overlying measures within the Alston Formation, here usually comprising up to about 10 m of compact, hard, dark grey mudstone colloquially referred to as the Tyne Bottom Plate.

Thickness
Between 7.6 and 14.6 m.

Distribution and regional correlation
The member crops out in, or closely underlies, the bed of the River South Tyne between Alston and Tynehead. The limestone is well exposed along the Pennine escarpment in Teesdale and Weardale. It is well known from subsurface workings, boreholes and shafts within the Alston Block. The member occurs within the Alston Formation of the Alston and Lake District blocks in Cumbria, Northumberland and Durham, lying between the Jew (below) and the Scar (above) limestone members (Figure 11, Column 1; Figure 14, Column 2). It is present in the Rookhope Borehole (Figure 15, Column 1) (see above) and the Allenheads No. 1 Borehole (BGS Registration Number NY84NE/4) [NY 8604 4539].

Age and biostratigraphical characterisation
Brigantian. Cozar and Somerville (2004) record a single specimen of the foraminifer *Asteroarchaediscus* from the Tynebottom Limestone Member in the Rookhope Borehole (see above). This genus is only present in the uppermost lower Brigantian and mostly occurs in the upper Brigantian (Cozar and Somerville, 2004 and references therein).

6.7.2.5 Eelwell limestone Member (EWL)

Name
Previously known as the Harelawhill Limestone. See Frost and Holliday (1980); Chadwick et al. (1995); Day (1970); Gunn (1900); Lumsden and Wilson (1961).

Lithology
Limestone, grey, bioclastic, generally devoid of mudstone partings; typically rich in algal remains with a prominent fauna of brachiopods and corals; appreciably dolomitised in part, giving a brown-weathered and vuggy appearance.

Stratotype
The type areas are near Walwick, about 2 km west of Chollerford, Northumberland [NY 8878 7033 to 9083 7116] where Frost and Holliday (1980, p. 36) referred to the typically massive, grey, bioclastic limestone, devoid of mudstone partings, being well exposed; and Cargie's Plantation [NU 024 495] to Saltpan Rocks [NU 025 490], Seahouses, approximately 3 km south-east of Berwick-upon-Tweed, Northumberland where Fowler (1926, p. 25) described the limestone exposed on the shore as browned (as if dolomitised), steeply dipping, contorted and fossiliferous.

Lower and upper boundaries
The lower boundary is taken at the generally conformable, sharp base of the first bed of limestone that overlies measures of the Alston Formation; typically sandstone.

The upper boundary of the member is taken at the top of the uppermost limestone bed that is overlain by a sequence of dark grey mudstones and siltstones, containing ironstone nodules locally.

Thickness
Between 5 and 10 m.

Distribution and regional correlation
A widespread limestone member within the Alston Formation, occurring throughout the Northumberland Trough in northern England and the Scottish Borders, stratigraphically lying below the Three Yard Limestone and above the Oxford Limestone (Figure 11, Column 3; Figure 12, Columns 1–4). This definition incorporates its correlated unit in the Langholm and Bewcastle areas of the Scottish Borders region, the Harelawhill Limestone.

Age
Brigantian.

6.7.2.6 Scar Limestone Member (SCL)

Name
Named after the limestone exposures along the Pennine escarpment. See Arthurton and Wadge (1981); Dunham (1990); Burgess and Holliday (1979); Trotter and Hollingworth

(1932); Eastwood et al. (1968); Johnson and Nudds (1996); Johnson et al. (1980); Johnson and Dunham (1963).

Lithology
Limestone, pale to mid grey, wavy-bedded, crinoidal with fissile uppermost part and shaly partings; stylolitic. It is generally fossiliferous with bands of *Siphonodendron junceum*. Comparatively unfossiliferous in the south, though a bed rich in brachiopods is present at the base in the southern part of the Brough district (Burgess and Holliday 1979). Nodules of chert are commonly found in this limestone (Trotter and Hollingworth, 1932; Dunham, 1990). In the Longcleugh No. 1 Borehole (Johnson et al., 1980), Allenheads No. 1 Borehole (BGS Registration Number NY84NE/4) [NY 8604 4539] and Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] the upper part of the member includes an interbedded unit of black pyritic fossiliferous mudstone with sporadic small ironstone nodules.

Stratotype
The type section is in a disused quarry north-east of Croglin, Cumbria [NY 5834 4815 to 752 274] the Scar Limestone is 14.6 m thick with the lower 9.8 m of massive grey limestone, separated from rather darker beds with thin mudstone partings above, by 0.6 m of calcareous mudstone (see Arthurton and Wadge, 1981, p. 42). A reference section is the Rookhope Borehole (see above), in which the Scar Limestone, including a 1.62 m thick mudstone interbed, occurs from 137.95 to 147.26 m depth (see Johnson and Nudds, 1996, p. 191).

Lower and upper boundaries
The lower boundary is taken at the sharp base of limestone overlying measures within the Alston Formation; directly underlain locally by dark mudstone, seatearth sandstone or by a coal seam.

The upper boundary of the member is taken at the base of overlying strata within the Alston Formation typically comprising cyclical sedimentary rocks with thickly bedded, commonly bioclastic, limestones

Thickness
Between 4 and 14.6 m.

Distribution and regional correlation
The member falls within the Alston Formation of the Alston and Lake District blocks in Cumbria, Northumberland and Durham, and lies stratigraphically between the Tynebottom (below) and the Five Yard (above) limestone members (Figure 11, Column 1; Figure 14, Column 2; Figure 15, Column 1). The limestone is well exposed along the Pennine escarpment, in Teesdale and Weardale. It is well known from subsurface workings, boreholes and shafts within the Alston Block. It is present in deep boreholes including Longcleugh No 1 Borehole in the West Allen Valley (Johnson et al., 1980), and the Rookhope and the Allenheads No. 1 boreholes (see above).

Age
Brigantian. Goniatites of the *Lusitanoceras granosus* P_{2a} Subzone are found in mudstone just above the limestone at Bowlees in Teesdale.

6.7.2.7 Five Yard Limestone Member (FYL)

Name
No longer bed status, now a member of the Alston Formation. See Arthurton and Wadge (1981); Dunham (1990); Burgess and Holliday (1979); Trotter and Hollingworth (1932); Eastwood et al. (1968); Johnson and Nudds (1996); Johnson et al. (1980).

Lithology
Limestone, dark grey, argillaceous, becoming grey compact towards base. In the south, fine-grained with thin evenly bedded mudstone partings with many fossils; in the north becoming increasingly crinoidal and locally characterised by coarse crinoidal debris. Intercalated thin unit (up to 2.1 m thick) of black fossiliferous calcareous mudstone which divides the member into two parts. Stylolitic particularly near the base (Johnson and Nudds, 1996).

Stratotype
The type section is at Lunchy Beck [NY 6036 4822], a northern tributary of Croglin Water, Cumbria, where the Five Yard Limestone is a dark blue-grey, thick-bedded limestone with muddy partings, 4.9 m thick (Arthurton and Wadge, 1981, pp. 43–44). A reference section is provided by the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] from 109.7 to 114.3 m depth including a 0.53 m-thick interbed of black fossiliferous calcareous shale (see Johnson and Nudds, 1996, p. 190).

Lower and upper boundaries
The lower boundary is taken at the sharp base of the limestone overlying measures within the Alston Formation. It is directly underlain by burrowed, current and ripple-bedded, medium-grained sandstone; a thin coal is present in places.

The upper boundary of the member is taken at the base of the overlying mudstone within measures of the Alston Formation.

Thickness
Between 3 and 8.5 m.

Distribution and regional correlation:
A member within the Alston Formation of the Alston and Lake District blocks in Cumbria, Northumberland and Durham, lying stratigraphically between the Scar (below) and the Three Yard (above) limestone members (Figure 11, Column 1; Figure 14, Columns 2, 3; Figure 15, Column 1). Possibly correlated with the Eelwell Limestone Member of the Northumberland Trough. The limestone is well exposed along the Pennine escarpment in Teesdale and Weardale. It is well known from subsurface workings, boreholes and shafts within the Alston Block. It is present in deep boreholes including the Longcleugh No 1 Borehole in the West Allen Valley (Johnson et al., 1980), and the Rookhope and Allenheads No. 1 boreholes (see above).

Age
Brigantian. On Dun Fell the limestone has yielded goniatites indicating the *Neoglyphioceras subcirculare* P_{2b} Subzone (Johnson and Dunham, 1963; Dunham, 1990). In the Rookhope Borehole (see above) the first appearance of the foraminifers *Janischewskina typica* and *Endothyranopsis sphaerica*, and the alga *Calcifolium okense* indicate the late Brigantian upper Cf6γ Subzone (see Cozar and Somerville, 2004).

6.7.2.8 Three Yard Limestone Member (TYL)

Name
Formerly the Acre Limestone of Northumberland, and the Third Limestone of north of the Lake District. The Three Yard Limestone bed now has member status. See Mills and Hull (1976); Burgess and Holliday (1979); Chadwick et al.

(1995); Day (1970); Dunham (1990); Dunham and Wilson (1985); Eastwood et al. (1968); Frost and Holliday (1980); Gunn (1900); Johnson et al. (1962); Johnson and Nudds (1996); Lumsden and Wilson (1961); Young and Boland (1992).

Lithology
Limestone, packstone, fine-grained, mid and dark grey, thickly bedded; fissile and nodular in part, with styolites; thin mudstone partings, particularly in north Northumberland. Crinoid debris and foraminifers are typically characteristic, but the member is not particularly fossiliferous on the Alston Block. On the Askrigg Block, the limestone is split into two leaves by a ganister-like sandstone which thickens to up to 8 m westwards (Burgess and Holliday, 1979; Dunham and Wilson, 1985); a thin coal is shown at a similar horizon in the Barnard Castle district to the east (Mills and Hull, 1976).

Stratotype
The type area is coastal exposures at Saltpan Rocks [NU 026 493 to 026 481], about 3 km south-east of Berwick-upon-Tweed, Northumberland where Fowler (1926, p. 25) described the limestone exposed on the shore below tide-mark as pale grey, dipping eastward at about 12°, folded, and with marine fossils (including *Saccamminopsis*) about 4.5 m thick. The type section is in the River Greta at Scotchman's Stone [NY 0807 1245], about 8 km east of Bowes, Co. Durham where the limestone is 3.66 m thick and includes shale partings and a 3.5 cm coal (see Mills and Hull, 1976, p. 15).

Lower and upper boundaries
The lower boundary is taken at the generally conformable, sharp base of the first bed of limestone that overlies measures of the Alston Formation. On the Alston Block, it usually lies above a major sandstone body referred to as the Six Fathom Hazle. This typically displays a seatearth below the limestone, and in north Northumberland there is typically a coal; also, a few tens of centimetres of mudstone may intervene locally.

The upper boundary of the member is taken at the top of the uppermost limestone bed that is overlain by a sequence of dark grey mudstones and siltstones, in north Northumberland containing ironstone nodules locally.

Thickness
Between 1.8 and 4.6 m on the Alston Block; 3–10 m in the Whitehaven to Gilcrux district, north of the Lake District; an average of 2.7 m on the Askrigg Block; 5–6 m in Northumberland.

Distribution and regional correlation
Widespread limestone member occurring throughout northern England and the Scottish Borders within the Alston Formation, stratigraphically lying below the Four Fathom Limestone and above the Five Yard Limestone on the Alston Block (Figure 11, Column 1; Figure 14, Columns 2, 3; Figure 15, Columns 1–3) or the Eelwell Limestone in Northumberland (Figure 11, Column 3; Figure 12, Columns 1–4; Figure 13, Column 4). This definition incorporates its other local names of Acre Limestone in Northumberland and Third Limestone of Cumbria (Eastwood et al., 1968; Young and Boland, 1992). Geographical distribution therefore includes Cumbria, Northumberland, Durham and North Yorkshire. The member has been seen in numerous deep boreholes throughout the region including the Archerbeck Borehole (BGS Registration Number NY47NW/14) [NY 4160 7820] (Lumsden and Wilson, 1961), the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] (Johnson and Nudds, 1996), the Barrock Park Borehole (BGS Registration Number NY44NE/28) [NY 4613 4660], the Throckley Borehole (BGS Registration Number NZ16NW/45) [NY 1456 6762], the Harton Borehole (BGS Registration Number NZ36NE/80) [NZ 3966 6563], the Woodland Borehole (BGS Registration Number NZ02NE/4) [NZ 0910 2769] and the Seal Sands Borehole (BGS Registration Number NZ52SW/308) [NZ 538 239]. The member has also been widely seen on the Alston Block in many mine shafts and workings.

Age
Brigantian. A goniatite indicative of the *Lyrogoniatites georgiensis* P_{2c} Subzone has been recorded from mudstones above the Three Yard Limestone (Johnson et al., 1962).

6.7.2.9 Four Fathom Limestone Member (FFL)

Name
No longer bed status, now a member of the Alston Formation. Previously known as the Four Fathom Limestone, Sandbanks Limestone, Low Dean Limestone (Gunn, 1900), Eight Yard Limestone, Second Limestone, Buccleuch Limestone (Lumsden and Wilson, 1961), Undersett Limestone. See also Burgess and Holliday (1979); Chadwick et al. (1995); Day (1970); Dunham (1990); Dunham and Wilson (1985); Eastwood et al. (1968); Frost and Holliday (1980); Holliday et al. (1975); Johnson et al. (1962); Johnson and Nudds (1996); Young and Boland (1992).

Lithology
Limestone, packstone, fine-grained, mid and dark grey, thick bedded and wavy-bedded, with few mudstone partings; somewhat argillaceous, particularly at the top. Typically contains layers of nodules and lenses of black chert. Crinoidal but not particularly fossiliferous on the Alston Block; contains conspicuous coral biostromes to the north and south of the Alston Block.

Stratotype
The type area is coastal exposures of Near Skerr, Middle Skerr and Far Skerr, about 4 km south-east of Berwick-upon-Tweed [NU 028 487 to 036 481]. Here the limestone is earthy and bluish with many shale partings, about 8.5 m thick (Fowler, 1926, pp. 26–27). The type section is the Middlehope Burn, Westgate, Upper Weardale [NY 905 396] where a nearly complete section can be seen. A reference section is the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278] Rookhope, Weardale, Co. Durham from 57.99 to 63.70 m depth (see Johnson and Nudds, 1996, p. 187).

Lower and upper boundaries
The lower boundary is taken at the generally conformable, sharp base of the first bed of limestone that overlies strata of the Alston Formation. On the Alston Block, it usually overlies less than 2 m of dark grey seatearth mudstone and mudstone with abundant plants that overlies a prominent sandstone referred to there as the Natrass Gill Hazle. In the Bellingham district a coal underlies the limestone.

The upper boundary of the member is taken at the top of the uppermost limestone bed that is overlain by a sequence of dark grey mudstones, the lowermost of which are calcareous and fossiliferous. On the Askrigg Block the limestone member is overlain by a dark grey or almost black chert called the Underset Chert.

Thickness
Between 7 and 10 m north of the Lake District and in Northumberland; 5–12 m on the Alston Block; about 9 m on the Askrigg Block, but locally up to 25 m.

Distribution and regional correlation
Occurs throughout northern England and the Scottish Borders, lying below the Great Limestone near the top of the Alston Formation (Figure 10, Column 3; Figure 11, Columns 1–3; Figure 12, Columns 1, 3, 4; Figure 13, Columns 3, 4; Figure 14, Columns 2, 3; Figure 15, Columns 1–4). This definition incorporates the various other local names of Sandbanks, Lowdean and Eight Yard in Northumberland, the Buccleuch Limestone (Lumsden and Wilson, 1961) of the Langholm and Bewcastle area; the Second Limestone of Cumbria (Eastwood et al., 1968; Young and Boland, 1992) and the Underset Limestone of the Askrigg Block (for example Dunham and Wilson, 1985). Geographical distribution therefore includes Cumbria, Northumberland, Durham and North Yorkshire. The member has been seen in numerous deep boreholes throughout the region including the Archerbeck Borehole (BGS Registration Number NY47NW/14) [NY 4160 7820] (Lumsden and Wilson, 1961), the Rookhope Borehole (see above), the Barrock Park Borehole (BGS Registration Number NY44NE/28) [NY 4613 4660], the Throckley Borehole (BGS Registration Number NZ16NW/45 [NZ 1456 6762], the Harton Borehole (BGS Registration Number NZ36NE/80) [NZ 3966 6563], the Woodland Borehole (BGS Registration Number NZ02NE/4) [NZ 0910 2769] and the Seal Sands Borehole (BGS Registration Number NZ52SW/308) [NZ 538 239]. The member has also been widely seen on the Alston Block in many mine shafts and workings.

Age
Brigantian. Goniatites indicative of the *Lyrogoniatites georgiensis* P_{2c} Subzone have been found in mudstones above the Four Fathom Limestone in the Mount Pleasant Borehole [NZ 034 152] near Barnard Castle (Johnson et al., 1962).

6.7.2.10 Great Limestone Member (GL)

Name
No longer bed status, now a member of the Alston Formation (Yoredale Group). The member includes the former Main Limestone of the Askrigg Block, the Catsbit Limestone of Langholm, and the Dryburn Limestone of Northumberland. See Cossey et al. (2004), and Burgess and Holliday (1979); Chadwick et al. (1995); Day (1970); Dunham (1990); Dunham and Wilson (1985); Eastwood et al. (1968); Fairbairn (1978, 1980, 2001); Johnson (1958); Johnson and Nudds (1996); Lumsden and Wilson (1961); Young and Boland (1992).

Lithology
Limestone (bioclastic packstone), mid to dark blue-grey; thickly bedded with thin shaly mudstone partings along uneven or wavy bedding planes; there is much crinoid debris throughout and there are many other beds rich in brachiopods and/or corals. The internal stratigraphy of the member is in parts remarkably consistent throughout the region and four informal divisions are recognised (Fairbairn, 1980) and referred to, from the base upwards as the Bench, Main and Transitional posts and the Tumbler Beds. Beds rich in fossils are widespread. Most notable and widespread is the Chaetetes Band (Johnson, 1958) which occurs near the base; this comprises a sponge biostrome along with locally abundant brachiopods, corals and ostracods. Within the Main Posts are the Brunton Band comprising the rare alga *Calcifolium* (Johnson, 1958; Cossey et al., 2004), and the Frosterly Marble (Johnson, 1958). At the top, the Tumbler Beds, typically 2–5 m thick, comprise thick beds of limestone interbedded with persistent mudstone units.

Stratotype
The type section is Greenleighton Quarry, about 10 km south of Rothbury, Northumberland [NZ 034 917] (Figure 13, Column 3), which includes 12 m of limestone divisible into the Bench, Main and Transitional posts and Tumbler Beds of Fairbairn (1980) (see Cossey et al., 2004, pp. 144–147). Reference sections occur at Brunton Bank Quarry, about 1 km south-east of Chollerford, Northumberland [NY 928 699] where the Great Limestone is about 15 m thick and contains the type sections of the Brunton Band (with the rare alga *Calcifolium*), and the Chaetetes Band (a spectacular sponge biostrome) (see Cossey et al., 2004, pp. 141–144); Eastgate Quarry, Weardale, Co. Durham [NY 940 370] where a complete section, including the Frosterly Marble, can be seen; Tendley Hill Quarry, Cumbria [NY 088 289] where a full thickness of 15.8 m of mid grey, thickly bedded, prominently jointed packstone, typically with uneven or wavy bedding planes, and a development of the Chaetetes Band can be seen (Young and Boland, 1992, p. 21); the Archerbeck Borehole (BGS Registration Number NY47NW/1) [NY 4157 7815], 2 km north-east of Canonbie, Dumfriesshire from 215.8 to 238.3 m depth with massive limestone except for a few calcareous mudstone beds (see Lumsden and Wilson, 1961); and the Rookhope Borehole (BGS Registration Number NY94SW/1) [NY 9375 4278], Rookhope, Weardale, Co. Durham from rockhead, apparently near the top of the limestone at 6.86 to 25.07 m depth (see Johnson and Nudds, 1996, p. 185).

Lower and upper boundaries
The lower boundary is taken at the generally conformable, sharp base of the first bed of limestone that overlies strata of the Alston Formation (which is characterised by cyclical sedimentary rocks that include thick-bedded, commonly bioclastic limestones). In most localities the limestone directly overlies the Tuft Sandstone, a brown, micaceous fine-grained sandstone that has a rooty upper part and which locally may be overlain by a thin carbonaceous smear or a coal.

The upper boundary of the member is taken at the top of the uppermost limestone bed that is overlain by a sequence of dark grey siltstones and mudstones at the base of the Stainmore Formation (SMGP).

Thickness
About 12 m in the Vale of Eden; 16–22 m on the Alston Block; 22–24 m with a maximum of 40 m on the Askrigg Block and 8–15 m in the Northumberland Trough; about 22 m in the Langholm area and Archerbeck Borehole.

Distribution and regional correlation
Occurs throughout most of northern England at the top of the Alston Formation. This definition incorporates the Main Limestone of the Askrigg Block, and the Catsbit Limestone (Day, 1970) of the Scottish Borders near Langholm. Geographical distribution therefore includes, Northumberland, Durham and North Yorkshire. The Great Limestone has also been correlated with the the First Limestone (LM1) (Eskett Limestone Formation, Great Scar Limestone Group) of Cumbria (Figure 14, Column 1),

and the Top Hosie Limestone (TOHO) (Lower Limestone Formation, Clackmannan Group) of the Midland Valley of Scotland (Figure 6, Column 4).

The member has been seen in numerous deep boreholes throughout the region including the Archerbeck and Rookhope boreholes (see above), the Barrock Park Borehole (BGS Registration Number NY44NE/28) [NY 4613 4660], the Throckley Borehole (BGS Registration Number NZ16NW/45 [NZ 1456 6762], the Harton Borehole (BGS Registration Number NZ36NE/80) [NZ 3966 6563], the Woodland Borehole (BGS Registration Number NZ02NE/4) [NZ 0910 2769] and the Seal Sands Borehole (BGS Registration Number NZ52SW/308) [NZ 538 239] (Chadwick et al., 1995).

Age

Pendleian. At Fountains Fell on the Askrigg Block the Great Limestone (formerly the Main Limestone) overlies mudstone with the E_{1a} Subzone ammonoid *Cravenoceras* (=*Emstites*) *leion* (Arthurton et al., 1988). A change in foraminiferal assemblage at the base of the Catsbit Limestone (the local equivalent of the Great Limestone Member) in the Archerbeck Borehole (see above) suggests that the base of the Namurian occurs at this level (Cummings, 1961).

6.7.3 Stainmore Formation (SMGP)

Name

The name is derived from the former Stainmore Group, a chronostratigraphical term for the entire Namurian succession (Burgess and Holliday, 1979). In west Cumbria the Stainmore Formation now replaces the Hensingham Group of Akhurst et al. (1997).

Lithology

The Stainmore Formation comprises a cyclical succession of sedimentary rocks, with repetitive mudstones, laminated siltstones, sandstones, thin limestones and thin coals. It is distinguishable from the underlying Alston Formation by a decrease in the number and thickness of the limestones, which also tend to be darker grey and more impure. It extends from the top of the Great Limestone (or a correlative) to the base of the Subcrenatum Marine Band (SBMB) (or its equivalent) at the base of the Pennine Coal Measures Group. The limestones, which are more prominent in the south of the Askrigg Block, are dark grey with a diverse marine fauna. Limestones are rare or absent from the upper part of the formation. The sandstones are typically fine- to medium-grained, white to pale brown, commonly bioturbated and rooty. The mudstones may be very dark grey. On the Askrigg Block there are up to four main levels of chert within the formation, typically developed above the limestone component of the cyclothem. The Richmond Chert is the thickest at up to 40 m thick. It contains sponge spicules and displays rapid lateral transitions to crinoidal limestones. In west Cumbria the succession includes distinct, laterally discontinuous, major channel sand bodies, such as the Hensingham Grit and has an unusual limestone development the '*Tylonautilus*' or Snebro Gill Beds. At Canonbie, the Stainmore Formation is poorly exposed, but comprises repetitive cycles of sandstone, siltstone and claystone with thin beds of coal.

[It should be noted that the formerly widespread use across Northumberland and Durham, of the term 'Millstone Grit' to encompass sandstone-rich beds beneath undoubted Coal Measures rocks, appears to be traceable back to the long-obsolete threefold division of the British Carboniferous sequence into Mountain Limestone, Millstone Grit and Coal Measures. Whereas the first and third of these divisions could be readily recognised, it is clear that the original geological surveyors felt constrained, apparently with some difficulty, to define representatives of the Millstone Grit, even as recently as the latter half of the 20th century. Accordingly, beds between the former Upper Limestone Group and Coal Measures in Northumberland, and between the former Alston Group and Coal Measures of the Northern Pennines, have been classified as Millstone Grit. This usage was applied as recently as 1989 in the compilation of Geological Sheet 20 (Newcastle upon Tyne), though further confusion was introduced here with the synonymous use of the term Stainmore Group to classify these rocks. A more cautious, and arguably realistic, approach had previously been adopted on Geological Sheet 13 (Bellingham). Here the succession above the Liddesdale Group was classified as Stainmore Group, with no reference to Millstone Grit. Dunham (1990, p. 36) drew attention to the difficulty of correlating sandstones beneath the Coal Measures with the classic Millstone Grit of the mid Pennines, Yorkshire and Lancashire, adding that the difficulty of making this correlation had by then been appreciated for at least half a century.

Whereas use of the term Millstone Grit cannot at present be justified in this part of northern England, it is important to recognise that coarse-grained sandstone bodies, which exhibit many 'Millstone Grit' characteristics with strongly erosive bases and with channel-like morphologies are present within the succession classified as the Stainmore Formation. Current knowledge indicates that these are present at several horizons within the Stainmore Formation succession, though no clear evidence has yet emerged to view these as other than local lithofacies variations within the rocks classified as Stainmore Formation. In Northumberland such sand bodies include the Rothley and Shaftoe Grits of Geological sheets 14 (Morpeth) and 9 (Rothbury), which exhibit deep erosive bases close to the horizons of the Little and Oakwood limestones respectively (Young and Lawrence, 2002). Although not recently mapped in detail, the Longhoughton Grits of Geological Sheet 6 (Alnwick) appear to comprise a channel-based sandstone at the horizon of the Foxton limestones. In all of these cases there is evidence of contemporaneous tectonic control on sedimentation. Clearly, in these examples, 'Millstone Grit'-like sandstones occur at a variety of stratigraphical levels, and are underlain and overlain by successions of rocks characteristic of the Stainmore Group lithofacies.

Notwithstanding Dunham's (1990) comments on the stratigraphical affinities of certain coarse-grained, locally pebbly sandstones, noted above, evidence from recent mapping of the northern margin of the Alston Block (Whitfield to Hexhamshire Common) has shown that coarse-grained, channel, sand-bodies dominate the succession in the upper part of the Stainmore Formation. Thus, in this area, the formation comprises a lower division consisting of mudstone interbedded with tabular units of fine and medium-grained sandstone and thin limestone beds, and an upper division of coarse-grained sandstone, lacking limestone. Work in progress on the Alston Block will determine the distribution and significance of this upper division and hence its lithostratigraphical status.]

Genetic interpretation

Cyclical marine and deltaic environments.

Stratotype

The type area of the Stainmore Formation is the Stainmore Trough. Reference sections include Mousegill Beck (BGS

Registration Number NY81SW/7) [NY 8369 1242] from the base of the Subcrenatum (Swinstone Top) Marine band at 136.25 m depth to the top of the Great Limestone at 582.47 m depth (see Burgess and Holliday, 1979) and the Throckley Borehole (BGS Registration Number NZ16NW/45) [NZ 1456 6762] from about 69 to 577 m depth. In west Cumbria the formation occurs in the Distington Borehole (BGS Registration Number NX92SE/84) [NX 9972 2334] from below the inferred position of the Subcrenatum Marine Band (SBMB) at about 20 m depth to the top of the First Limestone, Eskett Limestone Formation, at about 121 m depth (see Akhurst et al., 1997, fig. 24); the Rowhall Farm Borehole (BGS Registration Number NY03NE/49) [NY 0851 3664] from the non-sequence at about 61.5 m depth to the top of the First Limestone, Eskett Limestone Formation, at about 203.2 m depth (see Akhurst et al. 1997, fig. 24; Brand, 2003); Bigrigg Quarry (disused) [NY 0052 1270] which includes Yeadonian strata (see Eastwood et al., 1931; Akhurst et al., 1997); Brigham Quarry (disused) [NY 083 302] which exposes more than 30 m thickness of the Hensingham Grit which is locally developed at the base of the formation (see Young and Boland, 1992; Akhurst et al., 1997); and Snebro Gill [NX 9835 1685] where stream sections and cuttings in the Hensingham inlier include impure marine limestones and mudstones.

Lower and upper boundaries
The base of the formation is conformable on the Great Limestone Member (or correlatives) at the top of the Alston Formation (Figure 6, Column 7; Figure 8, Columns 11, 12; Figure 9, Columns 13, 5–7; Figure 10, Column 3; Figure 11, Columns 1, 3; Figure 12, Columns 1, 3, 4; Figure 13, Columns 3, 4; Figure 14, Columns 2, 3; Figure 15, Columns 2–4). However, in west Cumbria, in the Egremont–Whitehaven–Maryport–Cockermouth area, the lower boundary occurs where the shelf carbonate sequence of the First Limestone Member is terminated and conformably overlain by the mostly clastic marine and deltaic facies of the Stainmore Formation (Figure 14, Column 1). Here, at outcrop the basal part of the Stainmore Formation generally comprises the coarse-grained, fluvial, Hensingham Grit with a thin basal mudstone.

The top of the formation is generally conformable beneath the Subcrenatum Marine Band (SBMB) at the base of the mostly fluviodeltaic mudstones, siltstones and sandstones of the Pennine Lower Coal Measures (PLCM), or at the base of the coal-bearing sequence if this marker band (or an equivalent) cannot be identified.

On the Askrigg Block, the top of the formation is at the base of the Pendleton Formation, Millstone Grit Group (Figure 9, Column 17; Figure 15, Columns 2–4). Here, the mixed shelf carbonate and deltaic succession of the Stainmore Formation is succeeded, at an unconformity of E1c age by sandstone-dominated strata (see Brandon et al., 1995).

In the Canonbie Coalfield, the boundary with the Pennine Lower Coal Measures Formation is uncertain in both position and nature. The Subcrenatum Marine Band has not been recognised here, and the unconformities inferred by Lumsden et al. (1967) and Picken (1988) have been discounted by Jones and Holliday (2006) on sedimentological and seismic reflection evidence.

Thickness
The formation tends to thicken into troughs and half-grabens. In north and west Cumbria it thickens northwards, the relatively thin succession on the Lake District Block being separated from the Solway Basin by the syndepositional Maryport Fault (Barnes et al., 1988; Chadwick et al., 1995). The formation is 50 m thick in the Lamplugh area (Young and Boland, 1992) and 110 m and 140 m thick in the Distington and Rowhall Farm boreholes respectively (Akhurst et al., 1997). Over 500 m of strata are present in boreholes north of Maryport (Ramsbottom, 1978). The thickest development on the Askrigg Block is about 180 m at the northern margin where the deltaic component of the cyclothems is thicker. The formation is up to 200 m thick in the Appleby district. Around Canonbie, seismic reflection data indicate that the formation is more than 400 m thick.

Distribution and regional correlation
Northern England, north of the Askrigg Block, including west Cumbria.

Age and biostratigraphical characterisation
Namurian (Pendleian to Yeadonian). The type localities of the Yeadonian ammonoids *Cancelloceras cancellatum* and *Gastrioceras cumbriense* occur within the mudstone beds at Bigrigg [NY 0010 1305]. In west and north Cumbria the formation is also Pendleian to Yeadonian, but there is a large non-sequence above the Snebro Gill Beds in which strata of Chokierian to Marsdenian age are absent (Akhurst et al., 1997). The limestones that are more prominent in the south of the Askrigg Block notably include crinoid debris and the nautiloid *Tylonautilus nodiferus*. The first appearance of common *Crassispora kosankei* miospores about 14 m above the base of the first thick sandstone ('First Grit') in the Throckley Borehole (see above) marks the base of the KV Zone (Stephenson et al., 2008) of Kinderscoutian age. The upper 140 m of the Stainmore Formation in the Langholm area includes strata of the FR miospore Zone (late Marsdennian to Yeadonian in age) in the Rowanburnfoot Borehole (BGS Registration Number NY47NW/27) [NY 41031 75743] (Owens, 1980).

6.8 CRAVEN GROUP (CRAV)

The Craven Group, of mainly *hemipelagic facies*, is dominated by deposits of calcareous mudstone interbedded with limestone and subordinate limestone breccia, conglomerate and sandstone. The limestones are typically pale coloured and coarsely bioclastic towards the base of the group and more argillaceous towards the top. The group largely occurs in southern Great Britain (see Waters et al., 2007, for a full description), but it also encroaches upon the onshore Northern England Province where:

In *south Cumbria and in the Askrigg Block–Craven Basin 'Transition Zone'* it comprises the Bowland Shale Formation;

On the *Isle of Man* it comprises the Hodderense Limestone and Bowland Shale formations.

Knoll-reef and slope carbonate turbidite facies also occur on the southern margin of the Askrigg Block. In south Cumbria the upper boundary of the Yoredale Group occurs at the base of the *Cravenoceras leion* Marine Band, where the thinly interbedded limestones, mudstones and subordinate sandstones of the Alston Formation pass upward into the thick mudstones and fine-grained siltstones of the Bowland Shale Formation, Craven Group. On the south Isle of Man, the upper boundary of the Great Scar Limestone Group occurs at a change from the wackestones and packstones of the Knockrushen Formation to massive lime mudstones with micrite nodules of the Hodderense Limestone Formation (see Dickson et al., 1987) and at a change from the limestones with subordinate claystones and siltstones of the Balladoole Formation to the overstepping claystone with detrital carbonates of the Bowland Shale Formation. The diachronous base of the Millstone Grit Group *(fluvio-deltaic ('Millstone Grit') facies)* defines the top of the Craven Group.

The type area of the Craven Group is the Craven Basin of Lancashire (after which it is named) and its main extent is across central England and North Wales. It is Chadian to Yeadonian in age and reaches a maximum thickness in excess of 5000 m in the Widmerpool half-graben (see Waters et al., 2007). In south Cumbria the group is about 120 m thick and Pendleian in age. In the Isle of Man it is about 264 m thick and Holkerian to late Arnsbergian in age.

6.8.1 Hodderense Limestone Formation (BOH)

Since the Bowland Shale Formation extends into onshore southern Great Britain the definition that follows has been unified with that of Waters et al. (2009).

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).

Lithology
Grey sandstone occurs 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*.

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.

Stratotype
The type section is the east bank of the River Hodder, Great Falls [SD 7035 3999], near Stonyhurst, near Clitheroe, Lancashire. The base and top of the formation are seen in the section (Earp et al., 1961). Reference sections include south of the old lime kilns at the Visitor Centre at Scarlett, Isle of Man [SC 2580 6620] where the base of the formation is seen, and a cliff section at Scarlett Point, Isle of Man [SC 2583 6633] where the top of the formation is seen.

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, Craven Group, of Chadian to Holkerian age.

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 (Figure 8, Column 8). 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 of the formation 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, Craven Group, of late Holkerian to Asbian age.

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 (Figure 8, Column 8).

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 Isle of Man.

Age and biostratigraphical characterisation
Holkerian. The ammonoid assemblage, including *Bollandoceras hodderense*, is indicative of the upper part of the *Bollandites–Bollandoceras* (BB) 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*.

6.8.2 Bowland Shale Formation (BSG)

Since the Bowland Shale Formation extends into southern Britain the definition that follows has been unified with that of Waters et al. (2009). Information relevant solely to northern Britain is, however, provided under the subhead *'Local notes'*.

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.

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 subfissile, 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 deposits of carbonate turbidites, debris flows, olistoliths, volcaniclastic 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 volcaniclastic debris flows and gravity slides. Claystone rafts and megaclasts are entrained within the volcaniclastic 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.

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, volcaniclastic 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.

Stratotype

Reference sections include: River Ribble at Dinckley [SD 689 366 to 686 366], on the south bank of the River Ribble between Dinckley Hall and the suspension bridge, about 400 m to the west downstream (Earp et al., 1961); Little Mearley Clough [SD 779 414 to 785 411], 400 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 1962 7687] (Davies et al., 2004); Duffield Borehole, near Derby (BGS Registration Number SK34SW/5) [SK 3428 4217], from 335.23 to 405.78 m depth (see Aitkenhead, 1977); Roosecote Borehole, Barrow-in-Furness (BGS Registration Number SD26NW/19) [SD 2304 6866], which includes an entire thickness of the formation from 491.68 to 613.31 m depth (see Rose and Dunham, 1977; Johnson et al., 2001); Shellag Point Borehole, north Isle of Man [NX 4565 9965] cored from 100.60 to 128.15 m, but proving neither the base nor the top of the formation (Chadwick et al., 2001).

Lower and upper boundaries

The conformable base of the formation upon the Pendleside Limestone Formation in the Craven Basin, on the Widmerpool Formation in the East Midlands, on the Pentre Chert and Cefn-y-Fedw Sandstone Formation in North Wales, and on the Hodderense Limestone Formation in the south of the Isle of Man (Figure 8, Column 8), 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 (E1A1), where the dark grey to black marine mudstone rests upon thinly interbedded limestones, mudstones and subordinate sandstones of the Alston Formation (Figure 9, Column 14).

The Bowland Shale Formation onlapped onto, and eventually, by the Pendleian, extended 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 (Figure 15, Column 6).

The top of the formation is taken at the base of the Millstone Grit Group over most of the Pennine Basin (Figure 9, Column 14; Figure 15, Column 6) and at the base of the Morridge Formation in Staffordshire and the East Midlands. The formation shows complex intertongueing 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 120–620 m thick. The formation thickens north-eastwards along the axis of the Central Lancashire High, from about 22 m in the Roddlesworth Borehole, 68 m thick in the Holme Chapel Borehole, and 102 m in the Boulsworth Borehole (Waters et al., 2009, fig. 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 30–200 m thick (see Arthurton et al., 1988, fig. 22). In south Cumbria, the Roosecote Borehole (see above) proved the formation to be 121.63 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, the Shellag Point Borehole (see above) proved only a part of the formation 27.55 m thick.

Distribution and and regional correlation

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. The upper part of the Bowland Shale Formation passes northward into the Millstone Grit Group and to the south into the Morridge Formation (Waters et al., 2009, fig. 10).

Age and biostratigraphical characterisation

Asbian to Yeadonian. In the type area of the Craven Basin the formation ranges from late Asbian (Cf6γ Zone) to early Pendleian ($E_{1c}1$ 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*.

Local notes
In the south Isle of Man, the Bowland Shale Formation oversteps the Balladoole Formation along the foreshore north-west of Salt Spring Cottage [SC 244 679], and the exposed middle part of the formation is seen for example at Black Marble Quarry [SC 244 676]. In northern England the Bowland Shale Formation is ?early Asbian to Namurian in age and includes the *Emstites leion, Eumorphoceras pseudobilingue* and *C. malhamense* Marine bands.

Formal subdivisions
See also Appendix 1. Members of the Bowland Shale Formation in northern Great Britain, in ascending stratigraphical order, include:

6.8.2.1 Scarlett Point Member (SCPT)

Name
From Scarlett Point, Isle of Man. Previous names include the Scarlett and Strandhall Beds (Lewis, 1930). The present definition is that of Chadwick et al. (2001); (see also Dickson et al., 1987; Lamplugh, 1903).

Lithology
The member is characterised by tabular beds of pale wackestone and lime-mudstone. These beds, which can be cherty and pyritous, have gradational (locally dolomitised) boundaries with the subordinate interbedded black fissile, blocky claystones.

Genetic interpretation
Deposition was in a deep marine hemipelagic environment, but with periodic fine clastic and carbonate supply (gravitational).

Stratotype
A partial type section is exposed in coastal sections at Scarlett Point [SC 2570 6620 to 2583 6633] where about 14 m of evenly bedded, pale grey wackestone and lime-mudstone with interbedded black claystone are seen (see Dickson et al., 1987, pp. 214–217; Chadwick et al., 2001, p. 62).

Lower and upper boundaries
The base of the member is taken at the lowest black claystone (about 0.12 m thick) overlying the fine-grained, pale mottled limestone (wackestone) of the Hodderense Limestone Formation at Scarlett Point [SC 2583 6633] (Figure 8, Column 8).

The top of the member is not exposed so the nature of the upper boundary is unknown. The overlying succession comprises black hemipelagic mudstones of the undivided Bowland Shale Formation.

Thickness
Some 14 m.

Distribution and regional correlation
Southern part of the Isle of Man, in the Castletown area, from Scarlett Point [SC 2583 6633] north-westwards to Poyllvaaish [SC 2440 6761]. Visean rocks in the northern part of the island are entirely concealed so it is unknown whether it is present in the north.

Age and biostratigraphical characterisation
Asbian. Chondritiform and *Helminthoides* burrows are common in the limestones. Inadunate crinoid lags and scattered ammonoids of genera *Beyrichoceras* or *Bollandoceras* also occur, some preserved in semi-buoyant resting position with the venter resting on the former sea bed.

6.8.2.2 Scarlett Volcanic Member (SCV)

Name
From Scarlett Point, Isle of Man. Previous names include the Scarlett Volcanic Series of Lewis (1930) and the Scarlett Volcanic Formation of Dickson et al. (1987). The present definition is that of Chadwick et al. (2001). See also Lamplugh (1903).

Lithology
The member is dominated by submarine volcaniclastic debris flows and gravity slides. Olistoliths of older Tournaisian and/or Visean carbonates and claystone rafts also occur, as do isolated vesicular basaltic clasts.

Genetic interpretation
The tuffs are waterlain, the volcaniclastic debris flows and gravity slides are submarine.

Stratotype
A partial type section (a strike section through the member) comprises largely continuous coastal outcrops from Scarlett Point [SC 2570 6610] to Close-ny-Clollagh Point [SC 2450 6710]. Here the sharp base of the member is succeeded by submarine volcaniclastic rocks (including debris flows, gravity slides and pillow lavas) with entrained claystone rafts and megaclasts. The section is no more than 50 m thick and the top of the member is not seen (see Dickson et al., 1987, pp. 219–223; Chadwick et al., 2001, p. 63).

Lower and upper boundaries
The base is clearly seen on the foreshore below Close-ny-Chollagh Point [SC 245 671] where volcaniclastic rocks rest with a sharp, baked contact on underlying dark claystones of the Bowland Shale Formation (Figure 8, Column 8).

The top of the member is not exposed, so the nature of the upper boundary is unknown.

Thickness
Some 50 m. The thickness of the member is difficult to estimate due to the numerous olistoliths and rolling dips present in the outcrop.

Distribution and regional correlation
Southern part of the Isle of Man, in the Castletown area, from Scarlett Point [SC 257 661] to Close-ny-Clollagh Point [SC 245 671]. Visean rocks in the northern part of the island are entirely concealed and hence it is unknown whether it is present in the north. Well 112/19-1, just off the north-east of the Isle of Man proved 198 m of Brigantian to Pendleian strata and no volcanic successions, so the member is likely to be absent in the northern part of the island.

Age
Brigantian.

6.9 MILLSTONE GRIT GROUP (MG)

The name 'Millstone Grit' is derived from the familiar 'gritstones' (coarse-grained sandstones) that were used historically in flourmills. Whitehurst (1778) first proposed the lithostratigraphical name 'Millstone Grit', since when it has become chronostratigraphical in concept. Synonymous with the Namurian, it was divided, in the Central Pennine Basin, into stages bound by key widespread marine bands (see George and Wagner, 1972; Ramsbottom et al., 1978). 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. The Stratigraphical Framework Committee concluded that this approach should be maintained, and each of the seven Namurian Stage successions was assigned a distinct formation name, with the exception of the thin, commonly mudstone-dominated successions of the Chokierian and Alportian, which were joined to form a single formation (see Waters et al., 2007). Where marine bands cannot be recognised, or other biostratigraphical data are absent, the group is left undivided.

In central England, the component formations of the group, in ascending order, are the (Pendleian) Pendleton, (Arnsbergian) Silsden, (Chokierian and Alportian) Samlesbury, (Kinderscoutian) Hebden, (Marsdenian) Marsden, and (Yeadonian) Rossendale formations. They are also present in northern England, but limited to the Askrigg Block, south Cumbria (the Pendleton Formation only) and north Isle of Man (the Rossendale Formation only). In northern England (Figure 7), 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 subarkosic arenite. Marine bands, representing transgressive events, are present in the succession, although fewer in number than the comparable succession in the Central Pennine Basin. The marine bands consist typically of dark grey to black, calcareous, shaly mudstone about 0.5 m thick. Distinct ammonoid faunas and the extensive correlation of the marine bands make them of primary stratigraphical importance.

In Britain, the Millstone Grit Group was deposited by repeated progradation of deltas, predominantly from the north and east. Delta-top subfacies are characterised by condensed, predominantly upward-fining cycles of sandstone to structureless clayrock. Thick, high-alumina seatclay, fireclay and bauxitic clay are common, with sporadic beds of limestone, ironstone, cannel and coal. This sub-facies is more typical of the succession developed in northern England, north of the Craven Fault System. It is probable that many of the sandbodies are linear in geometry and occupy incised valleys, with well-developed palaeosols developed on the interfluves. Sheet-like and laterally extensive deltaic sandbodies, upward-coarsening with a lower part dominated by mouth-bar deposits overlain by distributary sands, more typical of the late Namurian succession of the Central Pennine Basin may extend onto the southern margin of the Askrigg Block. Deep-water deltaic sequences deposited in a delta-front apron of coalescing turbidite lobes, a feature of the lower part of the group in the Central Pennine Basin, are absent north of the Craven Fault System.

The base of the Millstone Grit Group on the Askrigg Block is taken at the base of the 'Bearing' or Howgate Edge grits, Pendleton Formation. Here, the mixed shelf carbonate and deltaic succession of the underlying Stainmore Formation, Yoredale Group is succeeded, at an unconformity of E1c age, by sandstone-dominated strata (see Brandon et al., 1995). The base of the group in south Cumbria is taken at the diachronous base of the Pendleton Formation, where the mudstone-dominated succession of the underlying Bowland Shale Formation, Craven Group, gives way to a predominantly feldspathic sandstone succession. The base of the group on the north Isle of Man in the Ballavaarkish (Shellag North) Borehole [NX 4625 0070] appears to be within the Rossendale Formation at 164.55 m depth. This is at the base of listricated claystone that may lie in the upper part of the *Cancelloceras cumbriense* Marine Band (see Chadwick et al., 2001). This position lies immediately above faulted strata that comprise thin-bedded, listricated and shattered black claystone and siltstone, and pale fine-grained sandstone to a depth of 172.34 m. Below this level occurs a sequence of massive dolostones apparently assigned to either the Great Scar Limestone Group or the Yoredale Group by Chadwick et al. (2001). The base of the Pennine Coal Measures Group *(fluviodeltaic ('Coal Measures') facies)* defines the top of the Millstone Grit Group.

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, 1978). As the Namurian succession passes northwards over the Askrigg Block it becomes significantly reduced in thickness to about 400 m in the Colsterdale–Upper Nidderdale area (Dunham and Wilson, 1985), and the presence of a mid Carboniferous unconformity is indicated here by the absence of Alportian strata (Ramsbottom, 1977a). The Millstone Grit Group is represented on the north Isle of Man in the Ballavaarkish (Shellag North) Borehole (see above) solely by the Rossendale Formation. It is at least 26 m thick and Yeadonian in age (see Chadwick et al. 2001).

Since the Millstone Grit Group extends into southern Britain the definitions that follow for the constituent formations have been unified with those of Waters et al. (2009). Information relevant solely to northern Britain is, however, provided under the subhead *'Local notes'*.

6.9.1 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).

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.

Genetic interpretation

During the Pendleian the fluvial succession of the 'Bearing Grit' crossed the Askrigg Block occupying an incised valley (Waters et al., 2009, fig. 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 prodelta slope. These are cut by massive, laterally impersistent, 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 the shallow-water fluviodeltaic coarse-grained, cross-bedded successions of the Warley Wise Grit to extend several kilometres southwards into the basin.

Stratotype
Partial type sections occur at Pendleton Moor on the west flank of Pendle Hill between Light Clough [SD 7516 3764] (the basal stratotype for the Pendleian Stage) and the excellent section at Mearley Clough [SD 785 411] where the base of the formation is exposed (Earp et al., 1961). At 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).

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, is taken at an unconformity of E1c 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 (Figure 9, Column 17). 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 cowlingense* Marine Band (E2A1) with eponymous fauna, which is commonly underlain by a thin, fine-grained, calcareous and phosphatic sandstone of the Pendleton Formation (Figure 9, Column 17; Figure 15, Column 5). Locally, in the absence of the *Cravenoceras cowlingense* 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) (Figure 15, Column 2) 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 thickness is present in the Great Shunner Fell area (Figure 15, Column 3), where the formation is dominated by the Lower Howgate Edge Grit.

Distribution and regional correlation
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). The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Age and biostratigraphical characterisation
Pendleian (E_1). The top of the formation is defined at the base of the Cravenoceras cowlingense (E_{2a}) Ammonoid Zone.

Local notes
Within the southern part of the Askrigg Block the formation is dominated by two sandstones, the 'Bearing Grit' and overlying Underset (or Top) Grit. These sandstones pass southwards respectively into the thick turbiditic succession of the Pendle Grit Member (PG) (Figure 15, Column 6) (of thinly interbedded silty mudstone, siltstone and fine-grained sandstone, cut by massive, laterally impersistent, coarse-grained, pebbly sandstones) and the Warley Wise Grit (of coarse-grained, cross-bedded sandstone) (see Brandon et al., 1995). In the Great Shunner Fell area, a condensed succession is dominated by the Lower Howgate Edge Grit (Dunham and Wilson, 1985). Within the Stainmore Trough, the Mirk Fell Ganister (MKFG) occurs at the same stratigraphical level as the Lower Howgate Edge Grit of the Askrigg Block (Figure 15, Column 2).

6.9.2 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 *Cravenoceras cowlingense* (E_{2a}) Marine Band, but the top of the group was taken as the base of the *Nuculoceras nuculum* (E_{2c}) 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 the 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).

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 interpreted to be of turbiditic origin.

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).

Stratotype
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 occur along Bracken Hill Gill [SE 0304 4686 to 0324 4697] (Addison, 1997).

Lower and upper boundaries
The base is taken at a sharp base of dark grey fissile claystones of the *Cravenoceras cowlingense* Marine Band (E2A1) with a diagnostic eponymous fauna, commonly underlain by a thin, fine-grained, calcareous and phosphatic sandstone of the Pendleton Formation (Figure 9, Column 17; Figure 15, Column 5). 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 (Figure 15, Column 2) 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 (ISMB), with a diagnostic eponymous fauna (Figure 9, Column 17; Figure 15, Column 5). Where the marine band is not proven, the boundary is taken at the base of a thick, mid 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 and regional correlation
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). The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Age and biostratigraphical characterisation
Arnsbergian (E_2). The base is taken at the base of the *Cravenoceras cowlingense* Marine Band, and the top at the base of the lowermost *Isohomoceras subglobosum* Marine Band.

Local notes
Laterally impersistent cross-bedded sandstones are present along the northern margin of the Central Pennine sub-basin. Within the southern part of the Askrigg Block, the lower part of the formation is dominated by the Nidderdale Shales, comprising mudstones with common *Sanguinolites* bands (Wilson, 1977; Dunham and Wilson, 1985; Brandon et al., 1995). In the western part of the Askrigg Block a lenticular sandstone, the Upper Howgate Edge Grit, occurs towards the base of the formation. In the northern part of the Askrigg Block and Stainmore Trough, sandstones (for example, the Fossil Sandstone and High Wood Grit), ganisters (for example, the Kettlepot Ganister), and thin limestones (for example, the Lad Gill Limestone) occur interbedded with mudstones at this stratigraphical level (Figure 15, Columns 2, 3). The middle part of the formation is dominated by the Red Scar Grit (southern Askrigg Block), Pickersett Edge Grit (northern Askrigg Block) and High Wood Grit (Stainmore Trough). These sandstones are typically overlain by a marine succession (the Colsterdale, Shunner Fell (Figure 15, Column 3), Water Crag (Figure 15, Column 2) and High Wood marine bands), which in the southern part of the Askrigg Block are known as the 'Colsterdale Marine Beds'. These are overlain by a mudstone, siltstone and sandstone succession (the Scar House Beds of Wilson, 1977), which, in turn, are overlain by the Lower Follifoot Grit.

Brandon et al. (1995) postulated the presence of an intra-$E_{2a}3$ unconformity at the base of the Red Scar Grit. The Colsterdale Marine Beds comprise the *Eumorphoceras yatesae* ($E_{2a}3$), *Cravenoceratoides edalensis* ($E_{2b}1$) and *Cravenoceratoides nitidus* ($E_{2b}2$) marine bands (Cooper and Burgess, 1993). The Lower Follifoot Grit is known to be Arnsbergian in age as it is immediately overlain by the *Nuculoceras nuculum* (E_{2c}) Marine Band (Wilson, 1977).

6.9.3 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 [SD 618 291] where a complete basinal succession in the Chokierian and Alportian is exposed.

Lithology
Dark grey mudstone, common thin shaly mudstones, subordinate sandstone and siltstone, and locally, in the Bradford area, a thick, coarse-grained, cross-bedded sandstone (the Brocka Bank Grit) (Waters, 1999).

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).

Stratotype
The type section is a composite section in the River Darwin at Samlesbury Bottoms [SD 618 291]. This shows dark grey mudstones and common marine shales, including the marine bands that define the base and top of the formation (Moore, 1930; Price et al., 1963). Stonehead Beck, Cowling, North Yorkshire [SD 9473 4330], shows a continuously exposed 40 m succession including the base Chokierian stratotype. This equates to the base of the Samlesbury Formation, and defines the position of the mid Carboniferous boundary (Riley et al., 1995).

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 an eponymous fauna, where the formation overlies the interbedded sandstone, siltstone and mudstone succession of the Silsden Formation (Figure 9, Column 17; Figure 15, Column 5). 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 at the base of a mudstone succession with *Lingula* in the Stainmore Trough. In the southern part of the Central Pennine Basin, the boundary is taken at the base of the first thick quartz-feldspathic sandstone of Chokierian to Alportian age that is 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 an 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 and regional correlation
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. The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Age and biostratigraphical characterisation
Chokierian to Alportian (H_1–H_2). 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 (R_{1a}).

Local notes
Along the southern part of the Askrigg Block, the formation comprises a lower mudstone-dominated Follifoot Shale, overlain by the Upper Follifoot Grit (Wilson, 1977; Dunham and Wilson, 1985). Unlike in the Craven Basin to the south, no strata of Alportian age have been proved in the Askrigg Block and Stainmore Trough (Ramsbottom et al., 1978). In the Stainmore Trough, a thin Chokierian succession is postulated from miospore evidence (Owens and Burgess, 1965). A non-sequence is considered to be present above the Upper Follifoot Grit.

6.9.4 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 [SD 990 270] 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.

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).

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, 15–55 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, the 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, 1966). 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.

Stratotypes
Partial type sections include Crimsworth Dean, north of Hebden Bridge [SD 9899 3079 to 9926 3141], which 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); and Blackden Brook, Kinder Scout, Derbyshire [SK 1223 8842 to 1171 8833], which provides an excellent stream section 150 m thick of the Shale Grit, Grindslow Shales and the base of the Kinderscout Grit (Stevenson and Gaunt, 1971; Davies and McLean, 1996).

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 an eponymous fauna, where the formation overlies the mudstone-dominated Samlesbury Formation. Elsewhere, where this marine band has not been found (Figure 15, Column 5), 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 an 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 Marsden 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; southern part of the Askrigg Block about 100 m; Stainmore Trough 40 m.

Distribution and regional correlation
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. The formation passes southward into basinal mudstones of the Bowland Shale Formation (Craven Group).

Age and biostratigraphical characterisation
Kinderscoutian (R_{1a}). The base is taken at the base of the *Hodsonites magistrorum* Marine Band (R_{1a}) and the top at the base of the *Bilinguites gracilis* Marine Band (R_{2a}).

Local notes
Marine shales of the R_{1a} Zone (equivalents of the Mousegill Marine Beds of the Stainmore Trough) occur within the Cayton Gill Shale of the southern part of the Askrigg Block (see Owens and Burgess, 1965; Wilson, 1977). Thick sandstones present in the Askrigg Block area include the Libishaw Sandstone and the Lower and Upper Brimham Grits.

6.9.5 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 [SD 030 124], 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).

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.

Genetic interpretation
During the Marsdenian, shallow-water deltas dominated, extending by late Marsdenian 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). Later 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).

Stratotype
The partial type section is a stream section at Park Clough, Hey Green near Marsden, West Yorkshire [SE 0299 1246], where 20 m of dark grey mudstone from the lower part of the Marsden Formation includes the *Bilinguites gracilis* Marine Band, above 15 m of cross-bedded sandstone of the Hebden Formation (Ramsbottom, 1981).

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 (Figure 15, Column 5), 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 of the formation is taken at the sharp conformable base of the dark grey, fissile mudstone of the *Cancelloceras cancellatum* Marine Band (G1A1) with eponymous fauna, overlain by a dark grey mudstone-dominated succession in the lower part of the Rossendale Formation (Figure 9, Column 17; Figure 15, Column 5). 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 [SK 06], and the Askrigg Block and Stainmore Trough.

Age and biostratigraphical characterisation
Marsdenian (R_2). The base of the formation is taken at the base of the *Bilinguites gracilis* Marine Band and the top at the base of the *Cancelloceras cancellatum* Marine Band (G_{1a}).

Local notes
In both the Askrigg Block and Stainmore Trough areas the succession comprises a lower mudstone-dominated and upper sandstone-dominated unit. On the Askrigg Block the former unit is referred to as the Wandley Gill Shale (see Wilson and Thompson, 1965) and the latter unit as the Wandley Gill Sandstone (see Ramsbottom et al., 1978).

6.9.6 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 [SD 80 20].

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* (G1A1) and *Cancelloceras cumbriense* (G1B1) marine bands, and an upper sandstone-dominated succession, including the Rough Rock and Rough Rock Flags.

Genetic interpretation
During the early Yeadonian a thick succession of dark mudstones was 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). McLean and Chisholm (1996) showed this westerly source of sediment 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 from a southerly source in the proximity of the Wales–Brabant Massif (Chisholm and Hallsworth, 2005).

Stratotype
The type area is the Forest of Rossendale [SD 80 20] which 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 include the Orchard Farm stream section, south-west of Buxton [SK 0226 6903] which is the Stage stratotype for the Yeadonian, with both the *Cancelloceras cancellatum* and *Cancelloceras cumbriense* marine bands present within a section about 17 m thick (Ramsbottom, 1981). Elland Bypass (A629) roadcut, near Halifax [SE 103 215] provides a 500 m long and up to 30 m high section in the Rough Rock and Rough Rock Flags (Bristow and Myers, 1989). The BGS Winksley Borehole (BGS Registration Number SE27SE/9) [SE 2507 7150], in the southern part of the Askrigg Block, includes the Rossendale Formation from about 29.7 to 55.89 m depth (Cooper and Burgess, 1993). The Ballavaarkish (Shellag North) Borehole [NX 4625 0070], north Isle of Man includes the Rossendale Formation from 138.4 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 listric 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).

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 an eponymous fauna, where the formation overlies the Marsden Formation (Figure 9, Column 17; Figure 15, Column 5). It typically overlies quartz-feldspathic sandstone of the Huddersfield White Rock (Yorkshire), Holcombe Brook Grit (Lancashire), Chatsworth Grit (Derbyshire).

The top of the formation is taken at the sharp conformable base of the dark grey, fissile mudstone of the Subcrenatum Marine Band (SBMB) with an 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; Bradford and north Derbyshire 75 m; Stainmore Trough and Askrigg Block 45 m; north Isle of Man 26 m.

Distribution and regional correlation
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 [SK 06], 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].

Age and biostratigraphical characterisation
Yeadonian (G_1).The base of the formation is taken at the base of the *Cancelloceras cancellatum* Marine Band and the top at the base of the Subcrenatum Marine Band.

Local notes
In the Stainmore Trough, the equivalent of the *Cancelloceras cancellatum* marine band lacks the diagnostic ammonoid fauna and was referred to as the Swinstone Bottom Marine Band by Owens and Burgess (1965). The Subcrenatum Marine Band (at the base of the Pennine Coal Measures Group), has not been proved across most of northern Great Britain. However, the Swinstone Top Marine Band of Owens and Burgess (1965) and a *Lingula*-band proved in the BGS Winksley Borehole (see above) (Figure 9, Column 17) probably equate with it. On the north Isle of Man the top of the formation in the Ballavaarkish (Shellag North) Borehole (see above) occurs where the fine- to coarse-grained, cross-bedded, feldspathic sandstones of the Rossendale Formation (Figure 8, Column 9) are superseded by palaeosol and dark grey to black claystone, including sporadic fossils in the Subcrenatum Marine Band (SBMB).

6.10 PENNINE COAL MEASURES GROUP (PCM)

The 'Coal Measures' have historically had a chrono-stratigraphical name synonymous with Westphalian plus Stephanian strata. However, the name has recently been redefined lithostratigraphically, to describe the main body of coal-bearing strata in the Westphalian succession (Powell et al., 2000).

The Pennine Coal Measures Group *(fluviodeltaic ('Coal Measures') facies)* (Figure 7) extends from the Wales–Brabant Massif northwards to the Southern Uplands and Cumbria (see Waters et al., 2007; Waters et al., 2009). It also occurs in the north Isle of Man. The group has been given the epithet 'Pennine' to distinguish these coal measures from those present in central Scotland, and from those south of the Wales–Brabant Massif. The group is subdivided stratigraphically into three formations, the Lower, Middle and Upper Coal Measures, as defined by Stubblefield and Trotter (1957), and it comprises 10 m-scale cyclothems (more numerous than in the Millstone Grit) of alternating sandstone, grey siltstone and grey mudstone, with many coal seams, ironstone nodules or beds and seatearth (palaeosol) horizons. The base of the cycle is marked by grey mudstones, commonly recognised as nonmarine bands, or less commonly as marine bands. Both are important for correlation. Sandstones are typically very fine- to fine-grained, commonly overlain by leached ganisters or unleached gley seatearths. The Coal Measures accumulated in a delta-top environment with large distributary channels, freshwater lakes and lagoons with small deltas and crevasse splays, and swamps and bogs colonised by plants. Laterally widespread marine bands (generally lacking diagnostic ammonoids, but dominated by foraminifers, *Lingula* sp., fish remains and a shallow marine benthic productid fauna) probably resulted from eustatic sea level rises. Originally deposited in a broad basin, subsequent tectonism has isolated the Coal Measures into smaller coalfields.

As defined by Stubblefield and Trotter (1957), the base of the group is taken at the base of the Subcrenatum Marine Band (SBMB) or at the base of the coal-bearing sequence if this marker band cannot be identified. The Subcrenatum Marine Band is absent over much of north Cumbria and has a restricted occurrence in west Cumbria. There is also an equivalent in north-east England known as the Quarterburn Marine Band that contains a shallow-marine, benthic, productoid fauna (Calver, 1969).

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 typically repetitive mudstones, siltstones, sandstones, thin limestones and thin coals of the Yoredale Group, lie generally conformably below the base of the grey mudstone, siltstone and interbedded pale grey sandstone of the Pennine Lower Coal Measures Formation, Pennine Coal Measures Group. In the Canonbie Coalfield, the boundary between the Stainmore Formation, Yoredale Group and the Pennine Lower Coal Measures Formation is uncertain as to its position and nature (see Jones and Holliday, 2006). On the Askrigg Block, and north Isle of Man in the Ballavaarkish (Shellag North) Borehole [NX 4625 0070] the base of the group is also taken at the generally conformable base of the Pennine Lower Coal Measures Formation. Here, however, dominantly feldspathic sandstones of the underlying Rossendale Formation, Millstone Grit Group are succeeded by the claystone Subcrenatum Marine Band at the base of the Coal Measures cyclothemic sequence. The base of the Warwickshire Group or the Permo-Triassic unconformity defines the top of the Pennine Coal Measures Group.

The type area of the Pennine Coal Measures Group is the Pennine coalfields, where they are up to 1900 m thick near Manchester (see Waters et al., 2007; Waters et al.,2009). Within the Northern England Province they are about 1000 m thick in the Canonbie Coalfield where they thin westward as they overstep a structural high. They are up to 900 m thick in the main area of the Northumberland–Durham Coalfield, and between 300 and 400 m thick in west Cumbria where they thicken offshore to the north-west into the Solway Basin. On the north Isle of Man in the Ballavaarkish (Shellag North) Borehole (see above), about 16 m of the group was proved. The Pennine Coal Measures Group is Westphalian in age, typically Langsettian to Bolsovian.

Since the Pennine Coal Measures Group extends into onshore southern Great Britain the definitions that follow for the constituent formations have been unified with those of Waters et al. (2009). Information relevant solely to northern Britain is, however, provided under the subhead 'Local notes'.

6.10.1 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 Britain, 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 Lower Coal Measures Formation.

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 (Waters et al., 2009, fig. 13) or Pasture Coal (Waters et al., 2009, fig. 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 (Waters et al., 2009, fig. 13) or Kilburn (Better Bed) Coal (Waters et al., 2009, fig. 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 (Waters et al., 2009, figs. 13, 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.

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 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 force being continuous subsidence.

Some of the cycles, particularly in the early Langsettian, 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).

Stratotype
The type area is the North Staffordshire (Potteries) Coalfield, Stoke-on-Trent [SJ 50 90], where there are numerous borehole and shaft sections, but few exposures (see Waters et al., 2009, fig. 13). Reference sections include, for the top boundary: mudstone in the Vanderbeckei Marine Band at Miry Wood, Apedale [SJ 8118 4940], which is to be designated a RIGS site (Rees and Wilson, 1998). For the top part: from 640 to 318.5 m in the constructed stratigraphical section (V5 British Coal, G7 British Geological Survey), Hesketh Back Cut (Crosscut), at Chatterley Whitfield Colliery, Stoke-on-Trent [SJ 884 533] (Rees and Wilson, 1998). For the lower part and base: from surface to 550.7 m depth in the Ridgeway Borehole (BGS Registration Number SJ85SE/14) [SJ 8923 5381] (Rees and Wilson, 1998). For the base: the River Little Don, Langsett [SE 2215 0041], which is the basal Stratotype for the Langsettian Stage with a section up to 2 m thick including the Subcrenatum Marine Band (Owens et al., 1985); and the Ballavaarkish (Shellag North) Borehole [NX 4625 0070], north Isle of Man, which 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).

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 (SBMB) 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 upon the Rossendale Formation (Millstone Grit Group) (Figure 8, Column 9; Figure 9, Column 17). However, in north, west and east Cumbria (Figure 9, Column 13; Figure 14, Column 1) the Solway Basin (Figure 6, Column 7) (except the Canonbie area), the Stainmore (Figure 9, Column 16) and Northumberland troughs (Figure 8, Column 11; Figure 13, Columns 3, 4), on the Alston Block (Figure 9, Column 15) and in north-east Northumberland (Figure 8, Column 12), the formation overlies conformably the repetitive mudstones, siltstones, sandstones, thin limestones and thin coals of the Stainmore Formation (Yoredale Group). In the Canonbie Coalfield (Figure 8, Column 10), the formation is underlain by the Stainmore Formation (Yoredale Group) though the stratigraphical position and nature of the boundary is uncertain since the Subcrenatum Marine Band has not been recognised there (see Jones and Holliday, 2006).

The top of the formation is taken at the base of the mudstone of the Vanderbeckei Marine Band (VDMB) with eponymous fossils (Figure 8, Columns 10, 12; Figure 9, Columns 13, 16; Figure 10, Column 3; Figure 11, Column 1; Figure 13, Columns 3, 4; Figure 14, Columns 1, 2).

Thickness
Up to 650 m thick in the North Staffordshire (Potteries) Coalfield, and 720 m thick in Lancashire. In the Canonbie Coalfield the Pennine Lower Coal Measures Formation is about 100 m thick (Picken, 1988; Jones and Holliday, 2006).

Distribution and regional correlation
Central and northern England, North Wales and the north Isle of Man. 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 of Scotland.

Age and biostratigraphical characterisation
Langsettian. The base of the formation is taken at the base of the Subcrenatum Marine Band (SBMB), which marks the base of the Langsettian Stage. The top is taken at the base of the Vanderbeckei Marine Band (VDMB), which marks the base of the Duckmantian Stage.

Local notes
The Subcrenatum Marine Band, is absent over much of north Cumbria and has a restricted occurrence in west Cumbria, but has an equivalent in north-east England known as the Quarterburn Marine Band that contains a shallow marine benthic productoid fauna (Calver, 1969). In the north Isle of Man, in the Ballavaarkish (Shellag North) Borehole (see above), the Subcrenatum Marine Band contains *Lingula mytilloides* and *Gastrioceras subcrenatum*.

6.10.2 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 Britain, 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.

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. In southern Britain 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 (Waters et al., 2009, figs. 13, 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.

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 6.10.1). 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).

Stratotype
The type area is the Potteries (North Staffordshire) Coalfield, Stoke-on-Trent [SJ 50 90], where there are numerous borehole and shaft sections, but few exposures (Waters et al., 2009, fig. 13). Reference sections include: the basal Vanderbeckei Marine Band at Miry Wood, Apedale [SJ 8118 4940], which is to be designated a RIGS site (Rees and Wilson, 1998); the upper part of the formation, from below the Rowhurst Coal to the top of the Cambriense Marine Band, from 325.5 to 200.3 m depth, in the No. 4 underground borehole (BGS Registration Number SJ84NW/30) [SJ 8392 4850] at Holditch Colliery, Stoke-on-Trent (Rees and Wilson, 1998); the top part of the formation, from about 162 m depth at the top of the Cambriense Marine Band to the bottom of the borehole at 183.3 m depth in the No. 1 underground borehole (BGS Registration Number SJ85SW/19) [SJ 8396 5029] at Parkhouse Colliery, Stoke-on-Trent (Rees and Wilson, 1998); and the base and lower part of the formation, in the Hesketh Back Cut, Chatterley Whitfield Colliery from 318.5 m to the top of the constructed stratigraphical section (V5 British Coal, G7 BGS log) [SJ 884 533] (Rees and Wilson, 1998). The base and lower part also has a reference section at Duckmanton, north Derbyshire [SK 4237 7040], which is the basal Stratotype section for the Duckmantian Stage, and includes 50 m thickness of Pennine Middle Coal Measures above 75 m of Pennine Lower Coal Measures (Owens et al., 1985).

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 (VDMB), with an 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 (CAMB), with an eponymous fauna and/or other marine fossils. This definition is extended to the Scottish Solway area (Figure 6, Column 7; Figure 10, Column 3), which formerly used the top of the Aegiranum (Skelton) Marine Band (AGMB) 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 200–270 m thick around Canonbie.

Distribution and regional correlation
Central and northern England, North Wales. 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 of Scotland.

Age and biostratigraphical characterisation
Duckmantian to Bolsovian. The base of the formation is taken at the base of the Vanderbeckei Marine Band (VDMB), which marks the base of the Duckmantian Stage. The top is taken at the base of the Cambriense Marine Band (CAMB), which occurs within the Bolsovian Stage.

6.10.3 Pennine Upper Coal Measures Formation (PUCM)

Name
The formation has historically been referred to as the Upper Coal Measures, as defined by Stubblefield and Trotter (1957). The name was applied across Britain, 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.

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 (Waters et al., 2009, figs. 13, 14). Coal seams are thin. In Yorkshire sandstones are common and mainly medium-grained.

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 6.10.1). 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.

Stratotype
The type area is the Potteries Coalfield, Stoke-on-Trent, North Staffordshire [SJ 50 90], where there are numerous borehole and shaft sections, but few exposures (Waters et al., 2009, fig. 13). Reference sections include: the base of the formation, from 5.3 m depth (the start of coring at the top of the borehole) to about 162 m depth at the top of the Cambriense Marine Band in the Parkhouse Colliery No.1 underground borehole (BGS Registration Number SJ85SW/19) [SJ 8396 5029], Stoke-on-Trent (Rees and Wilson, 1998); the base and lower part of the formation, from 200.25 m depth to the top of borehole (interpreted as the top of the Cambriense Marine Band to above the Great Row Coal) in the Holditch Quarry No.4 underground borehole (BGS Registration Number SJ84NW/30) [SJ 8392 4850], Stoke-on-Trent (Rees and Wilson, 1998); and the top and upper part of the formation, from about 317 m to faulting beneath the Great Row Coal at about 547 m depth in the Wolstanton Colliery No.3 Shaft (BGS Registration Number SJ84NE/29) [SJ 8606 4800], Stoke-on-Trent (Rees and Wilson, 1998).

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 (CAMB). In the Scottish Solway area the base of the Upper Coal Measures was formerly taken at the base of the Aegiranum (Skelton) Marine Band (AGMB) but is now proposed to be taken at the top of the Cambriense Marine Band to conform with the position elsewhere in the Pennine Basin.

The top of the formation 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 the base of the sub-Permian unconformity.

Thickness
The formation is up to 350 m thick in the North Staffordshire (Potteries) Coalfield. Picken (1988, fig. 2) suggested a general thickness of up to about 650 m in the Canonbie Coalfield.

Distribution and regional correlation
Central and northern England and North Wales. 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 of Scotland.

Age and biostratigraphical characterisation
Bolsovian to Asturian (Westphalian D). The formation is characterised by the presence on nonmarine bivalves of the *Anthraconauta phillipsii* and *Anthraconauta tenuis* zones, of late Bolsovian and Asturian (Westphalian D) age, respectively.

Local notes
In the north-west of the Canonbie Coalfield (Figure 8, Column 10) the Upper Coal Measures, of *alluvial ('Barren Measures') facies*, were considered to rest unconformably on the Middle Coal Measures by Picken (1988), but on the evidence of seismic reflection and wireline logging correlation this was not supported by Jones and Holliday (2006). The strata are late Bolsovian to Asturian (Westphalian D) in age and include a Tenuis Chronozone fauna with *Anthraconaia pruvosti*, and *Leaia bristolensis* (see Eastwood et al., 1968; Lumsden et al., 1967; Ramsbottom et al., 1978; Jones and Holliday, 2006). Over much of the west Cumbria Coalfield, strata from the Upper Similis–Pulchra Chronozone appear to be cut out below the base of the Whitehaven Sandstone Formation (Warwickshire Group) (Figure 14, Column 1).

6.11 WARWICKSHIRE GROUP (WAWK)

The name 'Warwickshire Group' (Figure 7), derived from the Warwickshire Coalfield, was introduced to replace such collective terms as 'Barren (Coal) Measures' and 'Red Measures' that were previously used for predominantly red-bed strata of alluvial facies (Powell et al., 2000; Waters et al., 2007). In the Central England Province the Warwickshire Group *(alluvial ('Barren Measures') facies)* consists of mainly red, brown or purple-grey mudstone, siltstone and sandstone, with locally developed pebbly sandstone, conglomerate and breccia. The red-beds underwent oxidation at or close to the time of deposition. Minor components comprise grey mudstone, thin coals, lacustrine limestone ('*Spirorbis*' limestone) and pedogenic limestone (caliche or calcrete). However, the Warwickshire Group is also considered to extend to the Northern England Province (Figure 7) where it comprises the Eskbank Wood, Canonbie Bridge Sandstone and Becklees Sandstone formations at Canonbie (Jones and Holliday, 2006; Jones et al., in press), and the stand-alone fluvial and fluviolacustrine Whitehaven Sandstone Formation in north and west Cumbria (Akhurst et al., 1997).

The base of the group in the Canonbie Coalfield is taken at the conformable and gradational base of the Eskbank Wood Formation where the first major red-bed strata overlie the grey mudstone-dominated Pennine Upper Coal Measures Formation. The sharp, unconformable base of the Permian (Variscan) unconformity, overlying the Becklees Sandstone Formation, defines its top. The base of the group in north and west Cumbria is taken at the base of the Whitehaven Sandstone Formation where the non-reddened, cyclical, mudstone-dominated succession with thin coals of the underlying uppermost Pennine Coal Measures Group are succeeded unconformably by red sandstones. Over much of the west Cumbria Coalfield, strata from the upper Similis–Pulchra Chronozone appear to be cut out below the base of the Whitehaven Sandstone Formation. The base of the Permian unconformity defines the top of the group (see Akhurst et al., 1997).

The Type area of the Warwickshire Group is the Warwickshire Coalfield in central England, where the Duckmantian to early Permian (Autunian) succession attains its fullest thickness of 1225 m (see Powell et al., 2000; Waters et al., 2007; Waters et al., 2009). In the Canonbie Coalfield the group may be up to perhaps 500 m thick, whilst in north and west Cumbria it is at least 300 m thick. In both areas the group is late Bolsovian to Asturian (Westphalian D) in age.

6.11.1 Eskbank Wood Formation

Name
Newly named. The formation is exposed along the River Esk, Canonbie area, opposite Eskbank Wood. See Jones and Holliday (2006); Jones et al. (in press).

Lithology
Interbedded red mudstone (claystones and siltstones), fine- to medium-grained sandstones, calcrete palaeosols, thin beds of '*Spirorbis*' limestone and *Estheria*-bearing mudstones. Sparse thin coals and grey mudstones are present in the lower part of the formation; some of these coals have been oxidised and altered to limestone (Jones and Holliday, 2006; Jones et al., in press; see also Mykura, 1960). Mudstones form 60–70 per cent of the formation, with sandstones forming most of the rest.

Genetic interpretation
Deposition on an alluvial plain with lakes. The flood plain alternating from poorly to well drained.

Stratotype
The type area is Hush Pool, River Esk [NY 39149 77055 to 39194 76953]. Approximately 75 m of nearly continuous outcrops of the formation are present along the eastern bank of the River Esk. Reference sections include the Forge Diamond Bore (BGS Registration Number NY37NE/7) [NY 39456 76720] from 72.8 to 235.5 m depth (the full thickness being cored), and the Becklees Borehole (BGS Registration Number NY37SE/3) [NY 35166 71578] from 653 to 816.8 m depth (the formation being cored from 744.41 m depth to its base).

Lower and upper boundaries
The base of the formation was not identified at outcrop and is defined in boreholes. The boundary is taken at the first major red-bed strata overlying the grey mudstone-dominated Pennine Upper Coal Measures Formation (Figure 8, Column 10). It is a conformable, gradational boundary. In the Becklees Borehole (see above) the base of the formation (at 816.8 m depth) is defined by the last significant downhole occurrence of primary red-bed lithologies. In this instance it comprises 1.3 m of mottled reddish brown and greenish grey silty mudstone with abundant carbonate nodules. These nodules are interpreted as pedogenic calcrete glaebules and represent the first good evidence for the development of primary red-bed conditions. A limited number of red lithologies are known below 816.8 m depth, but it is not known whether these represent primary red-beds or could be linked to a later secondary reddening event. The gradational boundary to the formation is well demonstrated by the reversion higher in the borehole to grey lithologies. This includes a prominent coal (the 'High' Coal), which is about 1 m in thickness and must represent a significant amount of time in which reducing conditions prevailed. In the Forge Diamond Bore (see above) the base is taken at the change from pale greenish mudstones to red and green mudstones at 235.5 m depth. The lower boundary is difficult to pick in uncored boreholes, but analysis of cored boreholes shows that close to the base of the formation the distinctive 'High' Coal is typically present, and can be identified from suitable geophysical logs (e.g. sonic, density). It is suggested that the position of this coal be taken as the base of the formation where core data are absent.

The top of the formation is taken at the base of the lowermost sandstone bed of the Canonbie Bridge Sandstone Formation (Figure 8, Column 10). This is typically a thick (20–30 m) multistorey sandstone complex. The abrupt junction can be examined at outcrop at [NY 39194 76953] and has also been proven in numerous boreholes, including the Becklees Borehole (see above) (cored depth: 653 m; geophysical log depth: 656 m), and those at Broadmeadows (BGS Registration Number NY37NE/15) [NY 37646 76265] (geophysical log depth: 176.6 m) and Glenzierfoot (BGS Registration Number NY37SE/2) [NY 36514 74275] (geophysical log depth: 368.2 m).

Thickness
In the Forge Diamond, Becklees and Glenzierfoot boreholes (see above) the formation is about 163 m, 164 m and 146 m thick respectively. In the Rowanburnfoot Bore (BGS Registration Number NY47NW/27) [NY 41031 75743] it is 175 m thick.

Distribution and regional correlation
The formation is restricted to part of the Canonbie Coalfield between the Evertown [NY 3639 7594] and the Rowanburn [NY 41140 7687] areas. It is also known in its subsurface south-western extension, where it has been proven for at least a distance of approximately 6 km.

Age and biostratigraphical characterisation
Late Bolsovian (Westphalian C) to Asturian (Westphalian D). The section along the eastern bank of the River Esk north of Canonbie Bridge comprises some mudstones that contain a nonmarine fauna, particularly bivalves, at various points in the section. These have been identified as *Anthraconauta phillipsii, A.* aff. *phillipsii, A.* cf. *tenuis, A.* cf. *wrightii*, possibly *Anthracomya pruvosti* and also ostracods (A. E. Trueman in Barrett and Richey 1945, p. 39). Trueman suggested that this indicates the *A. tenuis* or even the *A. prolifera* Nonmarine Bivalve Zone of Trueman and Weir (1946), which are indicative of an Asturian (Westphalian D) age.

6.11.2 Canonbie Bridge Sandstone Formation

Name
Newly named. Outcrops of this formation occur in the River Esk upstream and downstream of Canonbie Bridge. See Jones and Holliday (2006); Jones et al. (in press).

Lithology
Interbedded fine- to coarse-grained reddish brown to greenish grey, moderately- to poorly sorted sandstones (50–70 per cent) and reddish brown mudstones and reddish brown, well-drained palaeosols including calcretes. Sandstones can be micaceous and are typically thick (10–30 m) forming sharp to erosively based channel sandstones in multistorey successions, cross-bedded and some show upwards-fining. Intraformational mudstone conglomerates occur scattered throughout the sandstones but are more common at channel bases. In hand specimen the sandstones contain a noticeable component of greenish grey grains, which, in thin section, can be seen to be lithic clasts. This high lithic component gives the sandstones a characteristic gamma ray log signature, with GR values ranging from 56–120 API (mean 97.3, median 99.53 API).

Genetic interpretation
Deposition generally on a well-drained alluvial plain with large fluvial systems and rare ephemeral floodplain lakes. Sporadic periods of poorer drainage.

Stratotype
The formation outcrops at its type locality along the River Esk for 250 m south of Canonbie Bridge, for example at [NY 39551 76501], and in discontinuous exposures for about 600 m to the north of the bridge, for example at [NY 39502 76735] and [NY 39317 76792]. A reference section is the Forge Diamond Bore (BGS Registration Number NY37NE/7) [NY 39456 76720], which cored the lower part of the formation from about 2.2 to 72.8 m depth.

Lower and upper boundaries
The base of the formation is taken at the base of the lowermost sandstone bed in a 20–30 m thick multistorey sandstone complex resting on the interbedded mainly mudstone and sandstone of the Eskbank Wood Formation (Figure 8, Column 10). The abrupt junction can be examined at outcrop at [NY 39194 76953] and has also been proven in numerous boreholes, including those at Becklees (BGS Registration Number NY37SE/3) [NY 35166 71578] (cored depth: 653 m; geophysical log depth: 656 m), Broadmeadows (BGS Registration Number NY37NE/15) [NY 37646 76265] (geophysical log depth: 176.6 m), and Glenzierfoot (BGS Registration Number NY37SE/2) [NY 36514 74275] (geophysical log depth: 368.2 m). In the Forge Diamond Bore (see above) the base is taken at a 0.6 m-thick conglomerate bed at 72.8 m depth.

At outcrop [NY 39360 76310] and [NY 39812 75760] the upper boundary is taken at the abrupt junction between the fine- to coarse-grained reddish brown lithic sandstones of the Canonbie Bridge Sandstone Formation and the overlying softer, orange brown, fine- to medium-grained sandstones that lack appreciable lithic grains (Becklees Sandstone Formation) (Figure 8, Column 10). In uncored boreholes the boundary is marked by a shift in the gamma ray log to lower values, reflecting the change in sandstone composition from lithic rich (higher GR values) to lithic poor, 'cleaner' sandstones with lower GR values. This can be seen for example at 485.3 m and 214 m depth in the Becklees and Glenzierfoot boreholes (see above) respectively.

Thickness
The formation varies in thickness. It is 131 m and 154 m thick in the Broadmeadows and Glenzierfoot boreholes (see above) respectively. It has a maximum thickness of 168 m in the Becklees Borehole (see above).

Distribution and regional correlation
The formation is restricted to part of the Canonbie Coalfield between the Evertown [NY 3639 7594] and Rowanburn [NY 41140 7687] areas. It is also known in its subsurface south-western extension, where it has been proven for at least a distance of approximately 6 km.

Age
Asturian (Westphalian D).

6.11.3 Becklees Sandstone Formation

Name
The new name is derived from the Becklees Borehole (BGS Registration Number NY37SE/3) [NY 35166 71578], which proves the greatest thickest of this formation. See Jones and Holliday (2006); Jones et al. (in press).

Lithology
Interbedded red sandstones (70–90 per cent) and reddish brown mudstones and reddish brown palaeosols including calcretes. Sandstones are fine- to medium-grained, orange brown to bright reddish brown and pinkish brown, moderately to well sorted and typically lack mica. Sandstones are generally cross-bedded and occur in thick successions (10–30 m thick), forming sharp to erosively based channel sandstones in multistorey units, some showing upwards-fining. In hand specimen the sandstones contain noticeably fewer lithic clasts than the underlying Canonbie Bridge Sandstone Formation; this is confirmed by thin section analysis. The sandstones have lower gamma ray API values compared to the underlying Canonbie Bridge Sandstone Formation, with GR values ranging from 39–120 API (mean 77.1, median 74.02 API). Limestones and thin coals are indicated in cuttings descriptions from the Becklees Borehole (see above), although these do not appear to be common and were not recorded at outcrop.

Genetic interpretation
Deposition on a well-drained alluvial plain with large fluvial systems and rare ephemeral floodplain lakes.

Stratotype
The formation outcrops at its type locality along the River Esk, Canonbie area, opposite Dead Neuk [NY 39360 76310], where approximately 28 m are present, including the base. Reference sections include outcrops along the River Esk at Mason's Stream [NY 39813 75760].

Lower and upper boundaries
The base of the formation occurs at outcrop at [NY 39360 76310] and [NY 39812 75760]. It is taken at the abrupt junction where fine- to coarse-grained reddish brown lithic sandstones of the Canonbie Bridge Sandstone Formation are overlain by softer, orange brown, fine- to medium-grained sandstones that lack appreciable lithic grains of the Becklees Sandstone Formation (Figure 8, Column 10). In uncored boreholes the boundary is marked by a shift in the gamma ray log to lower values, reflecting the change in composition from lithic rich (higher GR values) sandstones of the Canonbie Bridge Sandstone Formation to lithic poor, 'cleaner' sandstones with lower GR values (Becklees Sandstone Formation). This can be seen for example at 485.3 m depth in the Becklees Borehole (see above) and 214 m depth in the Glenzierfoot Borehole (BGS Registration Number NY37SE/2) [NY 36514 74275]. Unusual polygonal cracks have been recorded at the base of the formation along the River Esk at [NY 39360 76310].

The top of the formation is taken at the sharp boundary beneath Permian rocks (Figure 8, Column 10). This marks the Variscan unconformity.

Thickness
The full thickness of the formation is not proven but ranges from zero to a maximum of 203.6 m in the Becklees Borehole (see above).

Distribution
The formation is restricted to the central parts of the Canonbie Syncline, between the Evertown Borehole (BGS Registration Number NY37NE/14) [NY 36390 75938], the Becklees Borehole (see above), and the Knottyholm Borehole (BGS Registration Number NY37NE/6) [NY 39501 77124].

Age
Asturian (Westphalian D).

6.11.4 Whitehaven Sandstone Formation (WS)

Name
The name is derived from the area around Whitehaven in west Cumbria.

Lithology
A red-bed succession. The lower part, the Bransty Cliff Sandstone Member (the Whitehaven Sandstone of Akhurst et al., 1997), comprises red to deep purple or purplish brown, cross-bedded, micaceous, medium- to coarse-grained sandstone. There are interbeds of pink to red or grey mudstone and siltstone and thin palaeosols are present locally. These beds are overlain by a thick heterogenous, dominantly red succession (the Millyeat Member) of mudstone, sandstone and marl with thin coals and limestones with *Spirorbis* sp.

Genetic interpretation
The lower part of the formation was deposited from a major braided river system that flowed from the north-east. The upper part of the formation represents deposition in interdistributary bay or lacustrine environments with minor river channels (Akhurst et al., 1997). The reddening was either primary or early diagenetic.

Stratotype
Partial type sections in the formation include the Whitehaven Harbour cliff sections around [NX 974 192] where the lower arenaceous part of the formation (the Bransty Cliff Sandstone Member with mainly sandstone and subsidiary mudstone and siltstone interbeds) is well exposed, and the Frizington Hall Borehole (BGS Registration Number NY01NW/174) [NY 0189 1710] from 12.8 m depth to the bottom of the borehole at 174.65 m depth.

Lower and upper boundaries
The base of the formation is taken where the non-reddened, cyclical, mudstone-dominated succession with thin coals

of the underlying Pennine Coal Measures Group are succeeded unconformably by red sandstones (Figure 9, Column 13; Figure 14, Column 1). The unconformity cuts down to the Aegiranum Marine Band (AGMB) or, locally older strata (Akhurst et al., 1997).

The upper boundary of the formation is the base of the sub-Permian unconformity, which is overlain by the coarse, poorly bedded, poorly to moderately sorted, generally massive, matrix or clast-supported, typically pebble-grade, breccias of the Permian Brockram (Appleby Group).

Thickness
The formation is at least 280 m thick. The Bransty Cliff Sandstone Member is at least 100 m thick. The Millyeat Member is 180 m thick.

Distribution and regional correlation
Within the Northern England Province the formation is recognised in north and west Cumbria.

Age and biostratigraphical characterisation
Late Bolsovian to early Asturian (Westphalian D) as indicated by plant remains and the presence of the nonmarine bivalve *Anthraconauta phillipsii* (Eastwood et al., 1931). To the north-east similar strata have an Asturian (Westphalian D), Tenuis Chronozone fauna (Eastwood et al., 1968).

Formal subdivisions
See also Appendix 1. Members of the Whitehaven Sandstone Formation, in ascending stratigraphical order, include:

6.11.4.1 Bransty Cliff Sandstone Member (BYCS)

Name
Previously named the Whitehaven Sandstone by Eastwood et al. (1931; see also Akhurst et al., 1997; Brockbank, 1891; Jones, 1993).

Lithology
Red, to deep purple or purplish brown, cross-bedded, micaceous, medium- to coarse-grained sandstone, with subsidiary mudstone and siltstone interbeds, and thin palaeosols.

Genetic interpretation
The unit was deposited from a major braided river system that flowed from the north-east. The reddening was either primary or early diagenetic.

Stratotype
The type section is the Whitehaven harbour cliffs [NX 9735 1950 to 9750 1895] where the mainly sandstone and subsidiary mudstone and siltstone interbeds of the member are well exposed.

Lower and upper boundaries
The lower boundary, at the base of the lowest major reddened channel sandstone unit, is unconformable cutting down to the interbedded mudstones, siltstones, and sandstones, with coal seams, of the Pennine Middle Coal Measures Formation (Figure 14, Column 1).

The upper boundary with the mudstone dominated Millyeat Member, is at the top of the highest major channel sandstone unit in the Bransty Cliff Sandstone Member.

Thickness
Greater than 100 m

Distribution and regional correlation
The West Cumbria Coalfield.

Age
Bolsovian (Westphalian C) to Asturian (Westphalian D).

6.11.4.2 Millyeat Member (MYTB)

Name
See Akhurst et al. (1997); also Brockbank (1891); Eastwood et al. (1931); Jones (1993). In the former name 'Millyeat Beds Member' the term 'Beds' has now been abandoned.

Lithology
A thick heterogeneous, dominantly red succession of purple–red mudstone, with subsidiary sandstone and siltstone, and minor 'marl', thin coals and thin beds of limestone with *Spirobis* sp.

Genetic interpretation
The member was deposited in interdistributary bay or lacustrine environments with minor river channels (Akhurst et al., 1997). The reddening was either primary or early diagenetic.

Stratotype
The type section is the Frizington Hall Borehole (BGS Registration Number NY01NW/174) [NY 0189 1710] from 12.8 to 155 m depth. A reference section is the Millyeat Borehole (BGS Registration Number NY01NW/175) [NY 023 178] from about 7.5 to 158 m depth.

Lower and upper boundaries
The base of the unit is the top of the highest major channel sandstone unit in the Bransty Cliff Sandstone Member (Figure 14, Column 1).

The upper boundary of the member is the sub-Permian unconformity, which is overlain by the coarse, poorly bedded, poorly to moderately sorted, generally massive, matrix or clast-supported, typically pebble-grade, breccias of the Permian Brockram (Appleby Group).

Thickness
Up to 180 m maximum.

Distribution and regional correlation
West Cumbria Coalfield.

Age
Bolsovian (Westphalian C) to Asturian (Westphalian D).

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

ADDISON, R. 1997. Geology of the Silsden and Cononley district (SE04NW and SD94NE). *British Geological Survey Technical Report*, WA/97/22.

AITKENHEAD, N. 1977. Report of borehole at Duffield, Derbyshire. *Bulletin of the Geological Survey of Great Britain*, Vol. 59, 1–36.

AITKENHEAD, N, BRIDGE, D M, RILEY, N J, and KIMBELL, S F. 1992. Geology of the country around Garstang. *Memoir of the British Geological Survey*, Sheet 67 (England and Wales).

AITKENHEAD, N, BARCLAY, W J, BRANDON, A, CHADWICK, R A, CHISHOLM, J I, COOPER, A H, and JOHNSON, E W (editors). 2002. *British regional geology: The Pennines and adjacent areas*. (Keyworth, Nottingham: British Geological Survey.)

AKHURST, M C, CHADWICK, R A, HOLLIDAY, D W, MCCORMAC, M, MCMILLAN, A A, MILLWARD, D, and YOUNG, B. 1997. Geology of the west Cumbria district. *Memoir of the British Geological Survey*, Sheets 28, 37 and 47 (England and Wales).

ALLEN, J R L. 1960. The Mam Tor sandstones: a 'turbidite' facies of the Namurian deltas of Derbyshire, England. *Journal of Sedimentary Petrology*, Vol. 30, 193–208.

ANDREWS, J E, and NABI, G. 1994. Lithostratigraphy of the Dinantian Inverclyde and Strathclyde groups, Cockburnspath Outlier, East Lothian–North Berwickshire. *Scottish Journal of Geology*, Vol. 30, 105–119.

ANON. 1983. North American stratigraphic code–North American commission on stratigraphic nomenclature. *American Association of Petroleum Geologists Bulletin*, Vol. 67.

ANON. 2005. North American stratigraphic code–North American commission on stratigraphic nomenclature. *American Association of Petroleum Geologists Bulletin*, Vol. 89.

ARMSTRONG, H A, and PURNELL, M A. 1987. Dinantian conodont biostratigraphy of the Northumberland Trough. *Journal of Micropalaeontology*, Vol. 6, 97–112.

ARTHURTON, R S, and WADGE, A J. 1981. Geology of the country around Penrith. *Memoir of the Geological Survey of Great Britain*, Sheet 24 (England and Wales).

ARTHURTON, R S, JOHNSON, E W, and MUNDY, D J C. 1988. Geology of the Country around Settle. *Memoir of the British Geological Survey*, Sheet 60 (England and Wales).

AVELINE, W T, and HUGHES, T MCK. 1888. The geology of the country around Kendal, Sedbergh, Bowness and Tebay. *Memoir of the Geological Survey of Great Britain*, Sheet 98NE (England and Wales).

BARCLAY, W J, RILEY, N J, and STRONG, G E. 1994. The Dinantian rocks of the Sellafield area, West Cumbria. *Proceedings of the Yorkshire Geological Society*, Vol. 50, 37–49.

BARNES, R P, YOUNG, B R, FROST, D V, and LAND, D H. 1988. Geology of Workington and Maryport. *British Geological Survey Technical Report*, WA/88/3.

BARRACLOUGH, R. 1983. Tectonic versus eustatic sea-level changes in the Lower Carboniferous of northern England: a sedimentary study. Unpublished PhD thesis, University of Leeds.

BARRETT, B H, and RICHEY, J E. 1945. Economic geology of Canonbie Coalfield (Dumfriesshire and Cumberland). *Wartime Pamphlet of the Geological Survey of Great Britain*, No. 42.

BRAND, P J. 1983. Stratigraphical palaeontology of the Westphalian of the Ayrshire Coalfield, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, Vol. 73, 173–190.

BRAND, P J. 2003. Re-examination of the fossil collections made from the Rowhall Farm Borehole, Dearham. *British Geological Survey Internal Report*, IR/03/014R.

BRANDON, A, RILEY, N J, WILSON, A A, and ELLISON, R A. 1995. Three new early Namurian (E_{1c}–E_{2a}) marine bands in central and northern England, UK, and their bearing on correlations with the Askrigg Block. *Proceedings of the Yorkshire Geological Society*, Vol. 50, 333–355.

BRANDON, A, AITKENHEAD, N, CROFTS, R G, ELLISON, R A, EVANS, D J, and RILEY, N J. 1998. Geology of the country around Lancaster. *Memoirs of the Geological Survey of Great Britain*, Sheet 59 (England and Wales).

BRIGGS, D E G, CLARKSON, E N K, and ALDRIDGE, R J. 1983. The conodont animal. *Lethaia*, Vol. 16, 1–14.

BRISTOW, C S. 1988. Controls on the sedimentation of the Rough Rock Group (Namurian) from the Pennine Basin of northern England. 114–131 in *Sedimentation in a synorogenic basin complex: the Upper Carboniferous of Northwest Europe*. BESLY, B M, and KELLING, G (editors). (Glasgow and London: Blackie.)

BRISTOW, C S, and MYERS, K. 1989. Detailed sedimentology and gamma-ray log characteristics of a Namurian deltaic succession 1: Sedimentology and facies analysis. 75–80 *in* Deltas: Sites and Traps for Fossil Fuels. WHATELEY, M K G, and PICKERING, K T (editors). *Special Publication of the Geological Society of London*, No. 41.

BRITISH GEOLOGICAL SURVEY. 1987a. Arran. Scotland Special Sheet, 1:50 000 Series. Bedrock. (Southampton: Ordnance Survey for the British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1987b. NS57NE. Solid Geology. 1:10 000. (Edinburgh: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1987c. NS67NW. Solid Geology. 1:10 560. (Edinburgh: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1990. Greenock. Scotland Sheet 30W. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1992. Airdrie. Scotland Sheet 31W. Solid Geology. 1:50 000. (Southampton: Ordnance Survey for British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1993. Glasgow. Scotland Sheet 30E. Solid Geology. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1996. Campbeltown. Scotland Sheet 12, Provisional Series. Solid and Drift 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1997. Kirkby Stephen. England and Wales Sheet 40, Provisional Series. Solid and Drift .1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 2002a. Hawk's Nib and Little Cumbrae–west. Scotland Sheet NS15SW. Solid and Drift. 1:10 000. (Edinburgh: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 2002b. Hunterston, Millport and Little Cumbrae–east. Scotland Sheet NS15SE. Solid and Drift. 1:10 000. (Edinburgh: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 2002c. Great Cumbrae–east. Scotland Sheet NS15NE. Solid and Drift. 1:10 000. (Edinburgh: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 2005. Irvine. Scotland Sheet 22W, part 21E. Bedrock. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 2008. Dunoon and Millport. Scotland Sheet 29E with part of 21E. Bedrock and Superficial Deposits. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. In press. Irvine. Scotland Sheet 22W, part 21E. Bedrock. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. In preparation. Dunoon and Millport. Scotland Sheet 29E, part 21E. Bedrock. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BROCKBANK, W. 1891. On the occurrence of the Permian, *Spirorbis* limestones, and Upper Coal Measures at Frizington Hall in the Whitehaven district. *Memoir of the Proceedings of the Manchester Literary and Philosophical Society*, Vol. 4, 418–426.

BROWNE, M A E. 1980. The Upper Devonian and Lower Carboniferous (Dinantian) of the Firth of Tay, Scotland. *Institute of Geological Sciences Report*, No. 80/9.

BROWNE, M A E. 1986. The classification of the Lower Carboniferous in Fife and Lothian. *Scottish Journal of Geology*, Vol. 22, 422–425.

BROWNE, M A E, and MONRO, S K. 1989. Evolution of the coal basins of central Scotland. *XIe Congres International de Stratigraphie et de Geologie du Carbonifere. Beijing. Compte Rendu*, Vol. 5, 1–19.

BROWNE, M A E, HARGREAVES, R L, and SMITH, I F. 1985. The Upper Palaeozoic basins of the Midland Valley of Scotland. *Investigation of the geothermal potential of the UK*. (Keyworth, Nottingham: British Geological Survey.)

BROWNE, M A E, ROBINS, N S, EVANS, R B, MONRO, S K, and ROBSON, P G. 1987. The Upper Devonian and Carboniferous Sandstones of the Midland Valley of Scotland. *Investigation of the Geothermal Potential of the UK*. (Keyworth, Nottingham: British Geological Survey.)

BROWNE, M A E, DEAN, M T, HALL, I H S, MCADAM, A D, MONRO, S K, and CHISHOLM, J I. 1999. A lithostratigraphical framework for the Carboniferous rocks of the Midland Valley of Scotland. *British Geological Survey Research Report*, RR/99/07.

BROWNE, M A E, MCKIRDY, A, and MCADAM, A D. 2001. Fife and Tayside: a landscape fashioned by geology. (Perth: Scottish Natural Heritage.)

BROWNE, M A E, SMITH, R A, and AITKEN, A M. 2002. Strati-graphical framework for the Devonian (Old Red Sandstone) rocks of Scotland south of a line from Fort William to Aberdeen. *British Geological Survey Research Report*, RR/01/04.

BROWNE, M A E, MONAGHAN, A A, RITCHIE, J D, UNDERHILL, J R, HOOPER, M D, SMITH, R A, and AKHURST, M C. 2003. Revised tectonostratigraphical framework for the Carboniferous of the Midland Valley of Scotland, UK [Abstract], 15th International Congress on Carboniferous and Permian Stratigraphy, Utrecht, 2003, 68–70.

BRUCE, D R S, and STEMMERIK, L. 2003. Carboniferous. 83–89 in: *The millennium atlas: petroleum geology of the central and northern North Sea*. EVANS, D, GRAHAM, C, ARMOUR, A, and BATHURST, P (editors). (Bath: Geological Society of London.)

BURGESS, I C. 1986. Lower Carboniferous sections in the Sedbergh district, Cumbria. *Transactions of the Leeds Geological Association*, Vol. 11, 1–23.

BURGESS, I C, and HOLLIDAY, D W. 1979. Geology of the country around Brough-under-Stainmore. *Memoir of the Geological Survey of Great Britain*, Sheet 31, parts 25 and 30 (England and Wales).

CALVER, M A. 1969. Westphalian of Britain. *6e Congres Internationale Stratigraphie et Geologie Carbonifere. Sheffield 1967. Compte Rendu*, Vol. 1, 233–254.

CAMERON, I B, and MCADAM, A D. 1978. The oil shales of the Lothians, Scotland: present resources and former workings. *Report of the Geological Survey of Great Britain*, No. 78/28.

CAMERON, I B, and STEPHENSON, D. 1985. British regional geology: The Midland Valley of Scotland. (London: HMSO for the British Geological Survey.)

CAMERON, I B, AITKEN, A M, BROWNE, M A E, and STEPHENSON, D. 1998. Geology of the Falkirk district. *Memoir of the British Geological Survey*, Sheet 31E (Scotland).

CAMERON, T D J. 1993a. Triassic, Permian and pre-Permian of the Central and Northern North Sea. Vol. 4. *Lithostratigraphical nomenclature of the UK North Sea*.
KNOX, R W O B, and CORDEY, W G (editors). (Keyworth, Nottingham: British Geological Survey.)

CAMERON, T D J. 1993b. Carboniferous and Devonian of the Southern North Sea. Vol. 5. *Lithostratigraphical nomenclature of the UK North Sea*. KNOX, R W O B, and CORDEY, W G (editors). (Keyworth, Nottingham: British Geological Survey.)

CARRUTHERS, R G, CALDWELL, W, BAILEY, E M, and CONACHER, H R J. 1927. The oil shales of the Lothians (3rd edition). *Memoir of the Geological Survey of Great Britain*.

CHADWICK, R A, HOLLIDAY, D W, HOLLOWAY, S, and HULBERT, A G. 1995. The structure and evolution of the Northumberland–Solway Basin and adjacent areas. *Subsurface Memoir of the British Geological Survey*. (Keyworth, Nottingham: British Geological Survey.)

CHADWICK, R A, JACKSON, D I, BARNES, R P, KIMBELL, G S, JOHNSON, H, CHIVERRELL, R C, THOMAS, G S P, JONES, N S, RILEY, N J, PICKETT, E A, YOUNG, B, HOLLIDAY, D W, BALL, D F, MOLYNEUX, S G, LONG, D, POWER, G M, and ROBERTS, D H. 2001. The geology of the Isle of Man and its offshore area. *British Geological Survey Research Report*, RR/01/06.

CHISHOLM, J I. 1990. The Upper Band-Better Bed sequence (Lower Coal Measures, Westphalian A) in the central and south Pennine area of England. *Geological Magazine*, Vol. 127, 55–74.

CHISHOLM, J I, and BRAND, P J. 1994. Revision of the late Dinantian sequence in Edinburgh and West Lothian. *Scottish Journal of Geology*, Vol. 30, 97–104.

CHISHOLM, J I, and DEAN, J M. 1974. The Upper Old Red Sandstone of Fife and Kinross: a fluviatile sequence with evidence of marine incursion. *Scottish Journal of Geology*, Vol. 10, 1–30.

CHISHOLM, J I, and HALLSWORTH, C R. 2005. Provenance of Upper Carboniferous sandstones in east Derbyshire: role of the Wales–Brabant High. *Proceedings of the Yorkshire Geological Society*, Vol. 55, 209–233.

CHISHOLM, J I, MCADAM, A D, and BRAND, P J. 1989. Litho-stratigraphical classification of Upper Devonian and Lower Carboniferous rocks in the Lothians. *British Geological Survey Technical Report*, WA/89/26.

CHISHOLM, J I, WATERS, C N, HALLSWORTH, C R, TURNER, N, STRONG, G E, and JONES, N S. 1996. Provenance of Lower Coal Measures around Bradford, West Yorkshire. *Proceedings of the Yorkshire Geological Society*, Vol. 51, 153–166.

CLAYTON, G, COQUEL, R, DOUBINGER, J, GUEINN, K J, LOBOZIAK, S, OWENS, B, and STREEL, M. 1977. Carboniferous miospores of western Europe: illustration and zonation. *Mededelingen. Rijks Geologische Dienst*, Vol. 29, 1–71.

CLEAL, C J. 1991. Carboniferous and Permian biostratigraphy. 182–215 in CLEAL, C J (editor). *Plant Fossils in Geological Investigation: the Palaeozoic*. (Chichester: Ellis Horwood Limited.)

CLEAL, C J, and THOMAS, B A. 1995. British Upper Carboniferous stratigraphy. *Geological Conservation Review Series*, No. 11. (London: Chapman and Hall.)

CLIFF, R A, DREWERY, S E, and LEEDER, M R. 1991. Sourcelands for the Carboniferous Pennine river system: constraints from sedimentary evidence and U–Pb geochronology using zircon and monazite. 137–159 in *Developments in Sedimentary Provenance Studies*. Morton, A C, Todd, S, P, and Haughton, P D W (editors). *Geological Society of London Special Publication*, No. 57.

Clough, C T, Hinxman, L W, Wright, W B, Anderson, E M, and Carruthers, R G. 1916. The economic geology of the Central Coalfield of Scotland. Area V. *Memoir of the Geological Survey of Great Britain* (Scotland).

Clough, C T, Hinxman, L W, Wilson, J S G, Crampton, C B, Wright, W B, Bailey, E B, Anderson, E M, and Carruthers, R G. 1925. The geology of the Glasgow district. *Memoir of the Geological Survey of Great Britain*, Sheets part 30, 31, 22 and 23 (Scotland).

Collinson, J D. 1969. The sedimentology of the Grindslow Shales and the Kinderscout Grit: A delta complex in the Namurian of Northern England. *Journal of Sedimentary Petrology*, Vol. 39, 194–221.

Collinson, J D. 1988. Controls on Namurian sedimentation in the Central Province basins of northern England. 85–101 in *Sedimentation in a Synorogenic Basin Complex: the Upper Carboniferous of Northwest Europe*. Besly, B M, and Kelling, G (editors). (Glasgow and London: Blackie.)

Collinson, J D, and Banks, N L. 1975. The Haslingden Flags (Namurian G_1) of South East Lancashire: Bar finger sands in the Pennine Basin. *Proceedings of the Yorkshire Geological Society*, Vol. 40, 431–458.

Collinson, J D, Jones, C M, and Wilson, A A. 1977. The Marsdenian (Namurian R_2) succession west of Blackburn: implications for the evolution of Pennine Delta Systems. *Geological Journal*, Vol. 12, 59–76.

Conil, R, Longerstaey, P J, and Ramsbottom, W H C. 1980. Materiaux pour l'étude micropaléontologique du Dinantien de Grande-Bretagne. *Memoires de l'Institute Géologique de l'Université de Louvain*, Vol. 30, 1–186.

Conil, R, Groessens, E, Laloux, M, Poty, E, and Tourneur, F. 1991. Carboniferous guide foraminifera, corals and conodonts in the Franco-Belgian and Campine basins: their potential for widespread correlation. *Courier Forschungsinstitut Senckenberg*, Vol. 130, 15–30.

Cooper, A H, and Burgess, I C. 1993. Geology of the country around Harrogate. *Memoir of the British Geological Survey*, Sheet 62 (England and Wales).

Cope, J C W, Ingham, J K, and Rawson, P F. 1992. Atlas of palaeogeography and lithofacies. *Geological Society of London Memoir*, No. 13.

Cossey, P J, Adams, A E, Purnell, M A, Whiteley, M J, Whyte, M A, and Wright, V P. 2004. British Lower Carboniferous stratigraphy. *Geological Conservation Review Series*, No 29. (Peterborough: Joint Nature Conservation Committee.)

Cozar, P, and Somerville, I D. 2004. New algal–foraminiferal evidence for the recognition of the Asbian–Brigantian boundary in northern England. *Proceedings of the Yorkshire Geological Society*, Vol. 55, 43–65.

Cozar, P, Somerville, I D, and Burgess, I. 2008. New foraminifers in the Visean/Serpukhovian boundary interval of the Lower Limestone Formation, Midland Valley, Scotland. *Journal of Paleontology*, Vol. 82, 906–923.

Craig, G Y. 1956. The Lower Carboniferous outlier of Kirkbean, Kirkcudbrightshire. *Transactions of the Geological Society of Glasgow*. Vol. 22, 113–122.

Craig, G Y, and Nairn, A E M. 1956. The Lower Carboniferous outliers of the Colvend and Rerrick shores, Kirkcudbrightshire. *Geological Magazine*, Vol. 93, 249–256.

Craig, P M. 1980. The volcanic geology of the Campsie Fells area, Stirlingshire. Unpublished PhD Thesis, University of Lancaster.

Cummings, R H. 1961. The foraminiferal zones of the Carboniferous sequence of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bulletin of the Geological Survey of Great Britain*, No. 18, 107–128.

Currie, E D. 1954. Scottish Carboniferous goniatites. *Transactions of the Royal Society of Edinburgh*, Vol. 62, Pt. 2, 527–602.

Dakyns, J R, Tiddeman, R H, and Goodchild, J G. 1897. The geology of the country between Appleby, Ullswater and Haweswater. *Memoir of the Geological Survey of Great Britain*.

Davies, A. 1970. Carboniferous rocks of the Sanquhar outlier. *Bulletin of the Geological Survey of Great Britain*, No. 31, 37–87.

Davies, A, McAdam, A D, and Cameron, I B. 1986. Geology of the Dunbar district. *Memoir of the British Geological Survey*, Sheet 33E and part of Sheet 41 (Scotland).

Davies, J R, Wilson, D, and Williamson, I T. 2004. The geology of the country around Flint. *Memoir of the British Geological Survey*, Sheet 108 (England and Wales).

Davies, S J, and McLean, D. 1996. Spectral gamma-ray and palynological characterization of Kinderscoutian marine bands in the Namurian of the Pennine Basin. *Proceedings of the Yorkshire Geological Society*, Vol. 51, 103–114.

Davydov, V, Wardlaw, B R, and Gradstein, F M. 2004. The Carboniferous Period. 222–248 in *A geologic time scale 2004*. Gradstein, F M, Ogg, J G, and Smith, A G (editors). (Cambridge: Cambridge University Press.)

Day, A. 1992. Lower Carboniferous rocks near Orton, east of Shap. 12–18 in *Lakeland rocks and landscape a field guide*. Dodd, M (editor). (Maryport: Ellenbank Press.)

Day, J B W. 1970. Geology of the country around Bewcastle. *Memoir of the Geological Survey of Great Britain*, Sheet 12 (England and Wales).

Dean, M T. 2001. Faunas from and biostratigraphy of various exposures in the Appleby district. *British Geological Survey Internal Report*, IR/01/143.

Dean, M T. 2002. The Carboniferous macropalaeontology and biostratigraphy of Ayr and Mauchline (Scotland Sheet 14). *British Geological Survey Internal Report*, IR/02/006.

Deegan, C E. 1970. The petrology and sedimentology of the Lower Carboniferous rocks between White Port and Kirkbean, Kirkcudbrightshire. Unpublished PhD thesis, University of Wales, Aberystwyth.

Deegan, C E. 1973. Tectonic control of sedimentation at the margin of a Carboniferous depositional basin in Kirkcudbrightshire. *Scottish Journal of Geology*, Vol. 9, 1–28.

Dickson, J A D, Ford, T D, and Swift, A. 1987. The stratigraphy of the Carboniferous rocks around Castletown, Isle of Man. *Proceedings of the Yorkshire Geological Society*, Vol. 46, 203–229.

Dunham, K C. 1990. Geology of The Northern Pennine Orefield: Volume 1, Tyne to Stainmore (2nd edition). *Economic Memoir of the British Geological Survey*, Sheets 19 and 25, parts 13, 24, 26, 31 and 32 (England and Wales).

Dunham, K C, and Wilson, A A. 1985. Geology of the Northern Pennine Orefield: Volume 2, Stainmore to Craven. *Economic Memoir of the British Geological Survey*, Sheets 40, 41 and 50, parts 31, 32, 51, 60 and 61(England and Wales).

Dunham, K C, Dunham, A C, Hodge, B L, and Johnson, G A L. 1965. Granite beneath Visean sediments with mineralisation at Rookhope, northern Pennines. *Quarterly Journal of the Geological Society of London*, Vol. 121, 383–417.

Dunham, R J. 1962. Classification of carbonate rocks according to depositional texture. 108–121 in Classification of Carbonate Rocks. Ham, W E (editor). *Memoirs of the American Association of Petroleum Geologists*, Vol. 1.

Earp, J R, Magraw, D, Poole, E G, Land, D H, and Whiteman, A J. 1961. Geology of the country around Clitheroe and Nelson. *Memoir of the Geological Survey of Great Britain*, Sheet 68 (England and Wales).

Eastwood, T. 1928. The Cockermouth Lavas, Cumberland–a Carboniferous volcanic episode. 15–22 in *Summary of progress of the Geological Survey of Great Britain and the*

Museum of Practical Geology for the year 1927, Pt. 2. (London: His Majesty's Stationary Office.)

Eastwood, T, Dixon, E E L, Hollingsworth, S, and Smith, B. 1931. The geology of the Whitehaven and Workington District. *Memoir of the Geological Survey*, Sheet 28 (England and Wales).

Eastwood, T, Hollingworth, S E, Rose, W C C, and Trotter, F M. 1968. Geology of the country around Cockermouth and Caldbeck. *Memoir of the Geological Survey of Great Britain*, Sheet 23 (England and Wales).

Eckford, R J A, and Ritchie, M. 1939. The igneous rocks of the Kelso district. *Transactions of the Edinburgh Geological Society*, 13, 464–472.

Elliott, T. 1975. The sedimentary history of a delta lobe from a Yoredale (Carboniferous) cyclothem. *Proceedings of the Yorkshire Geological Society*, Vol. 40, 505–536.

Evans, D J, and Kirby, G A. 1999. The architecture of concealed Dinantian carbonate sequences over the Central Lancashire and Holme highs, northern England. *Proceedings of the Yorkshire Geological Society*, Vol. 52, 297–312.

Eyles, V A, Simpson, J B, and Macgregor, A G. 1949. Geology of central Ayrshire. *Memoir of the Geological Survey of Great Britain*, Sheet 14, parts 8, 13, 15 and 22 (Scotland).

Fairbairn, R A. 1978. Lateral persistence of beds within the Great Limestone (Namurian E_1) of Weardale. *Proceedings of the Yorkshire Geological Society*, Vol. 41, 533–544.

Fairbairn, R A. 1980. The Great Limestone (Namurian) of south Northumberland. *Proceedings of the Yorkshire Geological Society*, Vol. 43, 159–167.

Fairbairn, R A. 2001. The stratigraphy of the Namurian Great/Main Limestone on the Alston Block, Stainmore Trough and Askrigg Block of northern England. *Proceedings of the Yorkshire Geological Society*, Vol. 53, 265–274.

Fewtrell, M D, and Smith, D G. 1980. Revision of the Dinantian stratigraphy of the Craven Basin, N England. *Geological Magazine*, Vol. 117, 37–49.

Floyd, J D. 1999. Geology of the Carrick–Loch Doon district. *Memoir of the British Geological Survey*, Sheets 8W and 8E (Scotland).

Folk, R L. 1959. Practical petrographic classification of limestones. *Bulletin of the American Association of Petroleum Geologists*, Vol. 43, 1–38.

Folk, R L. 1962. Spectral subdivision of limestone types. 62–84 in Classification of Carbonate Rocks. Ham, W E (editor). *Memoirs of the American Association of Petroleum Geologists*, Vol. 1.

Ford, T D. 1954. The Upper Carboniferous rocks of the Ingleton Coalfield. *Quarterly Journal of the Geological Society of London*, Vol. 110, 231–265.

Forsyth, I H, and Chisholm, J I. 1977. The geology of east Fife. *Memoir of the Geological Survey of Great Britain*, Sheets 41 part 49 (Scotland).

Forsyth, I H, and Read, W A. 1962. The correlation of the Limestone Coal Group above the Kilsyth Coking Coal in the Glasgow–Stirling region. *Bulletin of the Geological Survey of Great Britain*, No. 19, 29–52.

Forsyth, I H, Hall, I H S, and McMillan, A A. 1996. Geology of the Airdrie district. *Memoir of the British Geological Survey*, Sheet 31W (Scotland).

Fowler, A. 1926. The geology of Berwick on Tweed, Norham and Scremerston. *Memoir of the Geological Survey of Great Britai*n, Sheets 1 and 2 (England and Wales).

Francis, E H. 1991. Carboniferous. 347–392 in Geology of Scotland (3rd edition). Craig, G Y (editor). (London: The Geological Society.)

Francis, E H, Forsyth, I H, Read, W A, and Armstrong, M. 1970. The geology of the Stirling district. *Memoir of the Geological Survey of Great Britain*, Sheet 39 (Scotland).

Fraser, A J, Nash, D F, Steele, R P, and Ebdon, C C. 1990. A regional assessment of the intra-Carboniferous play of northern England. 417–440 in Classic Petroleum Provinces. Brooks, J (editor). *Geological Society of London Special Publication*, No. 55.

Frost, D V, and Holliday, D W. 1980. Geology of the country around Bellingham. *Memoir of the Geological Survey of Great Britain*, Sheet 13 (England and Wales).

Garwood, E J. 1907. Geology of Teignmouth Parish, ('History of Northumberland'). *Museum Pamphlet, Northumberland*, No. 73.

Garwood, E J. 1913. The Lower Carboniferous succession in the north-west of England. *Quarterly Journal of the Geological Society*, Vol. 68, 449–596.

Geikie, A. 1877. Explanation of Sheet 9: Kirkcudbright (north-east part) and Dumfriesshire (south-west part). *Memoirs of the Geological Survey*, Scotland.

Geikie, A. 1900. The geology of central and western Fife and Kinross. *Memoirs of the Geological Survey*, Scotland.

Geological Survey Of Great Britain. 1924. Buteshire (Argyllshire). Scotland Sheet 226. Solid and Drift. 1:10 560. (Southampton: Ordnance Survey for Geological Survey of Great Britain.)

Geological Survey Of Great Britain. 1951. Elsdon. England and Wales Sheet 8. Solid. 1: 63 360 enlarged to 1: 50 000 without revision in 1993. (Southampton: Ordnance Survey for Geological Survey of Great Britain.)

George, T N, and Black, W W. 1971. The Lower Carboniferous (Dinantian) of England, Wales and Scotland. International Stratigraphical Lexicon, Part 3a Vii. International Union of Geological Sciences.

George, T N, and Wagner, R H. 1972. IUGS Subcommission on Carboniferous stratigraphy. Proceedings and report on the general assembly at Krefeld, August 21–22. *Compte Rendu 7me Cong. int. Strat. Geol. Carb. (Krefeld 1971)* 1, 139–147.

George, T N, Johnson, G A L, Mitchell, M, Prentice, J E, Ramsbottom, W H C, Sevastopulo, G D, and Wilson, R B. 1976. A correlation of Dinantian rocks in the British Isles. *Geological Society of London Special Report*, No.7.

Gillespie, M R, and Styles, M T. 1999. BGS Rock Classification Scheme. Volume 1: Classification of igneous rocks. *British Geological Survey Research Report*, RR/99/06.

Gradstein, F M, and Ogg, J G. 2004. Geologic Time Scale 2004 — why, how and where next! *Lethaia*, Vol. 37, 175–181.

Greensmith, J T. 1965. Calciferous Sandstone Series sedimentation at the eastern end of the Midland Valley of Scotland. *Journal of Sedimentary Petrology*, Vol. 35, 223–242.

Greig, D C. 1971. *British regional geology: the south of Scotland* (3rd edition). (Edinburgh: HMSO for Institute of Geological Sciences.)

Greig, D C. 1988. Geology of the Eyemouth District. *Memoir of the British Geological Survey*, Sheet 34 (Scotland).

Guion, P D, Jones, N S, and Fulton, I M. 1995. Sedimentary facies of the coal-bearing Westphalian A and B north of the Wales–Brabant High. 45–77 in European Coal Geology. Whateley M K G, and Spears, D A (editors). *Geological Society of London Special Publication*, No. 82.

Gunn, W. 1900. The geology of Belford, Holy Island, and the Farne Islands, Northumberland. *Memoir of the Geological Survey of Great Britain*, Sheet 4 (England and Wales).

Gunn, W, and Clough, C T. 1895. The geology of part of Northumberland, including the country between Wooler and Coldstream. *Memoir of the Geological Survey of Great Britain*, Sheet 3 (England and Wales).

Hall, I H S, Browne, M A E, and Forsyth, I H. 1998. Geology of the Glasgow district. *Memoir of the British Geological Survey*, Sheet 30E (Scotland).

Hallsworth, C R, and Chisholm, J I. 2000. Stratigraphical evolution of provenance characteristics in Westphalian sandstones of the Yorkshire Coalfield. *Proceedings of the Yorkshire Geological Society*, Vol. 53, 43–72.

HAMPSON, G J. 1997. A sequence stratigraphical model for deposition of the Lower Kinderscout Delta, an Upper Carboniferous turbidite-fronted delta. *Proceedings of the Yorkshire Geological Society*, Vol. 51, 273–296.

HECKEL, P H, and CLAYTON, G. 2006. Use of the new official names for the Subsystems, Series, and Stages of the Carboniferous System in international journals. *Proceedings of the Geologists' Association*, Vol. 117, 393–396.

HODGSON, A V. 1978. Braided river bedforms and related sedimentary structures in the Fell Sandstone Group (Lower Carboniferous) of North Northumberland. *Proceedings of the Yorkshire Geological Society*, Vol. 41, 509–532.

HOLLAND, C H, AUDLEY-CHARLES, M G, BASSETT, M G, COWIE, J W, CURRY, D, FITCH, F J, HANCOCK, J M, HOUSE, M R, INGHAM, J K, KENT, P E, MORTON, N, RAMSBOTTOM, W H C, RAWSON, P F, SMITH, D B, STUBBLEFIELD, C J, TORRENS, H S, WALLACE, P, and WOODLAND, A W. 1978. A guide to stratigraphical procedure. *Geological Society of London Special Repor*t, No. 11.

HOLLIDAY, D, BURGESS, I C, and FROST, D V. 1975. A recorrelation of the Yoredale limestones (Upper Visean) of the Alston Block with those of the Northumberland Trough. *Proceedings of the Yorkshire Geological Society*, Vol. 40, 319–334.

HOLLIDAY, D W, NEVES, R, and OWENS, B. 1979. Stratigraphy and palynology of early Dinantian (Carboniferous) strata in shallow boreholes near Ravenstonedale, Cumbria. *Proceedings of the Yorkshire Geological Society*, Vol. 42, 343–356.

HORBURY, A D. 1987. The sedimentology of the Urswick Limestone in south Cumbria and north Lancashire. Unpublished PhD thesis, University of Manchester.

HUDSON, R G S. 1930. The Carboniferous of the Craven Reef Belt; and the Namurian unconformity at Scaleber, near Settle. *Proceedings of the Geologists' Association*, Vol. 41, 290–322.

INSTITUTE OF GEOLOGICAL SCIENCES. 1966. Rothbury. England and Wales Sheet 9. Solid. 1:63 360. (Southampton: Ordnance Survey for the Institute of Geological Sciences.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1972. Alnwick. England and Wales Sheet 6. Solid and Drift. 1:50 000. (Southampton: Ordnance Survey for the Institute of Geological Sciences.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1973. Alston. England and Wales Sheet 25. Solid and Drift. 1:50 000. (Southampton: Ordnance Survey for the Institute of Geological Sciences.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1974. Holy Island. England and Wales Sheet 4. Solid and Drift. 1:50 000. (Southampton: Ordnance Survey for the Institute of Geological Sciences.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1976. Ford. England and Wales Sheet 3. Solid. 1:50 000. (Southampton: Ordnance Survey for the Institute of Geological Sciences.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1977. Berwick-upon-Tweed and Norham. England and Wales Sheets 1 and 2. Solid and Drift. 1:50 000. (Southampton: Ordnance Survey for the Institute of Geological Sciences.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1978. Institute of Geological Sciences boreholes 1977. *Report of the Institute of Geological Sciences*, No. 78/21.

INSTITUTE OF GEOLOGICAL SCIENCES. 1981. Institute of Geological Sciences boreholes 1980. *Report of the Institute of Geological Sciences*, No. 81/11.

JOHNSON, E W, SOPER, N J, and BURGESS, I C. 2001. Geology of the country around Ulverston. *Memoir of the British Geological Survey*, Sheet 48 (England and Wales).

JOHNSON, G A L. 1958. Biostromes in the Great Limestone of northern England. *Palaeontology*, Vol. 1, 147–157.

JOHNSON, G A L, and DUNHAM, K C. 1963. The geology of Moor House. *Monographs of the Nature Conservancy*, No 2.

JOHNSON, G A L, and MARSHALL, A E. 1971. Tournaisian beds in Ravenstonedale, Westmorland. *Proceedings of the Yorkshire Geological Society*, Vol. 38, 261–280.

JOHNSON, G A L, and NUDDS, J R. 1996. Carboniferous biostratigraphy of the Rookhope Borehole, County Durham. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, Vol. 86, 181–226.

JOHNSON, G A L, HODGE, B L, and FAIRBAIRN, R A. 1962. The base of the Namurian and the Millstone Grit in north-east England. *Proceedings of the Yorkshire Geological Society*, Vol. 33, 341–362.

JOHNSON, G A L, NUDDS, J R, and ROBINSON, D. 1980. Carboniferous stratigratigraphy and mineralisation at Ninebanks, West Allendale, Northumberland. *Proceedings of the Yorkshire Geological Society*, Vol. 43, 1–16.

JOHNSTONE, G S. 1965. The volcanic rocks of the Misty Law–Knockside Hills district, Renfrewshire. *Bulletin of the Geological Survey of Great Britain*, No. 22, 53–64.

JONES, C M, and CHISHOLM, J I. 1997. The Roaches and Ashover Grits: sequence stratigraphical interpretation of a 'turbidite fronted delta' system. *Geological Journal*, Vol. 32, 45–68.

JONES, N S. 1993. Stratigraphical and sedimentological characteristics of the 'Whitehaven Sandstone Series', Westphalian C, West Cumbria coalfield. *British Geological Survey Technical Report*, WH/93/102R.

JONES, N S. 1994. Core log of the BGS Closeburn Borehole [NX 90210 91450]. *British Geological Survey Technical Report*, WH/94/147R.

JONES, N S, and HOLLIDAY, D W. 2006. The stratigraphy and sedimentology of Upper Carboniferous Warwickshire Group red-bed facies in the Canonbie area of S.W. Scotland. *British Geological Survey Internal Report*, IR/06/043.

JONES, N S, HOLLIDAY, D W, and MCKERVEY, J A. In press. Warwickshire Group (Pennsylvanian) red-beds of the Canonbie coalfield, England–Scotland border, and their regional palaeogeographical implications. *Geological Magazine*.

LAGIOS, E. 1983. A gravity study of the eastern Berwickshire Devonian basins, SE Scotland. *Scottish Journal of Geology*, Vol. 19, 189–203.

LAMPLUGH, G W. 1903. The geology of the Isle of Man. *Memoir of the Geological Survey of Great Britain*.

LEEDER, M R. 1974. Lower Border Group (Tournaisian) fluviodeltaic sedimentation and palaeogeography of the Northumberland Basin. *Proceedings of the Yorkshire Geological Society*, Vol. 40, 129–180.

LEEDER, M R. 1982. Upper Palaeozoic basins of the British Isles: Caledonide inheritance versus Hercynian plate margin processes. *Journal of the Geological Society of London*, Vol. 139, 481–494.

LEEDER, M R. 1988. Recent developments in Carboniferous geology: a critical review with implications for the British Isles and NW Europe. *Proceedings of the Geologists Association*, Vol. 99, 73–100.

LEEDER, M R. 1992. Dinantian. 207–238 in Geology of England and Wales. DUFF, P M D, and SMITH, A J (editors). (London: The Geological Society.)

LEEDER, M R, FAIRHEAD, D, LEE, A, STUART, G, CLEMMY, H, AL-HADDEH, B, and GREEN, C. 1989. Sedimentary and tectonic evolution of the Northumberland Basin. 143–152 in The Role of Tectonics in Devonian and Carboniferous Sedimentation in the British Isles. ARTHURTON, R S, GUTTERIDGE, P, and NOLAN, S C (editors). *Occassional Publications of the Yorkshire Geological Society*, Vol. 6.

LEVISTON, D. 1979. A study of four localities, the Martin Limestone (Lower Carboniferous, Dinantian) of Furness and Grange-over-Sands. *Proceedings of the Cumberland Geological Society*, Vol. 4, 3–20.

LEWIS, H P. 1930. The Avonian succession in the south of the Isle of Man. *Quarterly Journal of the Geological Society of London*, Vol. 86, 234–290.

LINTERN, B C, and FLOYD, J D. 2000. Geology of the Kirkcudbright–Dalbeattie district. *Memoir of the British Geological Survey*, Sheets 5W and 5E, part 6W (Scotland).

LUMSDEN, G I, and WILSON, R B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bulletin of the Geological Survey of Great Britain*, No. 18, 1–89.

LUMSDEN, G I, TULLOCH, W, HOWELLS, M F, and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Memoir of the Geological Survey of Great Britain*, Sheet 11 (Scotland).

MACDONALD, R, and WALKER, B H. 1985. Geochemistry and tectonic significance of the Lower Carboniferous Cockermouth lavas, Cumbria. *Proceedings of the Yorkshire Geological Society*, Vol. 45, 141–146.

MACGREGOR, A G. 1928. The classification of Scottish Carboniferous olivine-basalts and mugearites. *Transactions of the Geological Society of Glasgow*, Vol. 18, 324–360.

MACGREGOR, A R. 1968. Fife and Angus geology: an excursion guide. (Edinburgh: Scottish Academic Press Ltd for the University of St Andrews.)

MACPHERSON, K A T, and PHILLIPS, E R. 1997. The geology of the Clyde Plateau Volcanic Formation of the Kilmarnock district (Sheet 22E), central Scotland. *British Geological Survey Technical Report*, WA/97/88.

MACPHERSON, K A T, and PHILLIPS, E R. 1998. A welded pyroclastic deposit within the Dinantian Clyde Plateau Volcanic Formation, near Eaglesham, in the East Renfrewshire Hills of the Midland Valley. *Scottish Journal of Geology*, Vol. 34, 165–172.

MACPHERSON, K A T, SMITH, R A, and AKHURST, M C. 2000. Geology of the Kilmarnock district. *Sheet description of the British Geological Survey*, Sheet 22E (Scotland).

MCADAM, A D, and CLARKSON, E N K. 1986. Lothian Geology: an excursion guide. (Edinburgh: Edinburgh Geological Society.)

MCADAM, A D, and TULLOCH, W. 1985. Geology of the Haddington district. *Memoir of the British Geological Survey*, Sheet 33W, part 41 (Scotland).

MCCABE, P J. 1978. The Kinderscoutian delta (Carboniferous) of northern England; A slope influenced by density currents. 116–126 in *Sedimentation in submarine canyons, fans and trenches*. STANLEY, D J, and KELLING, G (editors). (Stroudsburg: Dowden, Hutchinson and Ross).

MCCORMAC, M. 2001. The Upper Palaeozoic rocks of the Shap and Penrith district, Edenside, Cumbria. *British Geological Survey Research Report*, RR/01/10.

MCLEAN, D, and CHISHOLM, J I. 1996. Reworked palynomorphs as provenance indicators in the Yeadonian of the Pennine Basin. *Proceedings of the Yorkshire Geological Society*, Vol. 51, 141–151.

MCMILLAN, A A. 1991. Loch Ettrick. 1:10 000 Scale Geological Sheet NX99SW (Solid). *British Geological Survey*.

MCMILLAN, A A. 2002. Geology of the New Galloway and Thornhill district. *Memoir of the British Geological Survey*, Sheets 9E and 9W (Scotland).

MCMILLAN, A A, and BRAND P J B. 1995. Depositional setting of Permian and Upper Carboniferous strata of the Thornhill Basin, Dumfriesshire. *Scottish Journal of Geology*, Vol. 31, 43–52.

MCROBERT, R W. 1925. Igneous rocks of Teviot and Liddesdale. *Transactions of the Edinburgh Geological Society*, Vol.11, 86–103.

MENNING, M, WEYER, D, DROZDZEWSKI, G, VAN AMEROM, H W J, and WENDT, I. 2000. A Carboniferous time scale 2000: discussion and use of geological parameters as time indicators from central and western Europe. *Geologisches Jahrbuch*, A156, 3–44.

MENTEATH, J S. 1845. The Geology of Dumfriesshire. *Transactions of the Highland and Agricultural Society*, Vol. i, 289–311.

MILLER, H. 1887. The geology of the country around Otterburn and Elsdon. *Memoir of the Geological Survey of Great Britain*, Sheet 8 (England and Wales).

MILLS, D A C, and HOLLIDAY, D W. 1998. Geology of the district around Newcastle upon Tyne, Gateshead and Consett. *Memoir of the British Geological Survey*, Sheet 20 (England and Wales).

MILLS, D A C, and HULL, J H. 1976. Geology of the country around Barnard Castle. *Memoir of the Geological Survey of Great Britain*, Sheet 32 (England and Wales).

MILLWARD, D, MCCORMAC, M, HUGHES, R A, ENTWISTLE, D C, BUTCHER, A, and RAINES, M G. 2003. Geology of the Appleby district. *Sheet explantion of the British Geological Survey*, Sheet 30 (England and Wales).

MITCHELL, G H, and MYKURA, W. 1962. The Geology of the neighbourhood of Edinburgh. *Memoir of the Geological Survey of Great Britain*, Sheet 32 (Scotland).

MITCHELL, M. 1972. The base of the Viséan in south-west and north-west England. *Proceedings of the Yorkshire Geological Society*, Vol. 39, 151–160.

MITCHELL, M. 1978. Dinantian.168–177 in The geology of the Lake District. MOSELEY, F (editor). *Occasional Publication of the Yorkshire Geological Society*, No. 3.

MITCHELL, M. 1989. Biostratigraphy of Viséan (Dinantian) rugose coral faunas from Britain. *Proceedings of the Yorkshire Geological Society*, Vol. 47, 233–247.

MONAGHAN, A. 2004. Geology of the Dailly area, Ayrshire. *British Geological Survey Internal Report*, IR/04/035.

MONRO, S K. 1982. Stratigraphy, sedimentation and tectonics in the Dalry Basin, Ayrshire. Unpublished PhD Thesis, University of Edinburgh.

MONRO, S K. 1999. Geology of the Irvine district. *Memoir of the British Geological Survey*, Sheet 22W, part 21E (Scotland).

MOORE, E W J. 1930. A section in the Sabden Shales on the River Darwen, near Blackburn. *Journal of the Manchester Geological Association*, Vol. 1, 103–108.

MUNDY, D J C. 2000. Field meeting to the Craven Reef Belt: Settle and Cracoe, Sunday 23rd July 2000. (Calgary: Talisman Energy Inc.)

MUNDY, D J C, and ARTHURTON, R S. 1980. Field meetings: Settle and Flasby. *Proceedings of the Yorkshire Geological Society*, Vol. 43, 32–36.

MURRAY, D W. 1983. The limestone and dolomite resources of the country around Settle and Malham, North Yorkshire (with notes on the hard-rock resources of the Horton-in-Ribblesdale area): description of parts of 1:50 000 geological sheets 50 and 60. *Mineral Assessment Report Institute of Geological Sciences*, No. 126.

MYKURA, W. 1960. The replacement of coal by limestone and the reddening of Coal Measures in the Ayrshire coalfield. *Bulletin of the Geological Survey of Great Britain*, No. 16, 69–109.

MYKURA, W. 1967. The Upper Carboniferous rocks of south-west Ayrshire. *Bulletin of the Geological Survey of Great Britain*, No. 26, 23–98.

NAIRN, A E M. 1956. The Lower Carboniferous rocks between the rivers Esk and Annan, Dumfriesshire. *Transactions of the Geological Society of Glasgow*, Vol. 22, 80–93.

NAIRN, A E M. 1958. Petrology of the Whita Sandstone, southern Scotland. *Journal of Sedimentary Petrology*, Vol. 45, 362–367.

NEVES, R, READ, W A, and WILSON, R B. 1965. Note on recent spore and goniatite evidence from the Passage Group, of the Scottish Upper Carboniferous succession. *Scottish Journal of Geology*, Vol. 1, 185–188.

NEVES, R, GUEINN, K J, CLAYTON, G, IOANNIDES, N S, NEVILLE, R S W, and KRUSZEWSKA, K. 1973. Palynological correlations within the Lower Carboniferous of Scotland and northern England. *Transactions of the Royal Society of Edinburgh*, Vol. 69, 23–70.

OWENS, B. 1980. Palynological report on basal Westphalian samples from Rowanburn Foot Borehole. *Report of the Palaeontological Department, Institute of Geological Sciences*. PDL/80/224.

OWENS, B, and BURGESS, I C. 1965. The stratigraphy and palynology of the Upper Carboniferous outlier of Stainmore, Westmorland. *Bulletin of the Geological Survey of Great Britain*, No. 23, 17–44.

Owens, B, Riley, N J, and Calver, M A. 1985. Boundary stratotypes and new stage names for the lower and middle Westphalian sequences in Britain. *Compte Rendu - Dixieme congres international de stratigraphie et de geologie du Carbonifere*. Madrid, Spain. September 12–17, 1983.

Pallister, J W. 1952. The Birrenswark Lavas, Dumfriesshire. *Transactions of the Edinburgh Geological Society*, Vol. 14, 336–348.

Parkinson, D. 1926. The faunal succession in the Carboniferous Limestone and Bowland Shales at Clitheroe and Pendle Hill, Lancashire. *Quarterly Journal of the Geological Society of London*, Vol. 82, 188–249.

Paterson, I B, and Hall, I H S. 1986. Lithostratigraphy of the late Devonian and early Carboniferous rocks in the Midland Valley of Scotland. *Report of the British Geological Survey*, Vol. 8, No. 3.

Paterson, I B, Hall, I H S, and Stephenson, D. 1990. Geology of the Greenock district. *Memoir of the British Geological Survey*, Sheet 30W part 29E (Scotland).

Pattison, J. 1990. Geology of the Orton and Sunbiggin Tarn districts: 1:10 000 sheets NY60NW and NE. *British Geological Survey Technical Report*, WA/90/12.

Peach, B N, and Horne, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the North of England and Central Scotland. *Transactions of the Royal Society of Edinburgh*, Vol. 40, 835–877.

Phillips, E R, and Browne, M A E. 2000. Mineralogy and petrology of a suite of sedimentary and igneous rocks from the Salsburgh Number 1 Test Well, Scotland. *British Geological Survey Short Report*, MPSR/00/12.

Phillips, E R, and Macpherson, K A T. 1996. Petrology, geochemistry and classification of the Clyde Plateau Volcanic Formation, Kilmarnock district (Sheet 22), Midland Valley, Scotland. *British Geological Survey Technical Report*, WG/96/24.

Phillips, J. 1836. *Illustrations of the geology of Yorkshire. Part 2 The Mountain Limestone Distric*t. (London: John Murray).

Picken, G S. 1988. The concealed coalfield at Canonbie: an interpretation based on boreholes and seismic surveys. *Scottish Journal of Geology*, Vol. 24, 61–71.

Powell, J H, Chisholm, J I, Bridge, D M, Rees, J G, Glover, B W, and Besly, B M. 2000. Stratigraphical framework for Westphalian to early Permian red-bed successions of the Pennine Basin. *British Geological Survey Technical Report*, WA/99/101.

Price, D, Wright, W B, Jones, R C B, and Whitehead, T H. 1963. Geology of the country around Preston. *Memoirs of the Geological Survey of Great Britain*, Sheet 75 (England and Wales).

Pringle, J, and Richey, J E. 1931. Carboniferous rocks of the Thornhill Basin, Dumfriesshire. 25–33 in Summary of Progress of the Geological Survey of Great Britain for 1930. (London: His Majesty's Stationary Office.)

Ramsbottom, W H C. 1955. Unpublished palaeontological report on boreholes NY01NE 8 and 9. British Geological Survey.

Ramsbottom, W H C. 1973. Transgressions and regressions in the Dinantian: a new synthesis of British Dinantian stratigraphy. *Proceedings of the Yorkshire Geological Society*, Vol. 39, 567–607.

Ramsbottom, W H C. 1977a. Major cycles of transgression and regression (mesothems) in the Namurian. *Proceedings of the Yorkshire Geological Society*, Vol. 41, 261–291.

Ramsbottom, W H C. 1977b. Correlation of the Scottish Upper Limestone Group (Namurian) with that of the North of England. *Scottish Journal of Geology*, Vol. 13, 327–330.

Ramsbottom, W H C. 1978. Namurian. 178–180 in The geology of the Lake District. Moseley, F (editor). *Occasional Publication of the Yorkshire Geological Society*, No. 3.

Ramsbottom, W H C. 1981. Fieldguide to the boundary stratotypes of the Carboniferous stages in Britain. Biennial Meeting of the Subcommisson of Carboniferous Stratigraphy, Leeds.

Ramsbottom, W H C, Calver, M A, Eagar, R M C, Hodson, F, Holliday, D W, Stubblefield, C J, and Wilson, R B. 1978. A correlation of Silesian rocks in the British Isles. *Geological Society of London Special Report*, No. 10.

Rawson, P F, Allen, P M, Bevins, R E, Brenchley, P J, Cope, J C W, Evans, J A, Gale, A S, Gibbard, P L, Gregory, F J, Hesselbo, S P, Marshall, J E A, Knox, R W O'B, Oates, M J, Riley, N J, Rushton, A W A, Smith, A G, Trewin, N H, and Zalasiewicz, J A. 2002. Stratigraphical Procedure. *Geological Society of London*, Professional Handbook.

Read, W A. 1965. Shoreward facies changes and their relation to cyclical sedimentation in part of the Namurian east of Stirling, Scotland. *Scottish Journal of Geology*, Vol. 1, 69–92.

Read, W A. 1981. Facies breaks in the Scottish Passage Group and their possible correlation with the Mississipian–Pensylvanian hiatus. *Scottish Journal of Geology*, Vol. 17, 295–300.

Read, W A. 1988. Controls on Silesian sedimentation in the Midland Valley of Scotland. 222–241 in *Sedimentation in a synorogenic basin complex: The Upper Carboniferous of northwest Europe*. Besley, B M and Kelling, G (editors). (Glasgow and London: Blackie.)

Read, W A, and Johnson, S R H. 1967. The sedimentology of sandstone formations within the Upper Old Red Sandstone and lowest Calciferous Sandstone Measures west of Stirling, Scotland. *Scottish Journal of Geology*, Vol. 3, 242–267.

Read, W A, Browne, M A E, Stephenson, D, and Upton, B G J. 2002. Carboniferous. 251–299 in *The Geology of Scotland* (4th edition). Trewin, N H (editor). (London: The Geological Society.)

Rees, J G, and Wilson, A A. 1998. Geology of the country around Stoke on Trent. *Memoir of the British Geological Survey*, Sheet 123 (England and Wales).

Richey, J E. 1928. The north Ayrshire sequence of Calciferous Sandstone volcanic rocks. *Transactions of the Geological Society of Glasgow*. Vol. 18, 247–255.

Richey, J E, Anderson, E M, and MacGregor, A G. 1930. The geology of north Ayrshire. *Memoir of the Geological Survey of Great Britain*, Sheet 22 (Scotland).

Riley, N J. 1990. Stratigraphy of the Worston Shale Group (Dinantian), Craven Basin, North West England. *Proceedings of the Yorkshire Geological Society*, Vol. 48, 163–187.

Riley, N J. 1993. Dinantian (Lower Carboniferous) biostratigraphy and chronostratigraphy in the British Isles. *Journal of the Geological Society of London*, Vol. 150, 427–446.

Riley, N J, Claoué-Long, J C, Higgins, A C, Owens, B, Spears, A, Taylor, L, and Varker, W J. 1995. Geochronometry and geochemistry of the European mid-Carboniferous boundary global stratotype proposal, Stonehead Beck, North Yorkshire, UK. *Annales de la Société géologique de Belgique*, Vol. 116, 275–289.

Rose, W C C, and Dunham, K C. 1977. Geology and hematite deposits of South Cumbria. *Economic Memoir of the Geological Survey of Great Britain*, Sheet 58, part 48 (England and Wales).

Rowley, C R. 1969. The stratigraphy of the Carboniferous Middle Limestone Group of West Edenside, Westmorland. *Proceedings of the Yorkshire Geological Society*, Vol. 37, 329–350.

Scotese, C R, and McKerrow, W S. 1990. Revised World maps and introduction. 1–21 in Palaeozoic Palaeogeography and Biogeography. McKerrow, W S, and Scotese, C R (editors). *Geological Society of London Memoir*, No. 12.

Scott, A C. 1976. Environmental control of Westphalian plant assemblages from northern Britain. Unpublished PhD thesis, University of London.

Scrutton, C (editor). 1995. *Northumbrian Rocks and Landscape: a Field Guide*. (Maryport: Ellenbank Press for the Yorkshire Geological Society.)

SIMPSON, J B, and MACGREGOR, A G. 1932. The economic geology of the Ayrshire coalfields, Area IV. *Memoir of the Geological Survey* (Scotland).

SIMPSON, J B, and RICHEY, J E. 1936. The geology of the Sanquhar coalfield and adjacent basin of Thornhill. *Memoir of the Geological Survey of Great Britain*, Sheets part 9 and 15 (Scotland).

SMITH, R A. 1996. Geology of the Gass Water area. *British Geological Survey Report*, WA/96/22.

SMITH, R A. 1999. Geology of the New Cumnock district. *Sheet description of the British Geological Survey*, Sheet 15W (Scotland).

SMITH, R A, STEPHENSON, D, and MONRO, S. 1994. The geological setting of the southern Bathgate Hills, West Lothian, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*. Vol. 84, 189–196.

SMITH, T E. 1967. A preliminary study of sandstone sedimentation in the Lower Carboniferous of the Tweed basin. *Scottish Journal of Geology*, Vol. 3, 282–305.

SOWERBUTTS, A A. 1999. Geology of the Dunure, Carrick Hills and Heads of Ayr area. *British Geological Survey Technical Report*, WA/99/102.

STABBINS, R. 1969. The depositional history of the Lower Carboniferous rocks of West Cumberland. Unpublished PhD thesis, University of London.

STEPHENS, J V, MITCHELL, G H, and EDWARDS, W. 1953. Geology of the country between Bradford and Skipton. *Memoir of the Geological Survey of Great Britain*, Sheet 69 (England and Wales).

STEPHENSON, D, LOUGHLIN, S C, MILLWARD, D, WATERS, C N, and WILLIAMSON, I T. 2003. Carboniferous and Permian Igneous Rocks of Great Britain North of the Variscan Front. *Geological Conservation Review Series*, No. 27. (Peterborough: Joint Nature Conservation Committee.)

STEPHENSON, M H, WILLIAMS, M, MONAGHAN, A, ARKLEY, S, and SMITH, R A. 2002. Biostratigraphy and palaeoenvironments of the Ballagan Formation (lower Carboniferous) in Ayrshire. *Scottish Journal of Geology*, Vol. 38, 93–111.

STEPHENSON, M H, MILLWARD, D, LENG, M J, and VANE, C H. 2008. Palaeoecological and possible evolutionary effects of early Namurian (Serpukhovian, Carboniferous) glacioeustatic cyclicity. *Journal of the Geological Society of London*, Vol. 165, 993–1005.

STEVENSON, I P, and GAUNT, G D. 1971. The geology of the country around Chapel-en-le-Frith. *Memoir of the Geological Survey of Great Britain*, Sheet 99 (England and Wales).

STONE, P. 1995. Geology of the Rhins of Galloway district. *Memoir of the British Geological Survey*, Sheet 1 and 3 (Scotland).

STUBBLEFIELD, C J, and TROTTER, F M. 1957. Divisions of the Coal Measures on Geological Survey maps of England and Wales. *Bulletin of the Geological Survey of Great Britain*, No. 13, 1–5.

TAIT, A M. 1973. Sedimentation of the Craigmaddie Muir Sandstone Formation, western Midland Valley of Scotland. Unpublished PhD thesis, University of Glasgow.

TAYLOR, B J, BURGESS, I C, LAND, D H, MILLS, D A C, SMITH, D B, and WARREN, P T. 1971. British regional geology: northern England (4th edition). (London: HMSO for Institute of Geological Sciences.)

TOMKEIEFF, S. 1931. Lower Carboniferous igneous rocks. *Proceedings of the Geologists' Association*, Vol. 42, 259–261.

TROTTER, F M, and HOLLINGWORTH, S E. 1932. The geology of the Brampton district. *Memoir of the Geological Survey of Great Britain*, Sheet 18 (England and Wales).

TRUEMAN, A E, and WEIR, J. 1946. A monograph of British Carboniferous nonmarine lamellibranchia. *Palaeontographical Society*, London, monograph.

TULLOCH, W, and WALTON, H S. 1958. The geology of the Midlothian coalfield. *Memoir of the Geological Survey of Great Britain* (Scotland).

TURNER, J S. 1927. The Lower Carboniferous succession in the Westmorland Pennines and the relation of the Pennine and Dent faults. *Proceedings of the Geologists' Association*, Vol. 38, 339–374.

TURNER, J S. 1950. Notes on the Carboniferous Limestone of Ravenstonedale, Westmorland. *Transactions of the Leeds Geological Association*, Vol. 6, 124–134.

TURNER, J S. 1959. Pinskey Gill Beds in the Lune Valley, Westmorland and Ashfell Sandstone in Garsdale, Yorkshire. *Transactions of the Geological Association*, Vol. 7, 78–87.

TYRELL, G W. 1928. The Geology of Arran. Memoir of the Geological Survey of Great Britain, Arran Special Sheet, Sheets 13 and 21, (Scotland).

VARKER, W J, and HIGGINS, A C. 1979. Conodont evidence for the age of the Pinskey Gill Beds of Ravenstonedale, north-west England. *Proceedings of the Yorkshire Geological Society*, Vol. 42, 357–369.

VARKER, W J, and SEVASTOPULO, G D. 1985. The Carboniferous System: Part 1 — conodonts of the Dinantian Subsystem from Great Britain and Ireland. 167–209 in *A Stratigraphical Index of Conodonts*. HIGGINS, A C, and AUSTIN, R L (editors). (Chichester: Ellis Horwood Limited for the British Micropalaeontological Society).

VAUGHAN, A. 1905. The palaeontological sequence in the Carboniferous Limestone of the Bristol area. *Quarterly Journal of the Geological Society of London*, Vol. 61, 181–307.

WADGE, A J, BATESON, J H, and EVANS, A D. 1983. Mineral reconnaissance surveys in the Craven Basin. *Institute of Geological Sciences Mineral Reconnaissance Programme Report*, Vol. 66, 1–100.

WAGNER, R H. 1966. On the presence of probable Upper Stephanian beds in Ayrshire, Scotland. *Scottish Journal of Geology*, Vol. 2, 122–123.

WAGNER, R H. 1983. A lower Rotliegend flora from Ayrshire. *Scottish Journal of Geology*, Vol. 19, 135–155.

WALKER, R G. 1966. Shale Grit and Grindsow Shales: Transition from turbidite to shallow water sediments in the Upper Carboniferous of Northern England. *Journal of Sedimentary Petrology*, Vol. 36, 90–114.

WALTHAM, A C. 1971. Shale units in the Great Scar Limestone of the southern Askrigg Block. *Proceedings of the Yorkshire Geological Society*, Vol. 38, 285–292.

WARD, J. 1997. Early Dinantian evaporites of the Easton-1 well, Solway Basin, onshore Cumbria, England. 277–296 in Petroleum geology of the Irish Sea and adjacent areas. MEADOWS, N S, TRUEBLOOD, S P, HARDMAN, M, and COWAN, G (editors). *Geological Society of London Special Publication*, No. 124.

WATERS, C N. 1999. Geology of the Bradford district. *Sheet description of the British Geological Survey*, Sheet 69 (England and Wales).

WATERS, C N, GLOVER, B W, and POWELL, J H. 1994. Structural synthesis of S Staffordshire, UK: implications for the Variscan evolution of the Pennine Basin. *Journal of the Geological Society of London*, Vol. 151, 697–713.

WATERS, C N, BROWNE, M A E, DEAN, M T, and POWELL, J H. 2007. Lithostratigraphical framework for Carboniferous successions of Great Britain (Onshore). *British Geological Survey Research Report*, RR/07/01.

WATERS, C N, WATERS, R A, BARCLAY, W J, and DAVIES, J R. 2009. BGS Stratigraphical framework for Carboniferous successions of Southern Great Britain (Onshore). *British Geological Survey Research Report*, RR/09/01.

WHITEHURST, J. 1778. An enquiry into the original state and formation of the earth. London.

WHYTE, F. 1964. The Heads of Ayr vent. *Transactions of the Geological Society of Glasgow*, Vol. 25, 72–97.

WHYTE, F. 1992. Heads of Ayr. In LAWSON, J D, and WEEDON, W S (editors). *Geological excursions around Glasgow and Girvan*. (Glasgow: the Geological Society of Glasgow.)

Whyte, F, and Macdonald, J G. 1974. Lower Carboniferous vulcanicity in the northern part of the Clyde plateau. *Scottish Journal of Geology*, Vol. 10, 187–198.

Whyte, F, and Macdonald, J G. 1975. The lower Carboniferous rocks of the Campsie–Kilpatrick area. *Scottish Journal of Geology*. Vol. 11, 364–365.

Wignall, P B, and Maynard, J R. 1996. High-resolution sequence stratigraphy in the early Marsdenian (Namurian, Carboniferous) of the central Pennines and adjacent areas. *Proceedings of the Yorkshire Geological Society*, Vol. 51, 127–140.

Wilson, A A. 1977. The Namurian Rocks of the Fewston Area. *Transactions of the Leeds Geological Association*, Vol. 9, 1–44.

Wilson, A A, and Cornwell, J D. 1982. The Institute of Geological Sciences Borehole at Beckermonds Scar, North Yorkshire. *Proceedings of the Yorkshire Geological Society*,Vol. 44, 59–88.

Wilson, A A, and Thompson, A T. 1965. The Carboniferous succession in the Kirkby Malzeard area, Yorkshire. *Proceedings of the Yorkshire Geological Society*, Vol. 35, 203–227.

Wilson, H H. 1952. The Cove Marine Bands in East Lothian and their relation to the Ironstone Shale and Limestone of Redesdale, Northumberland. *Geological Magazine*, Vol. 89, 305–319.

Wilson, R B. 1967. A study of some Namurian marine faunas of central Scotland. *Transactions of the Royal Society of Edinburgh*, Vol. 66, 445–490.

Wilson, R B. 1974. A study of the Dinantian marine faunas of South-East Scotland. *Bulletin of the Geological Survey of Great Britain*, No. 46, 35–65.

Wilson, R B. 1989. A study of the Dinantian marine macrofossils of central Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, Vol. 80, 91–126.

Woolacot, D. 1923. A boring at Roddymoor Colliery, near Crook, Co. Durham. *Geological Magazine*, Vol. 60, 50–62.

Wright, W B, Sherlock, R L, Wray, D A, Lloyd, W, and Tonks, L H. 1927. The Geology of the Rossendale Anticline. *Memoir of the Geological Survey of Great Britain*.

Young, B. 1998. The Liddesdale Group of 1:50 000 scale sheet 14 (Morpeth): lithostratigraphy and local details. *British Geological Survey Technical Report*, WA/98/09.

Young, B, and Boland, M P. 1992. Geology and land-use planning: Great Broughton–Lamplugh area, Cumbria. *British Geological Survey Technical Report*, WA/92/54.

Young, B, and Lawrence, D J D. 1998. The Morpeth Group of 1:50 000 scale Sheet 14 (Morpeth): lithostratigraphy and local details. *British Geological Survey Technical Report*, WA/98/10.

Young, B, and Lawrence, D J D. 2002. Geology of the Morpeth district. *Sheet description of the British Geological Survey*, Sheet 14 (England and Wales).

Young, S W. 1867a. On the Ballagan series of rocks. *Transactions of the Geological Society of Glasgow*, Vol. 2, 209–212.

Young, S W. 1867b. On the presence of magnesia in rocks. *Transactions of the Geological Society of Glasgow*, Vol. 2, 64–68.

Appendix 1 Alphabetical listing of lithostratigraphical units

Alphabetical listing of lithostratigraphical units (by group) and their BGS Lexicon of Named Rock Units computer codes (where allocated).

Definitive information about all the lithostratigraphical units listed below can be found in the BGS Lexicon of Named Rock Units, accessible on the BGS website at http://www.bgs.ac.uk/lexicon (see also Appendices 2 and 3).

Supergroup	Group	Formation	Member
No relationship	Bathgate (BATH)	Bathgate Hills Volcanic (BHV)	
		Kinghorn Volcanic (KNV)	
		Salsburgh Volcanic (SALV)	
	Border (BDR)	Fell Sandstone (FELL)	Gillfoot Sandstone (GISD)
			Powillimount Sandstone (POSD)
			Rascarrel (RASC)
		Lyne (LYNE)	Bewcastle (BWCB)
			Cambeck (CMBB)
			Easton Anhydrite
			Lynebank (LYN)
			Main Algal (MAN)
			Southerness Limestone (SOLM)
	Clackmannan (CKN)	Enterkin Mudstone (ENT)	
		Limestone Coal (LSC)	Black Metals (BKME)
			Kilbirnie Mudstone (KLMD)
		Lower Limestone (LLGS)	
		Passage (PGP)	Ayrshire Bauxitic Clay (ABC)
			Townburn Sandstone (TWN)
			Troon Volcanic (TVL)
		Upper Limestone (ULGS)	
	Craven (CRAV)	Bowland Shale (BSG)	Scarlett Point (SCPT)
			Scarlett Volcanic (SCV)
		Hodderense Limestone (BOH)	
Carboniferous Limestone (CL)	Great Scar Limestone (GSCL)	Ashfell Limestone (AFL)	
		Ashfell Sandstone (AFS)	
		Balladoole (BOOL)	
		Breakyneck Scar Limestone (BRE)	
		Brownber (BNBF)	
		Chapel House Limestone (CHPL)	
		Coldbeck Limestone (CLK)	
		Cracoe Limestone (CCOE)	
		Dalton (DLB)	
		Danny Bridge Limestone (DBL)	
		Derbyhaven (DBH)	Sandwick (Isle of Man) (SWIK)
			Skillicore (SKIL)
			Turkeyland (TURK)
		Eskett Limestone (ESKT)	
		Fawes Wood Limestone (FWL)	

Supergroup	Group	Formation	Member
Carboniferous Limestone (CL)		Frizington Limestone (FRLI)	
		Garsdale Limestone (GAL)	
		Kilnsey (KLSL)	Scaleber Force Limestone (SFLM)
			Scaleber Quarry Limestone (SQLM)
		Knipe Scar Limestone (KNL)	
		Knockrushen (KNRN)	
		Malham (MALM)	Cove Limestone (CVLS)
			Gordale Limestone (GDLL)
		Martin Limestone (MTL)	
		Melmerby Scar Limestone (MEL)	
		Park Limestone (PKL)	
		Potts Beck Limestone (PBK)	
		Red Hill Limestone (RHO)	
		Scandal Beck Limestone (SCBL)	Coupland Syke Limestone (COSL)
			Park Hill Limestone (PAL)
		Tom Croft Limestone (TCL)	
		Urswick Limestone (UL)	
No relationship	Inverclyde (INV)	Ballagan (BGN)	Drumwhirn (DRWN)
			Kirkbean Cementstone (KICM)
			Lindsayston Burn (LSBU)
			Orroland (ORR)
			Wall Hill (WLH)
		Birrenswark Volcanic (BIRV)	
		Cottonshope Volcanic (COVO)	
		Clyde Sandstone (CYD)	Ascog (ASO)
			Broadlee Glen Sandstone (BRLG)
			Eileans Sandstone (ELN)
			Gourock Sandstone (GKA)
			Knocknairshill (KKS)
			Laggantuin Cornstone (LGT)
			Millport Cornstones (MLC)
			Millstone Point Sandstone (MPS)
			Overtoun Sandstone (OVS)
		Kelso Volcanic (KT)	
		Kinnesswood (KNW)	Doughend Sandstone (DHS)
			Foulport Mudstone (FMN)
			West Bay Cornstone (WBC)
		Roddam Dene Conglomerate (RDCO)	
	Millstone Grit (MG)	Hebden (HEBD)	
		Marsden (MARSD)	
		Pendleton (PENDL)	Pendle Grit
		Rossendale (ROSSE)	
		Samlesbury (SAML)	
		Silsden (SILS)	
	Ravenstonedale (RVS)	Langness Conglomerate (LNCO)	
		Penny Farm Gill (PFD)	
		Pinskey Gill (PNKG)	
		Raydale Dolostone (RDO)	
		Shap Village Limestone (SHVI)	

Supergroup	Group	Formation	Member
No relationship	Ravenstonedale (RVS)	Stone Gill Limestone (STE)	
		Cockermouth Volcanic (CKML)	
		Marsett (MASA)	Duddon Conglomerate (DUCO)
Coal Measures	Pennine Coal Measures (PCM)	Pennine Lower Coal Measures (PLCM)	
		Pennine Middle Coal Measures (PMCM)	
		Pennine Upper Coal Measures (PUCM)	
	Scottish Coal Measures (CMSC)	Scottish Lower Coal Measures (LCMS)	
		Scottish Middle Coal Measures (MCMS)	
		Scottish Upper Coal Measures (UCMS)	
No relationship	Strathclyde (SYG)	Aberlady (ABY)	
		Anstruther (ARBS)	Charles Hill Volcanic (CHVO)
		Arthur's Seat Volcanic (ASV)	
		Birgidale (BID)	
		Clyde Plateau Volcanic (CPV)	Auchineden Lava
			Baston Burn Lava
			Beith Lava
			Black Mount Lava
			Boyd's Burn Lava
			Burncrooks Volcaniclastic
			Burnhouse Lava
			Campsie Lava
			Carbeth Lava
			Carron Bridge Lava
			Cochno Lava
			Corrie Lava
			Craigdouffie Lava
			Craigentimpin Lava
			Cringate Volcaniclastic
			Darvel Lava
			Denny Muir Lava
			Drumnessie Lava
			Dumdruff Hill Lava (DHLA)
			Eaglesham Lava
			Faughlin Lava
			Fereneze Lava
			Fin Glen Lava
			Fintry Hills Lava
			Gargunnock Hills Lava
			Garvald Lava
			Glenburn Volcaniclastic (GBV)
			Gleniffer Lava
			Gowk Stane Volcaniclastic (GOWK)
			Greenan Castle Pyroclastic (GCP)

Supergroup	Group	Formation	Member
No relationship	Strathclyde (SYG)	Clyde Plateau Volcanic (CPV)	Greenside Volcaniclastic
			Greeto Lava
			Harelaw Lava
			Holehead Lava
			Kilbarchan Lava
			Kilsyth Hills Lava
			Knowehead Lava
			Laird's Hill Lava
			Laird's Loup Lava
			Langhill Lava
			Largs Lava
			Lees Hill Lava
			Loup of Fintry Lava
			Lower Flow Moss Lava
			Lower Lecket Hill Lava
			Marshall Moor Lava
			Misty Law Trachytic
			Moyne Moor Lava (MMLA)
			Mugdock Lava
			Neilston Lava (NNLA)
			Noddsdale Volcaniclastic
			North Campsie Pyroclastic
			Overton Lava
			Sargeantlaw Lava
			Saughen Braes Lava
			Shelloch Burn Lava
			Skiddaw Lava
			Slackdown Lava
			Slackgun Volcaniclastic
			Spout of Ballochleam Lava
			Strathgryfe Lava
			Stronend Volcaniclastic
			Tambowie Lava
			Tappetknowe Lava
			Touch House Lava
			Upper Flow Moss Lava
			Upper Lecket Hill Lava
		Fife Ness (FNB)	
		Garleton Hills Volcanic (GHV)	Bangley Trachytic (BYTRC)
			East Linton Lava (ELLA)
			Hailes Lava (HSLA)
			North Berwick Pyroclastic (NBPY)
		Gullane (GUL)	
		Kirkwood (KRW)	
		Laggan Cottage Mudstone (LNT)	

Supergroup	Group	Formation	Member
No relationship		Lawmuir (LWM)	Craigmaddie Muir Sandstone (CRMS)
			Douglas Muir Quartz-Conglomerate (DMQ)
		Pathhead (PDB)	
		Pittenweem (PMB)	
		Sandy Craig (SCB)	
		West Lothian Oil-Shale (WLO)	Calders (CDE)
			Hopetoun (HON)
	No relationship	Stockdale Farm (STFA)	
	Warwickshire (WAWK)	Becklees Sandstone	
		Canonbie Bridge Sandstone	
		Eskbank Wood	
		Whitehaven Sandstone (WS)	Bransty Cliff Sandstone (BYCS)
			Millyeat (MYTB)
	Yoredale (YORE)	Alston (AG)	Askham Limestone (ASKL)
			Eelwell Limestone (EWL)
			Five Yard Limestone (FYL)
			Four Fathom Limestone (FFL)
			Great Limestone (GL)
			Jew Limestone (JWL)
			Oxford Limestone (OXL)
			Scar Limestone (SCL)
			Three Yard Limestone (TYL)
			Tynebottom Limestone (TBL)
		Closeburn Limestone (CLO)	
		Stainmore (SMGP)	
		Tyne Limestone (TYLS)	Arbigland Limestone (ARLM)
			Dun Limestone (DNL)
			Wintertarn Sandstone (WTRS)

Appendix 2 BGS Lexicon of Named Rock Units computer codes

BGS Lexicon of Named Rock Units computer codes and lithostratigraphical beds shown in Figures 6 and 8, and any Lower Palaeozoic lithostratigraphical units referred to.

Key: Fm-Formation; L=Lower; Lst=Limestone; M=Middle; MB = Marine Band; Sst = Sandstone; U = Upper.

Lexicon code	Bed (unless otherwise stated)
AGMB	Aegiranum MB
AKB	Archerbeck Beds
AMMB	Amaliae MB
AOB	Archerbeck Ochre Bed
APL	Appletree Lst
ASKL	Askham Lst
BARL	Barrasford Lst
BGSL	Bogside Lst
BHGL	Brainshaugh Lst
BMET	Black Metals MB
BNKL	Bankhouses Limestones
BPLS	Blae Pot Lst
BRDL	Bridge Lst
BSDL	Belsay Dene Lst
BTL	Barrock Top Lst
BUBE	Burns Beds
BULS	Burdiehouse Lst
BZB	Bryozoa Band
CALS	Callant Lst
CAMB	Cambriense MB
CAS	Castlecary Lst
CBLM	Cawledge Bend Lst
CEBS	Carlyle Beds
CFL	Common Flat Lst
CGLM	Crag Lst
CHMB	Cockhill MB
CHML	Carham Lst
CMB	Colsterdale Marine Beds
CORL	Corbridge Lst
CROL	Crow Lst
CSL	Cockleshell Lst
CTB	Clattering Band
CUL	Cushat Lst
CWELL	Colwell Lst
CWMB	Clown MB
DDL	Duddo Lst
DIB	Dinwoodie Beds
DNL	Dun Lst
DNML	Denton Mill Lst
DPL	Dunkpool Lst
DSL	Desoglin Lst
DTNL	Dalton Lst
E1A1	*Cravenoceras leion* MB
E2A1	*Cravenoceras cowlingense* MB
EMMB	Edmondia MB
ESL	Ellery Syke Lst
FENL	Fenwick Lst
FLL	Fourlaws Lst
G1A1	*Cancelloceras cancellatum* MB
G1B1	*Cancelloceras cumbriense* MB
GGL	Greengate Well Lst
GNWL	Greenhow Lst
GUMB	Gubeon MB
GV	Glencartholm Volcanic Beds
GVB	*Girvanella* Nodular Band
GYL	Gayle Lst
H1B1	*Homoceras beyrichianum* MB
HAMB	Harvey MB
HGEL	Hargate End Lst
HGLS	Hogg Lst
HLAB	Hillend Algal Band
HMMB	High Main MB
HNB	Harden Beds
HNMB	Honley MB
HSCL	Hardraw Scar Lst
HTMB	Haughton MB
HUR	Hurlet Lst
HWL	Hawes Lst
HYMB	Hylton MB
ILS	Index Lst
IPL	Iron Post MB
ISMB	*Isohomoceras subglobosum* MB
KBL	Kingbridge Lst
KHB	Kershopefoot basalts
KLMB	Kays Lea MB
KMB	Kirkby’s MB
KMMB	Knottyholm MB
KTLS	Kinmont Lst
LANL	Lanercost Lst
LAQB	L *Antiquatonia* Band
LARS	Larriston Sst Beds
LBWL	L Bath-house Wood Lst
LCRT	Low Carriteth Lst
LDML	L Demesne Lst
LFTL	L Felltop Lst;
LGFLL	L Gunnerton Fell Lst
LGLL	Lad Gill Lst
LGMB	Langley MB
LHL	Leahill Lst

LKL	Lickar Lst
LLLM	L Little Lst
LM1	First Lst
LM2	Second Lst
LM3	Third Lst
LM4	Fourth Lst
LM5	Fifth Lst
LM6	Sixth Lst
LM7	Seventh Lst
LMIL	L Millerhill Lst
LNN	Lonan Formation (Ordovician)
LOCH	L Camphill Lst
LOL	L Oakwood Lst
LOMB	Lowstone MB
LSMB	Listeri MB
LSRL	Little Strickland Lst
LSTL	L Stonesdale Lst
LTL	Low Tipalt Lst
LTLS	Little Lst
LTMB	Little MB
LWSL	Lawston Lst
MANX	Manx Group (Ordovician)
MDL	Middle Lst
MFC	Mell Fell Conglomerate (Devonian)
MIL	Millerhill Lst
MKFG	Mirk Fell Ganister
MKFI	Mirk Fell Ironstone
MTMB	Maltby MB
NL	Naworth Lst
NWBB	Naworth Bryozoa Band
NWL	Newton Lst
NWNL	Netherwitton Lst
OKL	Oakwood Lst
OKSS	Oakshaw Sst
ORS	Old Red Sst Supergroup (Devonian)
PCL	Piper's Cross Lst
PFLS	Penchford Lst
PGL	Peghorn Lst
PHL	Pike Hill Lst
PILS	Pigdon Lst
PLDL	Plashetts Dun Lst
PNLS	Penton Lst
QBMB	Quarterburn MB
QMB	Queenslie MB
RBLL	Redhouse Burn L Lst
RBML	Redhouse Burn M Lst
RBUL	Redhouse Burn U Lst
RDL	Redesdale Lst
RGL	Raughton Gill Lst
RLM	Rough Lst
RNL	Robinson Lst
RSMB	Riddings MB
RTMB	Rowanburnfoot MB
RWNL	Rawney Lst
RYMB	Ryhope MB
SBMB	Subcrenatum MB
SCMB	St Andrew's Castle MB
SCOT	Scott Beds
SCSL	Stump Cross Lst
'SDV'	'St Davids Volcanic Beds'
SFMB	Shafton MB
SHL	Spy Hole Lst
SHMB	Sandwich MB
SHWC	Shap Wells Conglomerate Fm (Devonian)
SIL	Simonstone Lst
SNMB	Skelton MB
SOMB	Sutton MB
SPL	Single Post Lst
STFL	Styford Lst
SUS	Sugar Sands Lst
SWMB	Stobbswood MB
SWOL	Shotto Wood Lst
SWYMB	Solway MB
SXYL	Six Yard Lst
SYGL	*Syringothyris* Lst
THL	Thornborough Lst
THSD	Thirlstane Beds
TMB	Tait's MB
TMBL	Tombstone Lst
TOHO	Top Hosie Lst
UAQB	U *Antiquatonia* Band
UBWL	U Bath-house Wood Lst
UDML	U Demesne Lst
UFTL	U Fell Top Lst
UGFL	U Gunnerton Fell Lst
UMIL	U Millerhill Lst
UOL	U Oakwood Lst
USTL	U Stonesdale Lst
VDMB	Vanderbeckei MB
VMB	Viaduct MB
WBB	Whitberry Band
WBMB	West Braes MB
WDEL	Woodend Lst
WTL	White Lst
WTLL	Watchlaw Lst

Appendix 3 Alphabetical listing of obsolete lithostratigraphical terms

Alphabetical listing of obsolete lithostratigraphical terms mentioned in the text, and the units they are now equivalent to or included within.

For BGS Lexicon of Named Rock Units computer codes see Appendix 1.

Obsolete term:	**Now equivalent to or included within:**
Acre Limestone	Three Yard Limestone Member, Alston Formation
Alston Group	Yoredale Group
Arbigland Limestone Formation	Arbigland Limestone Member, Tyne Limestone Formation
Auchineden Lavas	Auchineden Lava Member, Clyde Plateau Volcanic Formation
Ayrshire Bauxitic Clay Formation	Ayrshire Bauxitic Clay Member, Passage Formation
Bangley Member	Bangley Trachytic Member, Garleton Hills Volcanic Formation
Barren (Coal) Measures	Warwickshire Group
Basal Cementstones	Kirkbean Cementstone Member, Ballagan Formation
Basal Group	Slackdown Member, Clyde Plateau Volcanic Formation
'Basal sandstone'	Drumwhirn Member, Ballagan Formation
Baston Burn Group	Baston Burn Lava Member, Clyde Plateau Volcanic Formation
Bathgate Lavas	Bathgate Hills Volcanic Formation
'bedded agglomerate of Greenan Castle'	Greenan Castle Pyroclastic Member, Clyde Plateau Volcanic Formation
Beith Lavas	Beith Lava Member, Clyde Plateau Volcanic Formation
Bewcastle Beds	Bewcastle Member, Lyne Formation
Beyrichoceras hodderense Bed	Hodderense Limestone Formation
Birdoswald Limestone Group	Tyne Limestone Formation, Yoredale Group
Black Metals	Black Metals Member, Limestone Coal Formation
Black Mount Group	Black Mount Lava Member, Clyde Plateau Volcanic Formation
Blea Tarn Limestones	Breakyneck Scar Limestone Formation
Bowland Shale Group	Bowland Shale Formation
Boyd's Burn Lavas	Boyd's Burn Lava Member, Clyde Plateau Volcanic Formation
Broadlee Glen Sandstones Formation	Broadlee Glen Sandstone Member, Clyde Plateau Volcanic Formation
Bucchleuch Limestone	Four Fathom Limestone Member, Alston Formation
Burncrooks Pyroclastic Member	Burncrooks Volcaniclastic Member, Clyde Plateau Volcanic Formation
Burnhouse Lavas	Burnhouse Lava Member, Clyde Plateau Volcanic Formation
Burntisland Lavas	Kinghorn Volcanic Formation, Bathgate Formation
Carbeth Lavas	Carbeth Lava Member, Clyde Plateau Volcanic Formation
Carboniferous Limestone	Carboniferous Limestone Supergroup
Carboniferous Limestone Series	Clackmannan Group
Carron Bridge Lavas	Carron Bridge Lava Member, Clyde Plateau Volcanic Formation
Catsbit Limestone	Great Limestone Member
Charles Hill Volcanic Beds	Charles Hill Volcanic Member, Anstruther Formation
Chief Limestone Group	Great Scar Limestone Group and Alston Formation (Yoredale Group)

Coal Measures Group	Pennine Coal Measures Group and Scottish Coal Measures Group
Cochno Lavas	Cochno Lava Member, Clyde Plateau Volcanic Formation
Cockermouth Lavas	Cockermouth Volcanic Formation
'Cornstone-bearing beds'	Lindsayston Burn Member, Ballagan Formation
Cornstone Beds	Kinneswood Formation
Corrie Lavas	Corrie Lava Member, Clyde Plateau Volcanic Formation
Cottonshope Lavas	Cottonshope Volcanic Formation
Craigdouffie Lavas	Craigdouffie Lava Member, Clyde Plateau Volcanic Formation
Craigentimpin Lavas	Craigentimpin Lava Member, Clyde Plateau Volcanic Formation
Craigmaddie Sandstone Formation	Craigmaddie Muir Sandstone Member, Lawmuir Formation
Craigmaddie Sandstones	Craigmaddie Muir Sandstone Member, Lawmuir Formation
Crichope Sandstone Member	Townburn Sandstone Member, Passage Group
Darvel Lavas	Darvel Lava Member, Clyde Plateau Volcanic Formation
Denny Muir Lavas	Denny Muir Lava Member, Clyde Plateau Volcanic Formation
Downie's Loop Sandstone Formation	Clyde Sandstone Formation, Inverclyde Group
Drumnessie Lavas	Drumnessie Lava Member, Clyde Plateau Volcanic Formation
Dryburn Limestone	Great Limestone Member, Alston Formation
Dug Head Sandstone Member	Doughend Sandstone Member, Kinnesswood Formation
Dumdruff Hill Lavas	Dumdruff Hill Lava Member, Clyde Plateau Volcanic Formation
Eaglesham Lavas	Eaglesham Lava Member, Clyde Plateau Volcanic Formation
East Linton Member	East Linton Lava Member, Garleton Hills Volcanic Formation
Eight Yard Limestone	Four Fathom Limestone Member, Alston Formation
Faughlin Lavas	Faughlin Lava Member, Clyde Plateau Volcanic Formation
Fereneze Lavas	Fereneze Lava Member, Clyde Plateau Volcanic Formation
Fin Glen Lavas	Fin Glen Lava Member, Clyde Plateau Volcanic Formation
Fintry Hills Group	Fintry Hills Lava Member, Clyde Plateau Volcanic Formation
Five Yard Limestone	Five Yard Limestone Member, Alston Formation
Flow Moss Lavas	Lower and Upper Flow Moss Lava members, Clyde Plateau Volcanic Formation
Four Fathom Limestone	Four Fathom Limestone Member, Alston Formation
Gargunnock Hills Group	Gargunnock Hills Lava Member, Clyde Plateau Volcanic Formation
Garvald Lavas	Garvald Lava Member, Clyde Plateau Volcanic Formation
Gillfoot Sandstone Formation	Gillfoot Sandstone Member, Fell Sandstone Formation
Gleaston Formation	Alston Formation
Glen Park Volcanic Detrital Member	Glenburn Volcaniclastic Member, Clyde Plateau Volcanic Formation
Gleniffer Lavas	Gleniffer Lava Member, Clyde Plateau Volcanic Formation
Grassington Grit Formation	Pendleton Formation
Great Limestone	Great Limestone Member, Alston Formation
Greeto Lavas	Greeto Lava Member, Clyde Plateau Volcanic Formation
Hailes Member	Hailes Lava Member, Garleton Hills Volcanic Formation
Harelaw Lavas	Harelaw Lava Member, Clyde Plateau Volcanic Formation
Harelawhill Limestone	Eelwell Limestone Member, Alston Formation
Hensingham Group	Stainmore Formation
Holehead Lavas	Holehead Lava Member, Clyde Plateau Volcanic Formation
Jew Limestone	Jew Limestone Member, Alston Formation
Kelso Lavas	Kelso Volcanic Formation
Kelso Traps	Kelso Volcanic Formation
Kettlewell Crag Member	Park Limestone Formation

Kilbarchan Lavas	Kilbarchan Lava Member, Clyde Plateau Volcanic Formation
Kilbirnie Mudstone Formation	Kilbirnie Mudstone Member, Limestone Coal Formation
Kilnsey Limestone Member	Scaleber Quarry Limestone Member, Kilnsey Formation
Kilnsey Limestone-with-mudstone Member	Scaleber Force Limestone Member, Kilnsey Formation
Kirkbean Cementstone Formation	Kirkbean Cementstone Member, Ballagan Formation
Knowehead Lavas	Knowehead Lava Member, Clyde Plateau Volcanic Formation
Ladies Wood Limestone	Dun Limestone Member, Tyne Limestone Formation
Laird's Hill Lavas	Laird's Hill Lava Member, Clyde Plateau Volcanic Formation
Laird's Loup Lavas	Laird's Loup Lava Member, Clyde Plateau Volcanic Formation
Lamberton Limestone	Dun Limestone Member, Tyne Limestone Formation
Langhill Lavas	Langhill Lava Member, Clyde Plateau Volcanic Formation
Largs Lavas	Largs Lava Member, Clyde Plateau Volcanic Formation
Lees Hill Group	Lees Hill Lava Member, Clyde Plateau Volcanic Formation
Leswalt Formation	Scottish Coal Measures Group
Limestone Coal Group	Limestone Coal Formation
Loup of Fintry Lavas	Loup of Fintry Lava Member, Clyde Plateau Volcanic Formation
Low Dean Limestone	Four Fathom Limestone Member, Alston Formation
Lower Border Group	Ballagan Formation, Inverclyde Group and Lyne Formation, Border Group
Lower Coal Measures	Pennine Lower Coal Measures Formation and Scottish Lower Coal Measures Formation
Lower Lecket Hill Lavas	Lower Lecket Hill Lava Member, Clyde Plateau Volcanic Formation
Lower Liddesdale Group	Tyne Limestone Formation
Lower Limestone Group	Tyne Limestone Formation and Alston Formation
Lower Limestone Group	Lower Limestone Formation, Clackmannan Group
Lower North Campsie Lavas	Campsie Lava Member, Clyde Plateau Volcanic Formation
Lower South Campsie Lavas	Campsie Lava Member, Clyde Plateau Volcanic Formation
Low Furness Basal Beds	Marsett Formation
Low Furness Basal Formation	Marsett Formation
Lynebank Beds	Lynebank Member, Lyne Formation
Main Algal Limestone Beds	Main Algal Member, Lyne Formation
Main Limestone	Great Limestone Member, Alston Formation
Main Limestone Group	Great Scar Limestone Group
'Marginal reef limestones'	Cracoe Limestone Formation
Marshall Moor Lavas	Marshall Moor Lava Member, Clyde Plateau Volcanic Formation
Michelinia grandis beds	Breakyneck Scar Limestone Formation
Middle Border Group	Fell Sandstone Formation
Middle Coal Measures	Pennine Middle Coal Measures Formation and Scottish Middle Coal Measures Formation
Middle Grit Group	Marsden Formation
Middle Limestone Formation	Alston Formation
Middle Limestone Group	Alston Formation
Millstone Grit Series	Clackmannan Group (undivided)
Misty Law Trachytic Centre	Misty Law Trachitic Member, Clyde Plateau Volcanic Formation
Moyne Moor Lavas	Moyne Moor Lava Member, Clyde Plateau Volcanic Formation
Mugdock Lavas	Mugdock Lava Member, Clyde Plateau Volcanic Formation
Neilston Lavas	Neilston Lava Member, Clyde Plateau Volcanic Formation
Noddsdale Volcaniclastic Beds	Noddsdale Volcaniclastic Member, Clyde Plateau Volcanic Formation
North Berwick Member	North Berwick Pyroclastic Member, Garleton Hills Volcanic Formation

Orroland Formation	Orroland Member, Ballagan Formation
Orton Formation	Frizzington Limestone Formation
Orton Group	Frizzington Limestone Formation
Overton Lavas	Overton Lava Member, Clyde Plateau Volcanic Formation
Overtoun Sandstone Formation	Overtoun Sandstone Member, Clyde Sandstone Formation
Passage Group	Passage Formation
Passage Group (undivided)	Townburn Sandstone Member, Passage Group
Penny Farm Gill Dolomite Formation	Penny Farm Gill Formation
Pinskey Gill Beds	Pinskey Gill Formation
Powillimount Beds	Powillimount Sandstone Member, Fell Sandstone Formation
Powillimount Sandstone Formation	Powillimount Sandstone Member, Fell Sandstone Formation
Rascarrel Formation	Rascarrel Member, Fell Sandstone Formation
'Red Measures'	Warwickshire Group
Roman Fell Beds	Marsett Formation
Roman Fell Sandstones	Marsett Formation
Roman Fell Shales	Marsett Formation
Sandbanks Limestone	Four Fathom Limestone Member, Alston Group
Sandwick Member	Sandwick (Isle of Man) Member, Derbyhaven Formation
Saughen Braes Lavas	Saughen Braes Lava Member, Clyde Plateau Volcanic Formation
Scarlett Beds	Scarlett Point Member, Bowland Shale Formation
Scarlett Volcanic Formation	Scarlett Volcanic Member, Bowland Shale Formation
Scarlett Volcanic Series	Scarlett Volcanic Member, Bowland Shale Formation
Second Limestone	Four Fathom Limestone Member, Alston Formation
Shap Limestone	Shap Village Limestone Formation
Shelloch Burn Group	Shelloch Burn Lava Member, Clyde Plateau Volcanic Formation
Sixth Shale Member	Sixth Limestone, Eskett Limestone Formation
Skiddaw Group	Skiddaw Lava Member, Clyde Plateau Volcanic Formation
Slackgun Interbasaltic Beds	Slackgun Volcaniclastic Member, Clyde Plateau Volcanic Formation
Southerness Beds	Southerness Limestone Member, Lyne Formation
Southerness Limestone Formation	Southerness Limestone Member, Lyne Formation
Spout of Ballochleam Group	Spout of Ballochleam Lava Member, Clyde Plateau Volcanic Formation
Strandhall Beds	Scarlett Point Member, Bowland Shale Formation
Strathgryfe Lavas	Strathgryfe Lava Member, Clyde Plateau Volcanic Formation
Stronend Interbasaltic Beds	Stronend Volcaniclastic Member, Clyde Plateau Volcanic Formation
Tambowie Lavas	Tambowie Lava Member, Clyde Plateau Volcanic Formation
Tappetknowe Lavas	Tappetknowe Lava Member, Clyde Plateau Volcanic Formation
Tarn Sike Limestones	Breakyneck Scar Limestone Formation
Third Limestone	Three Yard Limestone Member, Alston Formation
Thirlstane Sandstone	Powillimount Sandstone Member, Fell Sandstone Formation
Thorney Force Sandstone	Wintertarn Sandstone Member, Alston Formation
Touch House Group	Touch House Lava Member, Clyde Plateau Volcanic Formation
Troon Volcanic Formation	Troon Volcanic Member, Passage Formation
Tyne Bottom Limestone	Tynebottom Limestone Member, Alston Formation
Undersett Limestone	Four Fathom Limestone Member, Alston Formation
Upper Border Group	Tyne Limestone Formation
Upper Bowland Shale Formation	Bowland Shale Formation
Upper Coal Measures Formation	Pennine Upper Coal Measures and Scottish Upper Coal Measures Formation

Upper Lecket Hill Lavas	Upper Lecket Hill Lava Member, Clyde Plateau Volcanic Formation
Upper Liddesdale Group	Alston Formation
Upper Limestone Group	Upper Limestone Formation
Upper *Michelinia* Beds	Skillicore Member, Derbyhaven Formation
Upper North Campsie Lavas	Campsie Lava Member, Clyde Plateau Volcanic Formation
Upper Oil Shale Group	Hopetoun Member, West Lothian Oil-Shale Formation
Upper South Campsie Lavas	Campsie Lava Member, Clyde Plateau Volcanic Formation
Wall Hill Sandstone Formation	Wall Hill Member, Ballagan Formation
Wall Hill Sandstone Group	Wall Hill Member, Ballagan Formation
Wensleydale Group	Yoredale Group