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Lithostratigraphical framework for Carboniferous successions of Great Britain (Onshore)

Research Report RR/07/01

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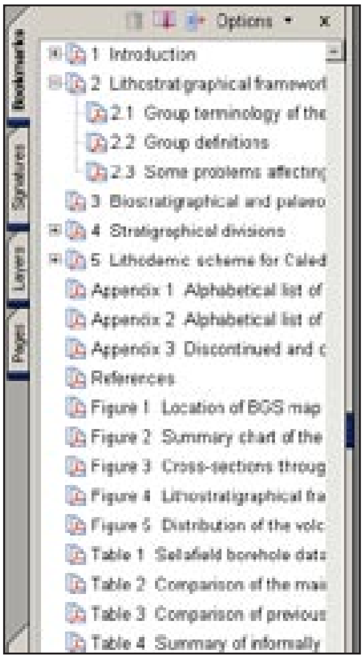

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BRITISH GEOLOGICAL SURVEY

RESEARCH REPORT RR/07/01

Lithostratigraphical framework for Carboniferous successions of Great Britain (Onshore)

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View of Ingleborough
(see p.ii for full caption)

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front cover

Ingleborough from Chapel-le-Dale [SD 7510 7707]. The limestone pavement in the foreground is in the Asbian Danny Bridge Limestone Formation of the Great Scar Limestone Group. The overlying Brigantian Alston Formation of the Yoredale Group forms the lower slopes of the hill. The Main Limestone, the top of which is taken at the top of the Alston Formation, forms the lowermost main crag. The capping of the hill, at 724 m OD, is formed by the Lower Howgate Edge Grit, the unconformable base of which forms the base of the Millstone Grit Group. BGS photograph (P005452) taken in September 1973.

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Preface

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:

1 to review the lithostratigraphical nomenclature of designated stratigraphical intervals for a given region, identifying problems in classification and correlation
2 to propose a lithostratigraphical framework down to formation level
3 to organise peer review of the scheme
4 to present the results in a document suitable for publication
5 to ensure that full definitions of the lithostratigraphical units are held in the web-accessible BGS Stratigraphical Lexicon for the areas of responsibility covered by the SFC.

This report is the published product of a study by the British Geological Survey (BGS) Stratigraphical Framework Committee (SFC) for the Carboniferous of the Great Britain. The report provides a summary of a lithostratigraphical scheme proposed by the SFC that aims to rationalise group and formation nomenclature for the Carboniferous of the entire onshore area of Great Britain. The study draws upon published SFC reports for the Midland Valley of Scotland (Browne et al., 1999) and the red-bed successions of the Pennine Basin (Powell et al., 2000). The report identifies a group framework based upon the identification of nine major lithofacies across Great Britain. Regional group names are proposed, recognising that each lithofacies may have accumulated in more than one isolated depositional area. The report provides guidance to formation nomenclature for each group, indicating 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. The report aims to provide an overview of the framework for the Carboniferous of Great Britain. Subsequent framework reports for Great Britain (North) and Great Britain (South) will provide details of the successions, with full definitions of all formally defined groups and formations.

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

Acknowledgements

This report is the result of much discussion and lively debate within the BGS regarding the formulation of a comprehensive hierarchical lithostratigraphical scheme for the onshore successions of Great Britain. In 1999 Dr Peter Allen (Assistant Director, BGS) requested that the chairmen of the established Stratigraphical Framework Committee, Mike Browne (Midland Valley of Scotland), Nick Riley (Namurian of the Pennines) and Brian Young (Carboniferous of the Scottish Borders and northern England) investigate the possibility of producing a UK wide subdivision of Dinantian and Namurian lithostratigraphy at the group level. Following a meeting held on 11th 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 the main lithofacies types. This proposal forms the basis of the subsequent scheme proposed within this report. This scheme was further modified at meetings held on 12th December 2000 to discuss the lithostratigraphy in the Scottish Borders and northern England, and on 31st January 2001 to discuss the lithostratigraphy of southern Britain. Both meetings were chaired by Robert Knox (BGS Stratigraphy Committee chair). It was accepted that additional expertise was required to complete the lithostratigraphy of southwest England, so a further meeting was held on 21st October 2004. Those attending the three main meetings have been credited as contributors to the report.

The authors of the report acknowledge the contribution of many others in BGS who have offered constructive advice. The comments of Dr John Collinson, Dr Chris Cleal and the external reviewers, Dr Sarah Davies (University of Leicester) and Dr Bernard Besly (Ichron Ltd.) are also acknowledged. Audrey Jackson is thanked for editing the report and Lauren Noakes is thanked for the drafting of the figures.

Summary

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

The economic importance of strata of Carboniferous age has resulted in over 200 years of research and attempts 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, resulting in a plethora of local names. This complexity in nomenclature has, to an extent, hindered the regional understanding of the Carboniferous successions of 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). 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 Great Britain.

The first part of the report describes the evolving palaeogeography of Great Britain throughout the Carboniferous Period. The identification of depositional basins, the presence of intervening ‘uplands’ or emergent areas and a broad understanding of the depositional environments is key to the derivation of the group framework, presented herein. Five main palaeogeographical provinces are defined.

The second part identifies nine principal lithofacies present within the Carboniferous of Great Britain that form the framework for the proposed group nomenclature. A description of the principal lithologies, environment of deposition, age range and distribution are provided.

The third, and largest part of the report, describes the group framework for each of the five palaeogeographical provinces. Examples of formation nomenclature for each group are provided, indicating criteria for rationalisation of existing nomenclature where appropriate. Where formation names have not previously existed, the report proposes a new nomenclature. Subsequent framework reports for Great Britain (North) and Great Britain (South) will provide details of the successions, with full definitions of all formally defined groups and formations.

An appendix (Appendix 1) provides an alphabetical listing of each supergroup, group, subgroup, formation and member respectively, also showing the heirarchical relationship between the lithostratigraphical units.

Appendix 2 summarises the chronostratigraphical framework and biostratigraphical zonations for the carboniferous.

1 Introduction

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

The diverse lithofacies that developed throughout the Carboniferous were also the consequence of tectonic processes. A phase of Late Devonian to early Carboniferous rifting produced a marked palaeorelief with numerous basins occupying subsiding graben and half-graben and emergent highs associated with horsts and tilt-block highs (Leeder, 1982). Cessation of most rifting processes throughout large parts of Great Britain in the Visean was followed by a period of regional subsidence and the resulting basins were infilled by widespread deposits.

1.1 TECTONIC SETTING

1.1.1 Tournaisian–Visean

Southern Britain is postulated by Leeder (1982) to have been located on the northern margin of a Rheno-Hercynian back-arc basin during Devonian time. In the Late Devonian a phase of north–south rifting started to affect all of central and northern Britain, initiating development of a series of graben and half-graben, 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. In south-west England four rift basins formed sequentially northwards during the Devonian, with the youngest and northernmost, the Culm Basin, initiating during the late Famennian.

The Midland Valley of Scotland is an east-north-east-trending graben, about 700 km long and up to 100 km wide, which was initiated during the Late Devonian by the reactivation of pre-existing east-north-east-trending Caledonian structures. 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. The origin of the graben remains controversial with interpretations that include:

- pure shear during east–west tension (Haszeldine, 1984)
- pure shear during Tournaisian to early Visean north–south tension followed by thermal subsidence in the late Visean to Westphalian (Leeder, 1982)
- Early Devonian crustal rifting followed by Late Devonian and Carboniferous thermal subsidence with superimposed dextral strike-slip (Dewey, 1982)

Recent developments suggest that the main influence was sinistral fault movement during the Late Devonian to early Carboniferous and largely dextral thereafter (Browne et al., 2003). Depocentres within the graben subsided at different rates over time, and their location 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 notable during the mid Carboniferous (Read, 1988).

The Southern Uplands separated the Northumberland Trough, including the Tweed and Solway Firth basins, from the Midland Valley of Scotland. However, this was breached by narrow basins of north-north-west trend. The Northumberland Trough was bounded to the north by the North Solway Fault and to the south by the Stublick–Ninety Fathom Fault, both 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 and Visean. The Stainmore Trough, a half-graben basin, lies farther to the south, with the southern margin defined by the Stockdale Monocline. This structure also marks a transition in sedimentation between the basin and the tilt-block of the Askrigg Block to the south. The Manx–Lake District High occurs to the west of the Alston and Askrigg blocks, and separated by a broadly north–south-trending strike-slip Pennine–Dent Fault System. The block areas are associated with development of platform carbonates during the Tournaisian and/or Visean.

The Craven Fault System defines the southern margin of the Askrigg Block. To the south of this fault system the block and basin structures persist, though generally the high subsidence rates created a province dominated by basinal facies. The Craven sub-basin of Lancashire and the Harrogate sub-basin of Yorkshire represent the northern examples of a series of linked narrow embayments. In the south of the basin, the Gainsborough Trough and Widmerpool Gulf are separated by platform carbonate shelves such as the linked East Midlands Shelf and Derbyshire High, and the West Midlands Shelf and Central Pennine High. These shelf areas represent the northern margin of the Wales–Brabant High, which formed a persistent topographical feature throughout the Carboniferous.

Along the southern margin of the Wales–Brabant High there is a gradual change southward from shelf/ramp carbonates into a deep marine succession of the North Devon Basin of north Devon and Culm Basin of north Cornwall and southern and central Devon. The Culm Basin evolved as a central graben flanked by half-graben sub-basins to the north and south. By the Late Devonian, continental collision resulted in the commencement of Hercynian compressional deformation. The deformation commenced with closure of the most southerly Gramscatho Basin (Leveridge et al., 1990); the deformation front migrated northwards during the Tournaisian and Visean (Selwood and Thomas, 1988), with progressive closure, inversion and deformation of the Looe, South Devon and Tavy basins.

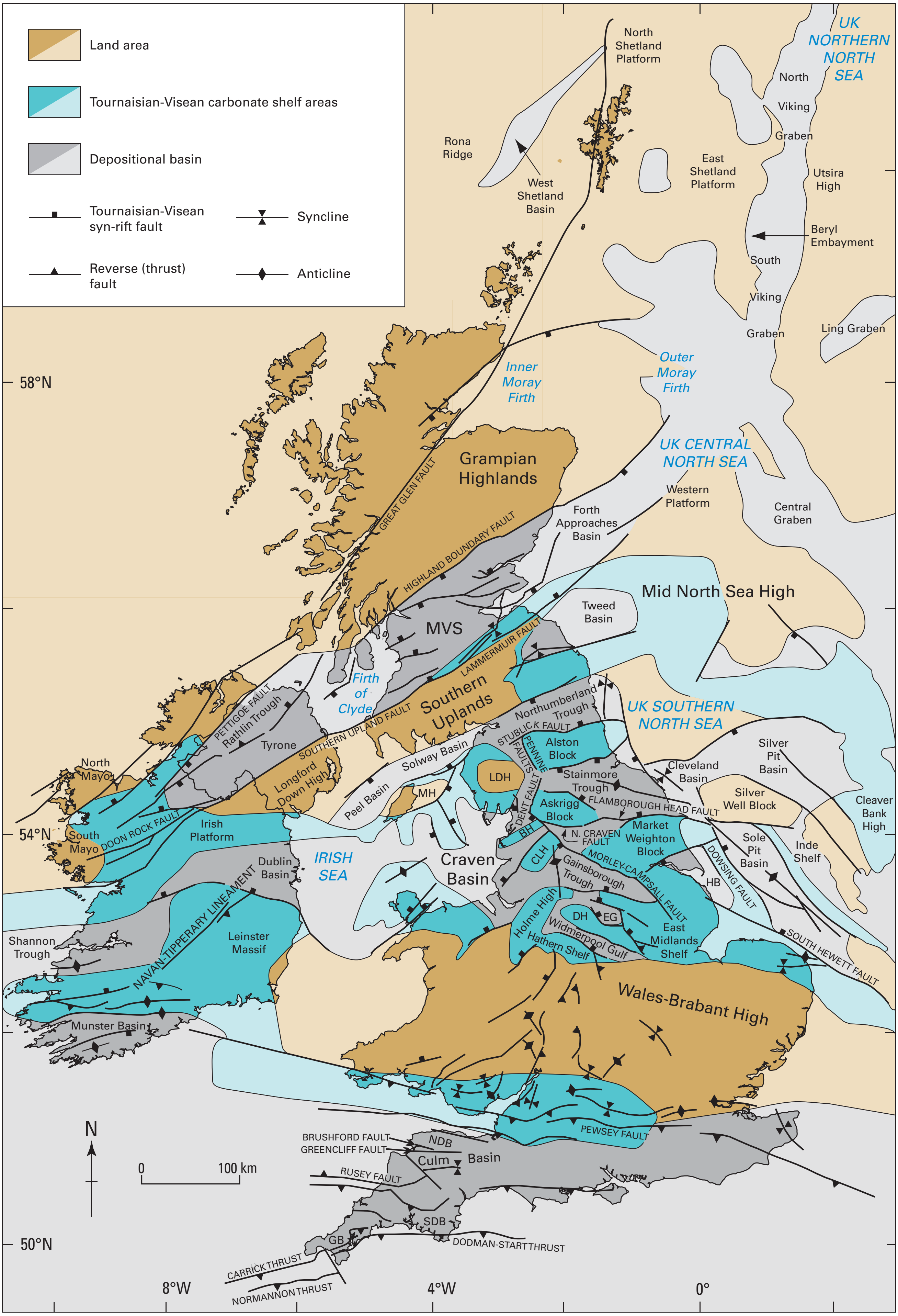

Figure 1 caption see page 3

1.1.2 Namurian and Stephanian

Transtensional rifting of the Midland Valley graben continued to be active during the Namurian and Stephanian. The graben is considered to have evolved as a transtensional basin with brief periods of transpression dominating during late Arnsbergian, late Marsdenian and late Westphalian times (Read, 1988), with transpression dominating by end Carboniferous times. Despite possible linkages to northern England across the Southern Uplands, the Midland Valley of Scotland 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 High resulted in a period dominated by thermally induced subsidence during Namurian and Westphalian times (Leeder, 1982). The Pennine Basin formed as part of this regional subsidence. The depocentre of the Pennine Basin was in south Lancashire and north Staffordshire, part of the Central Pennine Sub-basin, which extended between the Craven Fault System and the Wales–Brabant High. The thermal subsidence co-existed with small-scale, pulsatory phases of localised extension and compression, which reactivated basement lineaments (Waters et al., 1994). The sediment influx into the Pennine Basin changed from a dominantly northern provenance during the early Langsettian, to a western one during late Langsettian and early Duckmantian (Glover et al., 1996), and to a southern one from late Duckmantian and Bolsovian times (Hallsworth and Chisholm, 2000). Compressional deformation became increasingly influential during the Westphalian. Within the central parts of the Pennine Basin deformation is evident predominantly in the form of growth folds. At the basin margins, such as south Staffordshire, angular unconformities associated with folding and faulting are common.

The phase of compressional deformation that affected the southern basins of south-west England during the Late Devonian, Tournaisian and Visean reached the Culm Basin during the early mid Namurian. Tournaisian and Visean and early Namurian deposits present along the southern margin of the basin were inverted and thrust southwards out of the basin. Deformation continued to migrate northward, concurrent with Namurian and Westphalian deposition within the basin (Lloyd and Chinnery, 2002). With final closure of the Culm Basin, a phase of north–south compression was initiated no earlier than Bolsovian (Westphalian C) time. This was the second major deformation phase of the Tournaisian and Visean succession to the south, but the first deformation of the Namurian and Stephanian deposits and older rocks to the north of the Culm Basin and North Devon Basin. Inversion occurred along the controlling faults of the rift basin. In the north, basin deposits were thrust to the north with north-verging recumbent folds, and to the south, for a second time, deformation resulted in south-verging folds. The intervening rocks form a fan of chevron folds across the basin.

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 by Browne and Monro (1989).

1.2.1 Tournaisian

In the Midland Valley of Scotland, axial flow 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 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 appear to be developed along the southern margin of the Southern Uplands High, linking with the Midland Valley in the area of the Cheviot High. A greater marine influence is evident within the Craven Basin, where a carbonate-dominated succession formed at this time.

The open sea lay to the south of the Wales–Brabant High. Shelf carbonates developed along the southern fringe of the Wales–Brabant High (Waters and Lawrence, 1987; Kellaway and Welch, 1993). In the North Devon and Culm basins the early Tournaisian succession was dominated by deposition of greenish and medium grey (possibly oxic) muds containing sparse shelly faunas (brachiopods and trilobites), deposited in a relatively shallow marine shelf environment, comparable to the underlying Devonian succession of the North Devon Basin. During the late Tournaisian, subsidence of the basins resulted in a transition into deposition of deep marine pelagic and anoxic shales.

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 of Scotland (Figure 2b). In the east, the succession is largely fluviodeltaic and lacustrine (Browne and Monro, 1989), with the development of oil shales and freshwater.

Figure 1 (see page 2) Principal structural features of the 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 Tournaisian to Visean. 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, 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; GB Gramscatho Basin; HB Humber Basin; LDH Lake District High; MH Manx High; NDB North Devon Basin; MVS Midland Valley of Scotland; SDB South Devon Basin

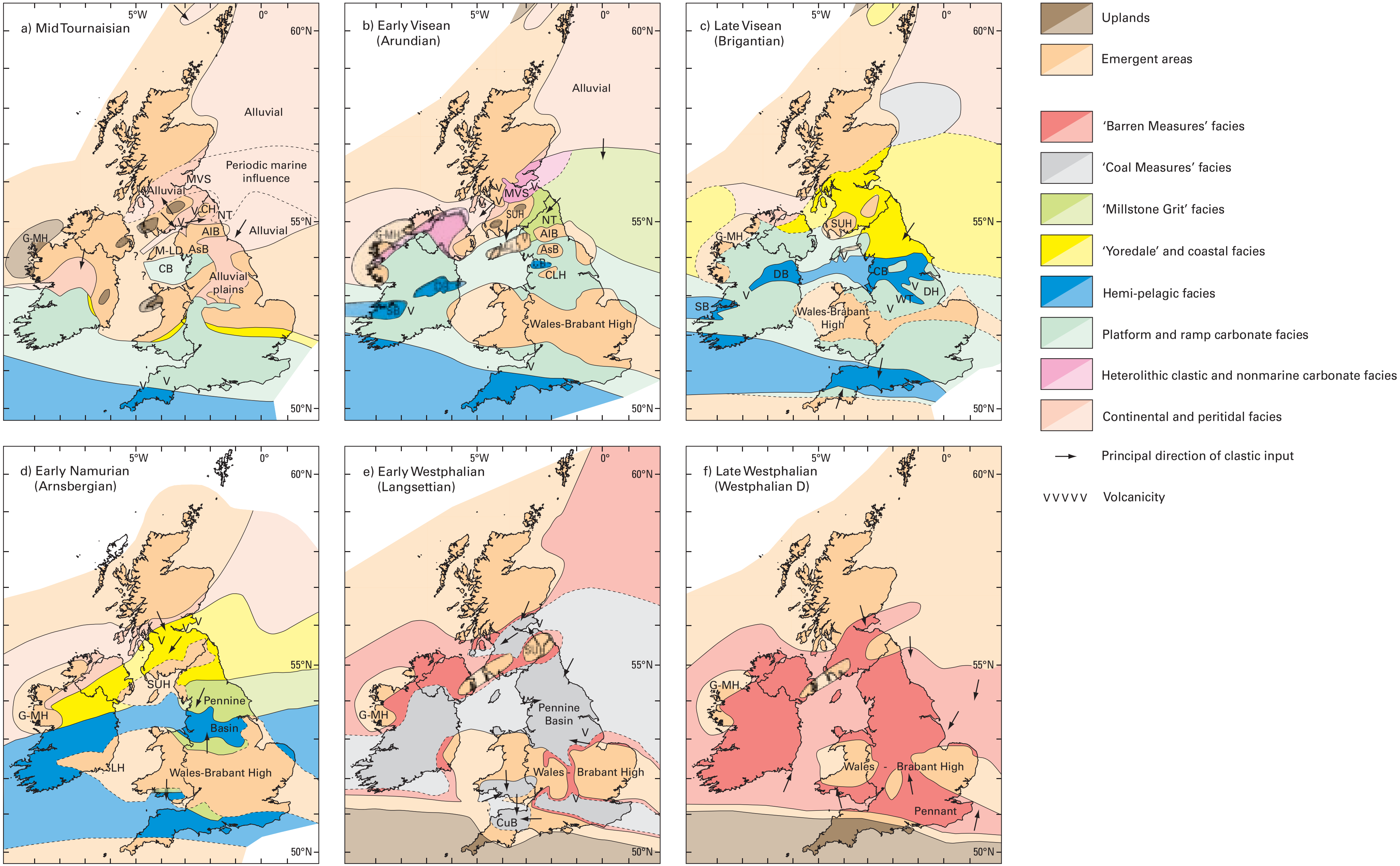

Figure 2 Palaeogeographical reconstructions for the Carboniferous of the British Isles, adapted from Cope et al. (1992).
AlB Alston Block; AsB Askrigg Block; CB Craven Basin; CH Cheviot High; CLH Central Lancashire High; CuB Culm Basin; DB Dublin Basin; DH Derbyshire High; GMH Galway–Mayo High; LH Leinster High; M-LD Manx–Lake District High; MVS Midland Valley of Scotland; NT Northumberland Trough; SB Shannon Basin; ST Stainmore Trough; SUH Southern Uplands High; WT Widmerpool Trough

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 was still dominated by fluviodeltaic and lacustrine deposits, but with periodic 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 the whole of the Midland Valley of Scotland.

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, a cyclic succession of fluviodeltaic clastic sediments, marine-reworked sandstones and shallow shelf marine carbonates (*Yoredale facies*[†]) dominated across northern England, terminating deposition of the platform carbonates.

Rifting during the early Visean led to the initiation of basinal marine conditions in the Craven Basin, which expanded with time into a series of linked embayments extending from the East Midlands to Republic of Ireland (Figure 2c).

Throughout the Visean the Wales–Brabant High was probably emerged, flanked to both the north and south by shelf carbonates (Waters and Lawrence, 1987; Davies et al., 2004). In south-west England these carbonates pass southward into the deep marine Culm Basin, which is associated predominantly with pelagic deposits. By the end of the Visean, thin siliciclastic turbidites were deposited, sourced in part from a highland area that developed to the south in response to closure, uplift and erosion of the more southerly basins (Figure 2c).

1.2.3 Namurian

The Midland Valley of Scotland is characterised by cyclic (*Yoredale facies*) sequences with interbedded fluviodeltaic sediments, coals and marine shelf limestones, the last marking highstands of sea level. 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 rather than coals.

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

In the North Devon and Culm basins, the early Namurian succession was dominated by a continuation of the deposition of pelagic shales. During the mid Namurian, following the first major compressional deformation event to affect the Culm Basin, siliciclastic turbidites, mainly sourced from the north, spread diachronously across the region.

1.2.4 Westphalian to Stephanian

From early in the Westphalian, a coal-forming delta-top environment became established across the Midland Valley of Scotland, the Pennine Basin and between south Wales and the Culm Basin and eastwards to Kent (Figure 2e). Although the 'Coal Measures' cyclic successions are lithologically similar, the three basinal areas were, at least in part, isolated by the upland areas of the Southern Uplands and Wales–Brabant highs. Marine incursions, represented by the widespread marine bands, were relatively rare during deposition of these successions. In the Culm Basin, relatively shallow water deltaic deposits accumulated, with coal-bearing strata deposited in the north of the basin

By Bolsovian times fluvial sediments ('Pennant Measures') derived from the northward propagating thrust sheets of the Hercynian Highlands encroached northward across much of southern England and south Wales (Figure 2f). Meanwhile, on the flanks of the Wales–Brabant High, reddened alluvial deposits accumulated. During Westphalian D and Stephanian times, the 'Pennant Measures' accumulated within the South Wales Basin. The 'Pennant Measures' breached the Wales–Brabant High and for a short period during the Westphalian D strata were deposited within the Pennine Basin.

[†] see Chapter 2 for use of terms

2 Principal lithofacies

Nine major lithofacies have been identified for the Carboniferous of Great Britain (Figure 3), and these names are shown in italics in the text that follows. The main lithologies, environment of deposition, distribution and age range are described below.

2.1 CONTINENTAL AND PERITIDAL FACIES

This facies occurs as two commonly interdigitating subfacies.

Continental fluvial clastic ('cornstone') subfacies

LITHOLOGY Purple-red conglomerate, sandstone and red mudstone, with characteristic nodules and thin beds of concretionary carbonate (calcrete).

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

Peritidal marine and evaporite ('cementstone') subfacies

LITHOLOGY Grey mudstone, siltstone and sandstone, characterised by the presence of nodules and beds of ferroan dolostone ('cementstone') and evaporites (mainly gypsum and anhydrite).

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

DISTRIBUTION OF BOTH SUBFACIES Widespread across northern Britain from the Midland Valley of Scotland to central England (Figure 2a), deposited from Late Devonian to Visean times. The two subfacies are commonly found to interdigitate. The continental fluvial clastic subfacies commonly forms the first basin infill and extends onto horst and tilt-block highs. The peritidal marine and evaporite subfacies is generally limited to troughs associated with graben and half-graben, for example the Midland Valley of Scotland, Northumberland Trough and Stainmore Trough.

2.2 HETEROLITHIC CLASTIC AND NON-MARINE CARBONATE FACIES

LITHOLOGY Interbedded grey sandstone, siltstone, mudstone and locally oil shale. Thin, subordinate beds of lacustrine limestone and dolostone, seatearth, coal and sideritic ironstone are present variably in different formations.

DEPOSITIONAL ENVIRONMENT Fluviatile, deltaic and lacustrine environments with relatively sparse marine mudstone deposits commonly alternating, in thin cycles.

DISTRIBUTION Principally present in the eastern part of the Midland Valley of Scotland, of Visean age (Figure 2b), passing laterally into dominantly volcanic rocks to the west. Also present as early Visean strata in parts of the Northumberland Trough.

2.3 OPEN MARINE, PLATFORM AND RAMP CARBONATES

This facies occurs as two subfacies.

Shallow shelf platform carbonate subfacies

LITHOLOGY Blanket bioclastic carbonate with crinoid banks, shelly or coral biostromes and algal (*Girvanella*) bands. The facies includes karstic bedding surfaces, overlain by thin bentonites, interpreted as emersion surfaces.

DEPOSITIONAL ENVIRONMENT Tropical shallow marine environment.

Ramp carbonate subfacies

LITHOLOGY Calcareous mudstone with common dark bituminous and bioclastic limestones, and locally the presence of carbonate breccias. 'Knoll reefs' or 'Waulsortian reefs', now commonly known as mud-mounds form a distinctive biogenically precipitated bioherm.

DEPOSITIONAL ENVIRONMENT Ramps generally develop during the early stage of platform carbonate evolution. They represent deposits upon gently inclined shallow marine slopes that may be marginal to platforms.

DISTRIBUTION OF BOTH SUBFACIES Upon platforms and ramps developed on horst-blocks and half-graben tilt-blocks during the Visean over the Alston and Askrigg blocks, fringing the Manx-Lake District High and on the north and south margins of the Wales–Brabant High (Figure 2b, c). Isolated platform carbonates also developed on the Derbyshire High, Holme High and Central Lancashire High within a broadly basinal environment. The above strata are collectively named the Carboniferous Limestone Supergroup.

2.4 HEMIPELAGIC FACIES

LITHOLOGY Dark grey to black mudstone, in part calcareous with calcareous nodules ('bullions'). Thin sandstone and limestone beds are locally common; breccia may be present.

DEPOSITIONAL ENVIRONMENT Quiet and relatively deep basinal environment with minor influx of sand-rich turbidites within prodelta environments, and carbonate-rich turbidites on carbonate slopes. Breccias may represent proximal turbidites or slump deposits.

DISTRIBUTION Basinal ('gulf') areas of central England and north Wales developed during the Visean and Namurian (Figure 2b, c, d). Also, this facies was present within the Culm Basin during the Late Devonian to Namurian (Figure 2a, b, c, d).

2.5 MIXED SHELF CARBONATE AND DELTAIC (YOREDALE) FACIES

LITHOLOGY Typically upward-coarsening cycles of limestone, mudstone, sandstone, seatearth or ganister and coal.

DEPOSITIONAL ENVIRONMENT The limestone, mudstone and some sandstone were deposited in marine environments. The majority of the sandstones and coals (the upper part of the cycles) were deposited as progradational lobate deltas.

DISTRIBUTION Widespread across the Midland Valley of Scotland and northern England, in strata of Visean to Namurian age, as far south as the Craven Fault System (Figure 2c).

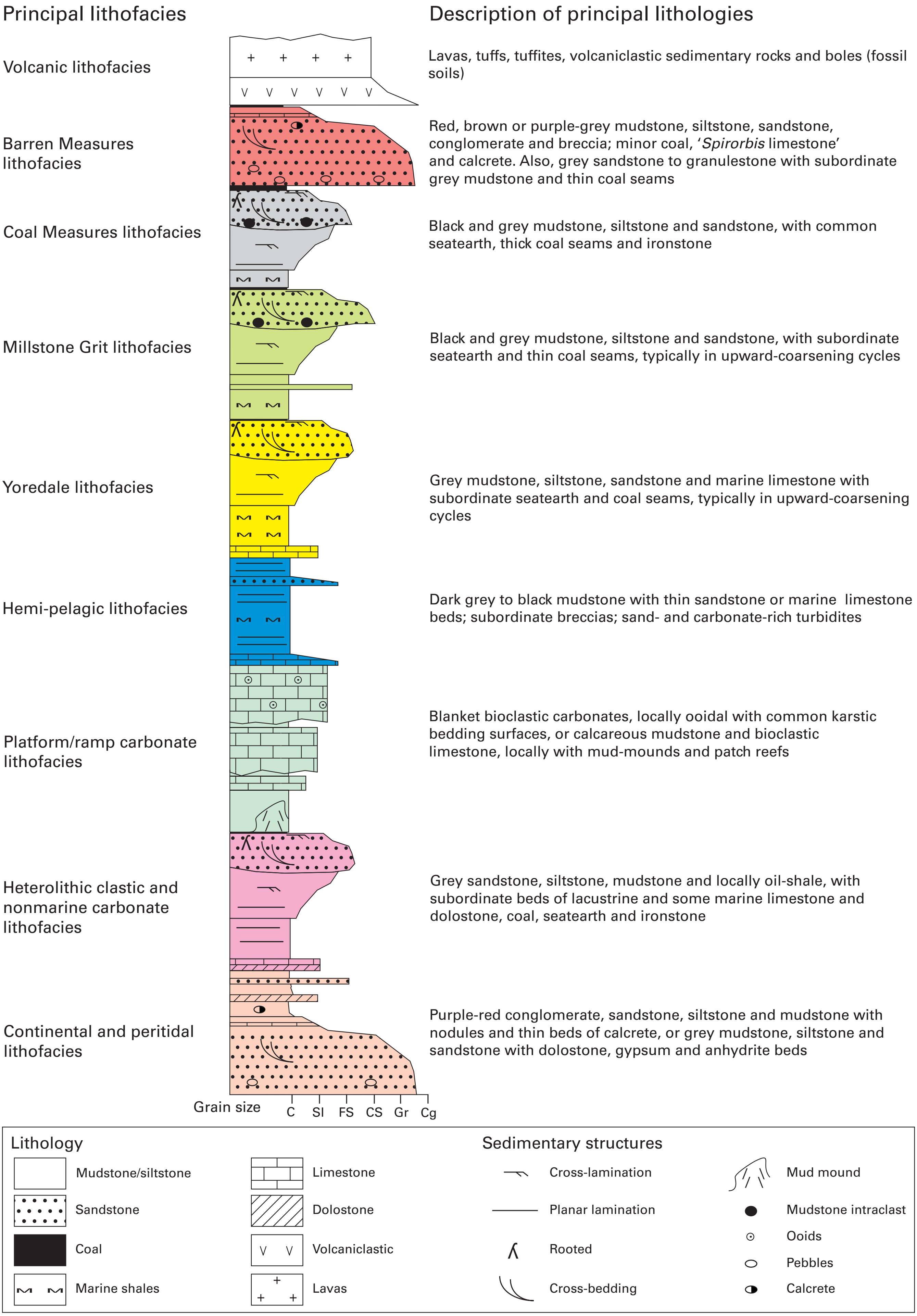

Figure 3 Schematic graphic log summarising the nine main lithofacies. Although the lithofacies are shown broadly in their order of superposition, youngest at the top, the lithofacies may interdigitate.
C claystone; Sl siltstone; FS fine-grained sandstone; CS Coarse-grained sandstone; Gr granulestone; Cg conglomerate

2.6 FLUVIODELTAIC (MILLSTONE GRIT) FACIES

LITHOLOGY Typically upward-coarsening cycles of black fissile, and grey mudstone, ironstone, fine- to very coarse-grained feldspathic sandstone, with seatearths and relatively thin coal seams. Cyclic sequences in the Millstone Grit facies are thicker and less numerous than in the Coal Measures facies. Disconformities are common.

DEPOSITIONAL ENVIRONMENT The cycles indicate periodic delta progradation with common black mudstone marine bands resulting from marine transgression and delta abandonment.

DISTRIBUTION Extending from the Midland Valley of Scotland, across northern and central England during the Namurian to early Westphalian (Figure 2d). Similar deposits occur within the Northumberland Trough during early Visean times (Figure 2b). Also, similar facies are evident in the Culm Basin during the Westphalian.

There are three subfacies:

- deep-water, turbidite-fronted lobate deltas, more typical of the lower part of the facies in the Pennine Basin. Coal and seatearth are typically absent
- shallow-water, sheet-like deltas more typical of the upper part of the facies in the Pennine Basin. Coal and seatearth are common, but typically thin
- delta-top subfacies characterised by condensed, predominantly upward-fining cycles of structureless clayrock to sandstone. Thick, high-alumina seatclay, fireclay and bauxitic clay are common, with subordinate beds of limestone, ironstone, cannel and coal. This subfacies is more typical of the Midland Valley of Scotland and northern England, north of the Craven Fault System.

2.7 FLUVIODELTAIC (COAL MEASURES) FACIES

LITHOLOGY Both upward-fining and upward-coarsening cycles, typically of grey to black mudstone, fine- to medium-grained sandstone, with numerous seatearth or ganister and relatively thick coal seams. Cyclic sequences in the Coal Measures are thinner and more numerous than in the Millstone Grit facies.

DEPOSITIONAL ENVIRONMENT Wetland forest and soils (coal and seatrock), floodplain (plant-rich 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 less common generally than in the Millstone Grit facies.

DISTRIBUTION Extending from the Midland Valley of Scotland across northern and central England and also to the south of the Wales–Brabant High from south Wales to Kent during the early Westphalian (Figure 2e). Strata from these areas are collectively named the Coal Measures Supergroup.

2.8 ALLUVIAL (BARREN MEASURES) FACIES

This facies occurs as two subfacies.

'Red-bed' subfacies

LITHOLOGY Red, brown or purple-grey mudstone, siltstone and sandstone, with local pedogenic alteration. Pebbly sandstone, conglomerate and breccia are locally developed. Minor components comprise grey mudstone, thin coal, lacustrine limestone ('*Spirorbis* limestone') and pedogenic limestone (calcrete).

DEPOSITIONAL ENVIRONMENT Alluvial fan, fluvial channel, fluvial overbank, and lacustrine. The red beds have undergone oxidation at, or close to, the time of deposition, indicating a semi-arid climate.

DISTRIBUTION Central England and north Wales, southern flank of the Wales–Brabant High and north Cumbria during the late Westphalian (Figure 2f).

'Pennant' subfacies

LITHOLOGY Grey sandstone, pebbly sandstone to granulestone, commonly thick-, massive- or cross-bedded. Subordinate components comprise grey mudstone and thin coal.

DEPOSITIONAL ENVIRONMENT Fluvial channel and fluvial overbank deposits and minor wetland forest and soils; southerly provenance.

DISTRIBUTION South Wales to Oxfordshire Coalfield, and Westphalian D of the southern parts of the Pennine Basin during Bolsovian to Westphalian D times.

2.9 VOLCANIC FACIES

LITHOLOGY Basaltic to hawaiitic lavas, bedded tuffites and volcaniclastic sedimentary rocks, with subordinate interbedded sedimentary rocks.

DEPOSITIONAL ENVIRONMENT Subaerial to submarine.

DISTRIBUTION Thickest development is in the Midland Valley of Scotland, with an Asbian to Arnsbergian succession identified as the Bathgate Group. Volcanic rocks are also common throughout the Carboniferous succession of the Midland Valley of Scotland. Significant, but less extensive developments include: Tournaisian and Visean age rocks in the Solway Firth, along the England – Scotland border, and Bristol region, Visean rocks in Derbyshire, Westphalian rocks in the West Midlands of England, and concealed volcanic rocks in the East Midlands.

3 Lithostratigraphical framework

The plethora of local group and formation names and the inconsistent application of lithostratigraphical hierarchies for the Carboniferous have, 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 development of these local nomenclatures can be attributed to the following:

- deposits restricted 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, others have created alternative, often conflicting, schemes

The Geological Society Special Reports for the Dinantian and Silesian (George et al., 1976; Ramsbottom et al., 1978) provided useful stratigraphical correlations between key sections across the British Isles. However, the reports did not attempt to provide a unified lithostratigraphical framework. Their purpose was to show the correlation of the then lithostratigraphical units within a standard biostratigraphical and chronostratigraphal framework (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, 1983), and more recently, Geological Society 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 aims to use existing nomenclature where suitable, whilst providing full definitions consistent with the guidance from the NASC and the Geological Society, London.

In rationalising the stratigraphy, it was decided to follow a 'top-down' approach by which the group nomenclature was based upon the recognition of nine major lithofacies (see Chapter 2 for descriptions). The committee discussed the possibility of having a single group name for each lithofacies applicable to the entire country. However, the lithofacies were often developed within distinct basinal areas and a single Great 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 Great Britain-wide lithofacies, it was recommended they should be defined as a supergroup.

This overview report provides a summary of the decisions made as to what constitutes a formation in the Carboniferous of Great Britain and suggests names for problematical successions. It also provides examples of formational nomenclature for certain areas to give an indication of group/ formation relationships. A list of approved terms is given in Appendix 1.

The details of formational nomenclature will be addressed by the GB (north) and GB (south) Stratigraphical Framework Committee reports.

The lithostratigraphical nomenclature detailed below has been subdivided into five provinces that represent distinct palaeogeographical regions for most, if not all, of the Carboniferous Period. These are, from north to south, the Midland Valley of Scotland, Northern England, central England and North Wales, South Wales and Bristol and south-west England (Culm Basin). The extent of these provinces and locations of representative stratigraphical columns are shown on Figure 4.

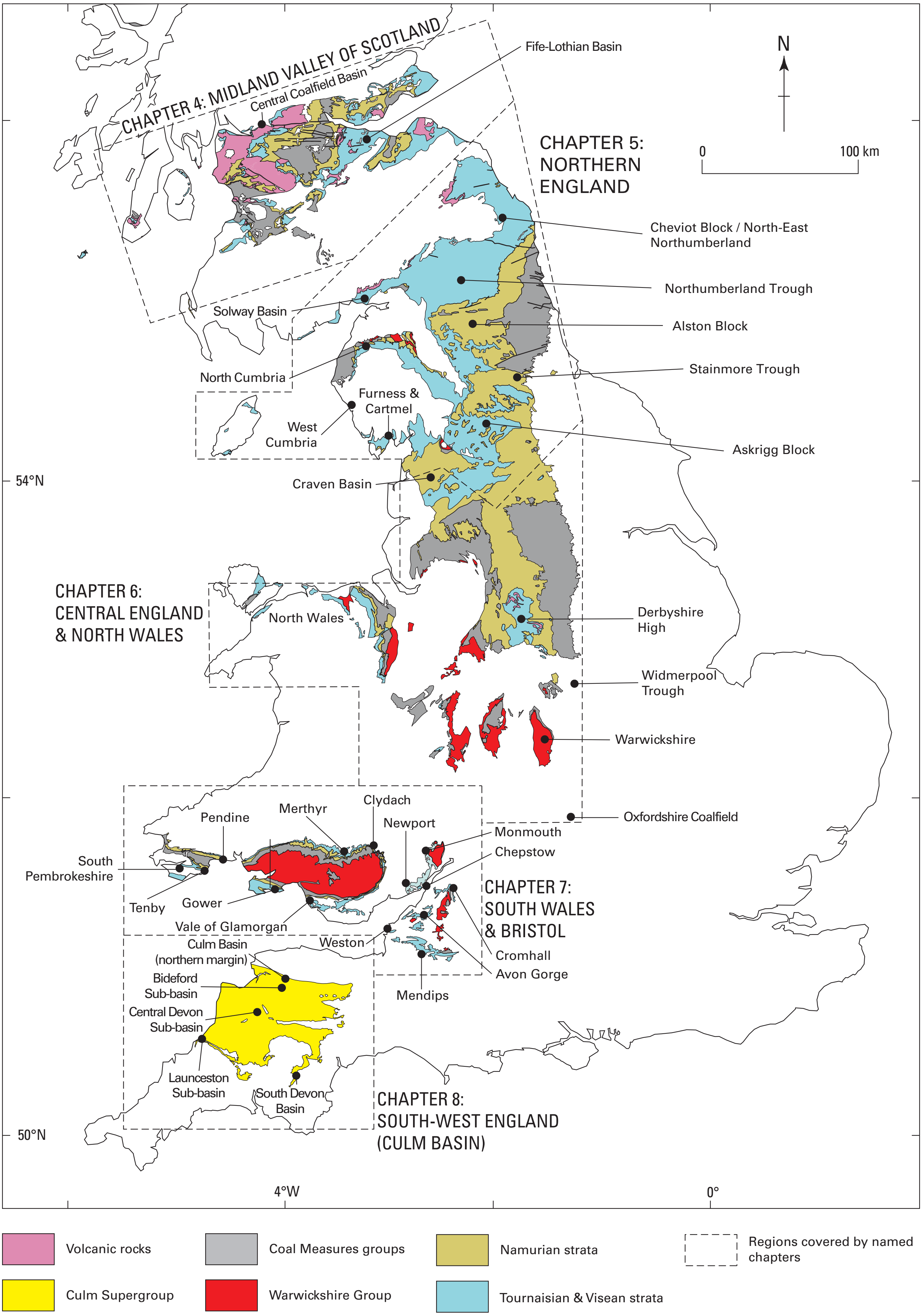

Figure 4 Extent of Carboniferous deposits and location of regions discussed in text

4 Midland Valley of Scotland

The group and formational nomenclature for the Midland Valley of Scotland proposed by Browne et al. (1999) has been retained. The boundaries between the main groups are defined by marker horizons that are widespread within the Midland Valley. There are four main sedimentary groups, in ascending order these are the Inverclyde (partly Devonian in age), Strathclyde, Clackmannan and Scottish Coal Measures groups (Figure 5), with the addition of the Bathgate Group. The Bathgate Group, together with part of the Strathclyde Group encompasses the major occurrences of Carboniferous extrusive rocks, which range from thin local basalts to widespread thick volcanic accumulations.

4.1 INVERCLYDE GROUP

The Inverclyde Group, of *Continental and peritidal facies*, comprises, in ascending order, the Kinnesswood, Ballagan, and Clyde Sandstone formations (Paterson and Hall, 1986) (Figure 5). The formations equate to variations between the '*Cornstone*' and '*Cementstone*' *subfacies*. The Inverclyde Group is about 1500 m thick.

The base of the Inverclyde Group is transitional, typically recognised by the appearance of cornstones, though it is locally marked by an unconformity in the west of the Midland Valley of Scotland.

The Kinnesswood Formation is characterised by purple-red, yellow, white and grey-purple, fine- to coarse-grained sandstone, mostly cross-bedded, with characteristic pedogenic carbonate nodules and horizons ('cornstones'). The Ballagan Formation is typified by grey silty mudstone containing nodules and thin beds of dolostone and limestone ('cementstone'). There may be some lateral passage between the two subfacies. The Clyde Sandstone Formation comprises white, fine- to coarse-grained sandstone, commonly pebbly, with beds of red-brown or grey mudstone and nodules or beds of pedogenic limestone.

The Kinnesswood and Clyde Sandstone formations were laid down in fluviatile environments ranging from braided stream to floodplain with pedogenetically altered overbank deposits. The intervening Ballagan Formation formed in a peritidal environment associated with intermittent emergence.

The discovery of miospores of Tournaisian age (LN–PC biozones) from near the base of the Kinnesswood Formation (Smith, 1996) confirms that this formation may straddle the Devonian–Carboniferous boundary, but that most of it is of early Carboniferous age. The Ballagan Formation typically contains miospores indicative of the CM biozone, although Smith (1996) also recorded a sample from the PC biozone. (The Carboniferous chronozones in current use are shown in Appendix 2.)

4.2 STRATHCLYDE GROUP

The Strathclyde Group, mainly of *Heterolithic clastic and nonmarine carbonate facies*, was introduced by Paterson and Hall (1986) in the west of the Midland Valley of Scotland, where the ascending sequence comprises the Clyde Plateau Volcanic, Kirkwood and Lawmuir formations (Figure 5). The group has been extended to the east, with five sedimentary formations at Fyfe: the Fife Ness, Anstruther, Pittenweem, Sandy Craig and Pathhead formations. These units were originally described by Forsyth and Chisholm (1977) and first called formations by Browne (1986). In the Lothians the group includes both volcanic and sedimentary formations (Figure 5), established by Chisholm et al. (1989). The Gullane Formation is overlain either by the West Lothian Oil Shale Formation or the laterally equivalent Aberlady Formation. Two volcanic formations are present; the Arthur's Seat Volcanic Formation and the Garleton Hills Volcanic Formation. The Strathclyde Group is in excess of 1250 m thick.

The base of the group is generally taken at a sharp irregular unconformity at the base of the Clyde Plateau Volcanic Formation in the west of the Midland Valley of Scotland, or the mainly conformable base of the Gullane Formation or Arthur's Seat Volcanic Formation in the east.

The group comprises typically mildly alkaline lavas, tuffs and volcaniclastic sedimentary rocks and interbedded sandstone, siltstone and mudstone, with common seatearth, coal and sideritic ironstone. A similar range of lithologies is present in each formation, but the emphasis varies between one formation and the next. Thin bioclastic limestones occur within the uppermost part of the group. There is commonly interdigitation between sedimentary and volcaniclastic rocks.

The sedimentary strata were deposited in fluviatile, deltaic and lacustrine environments. Oil shales formed in large freshwater lagoons, rich in algae and other organic matter. The uppermost part of the group is characterised by the incoming of Yoredale-type cyclothems representing increasing marine conditions (Francis, 1991a). The group ranges in age from late Chadian to Brigantian.

4.3 CLACKMANNAN GROUP

The Clackmannan Group comprises a variable succession of *Yoredale facies*, *Millstone Grit facies* and *Coal Measures facies*. The name was first used in the Airdrie district by Forsyth et al. (1996) to include the Lower Limestone Formation, the Limestone Coal Formation, the Upper Limestone Formation and the Passage Formation. The base of each formation, except the Passage Formation, is generally taken at the base of a prominent and laterally extensive limestone.

The group is up to 1800 m thick in the Clackmannan area. Condensed sequences in the Lower Limestone Formation are locally associated with areas of earlier or contemporaneous volcanicity (Francis, 1991b).

The conformable base of the group is taken at the base of the Hurlet Limestone. Minor unconformities are present near the top of the Upper Limestone Formation (Francis, 1991a) and in the Passage Formation (Read, 1981) in areas of greatest thickness. Three major disconformities are recognised in the Passage Formation. The lowermost occurs within the *Cravenoceratoides nitidus* Chronozone, the middle disconformity is associated with the absence of strata

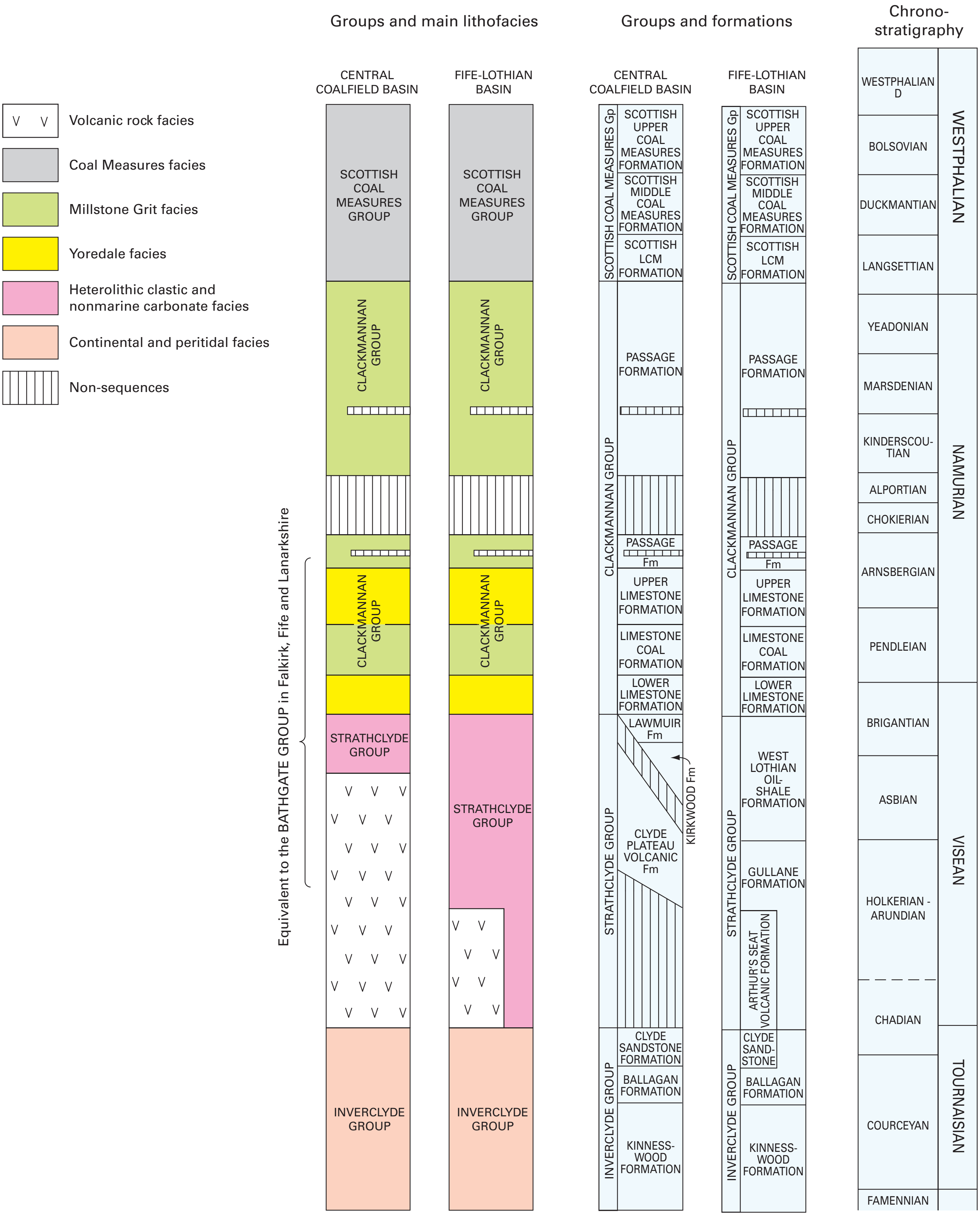

Figure 5 Lithostratigraphical nomenclature for the Midland Valley of Scotland. See Chapter 2 for description of lithofacies. A detailed lithostratigraphical classification for the Midland Valley of Scotland is provided by Browne et al. (1999, table 1). Fm Formation; Gp Group; LCM Lower Coal Measures

from late Arnsbergian to late Alportian age, and the uppermost occurs between marine bands of Kinderscoutian to Marsdenian age.

The group is characterised by *Yoredale* and *Millstone Grit facies*. Upward-coarsening Yoredale-type cycles of limestone, mudstone, siltstone and sandstone are capped by thin beds of seatearth and coal, the proportions differing in each of the formations. The limestones are typically marine and laterally extensive, with standard names for the individual limestone beds used throughout the region. The Passage Formation is characterised by upward-fining alternations of sandstone and structureless clayrock (including some economically important high-alumina seatclay, fireclay and bauxitic clay). Marine faunas, diverse and closely spaced at the base of the formation, become progressively impoverished upwards.

Depositional environments are related to the repeated advance and retreat of fluviodeltaic systems into an embayment of varying salinity. The Lower and Upper Limestone formations contain the highest proportion of marine deposits (*Yoredale facies*), whereas the Passage Formation is dominated by alluvial deposits (*Millstone Grit facies*); the Limestone Coal Formation occupies an intermediate position.

The Clackmannan Group is mostly Namurian in age, but ranges from late Visean to early Langsettian.

4.4 SCOTTISH COAL MEASURES GROUP

The Coal Measures (*Coal Measures facies*) were regarded as a lithostratigraphical group by Forsyth et al. (1996). The epithet 'Scottish' is proposed to distinguish the Coal Measures of the Midland Valley of Scotland from that of England and Wales on account of the different definitions of the base of the Upper Coal Measures and the base of the groups. The Lower, Middle and Upper divisions, recognised in the older classification, are retained and regarded now as informal formations. Again, the epithet 'Scottish' can be applied to the formations where it is necessary to distinguish them from formations in England and Wales.

The Scottish Lower and Middle Coal Measures are 220 to 240 m and 350 m thick, respectively. The maximum thickness of the Scottish Upper Coal Measures probably exceeds 1200 m.

The base of the group is 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 the Pennine Coal Measures Group, where it lies at the base of the Subcrenatum Marine Band, which is not recognised in Scotland. The base of Scottish Middle and Upper Coal Measures are also taken at the bases of marine bands, namely the Vanderbeckei (Queenslie) and Aegiranum (Skipsey's) marine bands, respectively. The base of the Scottish Upper Coal Measures is taken, here, at a lower stratigraphical level than the equivalent Pennine Upper Coal Measures. The top of the group is marked by an erosional unconformity of regional extent beneath Permian strata.

The group comprises repeated cycles of typically grey sandstone and mudstone with coal and seatearth, arranged in both upward-fining and upward-coarsening units. Marine bands are rare but provide important stratigraphical markers. The Scottish Lower and Middle Coal Measures are lithologically similar, with common, economically important coal seams, few of which can be correlated between coalfields. Minor lithologies include cannel coal, and blackband and clayband ironstone, the last is nodular as well as bedded. Bands composed mainly of nonmarine bivalves, the characteristic 'musselbands', usually occur in mudstone or ironstone. Upward-fining units are widely developed, dominated by fine- to coarse-grained sandstone, and thick multistorey sandstones are a characteristic part of the succession. Within the Scottish Upper Coal Measures coal seams are thin and uncommon, and the succession is extensively reddened.

Environments of deposition include wetland forest (soils), floodplain, river and delta distributary channel, prograding deltas and shallow lakes.

The group ranges from Langsettian to Westphalian D age. The Scottish Lower and Middle Coal Measures are equivalent to chronostratigraphical units of Langsettian and Duckmantian age. Within the Scottish Upper Coal Measures, faunas representative of the *A. phillipsii* and *A. tenuis* zones have been recognised (Mykura, 1967), and floras indicative of Bolsovian and Westphalian D stages (Scott, 1976). No Stephanian rocks have been identified in the Midland Valley of Scotland.

4.5 BATHGATE GROUP

The Bathgate Group (Figure 5) is of limited geographical extent (Falkirk, Fife, Lanarkshire, West Lothian) but interdigitates with a large thickness of the upper part of the Strathclyde Group and the larger part of the Clackmannan Group. The Bathgate Group comprises the Salsburgh Volcanic, Kinghorn Volcanic and Bathgate Hills Volcanic formations. The volcanic formations are separated from one another by sedimentary rocks, but their petrographical similarity and restricted geographical extent justify their treatment as a single group. The group is very variable in thickness, locally occurring in excess of 450 m. The base of the group is taken in most areas at an upward transition from sedimentary rocks of the Strathclyde or Clackmannan groups.

The Bathgate Group is characterised by olivine-rich microporphyritic basalts of Dalmeny and Hillhouse type, with some macroporphyritic olivine-basalts of Craiglockhart and Dunsapie types. Bedded tuffites and tuffaceous sedimentary rocks also occur. The group ranges from Asbian to Arnsbergian age.

4.6 CORRELATION WITH CENTRAL AND NORTHERN NORTH SEA

The Devonian and Carboniferous strata of the Central and Northern North Sea occupy a depositional basin that is laterally contiguous with, and located to the east of, the Midland Valley of Scotland (Figure 1). The succession, defined by Cameron (1993a), comprises a single group, the Upper Old Red Group, and a stand-alone formation, the Firth Coal Formation.

4.6.1 Upper Old Red Group

The Upper Old Red Group is the offshore equivalent of the onshore Upper Old Red Sandstone Group and the overlying Inverclyde Group (*Continental and peritidal facies*). In the Outer Moray Firth, Western Platform and Central Graben the group consists of two formations, the Buchan and Tayport formations. The upper part of the Buchan Formation is the offshore equivalent of the onshore Kinnesswood

Formation, Inverclyde Group. The Tayport Formation is similar to the onshore Clyde Sandstone Formation (Cameron, 1993b).

The Buchan Formation is at least 600 m thick in the Buchan Field, although only the upper 200 to 315 m includes calcretes, which are typical of the Kinnesswood Formation. The Tayport Formation has a maximum thickness of 735 m in the Outer Moray Firth.

The Buchan Formation comprises a sandstone-dominated succession, which in the Buchan Field has a broad upward-fining trend. The Tayport Formation comprises, interbedded red mudstones and fluvial sandstones (Cameron, 1993a), especially present in the Outer Moray Firth.

The Buchan Formation was deposited predominantly within a fluvial environment, whereas the Tayport Formation was probably deposited in fluvial and playa lake environments.

The palynology indicates that the group ranges from Famennian (Devonian) to late Visean (Hill and Smith, 1979).

4.6.2 Firth Coal Formation

The Firth Coal Formation comprises early Carboniferous strata of *Coal Measures facies* within the Forth Approaches Basin and Outer Moray Firth Basin. The formation is most similar to the onshore Limestone Coal Formation, though the Firth Coal Formation is more wide ranging in age. The formation is at least 1500 m thick. The conformable base of the formation is taken at the base of the lowest coal seam above the Tayport Formation.

The formation comprises cyclic interbedded sandstone, carbonaceous siltstone, mudstone and coal. In the Moray Firth Basin, volcanic rocks of possible Visean age are interbedded with the coal-bearing strata (Andrews et al., 1990).

The strata were deposited in a nonmarine, fluviodeltaic environment, with sands deposited as lenticular delta lobes or in fluvial channels, interbedded with overbank and prodelta muds.

Microfloral assemblages are diagnostic of a range from Arundian or Holkerian to Pendleian or Arnsbergian (Andrews et al., 1990).

5 Northern England

This province encompasses the area between the Southern Uplands and Craven Fault System (Figure 1), and includes the Northumberland and Stainmore troughs, the Alston and Askrigg blocks and the Manx–Lake District High. During Westphalian times this area formed the northern part of the Pennine Basin.

The Northumberland Trough has a Tournaisian and early Visean succession distinct from the rest of the province. Along the southern margin of the Southern Uplands High, 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 (Figure 6). Within the Northumberland Trough the Inverclyde Group is overlain by the Border Group of early Visean age.

Elsewhere, the continental fluvial clastic subfacies (*Continental and peritidal facies*) 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-graben that formed during the initial stages of extension in the Late Devonian–early Carboniferous. Within the Stainmore Trough and margins of the Askrigg Block, both continental fluvial clastic and peritidal marine and evaporite subfacies are present as the Ravenstonedale Group.

South of the Northumberland Trough, the remainder of the province comprised basins and highs of which both formed largely distinct and isolated areas of deposition until Asbian times, and thus have been given different formational nomenclature. However, each structural entity showed a consistent development in facies with time, from platform carbonate (*Platform and ramp carbonate facies*) to cyclic marine carbonate and deltaic siliciclastics (*Yoredale facies*). *Platform and ramp carbonate facies* and *Yoredale facies* strata are assigned to the Great Scar Limestone Group and Yoredale Group respectively. During Namurian times, the Millstone Grit Group (*Millstone Grit facies*) extended over the Askrigg Block. Subsequently, during Westphalian times the Pennine Coal Measures Group (*Coal Measures facies*) extended across the entire province. *Barren Measures facies*, of late Westphalian age, have been assigned formation names within the Warwickshire Group.

5.1 INVERCLYDE GROUP

The Inverclyde Group, of *Continental and peritidal facies*, present within the Northumberland Trough, comprises strata directly equivalent to the group of the same name present within the Midland Valley of Scotland. The Kinnesswood and Ballagan formations also equate to their namesakes within the Midland Valley of Scotland. The Kinnesswood Formation occurs along parts of the northern margin of the Northumberland Trough. The Ballagan Formation is present in the north-east of the Northumberland Trough and 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. Locally, the Kinnesswood and Ballagan formations are separated by the Birrenswark and Kelso Volcanic formations in the Solway Basin (Lumsden et al., 1967) and Berwick area (Greig, 1988), respectively (Figure 6). There is no equivalent of the Clyde Sandstone Formation of the Midland Valley of Scotland.

The Inverclyde Group is up to 900 m thick in Tweed Valley, Northumberland and up to 640 m in the Solway Firth area. The base of the group is typically unconformable upon Silurian strata.

The Kinnesswood Formation comprises red sandstones, siltstones and conglomerates. The Kelso and Birrenswark Volcanic formations comprise alkaline olivine-basalts and subordinate tuffs and sedimentary strata. The Ballagan Formation comprises interbedded sandstone, mudstone, limestone and anhydrite.

The Kinnesswood Formation comprises calcrete-rich 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 overlying volcanic formations developed during the main initial phase of extensional faulting associated with development of the Northumberland Trough. The deposition of the Ballagan Formation was dominated by the influx of alluvial fans, fluvial and fluviodeltaic sediments from the Southern Uplands, intercalated with lacustrine and arid coastal plain deposits (Deegan, 1973; Leeder, 1974, 1993).

The Kelso and Birrenswark Volcanic formations are mid-Tournaisian in age, whereas the Ballagan Formation is Tournaisian to Chadian (Armstrong and Purnell, 1987).

5.2 RAVENSTONEDALE GROUP

The Ravenstonedale Group, of *Continental and peritidal facies*, consists of a typically thin succession, with geographically isolated outcrops present across parts of Cumbria. Over much of north, south and east Cumbria the group comprises a single formation, provisionally named the Marsett Formation. However locally within east Cumbria, the Stainmore Trough and northern part of the Askrigg Block additional formations are identified (Figure 6). The thickest and most diverse lithological development of the Ravenstonedale Group 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 Formation, the provisional Marsett Formation and the Stone Gill Formation. The Coldbeck Limestone Formation, formerly included within this group, is more suitably included as a formation within the newly defined Great Scar Limestone Group. On the Askrigg Block, the Carboniferous succession immediately above the concealed Wensleydale Granite comprises, in ascending order, the Raydale Dolostone, Marsett and Penny Gill Farm formations.

In the primary mapping survey of Cumbria, which was carried out in the latter part of the 19th century, all of the coarse-grained arenites below the Carboniferous Limestone were included in a single unit, the 'Basement Beds'. This approach persisted with subsequent surveys, even though it was recognised that a prominent unconformity was present

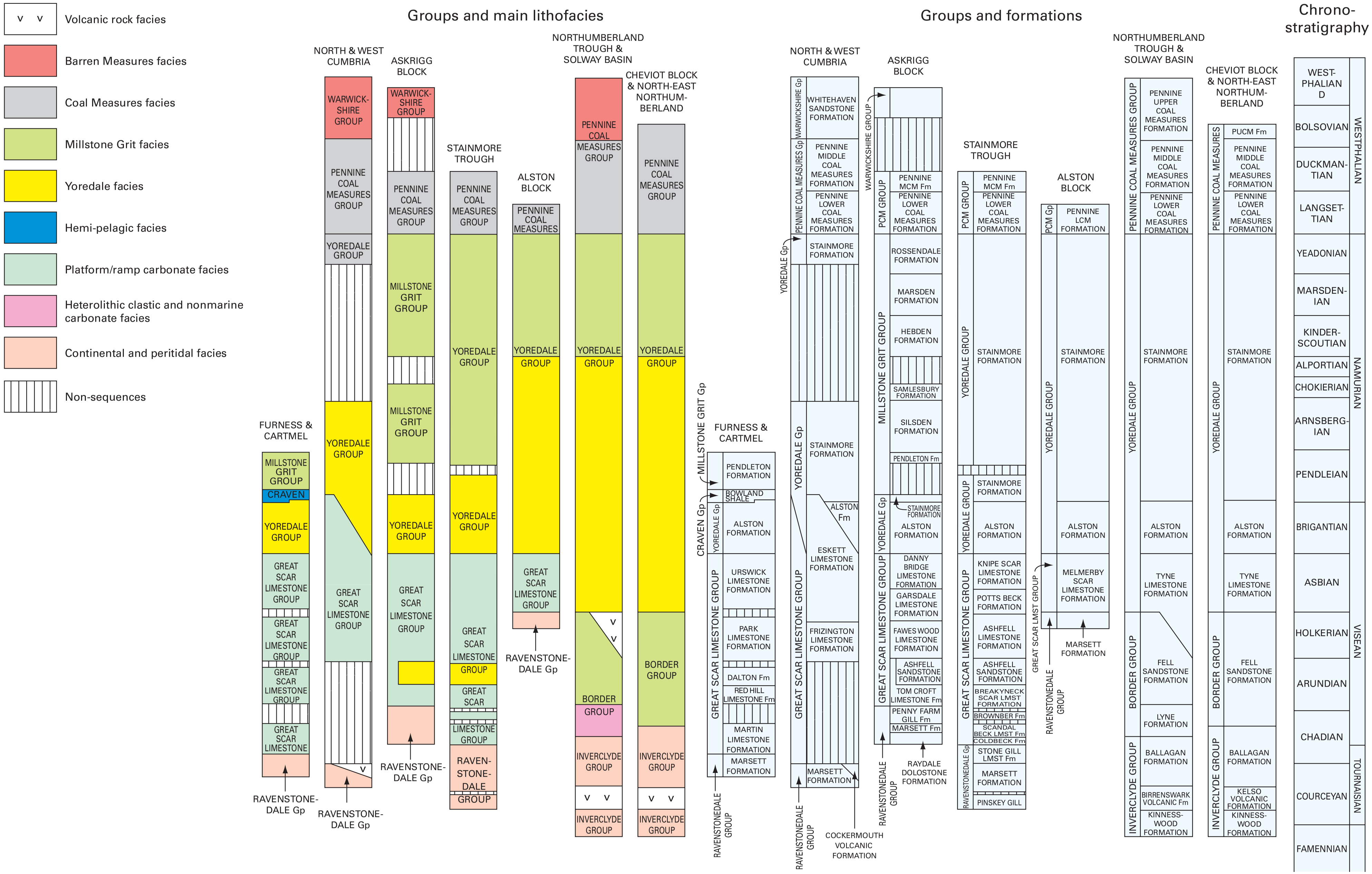

Figure 6 Lithostratigraphical nomenclature for the Northern England region (onshore). See Chapter 2 for description of lithofacies. Fm Formation; Gp Group; LCM Lower Coal Measures; LMST Limestone; MCM Middle Coal Measures; PCM Pennine Coal Measures; PUCM Pennine Upper Coal Measures

in the Mell Fell and Shap Wells areas. Capewell (1955) concluded that two groups can be recognised: an older one separated from Carboniferous strata by an unconformity, and a younger one conformably overlain by marine Carboniferous limestones. Since the time of the primary survey, the individual occurrences of conglomeratic rocks have acquired local names, such as Mell Fell Conglomerate, Shap Conglomerate and Sedbergh Conglomerate. Unfortunately, in most cases the names have been applied to all arenaceous and conglomeratic rocks up to the base of the overlying Carboniferous Limestone. It is proposed to distinguish this succession into an older Old Red Sandstone Group and a younger Ravenstonedale Group and to simplify the formation nomenclature.

The Upper Old Red Sandstone Group, of probable Devonian age, consists of pebble to cobble grade conglomerate, lithic sandstone, sandstone and mudstone. These strata were deposited in asymmetrical, fault- and topography-bounded troughs, within high-energy alluvial fan, aeolian-influenced fluvial channel and playa lake environments. There is a lithological mismatch between clast suites and local provenance areas, suggesting pene-contemporaneous uplift and erosion of local source areas. There is no direct dating of the strata, but they predate the Tournaisian 'Cockermouth' suite of lavas and minor intrusives. The rocks were tilted and eroded prior to deposition of basal Tournaisian strata of the Ravenstonedale Group. In north Cumbria, the Upper Old Red Sandstone Group comprises a single formation, the Mell Fell Conglomerate Formation. This formation has been correlated with, and now replaces, the local names of Shap Wells Conglomerate, of the eastern margins of the Lake District High, and the Sedbergh Conglomerate, present as laterally impersistent outcrops along the Dent–Pennine Fault System.

Within the Stainmore Trough, the Ravenstondale Group is about 380 m thick, whereas the younger succession present on the Askrigg Block is about 150 m thick. In south Cumbria, the Marsett Formation is up to 240 m thick in the Duddon estuary, thinning appreciably towards the south and east. The equivalent Marsett Formation of north and east Cumbria is typically less than 35 m thick.

The Ravenstondale Group rests unconformably upon strata ranging from Ordovician to Devonian in age. Locally, a nodular dolostone bed with rhizoliths marks the top of the group on the Askrigg Block, indicating emergence (Burgess, 1986).

The Ravenstonedale Group comprises a grey to green-grey and/or variably reddened pebble conglomerate (locally calcite cemented), lithic sandstone, sandstone or mudstone and 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. Tournaisian basaltic lavas, including the Cockermouth Volcanic Formation of north Cumbria, occur locally within the alluvial fan facies.

Within the Stainmore Trough the Pinskey Gill Formation comprises grey, dolomitic limestones and dolostones interbedded with calcareous mudstone and silty sandstone. Over much of the Stainmore Trough, the basal unit comprises red sandstone, green shale and conglomerate of the provisional Marsett Formation. The overlying Stone Gill Formation comprises grey, porcellanous limestone and thin dolostone, with beds of argillaceous limestone, sandstone and mudstone.

On the Askrigg Block the Raydale Dolostone Formation comprises thinly bedded and nodular dolostones interbedded with siltstone and sandstone. The overlying Marsett Formation comprises reddish brown and greenish grey sandstone and conglomerate with rare dolostone beds. The Penny Farm Gill Formation consists of interbedded limestone, dolostone, sandstone and siltstone, commonly with rhythmical bedding.

The onlapping succession of the Ravenstonedale Group was deposited within an epicontinental basin as alluvial fan, fluviodeltaic, marginal marine and peritidal deposits (Holliday et al., 1979). The deposition of the Ravenstonedale Group on the Askrigg Block occurred following an early Visean sea-level rise, with the succession located marginal to the more open marine conditions present in the Stainmore Trough at the time. Away from the Stainmore Trough and northern part of Askrigg Block, the Ravenstonedale Group is dominated by alluvial fan subfacies deposited within linked basins.

The group is of Tournaisian age within the Stainmore Trough and Chadian to early Holkerian age on the northern margin of the Askrigg Block. The Pinskey Gill Formation yields miospores (Johnson and Marshall, 1971; Holliday et al., 1979) and conodonts (Varker and Higgins, 1979) indicative of a Tournaisian age. The lower part of the Stone Gill Formation has a comparable miospore assemblage, whereas the upper part has a miospore assemblage more diagnostic of the Chadian *Lycospora pusilla* (Pu) Zone. Miospore assemblages are indicative of a Chadian (post-Tournaisian) age for the Raydale Dolostone Formation (B Owens *in* Dunham and Wilson, 1985) and *Lycospora pusilla* (Pu) Zone for the Penny Farm Gill Formation, although the presence of *Knoxisporites stephanephorus* suggests an Arundian to early Holkerian age (Burgess, 1986). In south Cumbria the Marsett Formation contains miospores characteristic of the *Schopfites claviger–Auroraspora macra* (CM) Zone of Tournaisian age (Rose and Dunham, 1977). A similar, though less diverse microfloral assemblage, has been recognised in the Marsett Formation of the Shap area (Holliday et al., 1979).

5.3 BORDER GROUP

The Border Group, restricted in extent to the Northumberland Trough, comprises two sedimentary formations (Figure 6). The Lyne Formation comprises strata of *Heterolithic clastic and nonmarine carbonate facies* and is overlain diachronously by the Fell Sandstone Formation of *Millstone Grit facies*. The Lyne Formation is restricted to the central part of the trough, passing northward into strata of the Inverclyde Group.

Lower, Middle and Upper Border groups were introduced as terms by Day et al. (1970) for the Bewcastle area of the Northumberland Trough. The bases of the three groups were defined using marker bands. Marked facies variations to the east of Bewcastle and difficulty in correlation of the marker bands prevented extension of this nomenclature across the trough. The Upper Border Group comprised a Yoredale-type cyclicity (*Yoredale facies*), considered by the Stratigraphical Framework Committee to belong to the newly defined Yoredale Group. In order to comply with standard stratigraphical procedures the Lower and Middle Border groups are renamed as Lyne and Fell Sandstone formations within a single Border Group.

The group is thickest, up to 1350 m, within the central part of the Northumberland Trough. Here, the Lyne Formation is at least 890 m thick. The Fell Sandstone Formation ranges from 130 to 300 m in the north-east of the Northumberland Trough and from 300 to 450 m thick in the central part of the trough.

The base of the group is not proved within the central part of the Northumberland Trough. In the north-east of the trough, where the Lyne Formation is absent, the base of the group is an unconformity at the base of the Fell Sandstone. Within the central part of the trough, the base of the Fell Sandstone is conformable, defined at the base of the Whitberry Band. Here, the top of the group is defined at the base of the Clattering Band.

The Lyne Formation comprises cyclical sequences of fine-grained subarkosic sandstone, siltstone, mudstone and thin limestone. The limestones commonly contain stromatolites and vermetid gastropod bioherms and biostromes.

The Fell Sandstone Formation present in the north-east of the Northumberland Trough comprises fine- to medium-grained, mica-poor, subarkosic sandstone with sparse interbeds of red mudstone (Smith, 1967). This passes, toward the central part of the trough, into a continuation of the cyclical succession present in the underlying Lyne Formation, although in the Fell Sandstone the sandstones are thicker and limestones thinner (Day et al., 1970). Seatearths are common, but are associated with thin coals only in the upper part of the formation.

The Lyne Formation limestones are typically peritidal, with the first incoming of marine limestones occurring later and towards the north-east of the Northumberland Trough. The Lyne Formation sandstones were deposited from lobate deltas that migrated periodically along the basin axis from north-east to south-west (Leeder, 1974). A second source of clastics within the formation is associated with the Whita Sandstone, present in the northern part of the trough and associated with a local source from the Southern Uplands High. The Fell Sandstone is interpreted as deposits 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.

The Lyne Formation contains strata of late Tournaisian to Chadian age. Deposition of the Fell Sandstone 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.

5.4 GREAT SCAR LIMESTONE GROUP

The Great Scar Limestone Group (*Platform and ramp carbonate facies*) has a widespread distribution that includes south Cumbria, Askrigg Block (the type area), Stainmore Trough, Alston Block and Lake District Block (Figure 6).

Historically, the thick limestone succession has been named, at least in part, as Great Scar Limestone. This name was formalised as a group on the Askrigg Block by George et al. (1976). These authors recognised the equivalent strata in Stainmore as the Orton Group and overlying Alston Group. In west Cumbria, the limestone succession was known as the Chief Limestone Group. The Stratigraphical Framework Committee considered that a unified group name for the lithofacies across northern England would improve understanding of the relationships of these carbonate platform successions. Historical precedent, and continued common use of the term, suggested that Great Scar Limestone Group was most suitable.

The Great Scar Limestone Group includes many formations, with a distinct formational nomenclature for the isolated horst and tilt-block highs.

ALSTON BLOCK Melmerby Scar Limestone Formation (Dunham, 1990).

STAINMORE TROUGH Coldbeck Limestone, Scandal Beck Limestone, Brownber, Breakyneck Scar Limestone, Ashfell Sandstone, Ashfell Limestone, Potts Beck Limestone and Knipe Scar Limestone formations (Dunham and Wilson, 1985).

ASKRIGG BLOCK Tom Croft Limestone, Ashfell Sandstone, Fawes Wood Limestone, Garsdale Limestone, Danny Bridge Limestone, Kilnsey Limestone and Malham formations (Dunham and Wilson, 1985).

SOUTH CUMBRIA Martin Limestone, Red Hill Limestone, Dalton, Park Limestone and Urswick Limestone formations (Rose and Dunham, 1977; Johnson et al., 2001).

NORTH CUMBRIA Frizington Limestone and Eskett Limestone formations.

The Great Scar Limestone Group is thickest, about 800 m, in the Stainmore Trough. In south Cumbria it is about 740 m thick and in west Cumbria about 190 m. The group is about 400 m thick on the Askrigg Block and up to 107 m thick on the Alston Block.

In the Stainmore Trough the base of the group, taken at the top of the Algal Nodular Beds, is conformable upon the Ravenstonedale Group. A disconformity occurs at the base of the group on the Askrigg Block, marking a low sea-level stand at the base of the Arundian Tom Croft Limestone Formation. This is also evident as an unconformity present at the base of the Breakyneck Scar Limestone Formation, within Stainmore Trough, and the base of the Red Hill Formation in south Cumbria. On the Alston Block, the unconformable base of the group rests upon conglomerates of the Ravenstonedale Group. In west Cumbria, the base of the Great Scar Limestone Group rests disconformably upon Tournaisian conglomerates of the Marsett Formation. In north and west Cumbria, the bases of the Frizington Limestone and Eskett Limestone formations are marked by disconformaties with non-deposition during Chadian to Arundian and late Holkerian to early Asbian times, respectively.

The succession comprises limestone, typically well washed, bioclastic, highly bioturbated with crinoid banks, shelly or coral biostromes and algal (*Girvanella*) bands. The group, common with other Visean platform areas in the British Isles, shows a trend from dark grey carbonates of Arundian to Holkerian age to pale grey limestones of Asbian to Brigantian age, with eight major palaeokarstic bedding surfaces overlain by thin mudstones (Waltham, 1971). In the Stainmore Trough the limestone succession includes numerous intercalated sandstone beds. From late Holkerian to early Brigantian times, apron knoll reefs developed along the southern margin of the Askrigg Block.

The lower, mostly Tournaisian to Chadian, part of the group present in the Stainmore Trough (Coldbeck Limestone) and south Cumbria (Martin Limestone Formation) were 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. Within the Stainmore Trough, there are brief incursions of siliciclastic deposits. The Brownber Formation represents alluvial deposits and the Ashfell Sandstone comprises fluviodeltaic strata, which encroached into the Stainmore Trough from the north, possibly as the distal extension of the Fell Sandstone Formation.

The group ranges from Tournaisian to earliest Brigantian in age. The Stainmore Trough has the most wide-ranging age for the group, from Tournaisian to Asbian, and includes the basal Asbian stratotype, taken at the base of the Potts Beck Limestone (George et al., 1976). On the Askrigg Block, the group ranges in age from Arundian to late Asbian. In south Cumbria, the group ranges from Tournaisian to Chadian to Asbian (Rose and Dunham, 1977), with the basal Holkerian stratotype taken at the base of the Park Limestone Formation (George et al., 1976). In north Cumbria, the group ranges in age from Holkerian to Pendleian. On the Alston Block the group is limited to strata of Asbian age.

5.5 YOREDALE GROUP

The Yoredale Group (*Yoredale* and *Millstone Grit facies*) extends across the entire Northern England Province (Figure 6). There is a long-established usage of the term *Yoredale facies*, based upon the description of Yoredale cycles as early as Phillips (1836). This term replaces the Wensleydale Group of the Askrigg Block, Alston Group of the Alston Block and Upper Border Group, Lower and Upper Liddesdale groups of the Northumberland Trough. The type locality of the group is the River Ure on the Askrigg Block.

The group, as proposed, comprises up to three formations over northern England; namely the Tyne Limestone, Alston and Stainmore formations. In south Cumbria, only the Alston Formation is recognised (formerly Gleaston Formation; Rose and Dunham, 1977). In north Cumbria, the term Alston Formation is now applied to Brigantian to Pendleian strata of *Yoredale facies*. The Alston Formation passes westward, approximately at the Bothel Fault, into the limestone-dominated Eskett Limestone Formation of the Great Scar Limestone Group. The upper part of the Stainmore Formation was shown historically on maps as Millstone Grit, though recent resurveys included this unit within a single chronostratigraphical group for the entire Namurian succession (Burgess and Holliday, 1979). A linkage between the Stainmore Formation and the Millstone Grit Group to the south is possible, but as yet unproven.

The greatest thickness for the group is 1219 m, proved in the eastern part of the Stainmore Trough (Dunham and Wilson, 1985). The group, formations and individual sandstones tend to thicken into troughs and half-grabens. There are marked thickness variations across the Stublick–Ninety Fathom Fault, separating the Northumberland Trough from the Alston Block, to the south. In south Cumbria, where only the Visean part of the succession is present, the group is 80 to 180 m thick. The Stainmore Formation, of north and west Cumbria, thickens northwards towards the Solway Basin, up to 125 m.

The conformable base of the Yoredale Group is typically taken at the base of marine limestone marker bands. In the Northumberland Trough this is the Clattering Band (or its correlative, the Kingbridge Limestone) at the base of the Asbian. On the Alston Block, the base of the group is taken at the base of the Peghorn (Lower Smiddy) Limestone, defined as the Brigantian Stage basal stratotype (George et al., 1976). The base of the group on the Askrigg Block and in the Stainmore Trough occurs at the base of the Lower Hawes Limestone. In the Langholm area of the Solway Basin the base of the group occurs at the base of the Glencartholm Volcanic Member. In north and west Cumbria there is a large non-sequence within the group, in which strata of Chokierian to Marsdenian age are absent (Akhurst et al., 1997).

The Yoredale Group comprises typically upward-coarsening cycles of basal thin, laterally extensive marine limestone, marine mudstone (commonly bioturbated), thin sandstone frequently topped with seatearth and ganister and an overlying coal. The limestones are typically dark blue-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 cycles, which range from 15 to 90 m thick in Northumberland, are named after the limestone present at the base of each cycle. Limestones are recognised as lithostratigraphical beds, unless they form a complex mappable unit, and can be identified as members. Details of limestone nomenclature, correlation and cycle thickness are provided by Dunham and Wilson (1985) for the Askrigg Block and Stainmore Trough, and by Dunham (1990) for the Alston Block.

In the Solway Basin, the Tyne Limestone Formation comprises a heterogeneous 'Yoredale' cyclicity, with limestone and sandstone components absent from parts of the succession. The formation includes the Glencartholm Volcanic Member, a succession of tuffs and basalts, up to 150 m thick (Lumsden et al., 1967).

The Alston Formation is distinguished from the underlying and overlying formations by the presence of thick, commonly, bioclastic limestones. The Great Limestone Member is the uppermost limestone of the formation.

The Stainmore Formation is distinguishable from the underlying Alston Formation by a decrease in the number and thickness of the limestones, which tend to be darker grey than those within the underlying formation. 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 upper part of the Stainmore Formation is characterised by the absence of limestones or the presence of only thin limestones within the Yoredale cycles, and the occurrence of thick, coarse-grained to pebbly sandstones with channel-like geometry. Historically, these fluvial sandstones have been mapped as First and Second Grit (Ramsbottom et al., 1978), although the correlation of such a simple stratigraphy for a complex of channel sandstones is now questioned.

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). The marine limestones were deposited as a consequence of sea-level rises and switching or abandonment of the delta lobes.

The base of the Yoredale Group is diachronous, ranging from early Asbian in the Northumberland Trough, early Brigantian on the Askrigg and Alston Blocks, the Stainmore Trough and south Cumbria, to Pendleian in north and west Cumbria. For all but the Askrigg Block, the group extends up to the base of the Pennine Coal Measures Group. On the Askrigg Block the group is overlain by the Millstone Grit Group, the latter present above an intra-Pendleian (E_{1c}) unconformity formed during the northward tilting of the block. The base of the Namurian, defined as the base of the Cravenoceras leion Marine Band is taken near to the base of the Great Limestone Member.

5.6 MILLSTONE GRIT GROUP

The Millstone Grit Group (*Millstone Grit facies*), is limited within the Northern England Province to the Askrigg Block (Figure 6).

The group is about 500 m thick, significantly thinner on the Askrigg Block than the equivalent strata present within the Central Pennine Basin to the south.

The base of the Millstone Grit Group is marked by a slightly angular intra-Pendleian (E_{1c}) unconformity. The presence of a mid-Carboniferous unconformity is indicated by the absence of Alportian strata across the Askrigg Block (Ramsbottom, 1977).

The group is typified by cyclic successions of quartz-feldspathic sandstone, grey mudstone, thin coal and prominent seatearths. Ammonoid-bearing marine mudstones are not common. Marine bands of mostly Kinderscoutian age comprise near-shore calcareous sandstones with a benthic fauna of brachiopods, crinoids and bryozoans, but lacking ammonoids.

The sandstones are typically fluviatile, with distributary channel palaeoflows to the south or south-west. Some seatearths may result from prolonged periods of emergence.

The group ranges from Pendleian to Yeadonian age.

5.7 PENNINE COAL MEASURES GROUP

The Pennine Coal Measures Group (*Coal Measures facies*) extends from the Wales–Brabant High northwards to the Southern Uplands. The group has been given the epithet of 'Pennine' to distinguish these coal measures from those present in the Midland Valley of Scotland, and from those south of the Wales–Brabant High.

The group is subdivided into Pennine Lower, Middle and Upper Coal Measures using the same marker marine bands used for the remainder of the Pennine Basin. The main description of the group is provided in the section for Central England and Wales, where this group is most extensively developed. Variations relevant to northern England are discussed here.

The Pennine Coal Measures Group in the main area of the Northumberland–Durham coalfield is up to 900 m thick. In west Cumbria, the group is between 300 and 400 m thick, thickening offshore to the north-west into the Solway Basin. In the Canonbie Coalfield, the group is about 1000 m thick, with a westward thinning and overstep of the Coal Measures onto a structural high. About 800 m of this succession belongs to the Pennine Upper Coal Measures.

The base of the group generally rests conformably upon the Yoredale Group. However, in the Canonbie Coalfield there is an unconformity at the base of the group. In the north-west of this coalfield, the Pennine Upper Coal Measures also rest unconformably upon the Pennine Middle Coal Measures. Over much of the West Cumbria Coalfield, strata from the upper *Similis-pulcra* Bivalve Zone appear to be cut out below the unconformable base of the Whitehaven Sandstone.

Marine bands are dominated by foraminifera, *Lingula* sp., fish remains and shallow marine benthic productid fauna. In the Northumberland–Durham Coalfield, the *Millstone Grit facies* with sheet-like coarse-grained sandstones (including the 'Third Grit'), common marine bands and thin coals persists into the Langsettian. The Pennine Upper Coal Measures of the Canonbie Coalfield is typically reddened secondarily.

The Pennine Coal Measures Group of the Northern England Province typically range from Langsettian to Bolsovian. The Pennine Upper Coal Measures of the Canonbie Coalfield include fauna indicative of the *Anthraconauta phillipsii* Zone, Bolsovian in age.

5.8 WARWICKSHIRE GROUP

The Warwickshire Group, of *Red-bed subfacies*, of the southern and central Pennine Basin (Powell et al., 2000) is here considered to extend to the northern parts of the basin. A single Whitehaven Sandstone Formation is recognised in north and west Cumbria. In the Canonbie Coalfield, a broadly upward-coarsening, primary red-bed succession is now considered to represent the Warwickshire Group and three new formations have been proposed, in ascending order: Eskbank Wood, Canonbie, Bridge Sandstone and Beckless Sandstone formations.

The Whitehaven Sandstone Formation is at least 300 m thick, whereas in the Canonbie Coalfield the group is up to 500 m thick.

The Whitehaven Sandstone Formation unconformably overlies the Pennine Coal Measures Group and comprises a red-bed succession. The lower 100 m consists of red to deep purple or purplish brown, cross-bedded, micaceous, medium- to coarse-grained sandstone, known as the Whitehaven Sandstone (Akhurst et al., 1997). There are interbeds of pink to red or grey mudstone and siltstone and thin palaeosols are present locally. The sandstones are overlain by a heterogeneous, dominantly red succession of mudstone, sandstone and marl with thin coals and limestones with *Spirorbis* sp.

The lower part of the Whitehaven Sandstone Formation is interpreted as deposits 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.

Plant remains and the presence of the zonal nonmarine bivalve *Anthraconauta phillipsii* (Eastwood et al., 1931) indicate a late Bolsovian to early Westphalian D age for the Whitehaven Sandstone Formation. To the north-east, similar strata have a Westphalian D *A.tenuis* Zone fauna (Eastwood et al., 1968), with the red beds of the Canonbie Coalfield of comparable age.

5.9 CORRELATION WITH THE NORTHERN IRISH SEA

The northern Irish Sea includes the Peel–Solway Firth Trough (the offshore continuation of the Northumberland Trough) and the Manx Massif and Ramsey–Whitehaven Ridge (the offshore continuation of the Lake District High). Carboniferous strata subcrop beneath Quaternary deposits in the western part of the region and beneath a thick Permo-Triassic cover in the east. The offshore information is detailed by Jackson et al. (1995), and the lithostratigraphical scheme of Jackson and Johnson (1996) identifies three groups for the Carboniferous: the Garwood, Bisat and Kidston. These groups, broadly equate with the chronostratigraphical subdivisions of Dinantian, Namurian and Westphalian–Stephanian.

5.9.1 Garwood Group

The Garwood Group is present in the East Irish Sea as two distinct facies. A *Platform and ramp carbonate facies* developed bordering the Manx-Lake District Ridge, equates with the Great Scar Limestone Group of the onshore Northern England Province. Within the Peel–Solway Firth basins the group comprises strata equivalent to the onshore Yoredale Group.

The full thickness of the group has not been proved; only the upper 169 m has been drilled. The base of the group has not been proved offshore, but is considered to lie unconformably upon pre-Carboniferous strata.

The group comprises pale to dark grey limestone, mostly packstone and grainstone. Secondary dolostone adjacent to faults and penecontemporaneous dolostones are present locally.

Onshore, on the northern part of the Isle of Man there is about 250 m of Balladoole Formation, comprising limestone with sparse shaly beds similar to the Brigantian Great Scar Limestone Formation of west Cumbria. In the south of the Isle of Man, alluvial fan conglomerates (30 m thick) of the Langness Formation are overlain by Visean shallow shelf carbonates (about 200 m thick) of the Derbyhaven, Knockrushen and Balladoole formations. In the Keys Embayment, between the Isle of Man and the west Cumbria coast, a well proved Brigantian strata comprising 108 m of grey argillaceous limestone, equated with the onshore Alston Formation.

5.9.2 Bisat Group

The Bisat Group is a dominantly argillaceous succession of Namurian age present in the East Irish Sea. On the crest and flanks of the Manx–Lake District Ridge the succession is similar to the Yoredale Group of west Cumbria, with comparable erosion or nondeposition of Chokierian to Marsdenian strata.

As with onshore analogues, the Bisat Group rests conformably upon strata of the Garwood Group.

5.9.3 Kidston Group

The Kidston Group comprises Westphalian and Stephanian strata lithologically comparable to the Pennine Coal Measures Group present onshore in west Cumbria. Secondary reddening, which may have developed during Stephanian times (Wagner, 1983), is almost ubiquitous and was formerly often taken to represent Permian strata. The secondary reddening occurs to greatest depths beneath the Permo-Triassic unconformity on the structural highs, with up to 546 m recognised to the south-east of the Isle of Man. In this area, the Langsettian is up to 224 m thick, with numerous thick coals, whereas the Duckmantian succession, up to 212 m thick, includes only one coal (Jackson et al., 1995). Bolsovian and Westphalian D strata have been proved off the west Cumbria coast (Taylor, 1961).

The group comprises mainly mudstone and siltstone with significant interbedded sandstones, especially in the upper part, and coals and seatearths, notably within the lower part.

5.10 CORRELATION WITH THE MID NORTH SEA HIGH AND SOUTHERN NORTH SEA

5.10.1 Upper Old Red Group

The term was introduced for the Late Devonian to early Carboniferous fluvial strata (*Continental and peritidal facies*) of the North Sea (Cameron, 1993a). The deposits extend eastwards from the coast of south-east Scotland along the crest and southern flanks of the Mid North Sea High. The Tayport Formation is the only formation of the group in part of early Carboniferous age. The formation probably does not extend far southward into the Southern North Sea, analogous to the onshore Kinnesswood Formation, with which the Tayport Formation equates. A maximum thickness drilled for the Tayport Formation is 649 m.

The group rests conformably upon marine Devonian strata of the Kyle Group on the Mid North Sea High. Elsewhere in the Southern North Sea the base of the group rests unconformably upon deformed Lower Palaeozoic strata. The Tayport Formation comprises mainly red, interbedded mudstones and sandstones.

The Tayport Formation was probably deposited in fluvial and playa lake environments within a low-lying alluvial floodplain, the sandstones representing major distributary channels or sheet floods (Cameron, 1993b). The Tayport Formation ranges from Famennian to early Tournaisian.

5.10.2 Farne Group

The term was introduced for the Tournaisian to early Namurian lacustrine, fluvial and fluviodeltaic sediments (*Continental and peritidal*, *Yoredale* and *Coal Measures facies*) of the Southern North Sea (Cameron, 1993b). The deposits extend eastwards from the Northumberland coast along the western crest and southern flanks of the Mid North Sea High. Elsewhere in the Southern North Sea the group has not been penetrated. The group comprises, in ascending order, the Cementstone, Fell Sandstone, Scremerston and Yoredale formations (Cameron, 1993b). The Cementstone Formation is the equivalent of the onshore Ballagan Formation. The base of the Fell Sandstone Formation is markedly diachronous, appearing earlier in the east. As a consequence, the Lyne Formation of the central and western parts of the onshore Northumberland Trough is not developed in the North Sea. The formation is equivalent to the onshore Fell Sandstone Formation, however, differing in the definition of the base and top. The Scremerston Formation is the equivalent of the onshore Scremerston Coal Member of the Alston Formation (Yoredale Group). The Yoredale Formation is equivalent to part of the onshore Yoredale Group.

The maximum drilled thickness in the Southern North Sea for the Cementstone, Fell Sandstone, Scremerston and Yoredale formations is 390 m, 382 m, 266 m and 704 m, respectively (Cameron, 1993b). The group rests conformably upon strata of the Tayport Formation. The base of the group is taken at the base of the lowest cementstone bed.

The Cementstone Formation comprises interbedded sandstone, mudstone and micritic dolostone. The Fell Sandstone Formation is characterised by fine- to coarse-grained sandstones with subordinate beds of grey mudstone. The Scremerston Formation comprises interbeds of sandstone, mudstone and coal with sparse dolostone and limestone. The Yoredale Formation is characterised by thin marine limestone occurring in cycles between 30 and 130 m thick, with intervening upward-coarsening deltaic deposits.

The environments of deposition of these formations are the same as for their onshore equivalents (see sections 5.3 and 5.5).

The Cementstone Formation is of Tournaisian to Chadian age. The Fell Sandstone Formation is of Chadian to possibly early Asbian age. The Scremerston Formation is of Asbian and possibly also early Brigantian age. The Yoredale Formation is a late Visean (late Asbian) to early Namurian succession.

The Whitehurst Group, offshore equivalent of the Bowland Shale Formation and Millstone Grit Group, is absent over the crest and southern flanks of the Mid North Sea High, largely due to Variscan uplift and erosion.

6 Central England and North Wales

This province includes ramp-to-shelf carbonates (*Platform and ramp carbonate facies*), present along the northern margin of the Wales–Brabant High, and Tournaisian to Namurian basinal deposits (*Hemipelagic facies*), south of the Craven Fault System (Figure 2c). Dinantian platform carbonates extend across north Wales (Clwyd Limestone Group) and the East Midlands (Peak Limestone Group). The nature of the subsurface East Midlands Shelf is based largely upon well records and geophysical information. A promontory of the East Midlands Shelf forms the Derbyshire High. The basinal deposits of the Craven Group were deposited within a series of linked embayments, such as the Craven, Harrogate, Edale, Gainsborough and Widmerpool sub-basins and isolated structural highs, such as the Derbyshire, Bowland, Holme and Central Lancashire highs (Figure 2c). Each of the highs developed a carbonate platform, at least during the early Dinantian. During the Namurian and Westphalian, thermal subsidence was greatest in this province, which is known as the Central Pennine Sub-basin of the Pennine Basin. Thick fluviodeltaic successions, including the Millstone Grit Group (*Millstone Grit facies*) and Pennine Coal Measures Group (*Coal Measures facies*), accumulated within this basin. The platform carbonates of the southern margin of the basin are overlain by relatively condensed Westphalian and Stephanian successions, including alluvial deposits of the Warwickshire Group (*Barren Measures facies*).

The lithostratigraphy of the province, shown in Figure 7, is described below.

6.1 NORTH WALES 'BASEMENT BEDS'

The 'Basement Beds' is an informal term used in north Wales to describe a number of isolated alluvial deposits (Davies et al., 2004). As with similar deposits present in northern England, the Stratigraphical Framework Committee did not consider these isolated deposits warranted group status. Formation names have been proposed for alluvial deposits present within what were distinct cuvettes, namely Lligwy Sandstone, Menai Straits, Ffernant, Penbedw, Fron-Fawr and Pant formations. These formations are distinguished not only by their geographical isolation at the time of deposition, but they also show different ages of deposition and clast composition, having been derived from the local upland areas that separated the cuvettes.

Locally, principally in the Vale of Clwyd, the basal part of the succession comprises up to 75 m of reddened alluvial breccia, conglomerate, sandstone, siltstone and mudstone. Replacive calcareous nodules ('cornstones'), and thin beds of variegated, red and green, argillaceous, nodular limestone or dolomite are present throughout the formation, and record varying stages in the development of calcrete (Davies et al., 2004).

The deposits record the infilling of an incised topography that was possibly influenced by faulting. Welsh upland areas to the immediate west and south were the principal sediment source (Davies et al., 2004).

The 'Basement Beds' are unfossiliferous, but may range down into the Tournaisian (Davies et al., 2004).

6.2 CLWYD LIMESTONE GROUP

In its type area east of the Clwydian Range, the Clwyd Limestone Group of north Wales comprises, in ascending order, the Foel, Llanarmon Limestone, Leete Limestone, Loggerheads Limestone, Cefn Mawr Limestone and Minera formations (Davies et al., 2004).

The Clwyd Limestone Group is up to 900 m thick. Its component formations exhibit pronounced lateral thickness and facies variations, which reflect the syndepositional influence of major faults, notably those associated with the Menai Straits and Bala lineaments.

The group rests locally upon 'Basement Beds', or elsewhere with marked unconformity on Silurian rocks.

The Foel Formation (Warren et al., 1984) comprises a thin- to medium-bedded sequence of porcellaneous calcitic mudstone and wackestone, argillaceous packstone, peloidal and locally ooidal grainstone, cryptalgal laminites and oncolitic floatstone, with intercalated red and green variegated mudstone, siltstone and calcareous sandstone (Davies et al., 2004).

The Llanarmon Limestone Formation comprises pale, thick-bedded, peloidal and skeletal grainstones, with subordinate dark, thinner bedded packstones. The upper part of the Llanarmon Limestone Formation intertongues with, and is progressively replaced by, the Leete Limestone towards the south (Davies et al., 2004).

The Leete Limestone Formation comprises rhythmic units of dark, argillaceous skeletal packstone and paler grainstone, overlain by porcellaneous limestone (Somerville and Strank, 1984b; Davies et al., 1989). The formation passes northward into the Llanarmon Limestone.

The Loggerheads Limestone Formation consists mainly of pale, thick-bedded, skeletal and peloidal packstone that may be massive, rubbly, pseudo-brecciated or mottled, present in cycles typically topped by palaeokarstic surfaces, in turn overlain by mudstone palaeosols.

The Cefn Mawr Limestone Formation consists of wackestone, packstone and grainstone arranged in cyclic sequences, the boundaries of which are defined by correlatable pedogenic and karstic features. Black, replacive chert nodules are common.

The Minera Formation comprises wackestone, packstone and grainstone arranged in cyclic sequences, with thick, calcareous sandstone commonly developed at the top of the cycles.

Visean 'knoll reef' limestones are recognised in the Llandudno and Prestatyn areas (Warren et al., 1984) and channelised sandstone and conglomerate bodies are a feature of the succession exposed on Anglesey (Davies, J R, 1991).

The group comprises a sequence of dominantly shallow marine ramp and platform carbonates (Davies et al., 2004). The Foel Formation accumulated in a lagoon or as intertidal and supratidal carbonate mud flats, interdigitating with contemporary high-energy and open marine facies that record invasion of sediment derived from offshore shoals or barriers. The Llanarmon Limestone Formation accumulated under relatively high-energy, warm, shallow marine conditions, the sharp base to the formation recording a major marine transgression. The lower part of the formation

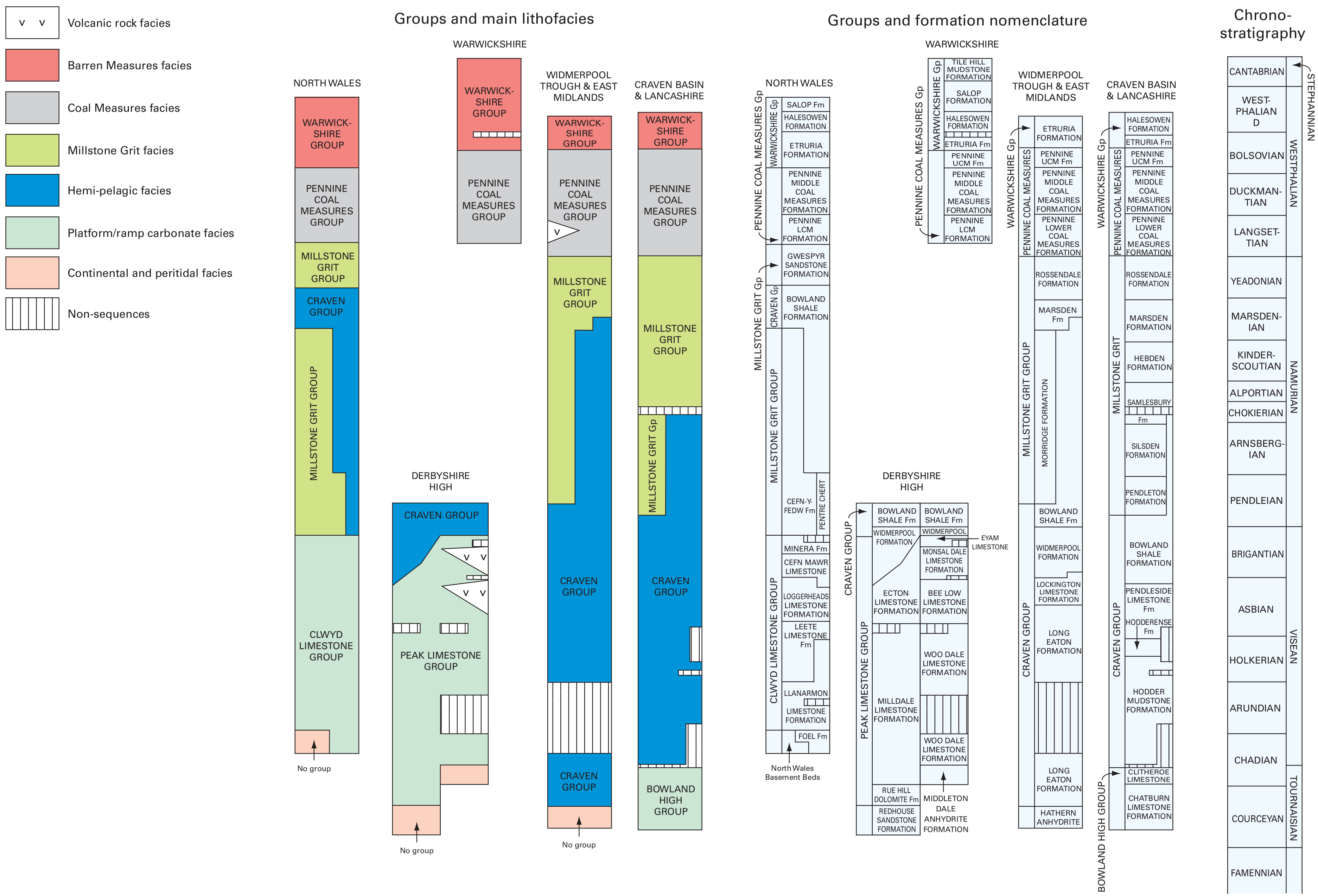

Figure 7 Lithostratigraphical nomenclature for the Central England and North Wales region. See Chapter 2 for description of lithofacies. Fm Formation; Gp Group; LCM Lower Coal Measures; UCM Upper Coal Measures

developed as an eastward-facing carbonate ramp (Somerville et al., 1989), which by late Arundian had evolved into a carbonate platform. The Leete Limestone records a return to deposition in restricted, probably hypersaline, lagoonal and peritidal settings (Somerville and Gray, 1984). The cyclic sequences of the Loggerheads Limestone and Cefn Mawr Limestone represent shoaling-upwards rhythms developed as the product of consecutive marine inundations. The karstic surfaces, bentonitic soils and well-developed calcrete profiles demonstrate long emergent intervals in response to marine regressions (Davies, J, 1991). The cyclic sequences of the Minera Formation also represent shoaling upwards sequences, the limestones ranging from storm wave base to fair-weather wave base. The sandstones were deposited within upper shoreface and beach environments.

The strata now included within the Clwyd Limestone Group were thought to comprise only Asbian and Brigantian strata (George et al., 1976). However, earlier Chadian, Arundian and Holkerian strata have subsequently been discovered (Somerville and Strank, 1984a, b; Davies et al., 1989; Davies et al., 2004).

6.3 PEAK LIMESTONE GROUP

The Peak Limestone Group (*Platform and ramp carbonate facies*) is exposed within the Peak District of Derbyshire, and present in the subsurface elsewhere in the East Midlands. Lateral continuity with the Clwyd Limestone Group of north Wales has not been demonstrated to date, and as such it is treated as a separate group.

The proposed lithostratigraphy of the 'Derbyshire High' is adapted from (Aitkenhead and Chisholm, 1982). The ramp carbonate succession shows a lateral passage from the Derbyshire High to the south and west into areas of slightly deeper water. The deeper water succession, which rests upon the Rue Hill Dolomite Formation, includes the Milldale Limestone and Hopedale Limestone formations. The shallower water succession includes, in ascending order, the Woo Dale Limestone, Bee Low Limestone, Monsal Dale Limestone and Eyam Limestone formations. The Fallgate Volcanic Formation interdigitates with the Monsal Dale Limestone and Bee Low Limestone formations.

The Peak Limestone Group comprises a deeper water succession in excess of 800 m thick, and a shallower water succession about 1000 m thick. The Falgate Volcanic Formation is at least 293 m thick.

The group generally rests unconformably upon deformed Lower Palaeozoic strata, but locally, the base is conformable on Late Devonian to early Dinantian strata of *Continental and peritidal facies*. These form a number of isolated, stand-alone formations. Alluvial fan gravels, the Redhouse Sandstone Formation, and Middleton Dale Anhydrite Formation have been proved in the subsurface adjacent to the Derbyshire High. The concealed Hathern Shelf includes comparable formations, namely the Calke Abbey Sandstone, Arch Farm Sandstone, Hathern Anhydrite and Scalford Sandstone formations. Whereas in Shropshire, the facies is represented by the Village Farm Formation. Internally, the group includes local disconformities at the base of the Hopedale Limestone, Monsal Dale Limestone and Eyam Limestone, resulting from localised tectonic uplift, particularly during Chadian and Brigantian times. Subaerial palaeokarstic dissolution hollows are common, particularly during the Asbian and Brigantian (Walkden, 1974). The uppermost part of the group is locally truncated beneath Westphalian strata.

The Milldale Limestone Formation comprises limestone of both knoll-reef and inter-reef facies. The single or compound knoll-reefs are composed of fossiliferous, massive micrite with common spar-filled cavities, whereas the inter-reef facies consists of poorly fossiliferous, well-bedded, crinoidal biosparite and subordinate dark grey, cherty, micritic limestone. The overlying Hopedale Limestone Formation comprises heterogeneous limestone, with a dominance of medium grey, fine to coarse calcarenite.

The Woo Dale Limestone Formation typically comprises a lower succession of grey-brown to dark grey dolomitic limestone, which passes up into medium and pale grey, thick-bedded biosparites. The top of the formation comprises thin-bedded pale to dark grey interbedded calcarenite biosparite and porcellanous micrite. The Bee Low Limestone Formation consists of a homogeneous succession of very thick beds of pale grey biosparite and biopelsparite calcarenites. The formation includes pedogenic crusts and palaeokarstic surfaces, commonly overlain by thin, red-brown and grey-green bentonites (Walkden, 1974, 1977). The Monsal Dale Limestone Formation comprises a heterogeneous succession of pale to medium grey, thin- to thick-bedded limestones with sporadic cherts, and dark grey, thin-bedded, cherty limestones with argillaceous partings. The Eyam Limestone Formation typically comprises dark grey, thin-bedded, cherty bioclastic limestone with dark grey mudstone intercalations. A reef facies comprises pale grey limestone, typically of massive biomicrite, with a distinctive brachiopod fauna.

The Falgate Volcanic Formation consists of basaltic lava, fragmented lava and tuff, with thin beds of limestone (Aitkenhead and Chisholm, 1982). Basaltic lava and tuff, erupted in both subaerial and subaqueous environments, are also locally a significant component of the Bee Low Limestone and Monsal Dale Limestone formations, and may be considered as beds or members.

During Tournaisian to early Visean times there was a slow onlap of marine ramp carbonates, with some evaporites at the base, onto an irregular palaeorelief. The presence of 'birdseye' structures and rare coals within the Woo Dale Limestone suggests a regressive event associated with development of an intertidal or supratidal environment during Holkerian times. By Asbian times a further sea-level rise and syn-rift subsidence led to a clear differentiation between a shelf province, fringed by apron-reefs, and off-shelf facies (Craven Group) (Gawthorpe et al., 1989).

The Peak Limestone Group ranges in age from late Tournaisian to late Brigantian.

6.4 BOWLAND HIGH GROUP

The Bowland High Group (*Platform and ramp carbonate facies*) comprises the Chatburn Limestone and Clitheroe Limestone formations (Figure 7), located within a restricted area of the Craven Basin. Lateral continuity with the Great Scar Limestone Group of the Askrigg Block cannot be demonstrated, and as a result a distinct group name has been proposed.

The Chatburn Limestone Formation (former group of Earp et al., 1961) of the type area of Chatburn provides the Basal Stratotype of the Chadian Stage (George et al., 1976).

The Bowland High Group has a minimum thickness of about 2300 m, but the base of the group has not been proved. The Chatburn Limestone is about 840 m and the Clitheroe

Limestone up to 1500 m thick. The group is overlain unconformably by the Craven Group.

The Chatburn Limestone Formation comprises packstone limestone, with abundant algal oncolites and thin subordinate beds of calcareous mudstone. The Clitheroe Limestone Formation comprises pale grey packstone, wackestone and floatstone and subordinate mudstone. Waulsortian limestone (knoll reefs or mud mounds) is also present.

The depositional environment of the Chatburn Limestone was a widespread and relatively uniform shallow marine carbonate shelf with a significant input of fine terrigenous clastic sediment. The Clitheroe Limestone is associated with the development of a carbonate ramp and northward retreat of shelf carbonates, which were replaced by Waulsortian limestones. The buildup of Waulsortian limestones was briefly interrupted by a phase of shallowing and development of storm-generated carbonates.

At its type locality, the Chatburn Limestone, has been attributed an age of Tournaisian (Courceyan) to Chadian (George et al., 1976) or entirely Tournaisian (Riley, 1990, 1993). The Clitheroe Limestone is considered early Chadian in age by Riley (1990; 1993), the absence of *Eoparastaffella* indicating a probable Tournaisian ($Cf4_{\alpha 1}$ Zone) age.

6.5 CONCEALED TOURNAISIAN–VISEAN CARBONATES

The concealed Tournaisian–Visean carbonates of the Central Lancashire High and Holme High are recognised as isolated platform successions of Chadian to Asbian age (Evans and Kirby, 1999). Seismic and geophysical logs have been used to identify a single lithofacies and no attempt has been made to divide these buried carbonates into formations. The informal names of Trawden Limestone Group (for the Central Lancashire High) and Holme High Limestone Group (for the Holme High) are proposed.

6.6 CRAVEN GROUP

The Craven Group (*Hemipelagic facies*) is introduced to replace numerous geographically localised group names; some former groups have been redefined as constituent formations of the Craven Group. The type area of the group is the Craven Basin of Lancashire. In the East Midlands the group occupies several embayments within the Wales–Brabant High. In north Wales the nomenclature of Dyserth and Gronant groups of Warren et al. (1984) was essentially chronostratigraphical, distinguishing pre-Brigantian and Brigantian strata. The new nomenclature takes account of the prominent facies variation between shelf carbonates and slope turbidites.

The group includes many formations, with separate nomenclature for geographically isolated areas.

CRAVEN BASIN (the type area) Hodder Mudstone, Hodderense Limestone and Pendleside Limestone formations, which were all formally defined by Riley (1990) for the now redundant Worston Shale Group, and the redefined Bowland Shale Formation (formerly of group status).

WEST OF THE DERBYSHIRE HIGH Ecton Limestone, Widmerpool and Bowland Shale formations (Aitkenhead and Chisholm, 1982).

WIDMERPOOL HALF-GRABEN Long Eaton, Lockington Limestone and Widmerpool formations (Carney, 2001) and Bowland Shale Formation (formerly Edale Shales).

NORTH WALES Prestatyn Limestone, Teilia, Pentre Chert and Bowland Shale formations (formerly Holywell Shales) (Davies et al., 2004).

Within the Craven Basin the group is in excess of 1450 m thick. In the Widmerpool half-graben the Craven Group may be in excess of 5000 m thick. The succession is dominated by the Long Eaton Formation, which seismic interpretations suggest is up to 4000 m thick. In north Wales, where the group is up to 400 m thick, both the Prestatyn Limestone and Telia formations pass southwards into Visean shelf carbonate facies of the Clwyd Limestone Group.

The base of the Craven Group within the Craven Basin rests unconformably upon the Clitheroe Limestone. In the Widmerpool half-graben the group rests unconformably upon Cambrian strata. West of the Derbyshire High the group may rest conformably upon upper Devonian strata. The base of the group in north Wales, taken at the base of the Pentre Chert Formation, is considered to be a disconformity above the Clwyd Limestone Group. Unconformities occur internally within the group at the base of the Pendleside Limestone and Hodder Mudstone formations. The absence of proven late Chadian and Arundian strata within the Long Eaton Formation of the Widmerpool half-graben, may also indicate the presence of an unconformity. The conformable, though highly diachronous, base of the Millstone Grit Group defines the top of the group over most of the Central Pennine Sub-basin. However, at the northern margin of the Wales–Brabant High the top of the group occurs at the base of the Cefn-y-fedw Sandstone and Morridge formations.

The Craven Group typically comprises a Tournaisian–Visean succession of calcareous mudstone and siltstone interbedded with limestones and subordinate limestone breccias, conglomerates and sandstones. This is overlain by a late Brigantian and Namurian succession of the Bowland Shale Formation, which comprises dark grey and black, organic-rich mudstone, with subordinate beds of siltstone, sandstone and dolomitic limestone. Impersistent coal seams and seatearths are present in north Wales (Davies et al., 2004).

The Tournaisian–Visean formations are broadly defined by the relative abundance of limestone and mudstone. The Hodder Mudstone, Long Eaton, Widmerpool and Pentre Chert formations are mudstone-dominated. The Hodderense Limestone, Pendleside Limestone, Lockington Limestone, Ecton Limestone, Prestatyn Limestone and Telia formations are limestone-dominated. The limestone beds are typically sharp-based, pale and coarsely bioclastic towards the base and more argillaceous towards the top. Locally the upper part of the Widmerpool Formation includes Brigantian subaqueous basaltic lavas, tuffs, agglomerates and hyaloclastites.

The group was deposited in a range of environments from slope carbonate turbidites to a hemi-pelagic basinal setting. Aprons of calcareous turbidites developed basinal to 'knoll-reef' facies, present on the southern margin of the Askrigg Block (e.g. Hodder Mudstone and Pendleside Limestone formations) and northern margin of the Wales–Brabant High (e.g. Long Eaton, Lockington Limestone, Widmerpool, Ecton Limestone, Prestatyn Limestone and Telia formations). Relatively steep slopes are locally evidenced by the presence of slumps, debris flows and gravity slides in the Hodder Mudstone Formation. The hemi-pelagic deposits (Hodderense Limestone, Bowland Shale and Pentre Chert formations) accumulated predominantly from suspension in moderately deep water, largely below the storm wave-base. Thin sandstone and limestone beds were possibly introduced by storms and/or as turbidites. The Bowland Shale Formation shows a decrease in carbonate turbidites and concomitant increase in siliciclastic sandstone turbidites derived from deltas accumulating on the margins of the Central Pennine Sub-basin.

The Craven Group ranges from Chadian to Yeadonian age. Within the Craven Basin, the succession ranges from late Chadian (Cf4$_{\alpha2}$ Zone) (Riley, 1990) to early Pendleian (E$_{1c}$1 Zone). In the Widmerpool half-graben, the group ranges in age from early Chadian to up to Arnsbergian age. West of the Derbyshire High, the group ranges from Arundian to Arnsbergian age. In north Wales, the group ranges from Asbian to Yeadonian age (Davies et al., 2004).

6.7 MILLSTONE GRIT GROUP

The Millstone Grit Group (*Millstone Grit facies*) is of Namurian age. It extends across most of the Central England and North Wales Province, and occurs on the flanks of the Wales–Brabant High. Historically, the group has been divided chronostratigraphically into the Namurian stages bounded by widespread marine bands. 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 for the mainly quartz-feldspathic deltaic succession of northern provenance. Each of the seven Namurian Stage successions has been assigned a distinct formation name, with the exception of the thin, and usually mudstone-dominated successions of the Chokierian and Alportian, which have been joined to form a single formation. The component formations, in ascending order, are the Pendleton, Silsden, Samlesbury, Hebden, Marsden and Rossendale formations (Figure 7). Where marine bands cannot be recognised, or other biostratigraphical data is absent, it is necessary to leave the group undivided.

The Cefn-y-fedw Sandstone Formation of north Wales and the Morridge Formation of Staffordshire and the East Midlands, both of *Millstone Grit facies*, were deposited along the northern margin of the Wales–Brabant High. Lateral continuity between these two broadly similar formations has not been established. Therefore, distinct formation names are maintained. The Morridge Formation, a new name, was formerly referred to as Millstone Grit.

The thickest development is in the northern part of the Central Pennine Sub-basin, where 1225 m is recorded in Wharfedale (Ramsbottom et al., 1978). In their type areas, the Pendleton Formation is up to 800 m, the Silsden Formation is about 400 m and the Samlesbury Formation is 64 m thick. The Hebden Formation is thickest in the Pennines, thinning westwards into Lancashire. There is also a marked southward thickening from about 275 m in the Bradford district to about 600 m in north Derbyshire. The Marsden Formation is about 320 m thick in its type area, thickening up to 600 m to the west of the Pennines, infilling the accommodation space to the south and west of the thick Kinderscoutian succession (Collinson et al., 1977). The Rossendale Formation is about 160 m thick in its type area.

The Cefn-y-fedw Sandstone and Morridge formations are up to 600 m thick. The Cefn-y-fedw Sandstone is thickest north of the Bala Lineament, where the formation occurs as three separate sandstone sequences, interbedded with the Bowland Shale Formation (Davies et al., 2004). The three sandstone sequences merge into a single, thick sandstone succession to the south.

In the northern part of the Central Pennine Sub-basin, the base of the group is taken at the base of the first thick quartz-feldspathic sandstone, of Namurian age, typically present above the Bowland Shale Formation.

In the southern part of the Central Pennine Sub-basin, the Cefn-y-fedw Sandstone Formation conformably overlies the Dinantian Minera Formation to the south and locally rests on the Cefn Mawr Limestone in the north. It intertongues with and onlaps the Pentre Chert Formation, and both intertongue with, and are conformably succeeded by, the Bowland Shale Formation. The Morridge Formation conformably overlies, and intertongues with, the Bowland Shale Formation.

The Millstone Grit Group comprises broadly upward-coarsening cyclic sequences of sandstone, siltstone and grey mudstone, with subordinate and typically thin coal seams and seatearth (palaeosol) horizons. The base of the cycles are typically marked by thin marine bands of dark grey to black, calcareous, shaly mudstone, with distinct ammonoid faunas. The widespread occurrence of the marine bands makes them of primary stratigraphical importance for correlating the successions.

The Pendleton Formation (Pendleian in age) is restricted to the northern margin of the Central Pennine Sub-basin. The formation includes the Pendle Grit Member, which comprises thinly interbedded silty mudstone, siltstone and fine-grained sandstone, cut by massive, laterally impersistent, coarse-grained, pebbly sandstones. The overlying Warley Wise Grit comprises coarse-grained, cross-bedded sandstone.

The Silsden Formation (Arnsbergian in age) is dominated by a great thickness of siltstone and thin sandstone with laterally impersistent cross-bedded sandstones present along the northern margin of the Central Pennine Sub-basin and thick mudstones, including the Caton Shales and Sabden Shales, in Lancashire.

The Samlesbury Formation (Chokierian to Alportian in age), in Lancashire, comprises a complete succession of dark grey shaly mudstone with numerous marine bands. In Yorkshire the Brocka Bank Grit is present in the northern part of the Harrogate Sub-basin, and part of the Alportian succession appears to be absent due to a mid-Carboniferous unconformity.

The Hebden Formation (Kinderscoutian in age) extends across most of the Central Pennine Sub-basin. The formation shows a broadly upwards-coarsening succession. The lowermost thin-bedded siltstone and sandstone (e.g. Mam Tor Sandstone) passes upward into very thick-bedded coarse-grained sandstone (Shale Grit). Overlying thin-bedded siltstone (e.g. Grindslow Shale) is in turn overlain by very thick-bedded, cross-bedded and very coarse-grained sandstone (e.g. Kinderscout Grit).

The Marsden Formation type locality is also the location of the Basal Stratotype of the Marsdenian Stage. The formation (Marsdenian in age) includes laterally extensive sandstones and typically thinner cycles than within the Hebden Formation.

The Rossendale Formation (Yeadonian in age) typically comprises a lower thick succession of dark shale including the Cancelloceras cancellatum and Cancelloceras cumbriense marine bands. Small influxes of sediment from the west are recognised in the formation as the Upper and Lower Haslingden Flags of Lancashire. The very coarse-grained sheet sandstone of the Rough Rock dominates the upper part of the formation. In north Wales, the formation is represented by the Lower Gwespyr Sandstone, which comprises fine-grained sandstone beds with subordinate thinly interbedded sequences of sandstone and mudstone and locally thick units of grey mudstone. Thin coals and seatearths are intermittently developed.

The Cefn-y-fedw Sandstone and Morridge formations comprise quartzose sandstone, locally pebbly, and thin beds of quartz conglomerate, interbedded with mudstone, siltstone and subordinate chert. These are commonly arranged in upwards-coarsening cycles that are up to 20 m thick. In the Widmerpool half-graben, intermixing obscures the distinction between sandstones of southern and northern provenance.

The Millstone Grit Group was deposited by repeated progradation of deltas. There are two main types of delta subfacies recognised in the Central Province.

- Deep-water deltaic sequences, commonly several hundred metres thick, for example Pendle Grit (550 m), Lower Kinderscout Grit (570 m), Roaches and Ashover grits (360 m). These represent deltas fed by large distributaries in which coarse sands were transported in feeder channels, by-passing the delta slope to be deposited in a delta-front apron of coalescing turbidite lobes (Walker, 1966; Collinson, 1969; McCabe, 1978).
- Shallow-water deltaic sequences, commonly tens of metres thick. These deltas lacked significant transport of sediment by turbidity currents. Mouth-bar deposits dominate the lower part of each cycle. These are overlain by mostly sheet-like and laterally extensive distributary sands, for example Guiseley Grit, Chatsworth Grit and Rough Rock. However, elongate deltas are locally developed, for example East Carlton Grit and Haslingden Flags (Collinson, 1988).

Generally, the deep-water deltaic succession occurs in the lower part of the group and the shallow-water deltaic succession in the upper part. However, there is complex interdigitation of the two subfacies along the northern margin of the Pennine Basin.

The Millstone Grit fluviodeltaic successions of the northern part of the Central Pennine Sub-basin typically show a palaeoflow direction broadly towards the south and have a provenance from the north. But locally, the deltaic deposits that appear to infill the Widmerpool Trough show a typically northern provenance (Jones and Chisholm, 1997) with a palaeocurrent direction of flow towards the north-west, along the axis of the trough. The Upper and Lower Haslingden Flags are interpreted as deposits within a birdsfoot delta (Collinson and Banks, 1975), with a westerly provenance, (McLean and Chisholm, 1996).

Both the Cefn-y-fedw Sandstone and Morridge formations record the northward progradation of a fluviodeltaic facies. Turbititic sand-bodies were deposited mostly to the north, and shallow-water fluviodeltaic facies predominated in the southern margins of the basin.

The Cefn-y-fedw Sandstone and Morridge formations range from Pendleian to late Marsdenian in age. The youngest sandstone of the Morridge Formation, the Brockholes Sandstones, is of mid-Marsdenian (R_{2b}) age and interdigitates with the basal sandstone of the Millstone Grit Group.

6.8 PENNINE COAL MEASURES GROUP

The Pennine Coal Measures Group (*Coal Measures facies*) accumulated in the broad Pennine Basin. Subsequent tectonism separated the Coal Measures into smaller coalfields at outcrop, and at depth beneath the Permo-Triassic strata (Ramsbottom et al., 1978). Historically, 'Coal Measures' has been used as a chronostratigraphical term synonymous with the combined Westphalian and Stephanian strata. However, the name, Pennine Coal Measures Group, has recently been defined lithostratigraphically to describe the main body of coal-bearing strata in the Westphalian succession (Powell et al., 2000). The group is divided into three formations, Pennine Lower Coal Measures, Pennine Middle Coal Measures and Pennine Upper Coal Measures (following Stubblefield and Trotter, 1957).

The thickest development of the group is up to 1900 m near Manchester, located in the depocentre of the Pennine Basin. Cyclic sequences in the Coal Measures are thinner (tens of metres) and more numerous than in the underlying Millstone Grit.

Over much of the basin the group rests conformably upon the Millstone Grit Group. Along the southern margin of the basin, the Coal Measures overstep the Millstone Grit and lie unconformably upon pre-Carboniferous strata of the Wales–Brabant High. The base of the group is taken as the base of the Subcrenatum Marine Band or at the base of the coal-bearing sequence if this marker band cannot be identified, as defined by Stubblefield and Trotter (1957). The bases of the Pennine Middle and Pennine Upper Coal Measures are taken at the base of the Vanderbeckei and Cambriense marine bands, respectively. The top of the group has recently been defined as the base of lowest, conformably overlying, major red-bed formation of the Warwickshire Group (Powell et al., 2000), in the south of the Pennine Basin, or the Permo-Triassic unconformity, elsewhere.

The group comprises cyclothems of alternating sandstone, siltstone and grey mudstone, with frequent 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 of importance in correlation of the strata. Sandstones are typically very fine to fine grained, commonly overlain by leached ganisters or unleached gley seatearths. There is a general upwards decrease in the number and thickness of marine bands and contrasting increase in the importance of coals and seatearths from the Millstone Grit into the overlying Coal Measures.

The Pennine Lower Coal Measures can be broadly divided into three unnamed members (Aitkenhead et al., 2002). The lower part of the formation includes numerous marine bands, the sandstones are typically micaceous and coals are of relatively poor quality. The middle part of the formation is characterised by coal seams that are thin and rare and very restricted marine band faunas. The upper part of the formation is a thick succession of laterally impersistent cyclothems, which 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.

The Pennine Middle Coal Measures can be broadly divided into two unnamed members (Aitkenhead et al., 2002). The lower part of the formation is similar to the upper part of the Pennine Lower Coal Measures. In the upper part of the formation marine bands are common and coals are thin. In Yorkshire, sandstones are generally thicker and coarser than is typical of the Coal Measures in general.

The Pennine Upper Coal Measures lack marine bands, although beds with estheriids are common, and coal seams are thin. Formally defined members have been recognised in the Potteries and West Yorkshire areas.

The Coal Measures accumulated in a delta-top environment with large distributary channels (Guion and

Fielding, 1988; Guion et al., 1995). The main channels, which were up to 20 m thick and 10 km wide, are filled by relatively thick, sharp-based sandstones. Between the channels, freshwater lakes and lagoons were associated with deposition of mudstone. The lakes and lagoons were filled by small deltas and crevasse splays producing upward-coarsening siltstones and sandstones. Near emergent surfaces became swamps or raised bogs, colonised by plants, which formed coals following burial. Subsidence rates were low along the southern margin of the Pennine Basin resulting in relatively few, thick seams. Northwards, towards the basin depocentre subsidence rates are greater and seams split. Some of the cycles, particularly in the early Langsettian, commence with a laterally widespread marine band that resulted from eustatic sea level rise.

The lower part of the Pennine Lower Coal Measures is considered to have the same source from the north or north-east as the underlying Millstone Grit (Chisholm et al., 1996). The sandstones from the middle part of the Pennine Lower Coal Measures include sandstones sourced both from the north and from the west (Chisholm, 1990; Chisholm et al., 1996; Hallsworth and Chisholm, 2000). The sandstones of the upper part of the Pennine Lower Coal Measures and lower part of the Pennine Middle Coal Measures also appear to be sourced from the west (Hallsworth and Chisholm, 2000). Within the upper part of the Pennine Middle Coal Measures there is 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).

The Pennine Coal Measures Group is entirely Westphalian in age. The Pennine Lower Coal Measures are of Langsettian age, the Pennine Middle Coal Measures of Duckmantian to Bolsovian age and the Pennine Upper Coal Measures are Bolsovian to Westphalian D in age.

6.9 WARWICKSHIRE GROUP

The predominantly red-bed strata (*Barren Measures facies*) have, in the past, been referred to collectively by terms such as the 'Barren (Coal) Measures' and 'Red Measures'; a new group name, the Warwickshire Group, has been introduced to replace these (Powell et al., 2000). The group is present along the southern margin of the Pennine Basin, notably in Warwickshire, the type area, the West Midlands and north Wales (Figure 7). The group is also proved in the subsurface in Lancashire, South Yorkshire, Nottinghamshire and Lincolnshire. The group includes the red-bed formations and the relatively coal-poor, grey formations that overlie the Pennine Coal Measures Group.

The group has its thickest development, 1225 m, in the Warwickshire Coalfield.

The lower boundary is taken generally at the base of the lowest red-bed formation (generally Etruria Formation) of late Carboniferous age. There is commonly a passage by alternation from grey strata of the Coal Measures in to red strata of the Etruria Formation. Locally, the base is erosional (Symon Unconformity) in Warwickshire, Coalbrookdale and Lincolnshire. An unconformity, below the Halesowen Formation (Westphalian D), is traceable throughout most of the southern part the Pennine Basin, but has not been widely recognised in the northern basinal successions of South Yorkshire and Lancashire (Waters et al., 1994). A further unconformity (or disconformity) is present at the base of the Clent Formation in the southern part of the South Staffordshire Coalfield, but the boundary becomes gradational in the north of the coalfield. The upper boundary of the group is taken at the base of unconformable (post-Variscan) Permian, or younger strata.

The succession is divided into formations, many of which can be correlated between coalfields; others are geographically restricted. In south Staffordshire, the typical succession is Etruria, Halesowen, Salop and Clent formations. In Warwickshire, where the Clent Formation is not developed, the Tile Hill Mudstone Formation rests conformably upon the Salop Formation.

The Etruria Formation consists predominantly of mudstone with subordinate sandstone and conglomerate, and thin coals are present locally. The mudstones are red, purple, brown, ochreous, green and grey mottled, and pedogenic horizons are common (Glover et al., 1993). Lenticular sandstones and conglomerates are commonly composed of lithic and volcanic clasts, and there are some intercalated volcaniclastic rocks in the Etruria Formation of south Staffordshire, which is also cut by dolerite sills and dykes (Glover et al., 1993).

The Halesowen Formation comprises grey-green, micaceous sandstone (litharenite) and grey-green mudstone, with thin coals, beds of *Spirorbis* limestone, local intraformational conglomerate, and caliche. The Halesowen Formation is interpreted as the northward equivalent of the Pennant Sandstone Formation of south Wales and south-west England (Besly, 1988).

The Salop Formation comprises red and red-brown interbedded mudstone and sandstone, with beds of pebbly sandstone and conglomerate. Thin *Spirorbis* limestone beds, caliche and sparse, thin coals are present in the lower part. The sandstones are mostly sublitharenite, and conglomerate clasts include Carboniferous Limestone and chert.

The Clent Formation of south Staffordshire shows a rapid northward transition from breccia to red mudstone.

The Tile Hill Mudstone Formation is limited to the southern part of the Warwickshire Coalfield where it comprises red-brown mudstone with subordinate thin red-brown and green flaggy sandstones and sparse thin conglomeratic lenses.

The red-beds have undergone oxidation at, or close to, the time of deposition. The Etruria Formation was deposited within a well-drained alluvial floodplain. The Halesowen Formation shows transitions from fluvial to floodplain deposition in association with relatively high water tables. The Salop and Tile Hill Mudstone formations represent a return to well-drained, proximal to distal alluvial plain settings with localised shallow lake formation within semi-arid conditions. The Clent Formation is interpreted as proximal alluvial fan deposits with pebble clasts derived locally from uplifted hinterland blocks associated with the Wales–Brabant High to the south. The formations typically include siliciclastic material derived by erosion of the Wales–Brabant High; the exception is the Halesowen Formation, which includes lithic arenites similar to the Pennant Sandstone Formation and indicative of a more distant southerly source.

The Warwickshire Group ranges in age from Westphalian (Duckmantian) to Early Permian (Autunian). The Etruria Formation is generally Bolsovian (Westphalian C), but ranges from late Duckmantian (Westphalian B) to early Westphalian D. The lower boundary is highly diachronous, with primary red beds having formed earlier along the margin of the Pennine Basin (Besly, 1988; Waters et al., 1994; Davies et al., 2004). The Halesowen Formation has yielded miospores (Smith and Butterworth, 1967; Butterworth and Smith, 1976) and plant macrofossils that indicate a Westphalian D age (Clayton et al., 1977; Cleal, 1984; Besly and Cleal, 1997). The Salop Formation is Westphalian D to Stephanian or Early Permian (Waters et al., 1995; Besly and Cleal, 1997). The Clent Formation is probably Early Permian or possibly late Stephanian in age (Waters et al., 1995), although there is no fossil evidence for this. The Tile Hill Mudstone Formation is of Westphalian D to Stephanian, or possibly Autunian age.

6.11 CORRELATION WITH THE SOUTHERN IRISH SEA

The Central Province Trough, located between the Manx-Lake District Ridge and the North Wales Shelf, is the western, offshore continuation of the Craven Basin. The lithostratigraphical scheme of Jackson (1996) identifies three groups for the Carboniferous; the Garwood, Bisat and Kidston groups. These equate broadly with the chronostratigraphical subdivisions of Tournaisian–Visean, Namurian and Westphalian–Stephanian.

Seismic records suggest that between the Isle of Man and Anglesey, the Garwood, Bisat and Kidston groups are about 2050 m, 2900 m and 1300 m thick, respectively (Jackson et al., 1987).

6.11.1 Garwood Group

Within the offshore extension of the Craven Basin, the Garwood Group equates with the Craven Group. From limited offshore data, the group is considered to comprise mudstone and beds of argillaceous limestone, mostly packstone and wackestone.

6.11.2 Bisat Group

Within the offshore extension of the Central Pennine Basin the Bisat Group equates with the Bowland Shale Formation and Millstone Grit Group.

The group comprises mudstones, both fissile and poorly bedded, with variable components of siltstone and sandstone, minor coal seams, seatearth, dolostone, limestone and chert.

Within the early Namurian strata (Pendleian to Kinderscoutian) grey to dark grey mudstone and fine-grained distal turbidite sandstone are the dominant lithologies, equivalent to the onshore Bowland Shale Formation of England and Wales and Leinster Shale Formation of Ireland (Jackson et al., 1995). These offshore shales are oil-prone source rocks. The Kinderscoutian to Yeadonian succession is comparable to the onshore Millstone Grit Group.

6.11.3 Kidston Group

The Kidston Group is preserved beneath the Permo-Triassic unconformity in the East Irish Sea, at outcrop to the south and south-west of the Isle of Man and in the Caernarfon Bay Basin. The group equates with the Pennine Coal Measures Group and probably the Warwickshire Group, although the latter has not been drilled in offshore wells.

The Kidston Group rests conformably upon the Bisat Group in the central parts of the basinal area, but progressively overlaps Namurian strata on basin margins, a comparable relationship to that seen onshore. Presumed Duckmantian strata rest on probable Cambro-Ordovician rocks in the Kish Bank Basin and Bolsovian and Westphalian D strata overlie Precambrian strata.

The group comprises mainly mudstone with significant interbedded sandstones, especially in the upper part, and coals and seatearths, notably within the lower part.

6.12 CORRELATION WITH THE SOUTHERN NORTH SEA

6.12.1 Zeeland Formation

The Zeeland Formation was used by Cameron (1993b) to refer to Tournaisian–Brigantian platform carbonates (*Platform and ramp carbonate facies*) present along the northern flank of the Wales–Brabant High in the Southern North Sea. The formation is the offshore equivalent of the Peak Limestone Group. The northern limit of the carbonate platform coincides with the north-west- trending Dowsing Fault Zone (Cameron, 1993b; Figure 1).

The base of the formation has not been proved in the offshore UK sector, but seismic surveys suggest a total thickness locally in excess 1000 m.

The formation comprises a lower dark brown or dark grey finely crystalline dolostone, overlain by pale brown to dark brown microcrystalline or very finely crystalline dolomitic limestone with some ooidal beds.

The presence of condensed sequences and reworking of Courceyan fossils into younger Visean sediments in the Netherlands and eastern England (Strank, 1987) suggest local erosion of the platform, either through uplift or regression.

6.12.2 Whitehurst Group

The broadly Namurian succession of the Whitehurst Group is recognised offshore as comprising the lower Bowland Shale Formation (*Hemipelagic facies*) and overlying Millstone Grit Formation (*Millstone Grit facies*). This group equates with part of the onshore Craven Group and the entire Millstone Grit Group, and was deposited in comparable environments.

The Whitehurst Group onlaps onto and is absent over the crest of the Wales-Brabant High to the south. The Bowland Shale Formation present off the east Yorkshire coast is only 47 m thick, but is known to have a maximum thickness in the Southern North Sea in excess of 277 m. The maximum thickness proved to date for the Millstone Grit Formation is 1308 m.

The base of the Millstone Grit Formation is regionally diachronous, resting conformably upon the Bowland Shale Formation over most of the region; the base is taken at the base of the lowermost thick sandstone. On the southern flanks of the Mid North Sea High the formation rests conformably upon the Yoredale Formation, and the base is taken at the top of the highest marine limestone. Along the northern flanks of the Wales–Brabant High the formation onlaps the Zeeland Formation or folded Lower Palaeozoic strata. Offshore, the top of the formation is taken at the base of the lowermost Westphalian coal seam, and hence the formation ranges up into early Langsettian.

The Bowland Shale Formation of Cameron (1993b) consists of dark grey hemipelagic mudstone, equivalent to the onshore Bowland Shale Formation. The Millstone Grit Formation of the Southern North Sea comprises grey, white and brown, typically fine- to medium-grained, locally conglomeratic sandstone and interbedded grey or dark grey, partly carbonaceous mudstone and siltstone (Cameron, 1993b). Thin coal seams and seatearths are relatively rare. Lithological cycles are typically about 50 m thick, but with a wide range, and generally show upward-coarsening trends.

The Bowland Shale Formation is of late Visean to early Namurian. The base of the formation in the Southern North Sea, as with the onshore equivalent, is regionally diachronous, ranging from late Asbian (late Visean) to mid Namurian in age.

6.12.3 Conybeare Group

In the Southern North Sea, the Conybeare Group, defined by Cameron (1993b), is equivalent of the onshore Coal Measures (*Coal Measures facies*) and Warwickshire Group (*Barren Measures facies*). The Conybeare Group cannot be readily subdivided offshore using the presence of major marine bands, as used onshore. A purely lithostratigraphical scheme is employed.

The *Coal Measures facies* component of the Conybeare Group comprises the Caister Coal and Westoe Coal formations and lower part of the Schooner Formation. The Ketch Member of the Schooner Formation and the Brig Formation equate to the onshore Warwickshire Group.

The *Coal Measures facies* succession is most extensively preserved beneath the angular unconformity in the Silver Pit area, where it is more than 1150 m thick (Cameron, 1993b). The thickness of the Ketch Member and Brig Formation, proved by drilling, is 357 m and 277 m, respectively. The group is thin or absent over the crest and southern flanks of the Mid North Sea High, and over crests of west-north-west-trending Variscan anticlines in the south (Leeder and Hardman, 1990).

The base of the group is taken at the base of the lowest Westphalian coal seam. On the northern flank of the Wales–Brabant High the Conybeare Group onlaps the Millstone Grit Formation, Zeeland Formation and Lower Palaeozoic strata. The base of the Brig Formation is marked by an intra-Westphalian unconformity. The group was folded, faulted and variably eroded prior to deposition of the overlying Lower Permian Rotliegend Group.

The Caister Coal Formation comprises a coal measures succession with a significant component of sandstone, locally up to 50 m thick, and thick coal seams up to 3 m thick. There is a southward facies transition into argillaceous strata of the Westoe Coal Formation, a dominantly argillaceous coal measures succession of grey and silty mudstone. Cycles are generally thin, less than 20 m, and upward-coarsening. Coal seams are up to 5 m thick and are relatively widespread.

The Schooner Formation is present in the Silver Pit area and in Variscan synclinal axes in the northern part of the Southern North Sea. The formation was more extensive prior to Variscan deformation and erosion. The lower part of the formation comprises grey sandstone-dominated coal measures with interbedded mudstone. In the lower part, coal seams are typically less than 2 m thick.

The Ketch Member commonly has coarser, pebbly sandstones than the underlying Coal Measures facies component of the Schooner Formation. Reddish brown and purple mudstones with mature palaeosols are present in the lower part of the member, whereas grey, coal-bearing intercalations and caliche horizons are common in the upper part (Besly et al., 1993). The lower and upper parts of the Ketch Member equate with the Etruria and Salop formations of the Warwickshire Group (Besly et al., 1993).

The Brig Formation commonly comprises a thin basal Coal Measures component of grey, purple and reddish brown mudstone and siltstone with thin coal seams and thin, very fine-grained sandstone beds. The overlying red beds are characterised by alternating grey, reddish brown or white, very fine- or fine-grained sandstone and reddish brown, purple or greenish grey mudstone.

The *Coal Measures facies* succession ranges from early Langsettian to Bolsovian age. Late Bolsovian palynomorphs were found in the Ketch Member (Besly et al., 1993). Palynomorphs show that the lower part of the Brig Formation ranges from late Bolsovian to Westphalian D (Ramsbottom et al., 1978).

7 South Wales–Bristol

The area south of the Wales–Brabant High developed a succession similar to that seen north of the high. The earliest Carboniferous strata are the Avon Group, a mudstone-dominated shelf succession. This is overlain by a carbonate succession, the Pembroke Limestone Group, which shows an evolution from ramp to platform facies during the Tournaisian–Visean. The platform carbonates are overlain by latest Visean to early Namurian, dominantly basinal shales and cherts. The Marros Group, of Namurian age, represents incursions of mainly quartzose siliciclastic sediments derived from the Wales–Brabant High to the north. The overlying South Wales Coal Measures Group, of Westphalian age, comprises fluviodeltaic facies comparable to Pennine Coal Measures present to the north of the Wales–Brabant High. Southerly derived sandstones of the Pennant Sandstone Formation, part of the Bolsovian to Stephanian Warwickshire Group, overlie the South Wales Coal Measures Group in the South Wales Basin.

7.1 AVON GROUP

The Avon Group is a new name proposed to replace the obsolete terms Lower Limestone Shale Group and Cefn Bryn Shales. The Avon Group is named from the type area of the Avon Gorge, south of Bristol, but also extends across south Wales. The mudstone-dominated succession is considered to be sufficiently distinct from the overlying platform and ramp carbonates of the Pembroke Limestone Group to be recognised as a separate group.

Existing mapping allows only an undifferentiated group to be identified over large areas of the South Wales and Bristol region, for example in Pembrokeshire, Gower, Monmouth and Chepstow. However, recent mapping has allowed the group to be subdivided in south Wales into the Tongwynlais, Castell Coch Limestone and Cwmyniscoy Mudstone formations (Figure 8) (Waters and Lawrence, 1987; Wilson et al., 1990; Davies et al., 1991). In the Bristol district, the Avon Group comprises a lower Shirehampton Formation overlain by undivided Avon Group (formerly Maesbury Mudstone Formation of Barton et al., 2002), although the extension of this nomenclature southwards towards the Mendip Hills is uncertain and in need of further work.

The Avon Group in south Wales is up to 135 m thick. The Tongwynlais Formation thins northward and is absent in the north crop of the Carboniferous strata of south Wales (Barclay et al., 1989). In the Bristol region, the group is up to 150 m thick within its type area. The Shirehampton Formation is about 30 to 50 m thick in the Bristol area, but thins southward and passes into undivided Avon Group in the Mendip Hills.

The base of the Avon Group is commonly sharp, but conformable. In the north crop of the Carboniferous strata of south Wales, the Tongwynlais Formation is absent, with the Castell Coch Limestone formation resting disconformably upon the Devonian Upper Old Red Sandstone Group.

The Avon Group comprises dark grey or black mudstone with interbedded crinoidal bioclastic or ooidal limestone. The Tongwynlais Formation consists of interbedded thin skeletal packstone limestone and grey mudstone, with subordinate calcareous sandstone, oolite and hematitic skeletal grainstones (Gayer et al., 1973; Waters and Lawrence, 1987). The Castell Coch Limestone Formation comprises thick to well-bedded, commonly cross-bedded, skeletal and ooidal grainstones, rich in crinoidal debris (Waters and Lawrence, 1987; Wilson et al., 1990). The formation shows secondary reddening, commonly associated with dolomitisation. The Cwmyniscoy Mudstone Formation comprises dark grey, silty mudstone, sparsely fossiliferous, with subordinate thin bioclastic limestone and calcareous siltstone beds (Waters and Lawrence, 1987; Barclay et al., 1989; Wilson et al., 1990). The mudstone beds are thinner toward the gradational boundary with the overlying Pembroke Limestone Group.

The Shirehampton Formation comprises coarse bioclastic and ooidal limestone with subordinate calcareous sandstone and mudstone that has a brackish water fauna with *Lingula*. Some interbeds of sandstone and red and green mudstone of *Old Red Sandstone facies* occur locally. A reddened crinoidal limestone, the 'Bryozoa Bed' occurs at the top of the formation. The overlying undivided Avon Group consists of greenish grey mudstone with interbedded black crinoidal limestone with a rich shelly fauna.

The group is interpreted as a mudstone-dominated succession deposited within a shelf setting during a major phase of northward-directed marine transgression. The Castell Coch Limestone represents the first regional shallowing event to affect the Tournaisian shelf, with regional progradation of high-energy ooidal shoals.

The Avon Group is entirely Tournaisian in age (Davies et al., 1991).

7.2 PEMBROKE LIMESTONE GROUP

The Pembroke Limestone Group is a new name proposed for the *Platform and ramp carbonate facies* of the south Wales and Bristol region. In the Pembroke area, the group is well exposed and shows a wide range of lithological facies.

The Tournaisian to ?early Chadian succession of mid to inner ramp/shelf bioclastics present across the Bristol region and the south crop of the South Wales Coalfield are distinguished as the Black Rock Limestone Subgroup, formerly referred to as a group. Within the north crop of south Wales a separate subgroup, the Clydach Valley Subgroup, was deposited coevally in peritidal and oolitic shoal environments with numerous palaeosols. In Pembrokeshire, the reef facies of the Berry Slade Formation is considered to be separate from both the subgroups.

During the Chadian to Arundian no regional subgroup has been established, although the Burrington Oolite Subgroup has been defined as restricted to the Mendips.

During the latest Arundian to Holkerian the Hunts Bay Oolite Subgroup, which has received local usage in the past, is here extended across south Wales (Figure 8).

The Asbian to Brigantian succession has to date no subgroup classification. However, the establishment of marked cyclicity distinguishes this interval of strata from underlying successions and may warrant establishment of a subgroup.

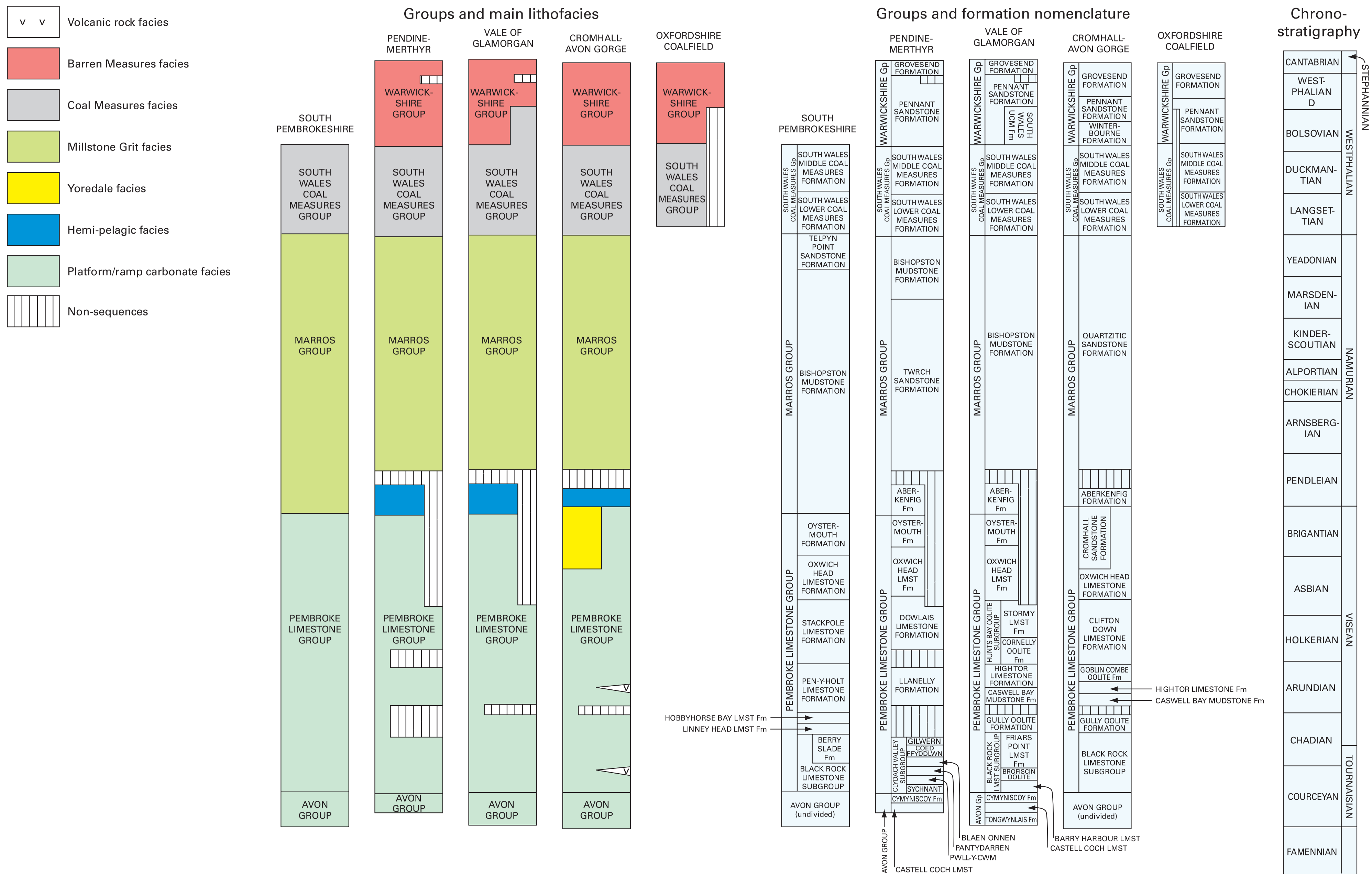

Figure 8 Lithostratigraphical nomenclature for south Wales and southern England. See Chapter 2 for description of lithofacies. Fm Formation; Gp Group; UCM Upper Coal Measures

There are similarities between a number of formations from the South Wales and Bristol regions, which may, following further investigation, be recognised as single laterally extensive formations.

7.2.1 Black Rock Limestone Subgroup

Formations within the Black Rock Limestone Subgroup have been identified in areas of recent mapping in the Vale of Glamorgan; namely the Barry Harbour Limestone, Brofiscin Oolite and Friars Point Limestone formations (Waters and Lawrence, 1987; Wilson et al., 1990) (Figure 8).

In the Bristol region the subgroup was formerly subdivided into Black Rock Limestone and Black Rock Dolomite formations. The dolostone generally occurs within the upper part of the subgroup over the Bristol–Mendips area, but is present throughout the succession at Chepstow and the Forest of Dean. These formation names are now considered obsolete as they represent non-dolomitised and dolomitised limestone, respectively, rather than distinguished by primary lithological variations. Further studies are necessary to determine if component formations of the subgroup can be identified in the Bristol region.

In Pembrokeshire, the Black Rock Limestone Subgroup is overlain by the laterally impersistent Berry Slade Formation, which is of reef facies and is excluded from the subgroup. In the Gower, the subgroup replaces the obsolete Penmaen Burrows Limestone Group, which comprised a lower Shipway Limestone, Tears Point Limestone and upper Langland Dolomite (George et al., 1976). Neither area has been mapped recently, and the relationship of the stratigraphy with that defined for the Black Rock Limestone Subgroup of the Vale of Glamorgan is in need of further research.

The subgroup shows a prominent southwards thickening, to a maximum of 500 m in the Vale of Glamorgan (Waters and Lawrence, 1987; Wilson et al., 1990), and more than 250 m in the Mendip Hills. At Chepstow and the Forest of Dean the subgroup is 90 to 120 m thick. Component formations also thicken southward, with the exception of the Brofiscin Oolite, which thins southwards and is absent in the southern part of the Cardiff area (Waters and Lawrence, 1987; Wilson et al., 1990).

The base of the Pembroke Limestone Group in the Vale of Glamorgan is sharp and conformable upon the mudstone of the Avon Group. In the Bristol region the base of the subgroup is gradational and is marked by upward increase in the proportion of limestone.

The Black Rock Limestone Subgroup comprises dark grey to black, poorly sorted crinoidal limestone, locally with chert bands and nodules. The subgroup includes the Middle Hope Volcanic Member, a succession of up to 37 m of tuffs, and pillow basalts present in the Weston area of Bristol (Whittaker and Green, 1983; Waters, 2003).

The Barry Harbour Limestone Formation comprises thin-bedded, dark grey, fine- to coarse-grained, crinoidal, skeletal packstone with thin beds of shaly, calcareous mudstone and common replacive chert lenses (Waters and Lawrence, 1987; Wilson et al., 1990). Intercalated beds of ooidal grainstone occur locally towards the top of the formation. The Brofiscin Oolite Formation comprises pale to dark grey, massive to thick-bedded, well-sorted, predominantly ooidal and in part skeletal grainstone, locally extensively dolomitised. The Friars Point Limestone Formation comprises thickly bedded, dark grey to black, fine-grained, skeletal packstones with subordinate thin interbeds of shaly, argillaceous, skeletal packstone. The limestones are richly fossiliferous, particularly crinoidal. Bioturbation and pressure solution gives the limestone an irregular nodular appearance (Wilson et al., 1990). The upper part of the formation is everywhere dolomitised.

The Barry Harbour Limestone represents high-energy storm deposits. The Brofiscin Oolite Formation formed as oolite shoals in relatively shallow marine waters. The Friars Point Limestone Formation records renewed transgression and re-establishment of deeper water shelf conditions (Wilson et al., 1990).

The subgroup contains a rich fauna of conodonts, corals and foraminifera, and ranges from Tournaisian to Chadian age. The Tournaisian–Visean boundary is believed to occur within the Friars Point Limestone (Waters and Lawrence, 1987).

7.2.2 Clydach Valley Subgroup

The Clydach Valley Subgroup of the north crop of the South Wales Coalfield is of equivalent age to the Black Rock Limestone Subgroup, but is of distinctive lithofacies and is recognised as a distinct subgroup. The transition between the two subgroups, present within the east crop of south Wales, is obscured by extensive dolomitisation and the Namurian overstep. The interdigitating oolites and dolostones of the Clydach Valley Subgroup have been identified as informal formations, described by Barclay et al. (1989). In upward succession, these are: the Sychnant Dolomite, Pwll-y-Cwm Oolite, Pantydarren, Blaen Onnen Oolite, Coed Ffyddlwn and Gilwern Oolite formations. Towards the east of Abergavenny the succession becomes entirely dolomitic. To the west, in the Merthyr Tydfil district, the succession is entirely oolitic, forming the Abercriban Oolite Subgroup.

The Clydach Valley Subgroup rests conformably upon strata of the Avon Group. About 45 m thickness is recorded in the Abergavenny area (Barclay et al., 1989). The subgroup was deposited within peritidal and oolitic shoal environments with numerous palaeosols.

The Blaen Onnen Oolite Formation contains a conodont assemblage indicative of the *Pseudopolygnathus multistriatus* Conodont Zone, of Tournaisian age (Barclay et al., 1989). The Gilwern Oolite Formation has in the past been attributed to Chadian and Arundian age, though a solely Chadian age is now generally accepted.

7.2.3 Chadian and Arundian succession

The Burrington Oolite Subgroup is used in the Mendip Hills, where a monotonous ooidal limestone-dominated succession could not be subdivided into component formations. In the central and eastern parts of the Mendip Hills, the subgroup is underlain by, and passes into, a distinctively crinoidal, non-oolitic facies, mapped as the Vallis Limestone Formation.

In the Weston-super-Mare area the Chadian and Arundian succession has been subdivided (Figure 8) into the Gully Oolite, Caswell Bay Mudstone, High Tor (formerly Birnbeck) Limestone and Goblin Combe Oolite formations (Whittaker and Green, 1983). The relationship between the Caswell Bay Mudstone Formation and the Clifton Down Mudstone Formation of the Bristol district is in need of further research. It is probable that they are laterally equivalent, though the latter is thicker and with a greater chronostratigraphical range (late Chadian to Arundian). The High Tor Limestone and Goblin Combe Oolite formations are absent north of the Bristol area, where they pass laterally into the Clifton Down Mudstone Formation.

Over much of south Wales a comparable succession is identified, comprising in ascending order: the Gully Oolite, Caswell Bay Mudstone and High Tor Limestone formations (Figure 8). The lateral continuation of these formations into Pembroke and Tenby needs confirmation by modern mapping. In the north crop, the Llanelly Formation is the northward equivalent of the Caswell Bay Mudstone and High Tor Limestone.

The Gully Oolite Formation, first defined in the Bristol area, is considered to extend across south Wales, replacing the obsolete Caswell Bay Oolite of George et al. (1976). In the Forest of Dean this formation replaces the obsolete Crease Limestone.

Within the Mendips the Burrington Oolite Subgroup is 230 to 240 m thick. In the Vale of Glamorgan and Weston-super-mare districts the Chadian to Arundian succession is about 185 m thick. The Gully Oolite Formation shows a southward thickening, with a maximum thickness of 83 m recorded in Cardiff area. The Caswell Bay Mudstone Formation, up to 15 m thick in the Vale of Glamorgan, thins towards, and is absent from, the Mendips and the southern parts of the Cardiff and Bridgend areas. The High Tor Limestone Formation ranges in thickness from 65 to 133 m, the thickest development occurring where the Caswell Bay Mudstone Formation is absent. The Goblin Combe Oolite Formation ranges from 15 to 70 m. The Llanelly Formation has a maximum thickness of 20 m (Wright, 1981; Barclay et al., 1989). Towards the west the formation thins and is completely removed by overstep of the overlying Dowlais Limestone Formation. In the east crop, the formation is absent due to overstep by the Marros Group.

The base of the Gully Oolite Formation is sharp and flat. In south Wales, the formation rests conformably upon the Friars Point Limestone Formation, or on an emergent surface at the top of the latter. The Caswell Bay Mudstone and Clifton Down Mudstone formations rest upon a prominent non-sequence, sometimes referred to as the mid-Avonian unconformity. This is apparent as an irregular and pitted palaeokarst surface above the Gully Oolite Formation, capped by a clay palaeosol. The Llanelly Formation similarly rests upon a prominent palaeokarstic surface, above a pedified horizon at the top of the Clydach Valley Subgroup.

The Gully Oolite Formation is a distinctive pale grey, massive, medium- to fine-grained, cross-bedded ooidal, peloidal and skeletal grainstone, locally in upward-coarsening cycles (Waters and Lawrence, 1987).

The Caswell Bay Mudstone Formation (and the comparable Clifton Down Mudstone Formation) comprise pale grey to green, calcareous mudstone, interbedded with dark grey and brown shale and argillaceous skeletal wackestone and packstone. Cryptalgal lamination and bird's eye structures are common. On the south side of Broadfield Down, Bristol, about 12 m of basaltic lava and tuff occur in the lower part of the formation.

The High Tor Limestone Formation consists of thin- to thick-bedded, bioclastic limestone with a few thin beds of shaly dolomitic mudstone and siltstone. Lithological variations are described fully by Waters and Lawrence (1987) and Wilson et al. (1990). In the Weston-super-Mare area the High Tor Limestone Formation comprises grey to dark grey, thick- to very thick-bedded bioclastic limestone, the lower part is commonly ooidal (Whittaker and Green, 1983). The formation includes the 15 m-thick Spring Cove Lava Member, which comprises amygdaloidal olivine-basalt, with indistinct pillow structures and common reddened limestone fragments (Whittaker and Green, 1983). The overlying Goblin Combe Oolite Formation comprises pale grey to black, massive, medium- to coarse-grained, ooidal and crinoidal limestone.

The Llanelly Formation of the north crop of south Wales comprises mainly thinly bedded micritic limestone with subordinate oolitic grainstone. A basal member comprises conglomeratic limestone, clay with micritic nodules and clasts, calcrete and sandstone. The uppermost member comprises up to 7 m of red-brown, purple and green mottled clay with calcrete nodules and a coal at the top.

The Gully Oolite Formation was deposited during a Chadian regression that culminated in the non-sequence at the top of the formation (Figure 8). Basal Arundian marine transgression resulted in deposition of the Caswell Bay Mudstone Formation within a lagoonal/peritidal setting. The lowest parts of the High Tor Limestone Formation formed a barrier complex, which limited the peritidal deposits of the Caswell Bay Mudstone Formation to the north. During continued transgression the barrier complex migrated northwards over the peritidal facies (Wilson et al., 1988; Wilson et al., 1990). The upper part of the High Tor Limestone Formation records regression and subsequent return of high-energy shoreface deposits. The Llanelly Formation shows a comparable history of marine transgression, with basal fluvial deposits overlain by a shallow marine peritidal complex, with subsequent regression indicated by re-establishment of fluvial floodplain deposition.

The subgroup ranges in age from Chadian to late Arundian. The Llanelly Formation is restricted to Arundian age.

7.2.4 Hunts Bay Oolite Subgroup

The Hunts Bay Oolite Subgroup (formerly Group) of south Wales comprises two formations in the Vale of Glamorgan; the Cornelly Oolite and Stormy Limestone formations (Wilson et al., 1990). Subdivision of the subgroup in the east crop of the South Wales Coalfield is complicated by extensive dolomitisation. In the Bristol region, the equivalent strata are identified as the Clifton Down Limestone Formation.

The Stackpole Limestone Formation of south Pembrokeshire and Dowlais Limestone Formation of the north crop (George et al., 1976) are the same age, but are separated due to distinctive lithologies from the Hunts Bay Oolite Subgroup.

The thickest development of the subgroup is 245 m in the Bridgend area, thinning to the east and removed in the east crop by Namurian overstep. In the Chepstow–Monmouth area the subgroup, formerly known as the Drybrook Limestone, is 120 m thick. The Clifton Down Limestone Formation is about 190 m thick in its type section in the Avon Gorge.

The base of the subgroup is typically conformable upon Arundian strata. In the Vale of Glamorgan the base of the Cornelly Oolite Formation is gradational with the High Tor Limestone. Towards the north and east of the Bridgend area, the base of the Stormy Limestone Formation occurs at gradually lower stratigraphical levels, such that within the Cardiff area it forms the majority of the thickness of the Hunts Bay Oolite Subgroup (Waters and Lawrence, 1987).

The subgroup comprises an ooidal limestone with subordinate skeletal, peloidal, oncolitic and micritic limestone. The Cornelly Oolite Formation comprises a thickly bedded, cross-bedded, ooidal grainstone. The Stormy Limestone Formation comprises a heterolithic succession of interbedded porcellaneous micrite with common stromatolitic lamination and birds-eye structures, bioclastic limestone, and packstone-grainstone with skeletal grains, ooids, peloids and intraclasts. Locally, thrombolitic algal bioherms up to 2 m high are present.

The Clifton Down Limestone Formation includes a basal sequence of relatively unfossiliferous, porcellaneous limestone, overlain by shelly limestone, together with algal beds and cross-bedded oolites ('Seminula Oolite') in the upper part (Barton et al., 2002). The uppermost interval comprises a thick algal porcellaneous limestone sequence, with a widespread erosion surface at the top.

The lower part of the Cornelly Oolite Formation records continued late Arundian shoaling, which locally resulted in emergence and palaeokarst development. The succeeding strata record a basal Holkerian marine transgression and re-establishment of oolite shoals. The Stormy Limestone and Dowlais Limestone formations are interpreted as deposits within a lagoonal–peritidal back-barrier environment, which developed behind the Cornelly Oolite shoal (Barclay et al., 1988; Barclay et al., 1989; Wilson et al., 1990). The lower part of the Clifton Down Limestone Formation is interpreted as lagoonal and the oolite beds are interpreted as tidal channel or bar deposits. The formation is a laterally persistent unit in the region and represents a progressive change to a more open marine environment.

The subgroup ranges from late Arundian to Holkerian age. In the Bristol region, the base of the Holkerian Stage is taken at the sharp base of the 'Seminula Oolite' within the Clifton Down Limestone (George et al., 1976).

The stand-alone Stackpole Limestone Formation is largely bioclastic. The stand-alone Dowlais Limestone Formation is a distinctive foetid and bituminous peloidal grainstone, packstone and wackestone with dark grey shale interbeds. The Dowlais Limestone of the north crop rests unconformably on strata that range from Llanelly Formation to Avon Group, overstepping progressively older beds towards the west.

7.2.5 Asbian and Brigantian succession

The upper part of the Pembroke Limestone Group, of Asbian and Brigantian age, has not been identified as a subgroup. In south Wales the succession comprises the Oxwich Head Limestone and Oystermouth (formerly Upper Limestone Shales) formations. In the Bristol region, strata of equivalent age comprise the Oxwich Head (formerly Hotwells) Limestone and Cromhall Sandstone formations.

The Oxwich Head Limestone and Oystermouth formations are up to 130 m and 55 m thick, respectively, in the Bridgend area. The Oxwich Head Limestone Formation is about 225 m thick on Broadfield Down, but thins northward and is absent north of Bristol, as the formation passes laterally northward into the Upper Cromhall Sandstone. The absence of a diagnostic early Asbian fauna (Kellaway and Welch, 1993) may indicate a non-sequence at the sharp base of the Oxwich Head Limestone Formation. The Asbian and Brigantian strata become thinner and are cut out by overstep at the base of the Marros Group in the area of the Severn estuary.

In south Wales, the Oxwich Head Limestone Formation comprises thickly bedded, fine- to coarse-grained, recrystallised skeletal packstone, with distinctive pale to dark grey pseudobrecciation. The limestone contains conspicuous, hummocky and pitted palaeokarstic surfaces overlain by thin, red and grey mottled clay beds, interpreted as palaeosols. Locally, in the Bridgend and Merthyr Tydfil areas, a thin calcareous sandstone is present at the base of the formation. This may be the equivalent of the middle tongue of the Cromhall Sandstone Formation of the Bristol region. The Oystermouth Formation comprises interbedded thin limestone and shale beds, silicified limestone and chert.

The Oxwich Head Limestone Formation in the Bristol area comprises hard, massive, grey to dark grey, ooidal and crinoidal limestone with an abundant coral and brachiopod fauna. The Cromhall Sandstone Formation comprises grey, weathered red, coarse-grained quartzitic and calcareous sandstone, sandy crinoidal and ooidal limestone, dark grey mudstone and grey, rootlet-bearing fireclay. The sequence is markedly cyclic, of *Yoredale facies*; a typical cycle comprising limestone passing up into mudstone, siltstone and sandstone and overlain by a seatearth (Kellaway and Welch, 1993). The Lower, Middle and Upper Cromhall sandstones are best considered as tongues that merge together to the north, in proximity to the southern flank of the Wales–Brabant High. This suggests that the units should be considered as one, the Cromhall Sandstone Formation.

The basal sandstone of the Oxwich Head Limestone Formation and the middle tongue of the Cromhall Sandstone Formation probably represent terrigenous sands introduced onto an emergent carbonate shelf during marine regression at the end of the Holkerian, and subsequently marine-reworked during the base Asbian transgression (Wilson et al., 1990). The overlying Oxwich Head Limestone Formation accumulated on a mature carbonate platform that was subjected to periodic emergence during falls in sea level. In the Bristol area, the formation is dominated by high-energy platform facies. The Oystermouth Formation represents a significant increase in terrigenous mud supplied to the carbonate shelf and the sands of the upper tongue Cromhall Sandstone Formation were deposited in marginal marine and estuarine deltaic conditions.

Within the Bridgend area, the Oxwich Head Limestone Formation formation appears to be entirely Asbian in age (Wilson et al., 1990), but ranges up into Brigantian age in the Gower (George et al., 1976). In the Bristol area, the formation is considered Asbian in age. The Oystermouth Formation is entirely Brigantian in age.

7.3 MARROS GROUP

The Marros Group is a new name for the Namurian succession of *Millstone Grit facies* seen in the south Wales and Bristol areas. The succession has traditionally been named Millstone Grit, but this name is considered to be unsuitable as it was deposited in the South Wales Basin separated from the Millstone Grit Group of the Pennine Basin by the Wales–Brabant High. The South Wales and Bristol successions are similar and were probably laterally continuous before tectonic separation, and hence a single group name is appropriate. However, because of uncertainties in correlation between the two areas, separate formational names are necessary, and a new set is introduced to replace the traditional nomenclature of south Wales.

In south Wales (Figure 8) the succession, in ascending order, is the Aberkenfig, Twrch Sandstone, Bishopston Mudstone and Telpyn Point Sandstone formations. The Marros Group (undifferentiated) in the Bristol area equates with 'Quartzitic Sandstone Formation' of Kellaway and Welch (1993). A new name is required for this sandstone succession, but no members of the Stratigraphical Framework Committee have sufficient knowledge of this sequence to propose a new name.

The cherty mudstone of the Aberkenfig Formation of south Wales and an equivalent thin succession in the Bristol region is overlain by a predominantly quartzitic sandstone succession that typifies the Marros Group. Ideally, the Aberkenfig Formation should be considered a stand-alone formation between the Pembroke Limestone and Marros groups. However, in the Bristol region and over much of south Wales the unit has not been mapped separately from the overlying sandstone-dominated succession and would require future fieldwork to allow it to be isolated from the Marros Group.

The Marros Group (undifferentiated) is thickest, about 700 m, in the Gower of south Wales. The group thins and shows several depositional breaks both northwards, approaching the southern flank of the Wales–Brabant High, and eastward, approaching the Usk Anticline (George, 1970, fig. 25). The Aberkenfig Formation is up to 35 m thick. The Twrch Sandstone Formation has a maximum thickness of 190 m in the type area near Ammanford, in the north crop, thinning westwards into Pembrokeshire as it passes laterally into the Bishopston Mudstone Formation. The Bishopston Mudstone and Telpyn Point Sandstone formations are up to 120 m and 30 m thick in Pembrokeshire. The Bishopston Mudstone thickens to 700 to 850 m in the Gower, where it represents the entire thickness of Namurian strata. The Quartzitic Sandstone Formation is up to 300 m thick in the northern part of the Bristol coalfield, thinning southward.

A prominent unconformity at the base of the Twrch Sandstone Formation has locally removed the underlying Aberkenfig Formation in the east crop.

The Aberkenfig Formation comprises dark grey shales with thin cherts and coarse-grained sandstones (Wilson et al., 1990). The Twrch Sandstone Formation is dominated by quartzose sandstone with thin dark grey mudstone interbeds, some containing *Lingula*. The sandstone is medium- to coarse-grained, commonly pebbly and conglomeratic and may occur in upward-coarsening or upward-fining cycles. The Bishopston Mudstone Formation comprises coarsening-upward cycles of dark grey mudstone and siltstone, with marine bands and subordinate sandstone beds. The Telpyn Point Sandstone Formation comprises massive, cross-bedded, upwards-fining sandstone.

The Quartzitic Sandstone Formation consists of hard, pale grey quartzitic sandstone, some are conglomeratic with pebbles of white quartz, chert and ironstone, particularly above erosive surfaces (Kellaway and Welch, 1993). Grey mudstone, including some *Lingula* bands, and seatearths with thin carbonaceous or coaly beds occur as interbeds.

The sandstone-dominated successions are interpreted as deposits within a fluviodeltaic environment. The Bishopston Mudstone is interpreted as cycles of lagoonal or brackish water muds, passing upward into delta-front silts and occasionally capped by offshore sand shoals or beach barrier bars (George, 1970).

The Aberkenfig Formation is probably late Brigantian to early Pendleian in age. In the type area the Twrch Sandstone Formation is Pendleian to Marsdenian in age. Further to the east, successive overstep in the formation results in the base of the formation being Arnsbergian in age in the west of the Merthyr Tydfil district (Barclay et al., 1988) and Yeadonian in the east of the Abergavenny district (Barclay et al., 1989).

7.4 SOUTH WALES COAL MEASURES GROUP

Coal Measures Group is applied to the grey (productive) measures of *Coal Measures facies*, in accordance with its use in the Pennine Basin (Powell et al., 2000). The epithet of ‘South Wales’ is used to distinguish these Coal Measures from those present in the Pennine Basin and Midland Valley of Scotland. The group extends across the South Wales and Bristol region, and in the subsurface as the concealed Oxfordshire and Kent coalfields. Variscan (late Carboniferous –early Permian) deformation has isolated previously contiguous Coal Measures strata into a number of distinct areas or ‘basins’ in the Bristol–Somerset area, much of which are concealed beneath Mesozoic strata. The South Wales Coal Measures Group is absent in the Forest of Dean Coalfield.

Three component formations are recognised with the same name and bounding marine bands as for the Pennine Coal Measures Group. The Lower, Middle and Upper Coal Measures formations are proposed to have the epithet of ‘South Wales’ in order to distinguish these formations from those developed within the Pennine Basin.

Historically, South Wales Upper Coal Measures has been used synonomously with Pennant Measures. The Pennant Sandstone is now considered to be distinct from the South Wales Coal Measures Group. The South Wales Upper Coal Measures is now restricted to the grey measures above the Cambriense (Upper Cwmgorse) Marine Band within a small area of the eastern part of the South Wales Coalfield.

The South Wales Coal Measures Group is thickest in the west and south-west of the South Wales Coalfield (about 900 m) and attenuated in the east crop (about 240 m), adjacent to the Usk Anticline. The Pembrokeshire Coalfield is an attenuated westward extension of the main South Wales Coalfield. In the Bristol region the group is about 550 m thick. In the Kent Coalfield the group is up to 285 m thick.

In the South Wales and Bristol region, the group rests conformably upon strata of the Marros Group. In the Oxfordshire and Kent coalfields, the South Wales Lower Coal Measures rests unconformably upon Tournaisian, Visean or Devonian strata.

Lithologies present within the succession south of the Wales–Brabant High are equivalent to those described fully for the Pennine Coal Measures Group. The succession is predominantly argillaceous, with a few widespread sandstones.

The South Wales Lower Coal Measures shows two distinct lithological variations in south Wales. A lower succession, which equates with the *Lenisulcata* Biozone, includes thin and impersistent coal seams, relatively common marine bands and several thick quartzitic sandstone beds, collectively known as the Farewell Rock. Thick coals and relatively few marine bands dominate the upper part of the formation.

The South Wales Middle Coal Measures maintains broad lithological similarities with the upper part of the South Wales Lower Coal Measures. Thick, extensive coal seams, seatearths and numerous ironstone bands are common and a minor component of sandstone is present in the north-east of the South Wales Coalfield.

The sandstones of the South Wales Lower Coal Measures of south Wales represent mainly southward-prograding delta lobes, or fluvial sands with channelled bases. Some lenticular, coarse and pebbly sandstone on the east and south crops formed as littoral or sublittoral sandbodies (Kelling and Collinson, 1992). Locally, in the Oxfordshire Coalfield basic volcanic and intrusive rocks are dominant. In the South Wales Middle Coal Measures southward-prograding delta lobes become localised in the north-east of the South Wales Coalfield. However, in the west and notably in the Pembrokeshire Coalfield, fluviodeltaic sandbodies appear to be northward prograding.

The group is mainly Langsettian to Bolsovian in age.

7.5 WARWICKSHIRE GROUP

The Warwickshire Group was introduced in the Pennine Basin to replace terms such as the 'Barren (Coal) Measures' and 'Red Measures' for strata of Barren Measures facies that overlie the Pennine Coal Measures Group (Powell et al., 2000). In the Pennine Basin the group includes predominantly red-bed formations and a coal-bearing grey formation with Pennant-type sandstones, the Halesowen Formation. South of the Wales–Brabant High similar red and grey measures are found, though grey, coal-bearing strata with Pennant-type sandstones predominate.

A geographically restricted barren red measures succession is present above the Cambriense Marine Band in both the east crop of the South Wales Coalfield (Deri Formation) and the Bristol Coalfield (Winterbourne Formation). A younger, barren red measures succession is present in the Forest of Dean (Trenchard Formation). The overlying Pennant Sandstone Formation extends across the South Wales, Bristol and Forest of Dean coalfields at outcrop and the subsurface Oxfordshire and Berkshire coalfields. The formation is subdivided into members using marker coal seams. The Grovesend Formation within the Bristol and Oxfordshire–Berkshire coalfields are associated with alternating thicknesses of coal-bearing grey measures and barren red measures, defined as separate members. Distinct sandstone- and mudstone-dominated formations cannot be recognised within the subsurface Kent Coalfield.

The Oxfordshire Coalfield succession can be traced northward into the exposed Warwickshire Coalfield and Besly and Cleal (personal communication, 2006) suggest that the Grovesend Formation equates with the Halesowen Formation of the Pennine Basin. They recognise that due to seam-splitting and thickening towards the south, the Witney Coal and Burford Coal members are lateral equivalents of the single Milton and Broughton seams of Warwickshire. They also indicate that the Arenaceous Coal Formation is absent in north Oxfordshire and Warwickshire due to basal onlap.

The Deri Formation was traditionally considered part of the 'Upper Coal Measures' and the 'Llynfi and Rhondda beds' were forced through the red-bed succession, despite the local absence of correlateable coal seams. Formerly described as part of the Downend Formation, the Winterbourne Formation is interpreted as a lateral equivalent of the Deri Formation. The Pennant Sandstone Formation was referred to as Pennant Measures or Pennant Sandstone in earlier schemes. The Grovesend Formation was formerly known as Supra-Pennant Measures.

The Warwickshire Group is thickest, up to 1600 m, in the Swansea area of the South Wales Coalfield, decreasing to less than 650 m in the east crop of the same coalfield and within the Forest of Dean Coalfield. The Warwickshire Group is about 1000 m thick near Bristol and in the concealed Oxfordshire Coalfield, thinning northwards toward the southern flank of the Wales–Brabant High. In the concealed Kent Coalfield the group is about 600 m thick.

The base of the Warwickshire Group in the east crop of the South Wales Coalfield and the Bristol Coalfield is taken at the conformable and diachronous base of the barren red-bed successions of the Deri or Winterbourne formations, respectively. Farther to the north, within the Forest of Dean Coalfield, the base of the group is taken at the base of the Trenchard Formation, which rests unconformably upon Visean and older strata. Elsewhere within the South Wales, Somerset and Oxfordshire-Berkshire coalfields, the base of the Warwickshire Group is taken at the base of the Pennant Sandstone Formation. This boundary is markedly diachronous, placed at the base of the first thick sandstone of Pennant type, occurring at younger levels towards the north. In the South Wales Coalfield (except the east crop) the Somerset Coalfield and Berkshire Coalfield the Pennant Sandstone Formation rests conformably upon strata of the South Wales Coal Measures Group. In the Oxfordshire Coalfield, the Warwickshire Group rests unconformably upon strata of Devonian or older age. In the Kent Coalfield the group rests, above a non-sequence, on South Wales Upper Coal Measures; strata associated with the *A. phillipsii* Biozone are absent (Ramsbottom et al., 1978). The top of the Warwickshire Group is not present within the South Wales Coalfield and in England it is represented by an unconformity at the base of the overlying Permo-Triassic succession.

The Deri Formation consists of interbedded red, purple and green mottled mudstones and siltstones and channelised quartz arenites that are commonly pebbly and conglomeratic. Thin coals fail progressively eastwards. The Winterbourne Formation comprises grey and red mudstone with common thin and lenticular beds of quartz-conglomerate and pebbly sandstone. The Trenchard Formation consists of grey or pinkish grey quartzose sandstone. Quartzose conglomerate beds are common at the base of the formation, increasing in thickness and clast size toward the north (Jones, 1972). The Pennant Sandstone Formation comprises a grey, coal-bearing sandstone-dominated succession. The formation is characterised by the presence of bluish grey, weathering green, coarse-grained, locally conglomeratic, feldspathic and micaceous greywacke-type lithic arenites ('Pennant') of southern provenance. These sandstones are distinct from the quartz arenites of the South Wales Coal Measures Group of northern provenance. The Grovesend Formation comprises a mudstone-dominated succession with subordinate, though locally thick, sandstones of Pennant-type. Coals, though present, are not as thick or historically as economic to work as the coals of the underlying Pennant Sandstone Formation. Barren red measures within the Grovesend Formation comprise red mottled mudstone, seatearth, 'Pennant' type sandstone, but no coal seams.

The three red-bed formations were deposited on a well-drained alluvial plain. The Usk Anticline appears to have been active at the time of deposition. The raised topography associated with the anticline-enhanced drainage resulted in a primary reddened succession and provided a local source for conglomerates and sandstones. The Pennant Sandstone Formation formed in channels and floodplains within a broad alluvial tract, with low- to moderate-sinuousity rivers flowing northward from a rising Hercynian mountain belt to the south (Kelling and Collinson, 1992). The Grovesend Formation was deposited upon fluvial floodplains, predominantly within an overbank lacustrine environment. Periods of improved drainage are associated with oxidation and development of primary red beds.

The Warwickshire Group typically ranges from late Bolsovian to late Westphalian D, possibly Cantabrian (early Stephanian) in age in the South Wales, Bristol and Somerset coalfields (Ramsbottom et al., 1978). In the Forest of Dean, Oxfordshire and Kent coalfields the group is Westphalian D, and possibly Stephanian, in age.

8 South-west England (Culm Basin)

The Culm Basin was initiated in the latest Famennian by the onset of rifting in the shelf that lay to the north of two predominantly Devonian basins, the Tavy Basin and the more southerly South Devon Basin. Typical Culm lithofacies however, were not established in the gradually deepening Culm Basin for the most part until the mid to late Tournaisian. Successive extensional faulting gradually compartmentalised the Culm Basin into several sub-basins, comprising a central graben, the Central Devon Sub-basin, bounded by two half-grabens, the Bideford Sub-basin to the north and the Launceston Sub-basin to the south. Today, the Bideford Sub-basin is bounded to the north by the Brushford Fault, the Central Devon Sub-basin by the Greencliff Fault and the Launceston Sub-basin by the Rusey Fault (Figure 1). As a result of Variscan deformation that was dominated by thrusting, the Launceston Sub-basin today has no well defined southern margin, its deposits being contained in a series of tectonic slices locally interleaved with those of the Tavy Basin and its bounding highs, spread out southwards over the Tavy Basin. From the early Tournaisian, the remnant of the northern shelf, to the north of the Culm Basin, subsided sufficiently to allow shelf and Culm lithofacies to be deposited. Situated beyond the northern bounding structure of the Culm Basin, this area is termed the northern margin of the Culm Basin. During the Devonian, this northern shelf accumulated a very thick succession of shelf and progradational continental facies, which were deposited in an area of progressive, but intermittent subsidence, known as the North Devon Basin. The northern limit of the Culm Basin lies between the Cannington Park 'Carboniferous Limestone' inlier, 20 km south-west of the Mendip Hills, and the main Culm crop to the south. The Cannington Park sequence, proved in the Cannington Park Borehole, forms part of the Avon and Pembroke Limestone groups.

During the Tournaisian–Visean, the Culm Basin was separated from the Tavy Basin by a horst, the Laneast High. In turn, the Tavy Basin was separated from the South Devon Basin by a similar horst, the Landulph High. These positive features were predominantly submerged, thus allowing a range of depth-related Culm lithofacies to be deposited on them and in the intervening basins during the Tournaisian–Visean and locally during the earliest Namurian. During this period, the South Devon and Tavy basins were beginning to invert and be deformed, by a northward migrating phase of collision-related deformation (D_1) that reached the Launceston Sub-basin by the early Namurian. Inversion and southward out-thrusting of the sub-basin followed. To the north, in the rest of the Culm Basin, this deformation is manifested by local synsedimentary thrusting and slumping. The final phase of deformation (D_1 in the north, D_2 in the south) was late Carboniferous and fairly instantaneous.

A consequence of the complex extensional basinal structure and subsequent convergent tectonic activity, contemporaneous with its infilling, is that the Carboniferous deposits of the Culm Basin do not form a simple layer-cake succession. Polyphase folding and thrusting, particularly in the southern part of the basin, means that reconstruction of the original Carboniferous successions of the individual sub-basins and the Devonian basins to the south requires further work. Furthermore, the structural complexity results in thrust slices containing incomplete thicknesses of units and structural thickening associated with recumbent folding and, as a consequence, the thickness of many units is unknown or those given are very approximate in many areas.

Lithostratigraphical divisions and sequences are described below in the context of their interpreted relationship to the tectonic architecture of the Culm Basin, and a rational simplification of the region's current nomenclature is discussed.

The term Culm Measures, entrenched in the literature (Sedgwick and Murchison, 1840), has been retained as the Culm Supergroup, which embraces the Carboniferous, predominantly deep-water *Pelagic and Hemi-pelagic facies* and the *Millstone Grit facies*, deposited in the Culm, Tavy, North Devon and South Devon basins. Shallow and deeper water marine mudstones of late Devonian to early Tournaisian age, formerly included within the Culm Measures or a Transition Group, show stronger affinity in terms of facies with the underlying Devonian strata. These strata are assigned to the Tamar Group in south Devon and Exmoor Group in north Devon (Figure 9), both are excluded from the Culm Supergroup.

In the Culm Basin, the Culm Supergroup is subdivided into a lower Teign Valley Group, mainly of deep-water *Pelagic and Hemipelagic facies* and an overlying Holsworthy Group of *Millstone Grit facies* (Figure 9). These divisions broadly equate with the earlier terms, Lower and Upper Culm, initially employed by Sedgwick and Murchison (1840). In the Tavy Basin, the only preserved Carboniferous unit is the Laneast Quartzite Formation, a shallow water facies associated with the Laneast High. It is included in the Culm Supergroup but not in a group. In the South Devon Basin, the Culm Supergroup comprises only the Chudleigh Group of deep water *Hemipelagic lithofacies*.

8.1 TAMAR GROUP

The Tamar Group was first used as a term for the mid Devonian to earliest Tournaisian, mudstone-dominated succession of the South Devon and Tavy basins by Leveridge et al. (2002). As the group is mainly Devonian in age, it is outside the scope of this report to provide a full definition. However, as the upper part of the group extends into the early Tournaisian, it is necessary to provide a brief description of the Tournaisian succession.

The Tamar Group is nearly 7000 m thick on the north coast of Cornwall but elsewhere the thickness cannot be established because of structural complexity. The Tournaisian succession represents only a small component of the total thickness of the group and comprises the upper part of the Yeolmbridge Formation and the uppermost parts of the Saltash and Whiteway Mudstone (formerly Slate) formations. The Yeolmbridge Formation was deposited in the Tavy Basin on the flanks and crest of the Laneast High. The thickness of the formation is unknown but unlikely to exceed 100 m. The Whiteway Mudstone and Saltash formations were deposited in the South Devon Basin, the former on the flanks and crest of the Landulph High and the latter predominantly in the basin. The Whiteway Mudstone Formation ranges from 25 to

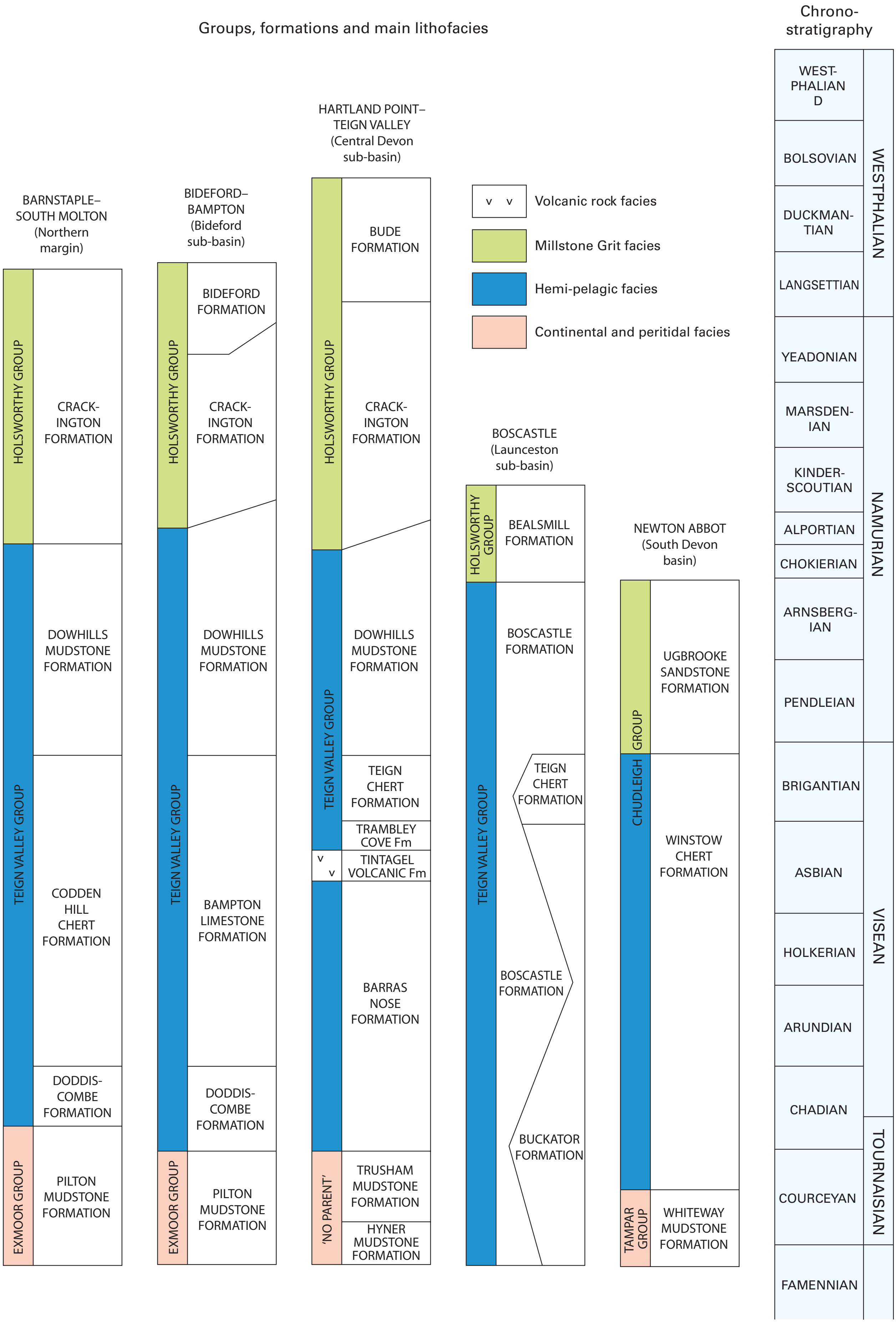

Figure 9 Lithostratigraphical nomenclature for the south-west England (Culm Basin) region. See Chapter 2 for description of lithofacies. Fm Formation

200 m, while the Saltash Formation is estimated to be up 3900 m thick on the north Cornish coast, but no Tournaisian age strata is present there. There is no information as to the exact thickness of the Tournaisian of these formations.

Discussion of the base of the Tamar Group is outside the scope of this report. The basal mid Devonian part of the group rests upon early Devonian blue-grey slates and thick sandstones of the Meadfoot Group (Leveridge et al., 2002). The top of the Tamar Group is seen only in the lower Tamar valley and Chudleigh areas, where it is overlain by the Chudleigh Group (Culm Supergroup); elsewhere the contact is either unexposed or tectonic.

The Tournaisian strata of the Tamar Group are mudstone-dominated. The Yeolmbridge Formation comprises grey to black, and dark green mudstone, with sporadic thin beds and lenses of calcareous sandstone, with lenticular beds of cephalopod limestone toward the top. The uppermost part of the Saltash Formation is preserved in thrust sheets near Landulph in the lower Tamar valley and comprises grey to dark grey mudstones. Here, it was deposited on the flanks of the Landulph High (Leveridge et al., 2002). In south-east Devon, in the Chudleigh area, the Whiteway Slate Formation comprises purple, green and grey-black mudstones with rare limestone nodules.

The cephalopod limestone of the Yeolmbridge Formation has yielded a *Gattendorfia* Zone (Tournaisian) macrofauna (Selwood, 1960). The uppermost part of the Saltash Formation is of early Tournaisian (T_{n1a} and possible T_{n2}) age with a diverse miospore population (Dean, 1992; Owens et al., 1993). Within the uppermost part of the Whiteway Mudstone Formation, ostracodes and trilobites indicate the *Gattendorfia* Zone (Tournaisian) (Selwood et al., 1984).

8.2 EXMOOR GROUP

The Exmoor Group is a new name proposed for that part of the succession (about 7000 m thick) of the North Devon Basin that is mainly Devonian in age, and thus outside of the scope of this report. However, as the uppermost part of the group extends into the early Tournaisian, it is necessary to provide a brief description of the Tournaisian succession, which comprises the upper part of the Pilton Mudstone Formation. Discussion of the base of the Exmoor Group is outside the scope of this report. The group is overlain conformably and gradationally by strata of the Teign Valley Group (Culm Supergroup).

The Tournaisian succession represents only a small component of the total thickness of the Exmoor Group. The Pilton Mudstone Formation is about 500 m thick and predominantly comprises grey shales with thin beds of sandstone, calcareous sandstone and fossiliferous limestone. Much of the upper part of the formation yields trilobites of the *Gattendorfia* and *Pericyclus* zones. The uppermost part of the formation (Unit D of Prentice, 1960) consists of grey unfossiliferous shales and is here regarded as part of the Teign Valley Group (Doddiscombe Formation). The formation was deposited within a broadly shallow marine, upward-deepening, shelfal environment.

8.3 HYNER MUDSTONE AND TRUSHAM MUDSTONE FORMATIONS

These two formations occur in the Teign valley area beneath the Culm Supergroup of the Central Devon Sub-basin. The upper part of the Hyner Mudstone Formation, and the whole of the younger Trusham Mudstone Formation is early Tournaisian in age. Both contain *Gattendorfia* Zone ostracods together with bivalves, brachipods and bryozoa (Selwood et al., 1984). The two formations have faunal and lithological affinities with both the Exmoor and Tamar groups, and for this reason are left as stand-alone units, not allocated to a group.

The Hyner Mudstone Formation is at least 244 m thick, overlain by up to 64 m of the Trusham Mudstone Formation. The Hyner Mudstone Formation comprises hard, dark-blue or bluish green, generally mottled, shales and mudstones. Calcareous bands and nodules, and calcareous shales and mudstones occur near the top. The formation passes conformably upward into pale grey and olive-green micaceous mudstones of the Trusham Mudstone Formation.

Both formations were deposited in the deepening conditions of the Culm Basin, developing in a distal shelf environment.

8.4 TEIGN VALLEY GROUP

The Teign Valley Group is a new term proposed for strata referable to the *Hemipelagic facies* in the Culm Basin. It broadly equates with the Dinantian succession, commonly referred to historically as 'Lower Culm', but also includes strata of early to mid Namurian age. The group crops out in north Devon and south Somerset, extending east of Barnstaple (Northern margin and Bideford Sub-basin), and into north Cornwall–south-east Devon, including the type area in the Teign valley (Central Devon and Launceston Sub-basins). The northern outcrop is largely continuous, whereas the southern outcrop is commonly broken by thrusts, with strata of the Central Devon and Launceston sub-basins locally found in thrust slices up to 25 km south of the main crop of Culm Supergroup, resting upon, and locally interleaved with, strata of the Tamar Group of the Tavy Basin (Leveridge et al., 2002). This tectonic disruption and presence of overfolds has resulted in difficulties in determining a lithostratigraphical succession along the south crop of the Teign Valley Group. Different lithostratigraphical schemes have evolved for distinct thrust slices, resulting in a plethora of names. An attempt is made here to rationalise this nomenclature.

The proposed scheme rationalises the abundant local names currently used in the Teign Valley Group, especially the chert-dominated formations. The following formations are to be retained and all other formational names should be discontinued.

Northern Margin and Bideford Sub-basin of the Culm Basin
Bampton Limestone Formation
Codden Hill Chert Formation
Doddiscombe Formation
Dowhills Mudstone Formation
Westleigh Limestone Formation

Central Devon and Launceston Sub-basins of the Culm Basin
Barras Nose Formation
Boscastle Formation
Brendon Formation
Buckator Formation
Combe Mudstone Formation
Dowhills Mudstone Formation

Meldon Shale and Quartzite Formation
St Mellion Formation
Teign Chert Formation
Tintagel Volcanic Formation
Trambley Cove Formation

The Variscan deformation makes it difficult to estimate the thickness of the group. The most reliable estimates come from the relatively structurally uncomplicated Teign Valley succession on the south crop where it is estimated to range from 330 to 590 m (Selwood et al., 1984). This may be compared with estimates of over 720 m in the Meldon Anticline in the Okehampton area (Edmonds et al., 1968). In contrast, a minimum thickness of 100 m is estimated for the Bideford area (Edmonds et al., 1979).

The base of the Teign Valley Group is taken where the strata reflect the onset of anoxic bottom conditions in the earliest Dinantian, generally in the mid to late Tournaisian. In most places the base is easily recognised as black anoxic mudstones, which overlie generally more oxic, pale grey, green, or purple and green, mudstone-dominated successions of the Exmoor and Tamar groups, and Trusham Mudstone Formation. However, in the structurally complex succession of the Launceston Sub-basin along the south crop of the group, this event cannot be easily identified and one unit, the Boscastle Formation, ranges down into the late Famennian. In this area the basal contact of the group is always tectonic. A further complication is that several coeval and intergradational facies are now structurally dislocated making formational diagnoses and palinspastic reconstruction of sedimentary architecture rather difficult. The top of the group is taken at the base of the Crackington Formation, except in the Launceston Sub-basin, where it is taken at the base of the proximal correlative of the Crackington Formation, the Bealsmill Formation.

The group comprises black mudstone, chert and limestone with local sandy or carbonate turbidite systems. Locally in north Cornwall, north Dartmoor and south-east Devon, spilitic lavas, tuffs and volcanic breccias form mappable units. In north Cornwall the volcanic rocks are included in the Tintagel Volcanic Formation.

The names used for the basal black mudstones have been rationalised. They now comprise the Doddiscombe Formation in the northern margin and Bideford Sub-basin, the Combe Mudstone Formation in the east of the Central Devon Sub-basin, the Barras Nose and Trambley Cove formations in the west of the Central Devon Sub-basin and the Meldon Shale and Quartzite Formation in north Dartmoor in the Central Devon Sub-basin.

Cherts interbedded with shales, limestones and tuffs are common within the Brigantian succession throughout the Culm Basin, but locally range throughout the Visean succession. The plethora of names for the chert formations has been reduced to the Codden Hill Chert Formation in the Bideford Sub-basin and northern margin of the Culm Basin and Teign Chert Formation in the Central Devon and Launceston Sub-basins. Lateral continuity between the two chert formations, although probable, has not been proved.

The Codden Hill Chert Formation passes eastwards in the Bideford Sub-basin into a succession of limestone turbidites, cherts and mudstones known as the Bampton Limestone Formation. It crops out between South Molton and Bampton. A few kilometres to the south, the upper part of the sequence is represented by coarse-grained, partly conglomeratic limestone turbidites and mudstones, known as the Westleigh Limestone Formation.

An upper, early Namurian turbiditic mudstone-prone succession occurs above the Codden Hill Chert and Teign Chert formations. Formerly referred to as the Dowhills Beds in the northern margin and Bideford Sub-basin, and Ashton Shale in the Exeter and Newton Abbot districts of the Central Devon Sub-basin, the names have been rationalised to the single Dowhills Mudstone Formation.

Sandstone turbidites deposited in the Launceston Sub-basin occur along the tectonically fragmented southern margin of the Culm Basin and show a northwards transition into mudstone-dominated formations. Those of the St Mellion outlier, situated between Dartmoor and Bodmin Moor, consist of the St Mellion and Brendon formations. The St Mellion Formation comprises fine- to coarse-grained sandstone turbidites and interbedded dark grey mudstone. The sandstone is feldspathic litharenite, conglomeratic in part, with graded bedding, and is locally rich in plant debris. The formation passes into the more distal succession of the Brendon Formation (Leveridge et al., 2002), composed of dark grey, locally siliceous, mudstone, with laminae and thin beds of siltstone, and sporadic packets of thin graded beds of blue-grey greywacke sandstone, with interbedded extrusive and interdigitated intrusive basic volcanic rocks.

In contrast to the St Mellion area, the deposits of the Launceston Sub-basin on the north Cornish coast, comprise the shallow water, sandstone-dominated succession of the Boscastle Formation. This comprises thin- to thick-bedded, grey, fine- to coarse-grained, quartzose sandstone, with sporadic cross-lamination, interbedded with finely laminated dark grey to black mudstone, and rare lenses and nodules of limestone. The Boscastle Formation passes laterally into the Buckator Formation, which comprises grey green mudstones and calcareous siltstones with sparse lenticular shelly limestones.

The group was deposited mainly within an anoxic, deep marine environment with subordinate influx of carbonate and siliciclastic turbidites. The shallow water succession (Boscastle and Buckator formations) of the Launceston Sub-basin on the north Cornish coast reflects deposition in more oxygenated nearshore to offshore environments (Selwood et al., 1985). The carbonate platform of the south Wales–Bristol area forms a source for many of the carbonate turbidites, notably the Bampton and Westleigh Limestone formations, whereas uplift to the south may have been the source of much of the siliciclastic turbidites, for example the St Mellion and Brendon formations. Radiolarian cherts were probably deposited within low-energy environments with high silica concentrations in the sea water leading to high radiolarian productivity. A wide range of water depths is likely.

The base of the group is generally mid to late Tournaisian. However, conodonts from the Buckator Formation indicate that the group ranges into the mid Famennian in the Launceston Sub-basin (Selwood et al., 1985.). The Barras Nose Formation yields conodonts indicative of late Tournaisian to late Asbian age (Freshney et al., 1972).

The Teign Chert Formation in the south crop yields late Tournaisian conodonts and ammonoids indicative of a Brigantian (P_{1a} to P_{2a} Zones) age. The upper part of the Codden Hill Chert Formation yields a similar Brigantian fauna, the remainder ranges down into the early Visean (late Chadian). The Bampton Limestone Formation yields ammonoids and trilobites ranging from topmost Tournaisian to the P_{2a} Zone. The Westleigh Limestone Formation yields B_2 to P_{2a} Zone ammonoids. The top of the group is early Namurian, the Dowhills Mudstone Formation ranging up to R_2 on the north crop and R_1 on the south crop.

8.5 CHUDLEIGH GROUP

The Chudleigh Group is a new term proposed for strata referable to the *Hemipelagic facies* developed in the South Devon Basin on the crest and flanks of the Landulph High. The group crops out in the Tamar valley and in the Newton Abbot area. It is estimated to be up to 550 m thick, but the top is nowhere seen.

The base of the group is taken where black mudstone, or black mudstone and chert, overlies generally grey, green, or purple and green, mudstone-dominated sequences of the Tamar Group. Thus the boundary reflects a change from oxic to anoxic bottom conditions that occurred in the earliest Dinantian (latest *Gattendorfia* Zone). The top of the group is not seen due to post D_1 inversion and erosion in the mid to late Namurian.

Two formations are present, the Winstow Chert Formation and the overlying Ugbrooke Sandstone Formation, which is restricted to the Newton Abbot area.

The Winstow Chert Formation comprises radiolarian cherts, siliceous mudstones and mudstones with a few limestones developed in the uppermost part. The cherts in the Tamar valley were originally included in the underlying Saltash Formation (Leveridge et al., 2002). The Ugbrooke Sandstone Formation consists predominantly of medium- to coarse-grained feldspathic sandstone, locally passing to fine-grained conglomerate, and subordinate siltstone and black mudstone. The conglomerates contain a wide range of clasts including granite, chert and other sedimentary rocks, which suggest derivation from the south.

Although the cherts are similar to those in the Teign Valley Group the condensed nature of the Winstow Chert Formation and its position above the carbonates of the Landulph High suggests that they were deposited in significantly shallower water. The sandstone beds of the Ugbrooke Sandstone Formation are interpreted as proximal turbidites and the conglomerate units as channel infill (Selwood et al., 1984.)

The presence of post-*Gattendorfia* pre-*Pericyclus* Zone s.l. conodonts (Matthews, 1969) from the lower part of the Winstow Chert is indicative of an early to mid Tournaisian age for the base of the group. The youngest date in the group comes from ammonoids at the base of the Ugbrooke Sandstone Formation suggesting a Namurian E or H age (House and Butcher, 1973).

8.6 LANEAST QUARTZITE FORMATION

The Laneast Quartzite Formation crops out in the area between Tavistock and Boscastle, in thrust- and fault-bounded sequences along the southern margin of the Culm Supergroup crop. The formation comprises coarse-grained quartzitic sandstones with some interbedded mudstone. No evidence of thickness is available.

The formation is interpreted as shore-zone clastics associated with the Laneast High on the southern margin of the Culm Basin (Selwood et al., 1985.). The age is uncertain but considered to be Tournaisian–Visean (Stewart, 1981a; Selwood et al., 1985.). The unit is recognised as a stand-alone formation, distinct from the deeper water deposits of the Teign Valley Group within the Culm Basin to the north.

8.7 HOLSWORTHY GROUP

The Holsworthy Group is referable to the deep water, turbidite-fronted, lobate delta subfacies of *Millstone Grit facies* (Figure 9). It broadly equates with the mid-Namurian–Westphalian succession and crops out mainly in north Cornwall and central Devon, between the northern and southern outcrops of the Teign Valley Group.

A simple threefold subdivision of the group into the Crackington, Bideford and Bude formations (Edmonds et al., 1975) is maintained for the northern margin, Bideford and Central Devon sub-basins. The Bealsmill Formation, which crops out in the northern part of the area between Bodmin and Dartmoor in the Launceston Sub-basin, is recognised as a distinct proximal correlative of the Crackington Formation.

The Crackington Formation ranges from 300 to 1500 m in thickness. The Bude and Bideford formations are about 1300 m and 800 m thick, respectively, though this is a minimum as the tops of the formations are not proven everywhere. The thickness of the Bealsmill Formation is unknown.

The base of the group over most of the Culm Basin is taken at the base of the Crackington Formation and lies conformably above the Dowhills Mudstone Formation. The base of the Bude Formation is generally taken at the base of the lowermost thick, massive sandstone above the Crackington Formation. The Bude Formation may pass laterally in some areas into the Bideford Formation, (Edmonds, 1974), and in other areas it is overlies the Bideford Formation. The base of the Bideford Formation is taken at the first appearance of channelised turbidite sandstones and slump units together with thick cross-bedded sandstones. The contact of its basal unit, the Westward Ho! Member with the Crackington Formation is nowhere exposed. In the Launceston Sub-basin, the base of the group and the Bealsmill Formation rests upon D_1 deformed rocks and is presumed to be an unconformity, but is nowhere seen, all contacts being tectonic.

The Crackington Formation comprises mudstones with turbidite sandstones (ranging in thickness from centimetres up to several metres) and siltstones. The Bude Formation consists of an assemblage of facies which includes massive amalgamated sandstones up to 10 m thick, thinner sandstone less than 1 m thick, slump beds and mudstone interbeds. Nodular shale beds are present at some levels and these can bear ammonoid and fish remains. The Bideford Formation comprises upward-coarsening cycles of dark grey mudstone, passing up into mudstone with thin sandstone beds, cross-laminated siltstones and finally erosion-based and cross-bedded sandstones. Turbidites are common in the lower part of the formation. The Bealsmill Formation comprises feldspathic, locally conglomeratic, thick-bedded sandstone with exotic clasts. Some mudstones are present.

The Crackington Formation comprises a predominantly marine, large-scale, sandy distal turbidite system that coarsens upwards, in the south into the Bude Formation and in the north into the Bideford Formation. The main axial flow of turbidity currents was towards the west or south-west (Edmonds et al., 1975), although a dominantly easterly flow is recorded within the Langsettian part of the formation. The Bude Formation, which is predominantly nonmarine, has been variously interpreted as a deep water turbidite system or as a delta. However, the debate has been reconciled by Higgs (1991), who interpreted the strata as lacustrine deposits laid down by river-fed turbidity currents in a large freshwater lake. Palaeocurrents reflect flow that was dominantly towards the south. To the north of the Greencliff Fault (Figure 1), the Crackington and Bude formations pass into an upward-coarsening deltaic succession of mudstone, siltstone and sandstone with impure coals of the Bideford Formation. The presence of turbiditic sandstones within mudstones suggests the deltas were prograding southward into moderately deep water. In the northern part of the Bideford Sub-basin, the Bideford Formation passes up into the Bude Formation. In the Launceston Sub-basin, the Bealsmill Formation is southerly derived and locally sourced, probably as a result of early Namurian movement along the Rusey Fault. It exhibits post D_1 structures and, therefore, cannot be one of the sandy turbidite formations of the Teign Valley Group.

The Crackington Formation ranges from early Namurian to early Westphalian age. The Gastrioceras listeri Marine Band forms a prominent marker towards the top of the formation. The Bude Formation is recognised as late Langsettian to earliest Bolsovian in age on the basis of ammonoids from scattered marine bands. The Bideford Formation is mid Langsettian to early Duckmantian.

9 References

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Appendix 1

LITHOSTRATIGRAPHICAL HIERARCHY OF THE CARBONIFEROUS STRATA OF THE UK

Approved names are listed in alphabetical order. The supergroups are subdivided, as appropriate, into groups, subgroups, formations and members. A separate list of groups that have not been assigned to a supergroup is also given, and finally a list of formations (no parent) that have not been assigned to a group or supergroup

Supergroup	Group	Sub-group	Formation	Member
Carboniferous Limestone	Avon		Castell Coch Limestone	
			Cwmyniscoy Mudstone	
			Shirehampton	
			Tongwynlais	
	Bowland High		Chatburn Limestone	
			Clitheroe Limestone	Bellman Limestone
				Coplow Limestone
				Peach Quarry Limestone
				Thornton Limestone
	Clwyd Limestone		Cefn Mawr Limestone	
			Foel	
			Leete Limestone	
			Llanarmon Limestone	Llwyn-y-fran Sandstone
				Nant-y-Gamar Limestone
			Loggerheads Limestone	Graig Fawr Limestone
				Little Orme Limestone
			Minera	
			Red Wharf Limestone	
	Great Scar Limestone		Ashfell Limestone	
			Ashfell Sandstone	
			Balladoole	
			Breakyneck Scar Limestone	
			Brownber	
			Chapel House Limestone	
			Coldbeck Limestone	
			Cracoe Limestone	
			Dalton	
			Danny Bridge Limestone	
			Derbyhaven	Sandwick
				Skillicore
				Turkeyland
			Eskett Limestone	
			Fawes Wood Limestone	
			Frizington Limestone	
			Garsdale Limestone	
			Kilnsey	Scaleber Force Limestone
				Scaleber Quarry Limestone
			Knipe Scar Limestone	
			Knockrushen	

Supergroup	Group	Sub-group	Formation	Member
Carboniferous Limestone	Great Scar Limestone		Malham	Cove Limestone
				Gordale Limestone
			Martin Limestone	
			Melmerby Scar Limestone	
			Park Limestone	
			Potts Beck Limestone	
			Red Hill Limestone	
			Scandal Beck Limestone	Coupland Syke Limestone
				Park Hill Limestone
			Tom Croft Limestone	
			Urswick Limestone	
	Holme High Limestone			
	Peak Limestone		Astbury	
			Bee Low Limestone	Chee Tor Rock
				Lower Miller's Dale Lava
				Miller's Dale Limestone
				Ravensdale Tuff
			Belvoir Limestone	
			Bowsey Wood	
			Cloud Hill Dolostone	Cloud Wood
				Scot's Brook
			Eyam Limestone	
			Fallgate Volcanic	Conksbury Bridge Lava
				Lathkill Lodge Lava
			Hopedale Limestone	
			Jackie Parr Limestone	
			Kevin Limestone	
			Lydebrook Sandstone	
			Milldale Limestone	Holly Bush
			Monsal Dale Limestone	Cressbrook Dale Lava
				Lees Bottom Lava
				Litton Tuff
				Lower Matlock Lava
				Shacklow Wood Lava
				Shothouse Spring Tuff
				Upper Matlock Lava
				Upper Miller's Dale Lava
				Winstermoor Lava
			Plungar Limestone	
			Rue Hill Dolomite	
			Sylvan Limestone	Little Wenlock Basalt
			Ticknall Limestone	
			Woo Dale Limestone	Iron Tors Limestone
	Pembroke Limestone	Abercriban Oolite		
		Black Rock Limestone	Undivided	Middle Hope Volcanic
			Barry Harbour Limestone	
			Berry Slade Formation	
			Brofiscin Oolite	
			Friars Point Limestone	
		Burrington Oolite		

Supergroup	Group	Sub-group	Formation	Member
Carboniferous Limestone	Pembroke Limestone	Clydach Valley	Blaen Onnen Oolite	
			Coed Ffyddlwn	Darren Ddu Limestone
			Gilwern Oolite	
			Pantydarren	
			Pwll-y-Cwm Oolite	
			Sychnant Dolomite	
		Hunts Bay Oolite	Cornelly Oolite	Argoed Limestone
				Cefnyrhendy Oolite
			Stormy Limestone	
			Caswell Bay Mudstone	
			Clifton Down Limestone	Cheddar Limestone
				Cheddar Oolite
			Clifton Down Mudstone	
			Cromhall Sandstone	
			Dowlais Limestone	
			Garn Caws Sandstone	
			Goblin Coombe Oolite	
			Gully Oolite	
			High Tor Limestone	Flat Holm Limestone
				Spring Cove Lava
			Hobbyhorse Bay Limestone	
			Linney Head	
			Llanelly	Cheltenham Limestone
				Clydach Halt
				Gilwern Clay
				Penllwyn Oolite
			Oreton Limestone	
			Oxwich Head Limestone	Honeycombed Sandstone
				Pant Mawr Sandstone
				Penderyn Oolite
			Oystermouth	
			Pen-y-holt Limestone	
			Stackpole Limestone	
			Vallis Limestone	
	Trawden Limestone			

Supergroup	Group	Formation	Member
Coal Measures	Pennine Coal Measures	Gloddaeth Purple Sandstone	
		Pennine Lower Coal Measures	
		Pennine Middle Coal Measures	
		Pennine Upper Coal Measures	Ackworth
			Badsworth
			Black Band Ironstone
			Brierley
			Clayband Ironstone
			Great Row
			Hemsworth
	Scottish Coal Measures	Scottish Lower Coal Measures	
		Scottish Middle Coal Measures	
		Scottish Upper Coal Measures	
	South Wales Coal Measures	South Wales Lower Coal Measures	
		South Wales Middle Coal Measures	
		South Wales Upper Coal Measures	

Supergroup	Group	Formation	Member
Culm	Chudleigh	Ugbrooke Sandstone	
		Winstow Chert	Winstow Mudstone
	Holsworthy	Bealsmill	
		Bideford	Westward Ho!
		Bude	
		Crackington	
	Teign Valley	Bampton Limestone	Kersdown Chert
		Barras Nose	
		Boscastle	
		Brendon	
		Buckator	
		Codden Hill Chert	Fremington
		Combe Mudstone	
		Doddiscombe	
		Dowhills Mudstone	Ashton Mudstone
		Meldon Shale and Quartzite	
		St Mellion	
		Teign Chert	
		Tintagel Volcanic	
		Trambley Cove	
		Westleigh Limestone	

Group	Formation	Member
Bathgate	Bathgate Hills Volcanic	
	Kinghorn Volcanic	
	Salsburgh Volcanic	
Border	Fell Sandstone	Gillfoot Sandstone
		Powillimount Sandstone
		Rascarrel
	Lyne	Bewcastle
		Cambeck
		Easton Anhydrite
		Lynebank
		Main Algal
		Southerness Limestone
Clackmannan	Enterkin Mudstone	
	Limestone Coal	Black Metals
		Kilbirnie Mudstone
	Lower Limestone	Hawthorn Limestone
	Passage	Ayrshire Bauxitic Clay
		Townburn Sandstone
		Troon Volcanic
	Upper Limestone	

Group	Formation	Member
Craven	Bowland Shale	Park Style Limestone
		Pendleside Sandstone
		Ravensholme Limestone
		Scarlett Point
		Scarlett Volcanic
	Ecton Limestone	
	Hodder Mudstone	Buckbanks Sandstone
		Chaigley Limestone
		Embsay Limestone
		Hetton Beck Limestone
		Leagram Mudstone
		Limekiln Wood Limestone
		Phynis Mudstone
		Rain Gill Limestone
		Twiston Sandstone
		Whitemoor Limestone
	Hodderense Limestone	
	Lockington Limestone	
	Long Eaton	
	Pendleside Limestone	Rad Brook Mudstone
	Pentre Chert	
	Prestatyn Limestone	
	Teilia	
	Widmerpool Formation	Ratcliffe Volcanic
		Tissington Volcanic
Exmoor	Pilton Mudstone	
Inverclyde	Ballagan	Drumwhirn
		Kirkbean Cementstone
		Lindsayston Burn
		Orroland
		Wall Hill
	Birrenswark Volcanic	
	Clyde Sandstone	Ascog
		Broadlee Glen Sandstone
		Eileans Sandstone
		Gourock Sandstone
		Knocknairshill
		Laggantuin Cornstone
		Millport Cornstones
		Millstone Point Sandstone
		Overtoun Sandstone
	Cottonshope Volcanic	
	Kelso Volcanic	
	Kinnesswood	Doughend Sandstone
		Foulport Mudstone
		West Bay Cornstone
	Roddam Dene Conglomerate	
Marros	Aberkenfig	
	Bishopston Mudstone	
	Quartzitic Sandstone	
	Rodway Siltstone	
	Telpyn Point	
	Twrch Sandstone	

Group	Formation	Member
Millstone Grit	Cefn-y-fedw Sandstone	
	Cornbrook Sandstone	
	Hebden	
	Marsden	
	Morridge Formation	
	Pendleton	Pendle Grit
	Rossendale	
	Samlesbury	
	Silsden	Claughton
		Roeburndale
Ravenstonedale	Cockermouth Volcanic	
	Langness Conglomerate	
	Marsett	Duddon Conglomerate
	Penny Farm Gill	
	Pinskey Gill	
	Raydale Dolostone	
	Shap Village Limestone	
	Stone Gill Limestone	
Strathclyde	Aberlady	
	Anstruther	Charles Hill Volcanic
	Arthur's Seat Volcanic	
	Birgidale	
	Clyde Plateau Volcanic	Numerous members (not listed)
	Fife Ness	
	Garleton Hills Volcanic	Bangley Trachytic
		East Linton Lava
		Hailes Lava
		North Berwick Pyroclastic
	Gullane	Wardie Sandstone
	Kirkwood	
	Laggan Cottage Mudstone	
	Lawmuir	Douglas Muir Quartz Conglomerate
		Craigmaddie Muir Sandstone
	Pathhead	
	Pittenweem	
	Sandy Craig	
	West Lothian Oil-Shale	Calders
		Hopetoun
Tamar	Rora Mudstone	
	Saltash	
	Whiteway Mudstone	
	Yeolmbridge	
Warwickshire	Becklees Sandstone	
	Canonbie Bridge Sandstone	
	Clent	
	Deri	
	Eskbank Wood	
	Etruria	
	Halesowen	Dark Slade

Group	Formation	Member
Warwickshire	Pennant Sandstone	Brithdir
		Coleford
		Downend
		Hughes
		Llynfi
		Mangotsfield
		Rhondda
		Swansea
	Salop	Allesley
		Alveley
		Enville
		Keresley
		Whitacre
	Grovesend	Barren Red
		Burford Coal
		Cinderford
		Crawley
		Farrington
		Publow
		Radstock
		Windrush
		Witney Coal
	Stallion Hill Sandstone	
	Tile Hill Mudstone	
	Trenchard	
	Whitehaven Sandstone	Bransty Cliff Sandstone
		Millyeat
	Winterbourne	
Yoredale	Alston	Askham Limestone
		Eelwell Limestone
		Five Yard Limestone
		Four Fathom Limestone
		Great Limestone
		Jew Limestone
		Oxford Limestone
		Scar Limestone
		Three Yard Limestone
		Tynebottom Limestone
	Closeburn Limestone	
	Stainmore	
	Tyne Limestone	Arbigland
		Dun Limestone
		Wintertarn Sandstone
No parent	Arch Farm Sandstone	
	Calke Abbey Sandstone	
	Ffernant	
	Fron-Fawr	
	Hathern Anhydrite	
	Hyner Mudstone	
	Laneast Quartzite	
	Lligwy Sandstone	
	Menai Straits	
	Middleton Dale Anhydrite	
	Pant	
	Penbedw	
	Redhouse Sandstone	
	Roddlesworth	
	Scalford Sandstone	
	Stockdale Farm	
	Trusham Mudstone	
	Village Farm	

Appendix 2

CHRONOSTRATIGRAPHICAL ZONATION FOR THE CARBONIFEROUS

Included here for reference are chronostratigraphical tables that appear in the more detailed report: WATERS, C N, BARCLAY, W J, DAVIES, J, and WATERS, R A, in press. Stratigraphical framework for Carboniferous successions of Southern Great Britain (Onshore). *British Geological Survey Research Report*.

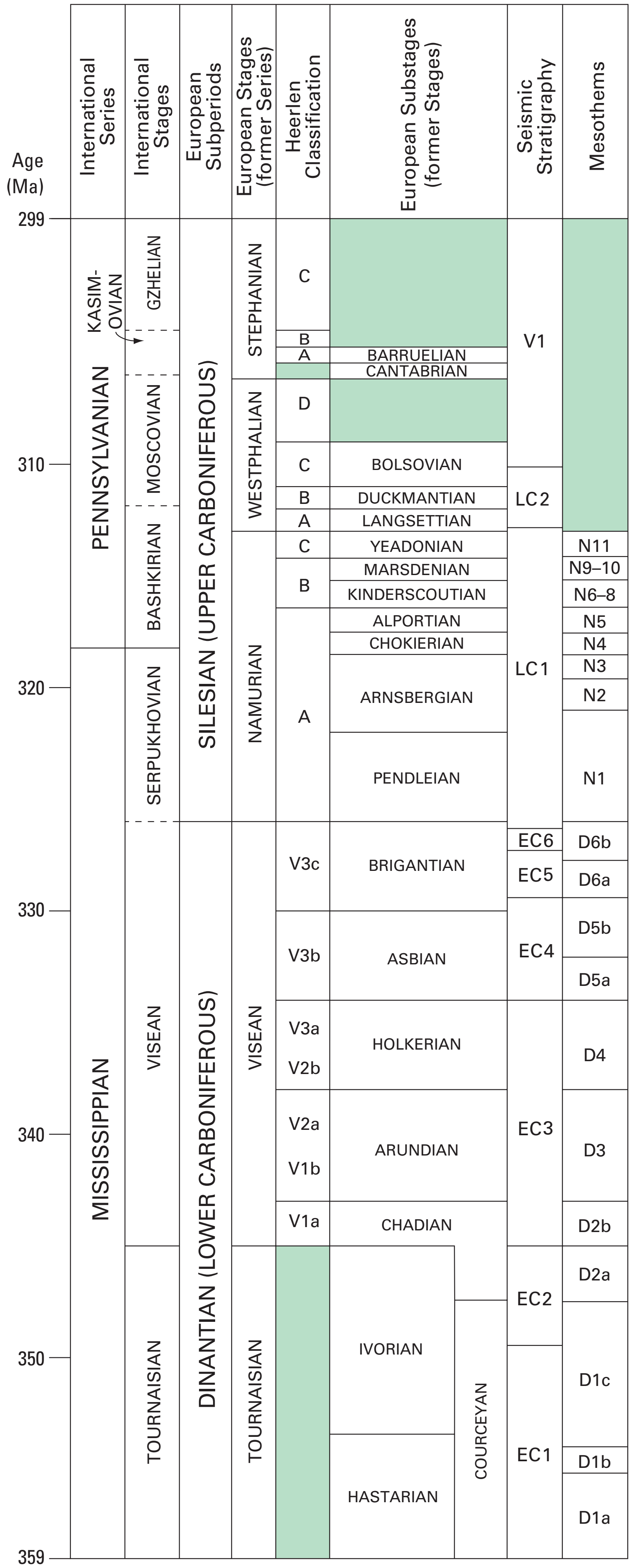

Table 1 Chronostratigraphical framework for the Carboniferous of England and Wales. Ages derived from Menning et al. (2000); Seismic sequences from Fraser et al. (1990); Mesothems from Ramsbottom (1973, 1977).

Table 2 Dinantian biostratigraphal 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*

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

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

STAGE	ZONE		WESTERN EUROPEAN MARINE BANDS		MIOSPORES	CONODONTS
	Index	**Ammonoid**	**Ammonoid**	**Index**		
Yeadonian	G_{1b}	*Cancelloceras cumbriense*	*Ca. cumbriense*	$G_{1b}1$	*Raistrickia fulva – Reticulatisporites reticulatus* (FR)	*Idiognathoides sinuatus – Idiognathoides primulus*
	G_{1a}	*Cancelloceras cancellatum*	*Ca. cancellatum*	$G_{1a}1$		
Marsdenian	R_{2c}	*Bilinguites superbilinguis*	*Verneulites sigma*	$R_{2c}2$		
			B. superbilinguis	$R_{2c}1$		
	R_{2b}	*Bilinguites bilinguis*	*B. metabilinguis*	$R_{2b}5$	*Crassispora kosankei – Grumosisporites varioreticulatus* (KV)	
			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*	$R_{1c}4$		*Idiognathoides corrugatus – Idiognathoides sulcatus*
			R. reticulatum	$R_{1c}3$		
			R. reticulatum	$R_{1c}2$		
			R. reticulatum	$R_{1c}1$		
	R_{1b}	*Reticuloceras eoreticulatum*	*R. stubblefieldi*	$R_{1b}3$		
			R. nodosum	$R_{1b}2$		
			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*	$H_{2c}2$	*Lycospora subtriquetra – Kraeuselisporites ornatus* (SO)	*Declinognathus noduliferus*
			V. eostriolatus	$H_{2c}1$		
	H_{2b}	*Homoceras undulatum*	*H. undulatum*	$H_{2b}1$		
	H_{2a}	*Hudsonoceras proteum*	*Hd. proteum*	$H_{2a}1$		
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	$H_{1a}1$		

Table 3 continued…

STAGE	ZONE		WESTERN EUROPEAN MARINE BANDS		MIOSPORES	CONODONTS
	Index	Ammonoid	Ammonoid	Index		
Arnsbergian	E_{2c}	*Nuculoceras stellarum*	*N. nuculum*	$E_{2c}4$	*Lycospora subtriquetra – Kraeuselisporites ornatus* (SO) continued...	*Gnathodus bilineatus bollandensis*
			N. nuculum	$E_{2c}3$		
			N. nuculum	$E_{2c}2$		
			N. stellarum	$E_{2c}1$		
	E_{2b}	*Cravenocera–toides edalensis*	*Ct. nititoides*	$E_{2b}3$		
			Ct. nitidus	$E_{2b}2$	*Stenzonotriletes triangulus – Rotaspora knoxi* (TK)	
			Ct. edalensis	$E_{2b}1$		
	E_{2a}	*Cravenoceras cowlingense*	*Eumorphoceras yatesae*	$E_{2a}3$		
			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.*	*Kladognathus – Gnathodus girtyi simplex*
	E_{1b}	*Cravenoceras brandoni*	*Tumulites pseudobilinguis*	$E_{1b}2$		
			C. brandoni	$E_{1b}1$		
	E_{1a}	*Cravenoceras leion*	*C. leion*	$E_{1a}1$		

Table 4 Westphalian chronostratigraphy and biostratigraphical zonations.

<table>
<tr><th rowspan="2">Stage</th><th rowspan="2">Ammonoids</th><th rowspan="2">Conodonts</th><th colspan="2">Palynomorphs</th><th colspan="2">Non-marine bivalves</th></tr>
<tr><th>Index</th><th>Zone</th><th>Zone</th><th>Sub-zone</th></tr>
<tr><td>Cantabrian</td><td rowspan="15"></td><td rowspan="15"></td><td></td><td></td><td rowspan="2">Anthraconauta tenuis</td><td rowspan="2"></td></tr>
<tr><td>Westphalian D</td><td>XI</td><td>Thymospora obscura</td></tr>
<tr><td rowspan="3">Bolsovian</td><td rowspan="2">X</td><td rowspan="2">Torispora securis</td><td>Anthraconauta phillipsi</td><td></td></tr>
<tr><td rowspan="2">'Upper similis- pulchra'</td><td></td></tr>
<tr><td rowspan="3">IX</td><td rowspan="3">Vestispora magna</td><td>adamsi-hindi</td></tr>
<tr><td rowspan="5">Duckmantian</td><td rowspan="3">'Lower similis-pulchra'</td><td>atra</td></tr>
<tr><td>caledonica</td></tr>
<tr><td rowspan="2">VIII</td><td rowspan="2">Dictyotriletes bireticulatus</td><td>phrygiana</td></tr>
<tr><td>Anthraconaia modiolaris</td><td>ovum</td></tr>
<tr><td rowspan="2">VII</td><td rowspan="2">Schulzospora rara</td><td rowspan="2"></td><td>regularis</td></tr>
<tr><td rowspan="7">Langsettian</td><td>cristagalli</td></tr>
<tr><td rowspan="3">VI</td><td rowspan="3">Radiizonates aligerens</td><td rowspan="3">Carbonicola communis</td><td>pseudorobosta</td></tr>
<tr><td>bipennis</td></tr>
<tr><td>torus</td></tr>
<tr><td rowspan="3">SS</td><td rowspan="3">Triquitrites sinani-Cirratriradites saturni</td><td rowspan="3">Carbonicola lenisulcata</td><td>proxima</td></tr>
<tr><td>Gastrioceras listeri</td><td>Idiognathoides sulcatus parvus</td><td>extenuata</td></tr>
<tr><td>Gastrioceras subcrenatum</td><td>Idiognathoides sinuatus – Idiognathoides primulus (pars.)</td><td>fallax-protea</td></tr>
</table>