Chapter 1 Introduction to British Lower Carboniferous stratigraphy

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Introduction

The Lower Carboniferous Subsystem is without doubt one of the most important subsystems in the British stratigraphical column, and its rock formations (responsible for some of the finest coastal and upland scenery) form an important element of Britain's outstanding geological heritage. Historically, these formations have proved pivotal in the development of evolutionary theory and in the understanding of ancient tropical marine environments. Recent scientific advances in these areas have led to sophisticated refinements in modern stratigraphical practice (Riley, 1993) and to a greatly improved level of understanding of the development of carbonate depositional systems (Ricker and Wright, 1990). In addition, the Lower Carboniferous sequence has been used as a test-bed for contemporary concepts in basin evolution and seismic sequence stratigraphy (Leeder, 1982, 1987a; Gawthorpe, 1987a; Gawthorpe *et al.,* 1989; Ebdon *et al.,* 1990; Martinsen, 1993; Chadwick *et al.,* 1995; Kirby *et al.,* 2000), and as a model for the exploration of metallogenic mineral deposits and subsurface petroleum reservoirs (Grayson and Oldham, 1987; Barrett, 1988; Burchette *et al.,* 1990; Fraser and Gawthorpe, 1990; Chadwick *et al.,* 1993a; Besly, 1998). The Lower Carboniferous Subsystem is, however, best known economically for its supply of raw materials (especially limestones and mudrocks) to the construction industry. The outcrop distribution of Lower Carboniferous rocks in Britain is illustrated in (Figure 1.1).

The 'Carboniferous' — a term first used by Conybeare and Phillips (1822) — was the first of the modern 'system' names to be used for a Phanerozoic time period (Ramsbottom, 1981). Its formal subdivision into the Dinantian (Munier-Chalmas and de Lapparent, 1893) and the Silesian (van Leckwijck, 1960) subsystems of Lower and Upper Carboniferous age respectively, was formally adopted at Krefeld in 1971 (see George and Wagner, 1972). However, following the International Union of Geological Sciences (IUGS) Subcommission on Carboniferous Stratigraphy's recent definition of a Mid-Carboniferous boundary and GSSP (Global Stratotype Section and Point) at Arrow Canyon in Nevada, USA (see Lane *et al.,* 1985, 1994; Lane, 1995; Metcalfe, 1997) the concept of Lower and Upper Carboniferous has been revised such that the lower part of the Silesian sequence (including the Pendleian and Arnsbergian stages) is now included within the upper part of the Lower Carboniferous succession (Figure 1.2); although regrettably there is, as yet, no formal agreement regarding either the names or status of these two new major subdivisions of the Carboniferous System (Metcalfe, 1998; Riley, 1998). It is this revised concept of Lower and Upper Carboniferous that has been used by the Joint Nature Conservation Committee (JNCC) in its Geological Conservation Review (GCR) volumes (see Ellis *et al.,* 1996) on British Lower Carboniferous stratigraphy (this volume) and British Upper Carboniferous stratigraphy (Cleal and Thomas, 1996). For further information on the historical development of the classification of the Carboniferous System, see George *et al.* (1976), Ramsbottom *et al.* (1978), Ramsbottom (1981, 1984), Wagner and Winkler Prins (1994) and Cleal and Thomas (1996).

Although a significant number of scientists have contributed to our current understanding of British Lower Carboniferous geology, certain names stand out as having been particularly influential. Among the most notable of these are Morton, Vaughan, Garwood, Parkinson, Hudson, Bisat, T.N. George, Johnson and Ramsbottom, each of whom is renowned especially for his exceptional and in some cases pioneering work, over a great many years, on aspects of Lower Carboniferous stratigraphy. Other significant contributors to Lower Carboniferous biostratigraphy and/or palaeontology include Conil, Fewtrell and Strank (foraminifera), Clayton, Higgs, Neves and Owens (miospores), Armstrong, Austin, Higgins, Metcalfe, Purnell, Reynolds, Rhodes and Varker (conodonts), Mitchell and Nudds (corals), Brunton, Mundy and Pattison (brachiopods), J. Wright (echinoderms) and Riley (all groups, but especially trilobites and ammonoids). Important contributions to Lower Carboniferous geology have also been made by Adams, Gawthorpe, Gutteridge, Horbury, Leeder, J. Miller, Somerville, Walkden and V.P. Wright on aspects of the sedimentology. Of particular significance has been the immeasurable contribution made by officers of the British Geological Survey (BGS) in the production of numerous geological maps and memoirs covering areas of Lower Carboniferous outcrop.

Britain offers some of the finest sections of Lower Carboniferous strata in western Europe and has been at the forefront of Lower Carboniferous stratigraphical research since the first biostratigraphical zonation schemes were established by Vaughan, Garwood and Bisat in the earlier part of the 20th century. Arguably the most significant of these schemes was produced by Vaughan (1905) in his seminal account of the faunal succession (coral–brachiopod zonation) in the Carboniferous Limestone at Avon Gorge, Bristol (see GCR site report, Chapter 9). A similar biostratigraphical scheme for the subdivision of the Lower Carboniferous sequence was later developed by Garwood (1913, 1916) who established north-west England as the type area for the British Dinantian Subsystem, and following this, an important zonation scheme based on the distribution of goniatites was developed for Lower Carboniferous successions outcropping in basinal areas (Hind, 1918; Bisat, 1924).

Later, these early biostratigraphical schemes were replaced by chronostratigraphical ones (George *et al.,* 1976; Ramsbottom *et al.,* 1978). This resulted in the subdivision of the British Lower Carboniferous Subsystem (as defined in this volume) into eight regional stages, six of which are currently defined at basal boundary stratotype sections in Britain (Ramsbottom, 1981). Although Riley (1993) has drawn attention to significant flaws in the choice of some of these stratotype sections, the development of a chronostratigraphical framework has undoubtedly provided a better basis for the correlation of the British Lower Carboniferous Subsystem.

Later, following a surge of interest from the oil industry Lower Carboniferous successions became the focus for a great deal of sedimentological research and a diverse range of depositional systems were soon demonstrated at many sites across Britain. Particular sedimentological highlights include the recognition of platform limestones with carbonate sand shoals, exposure surfaces and pedogenic fabrics; tidal-flat deposits with evaporites and microbial stromatolites; deep-water carbonate buildups and basinal debris deposits; fossiliferous, shallow-water, reef limestones; fluvio-deltaic sand bodies; and some of the finest examples of Lower Carboniferous hemipelagic and cyclic carbonate ramp sequences in the world. Seen in this context the sites documented in this volume are of vital importance to continuing research work on the Lower Carboniferous sequence and to the conservation of a significant part of Britain's Earth science heritage.

Scope of this volume

This volume documents the importance of Lower Carboniferous stratigraphical sites throughout Great Britain (i.e. England, Scotland and Wales, but excluding the Isle of Man and Northern Ireland). Together they constitute the 'network' of GCR sites (see Ellis *et al.,* 1996) for this part of the stratigraphical column, and have been (or will be) used to define geological Sites of Special Scientific Interest (SSSIs).

The concept of the Lower Carboniferous sequence used here derives principally from the IUGS Subcommission on Carboniferous Stratigraphy's decision to define a Mid-Carboniferous boundary and GSSP at the first entry of the conodont *Declinognathodus noduliferus,* which in Britain appears at a position just above the base of the Chokierian Stage of the European classification (see Lane *et al.,* 1985, 1994; Lane, 1995; Metcalfe, 1997). For convenience, and following the decision made for the Upper Carboniferous GCR volume by Cleal and Thomas (1996), the upper limit of the Lower Carboniferous Subsystem in this volume is drawn at the level of the Arnsbergian–Chokierian stage boundary, a horizon which, in Britain, is defined at the internationally recognized stratotype section at Gill Beck (Stonehead Beck), near Cowling, North Yorkshire (Ramsbottom, 1981; Riley, 1987; Riley *et al.,* 1987; Cleal and Thomas, 1996). The Lower Carboniferous sequence in this account therefore includes the lowest two stages of the Namurian Series (i.e. the Pendleian and the Arnsbergian); stages that were formerly regarded as part of the Upper Carboniferous Subsystem. While a Mid-Carboniferous boundary at this level is in keeping with current international opinion, its use in subdividing the Carboniferous System in Britain has yet to receive widespread acceptance (see Guion *et al.,* 2000). Furthermore, its adoption by the JNCC for the publication of its GCR Series has meant that site descriptions for the Namurian GCR 'block' are now split between its two Carboniferous volumes (i.e. the present volume and the Upper Carboniferous GCR volume of Cleal and Thomas, 1996).

In this account, the base of the Lower Carboniferous Subsystem has been taken at the base of the Courceyan Stage (George *et al.,* 1976). Although the base of the Courceyan Stage was originally positioned at a level that most closely corresponded to the base of the Carboniferous System according to the Heerlen Classification (Jongmans, 1928; Jongmans and Gothan, 1937), this definition has now been superseded. The base of the Carboniferous System is currently defined by a GSSP at La Serre, in the Montaine Noire, southern France (Paproth and Streel, 1984; Paproth *et al.,* 1991) and characterized by the first appearance of the conodont *Siphonodella sulcata.*

Relevant literature

In this volume, detailed accounts of the literature relevant to the areas described are given at the beginning of each chapter, thus only a brief review of some of the more useful general accounts and 'keynote' contributions on British Lower Carboniferous stratigraphy is presented here. Literature of specific relevance to individual sites is referred to in the 'Introduction' to each site report.

Two of the most important contributions on British Carboniferous stratigraphy are the 'Special Reports' of the Geological Society of London on the Dinantian sequence (George *et al.,* 1976) and the Silesian sequence (Ramsbottom *et al.,* 1978). Together these provided the first formal chronostratigraphical classification of the British Carboniferous System — the necessary framework for establishing comprehensive regional correlations of Carboniferous successions throughout Britain and Ireland. Another particularly significant contribution is the review of British Dinantian stratigraphy by Riley (1993). Regional syntheses covering other aspects of the British Lower Carboniferous succession — including recent developments, tectonics, basin evolution, sedimentation, palaeoenvironments, palaeo-communities and hydrocarbon habitat — are by Leeder (1988), Fraser and Gawthorpe (1990), Fraser *et al.* (1990) and Besly (1998), or are contained in the compilation volumes of McKerrow (1978), Miller *et al.* (1987), Besly and Kelling (1988), Arthurton *et al.* (1989) and Strogen *et al.* (1996). More general accounts of the British Carboniferous System are those by Cope *et al.* (1992), Leeder (1992) and Guion *et al.* (2000).

Structural setting

The major features controlling deposition in Britain during Early Carboniferous times owe much to structures inherited from the Caledonian Orogeny. Closure of the Iapetus Ocean had led to the development of a suture running ENE–WSW across northern England, with differing Lower Palaeozoic geological histories on either side. The Caledonian structure of England and Wales was strongly influenced by a 'Midlands Microcraton' in central England. To the east of this, Caledonian structures trend north-west–south-east, but to the west and north the trend is north-east–south-west. A major feature of the palaeogeography of Britain during Early Carboniferous times is the land area of the Wales–Brabant Massif, formerly known as 'St George's Land', which is, at least in part, a remnant of this Midlands Microcraton (Figure 1.3).

Major collision was taking place through Central Europe during Early Carboniferous times as a result of closure of the Rheic Ocean, but to the north of this, in Britain, extensional tectonics prevailed. An overall north–south stretching is envisaged by most workers (e.g. Leeder, 1988), although east–west tension has also been suggested (e.g. Haszeldine, 1984). In England and Wales north of the Wales–Brabant Massif, the combination of (probable) north–south extension combined with the inherited Caledonian structures led to the development of asymmetric graben with relative subsidence partly controlled by the position of low-density granite plutons. Rifting was pulsed, with particularly active episodes in Chadian–early Arundian and in mid–late Asbian times (Fraser and Gawthorpe, 1990). Significant rifting also took place during Courceyan times (Chadwick *et al.,* 1995).

Areas undergoing slow subsidence and thus accommodating a relatively thin Lower Carboniferous succession have been variously called 'blocks', 'highs', 'horsts', 'shelves' or 'platforms', and the areas undergoing more rapid subsidence as 'basins', 'troughs', 'gulfs' or 'lows'. This has led to some confusion in nomenclature, particularly as boundaries are not always fault-controlled, but may be transitional down ramps developed on asymmetric graben. Despite attempts to rationalize nomenclature (e.g. Grayson and Oldham, 1987) much variation in usage remains. The terminology used in this volume follows, wherever possible, that which appears to be in most common use (Figure 1.3).

South of the Wales–Brabant Massif, the Culm Trough and the shelf area bordering it are remnants of a back-arc basin relating to northwards subduction and closure of the Rheic Ocean. In Scotland, between the Grampian Mountains to the north and the Southern Uplands to the south, a major rift, the Midland Valley, formed, controlled by movements on inherited Caledonian faults (Figure 1.3).

In late Dinantian times, uplift of source areas led to southwards progradation of a giant clastic delta complex which rapidly filled the basinal areas. At this time, active rifting largely ceased and subsidence in Namurian and Westphalian times was regional and thermally driven (Leeder and McMahon, 1988).

The final closure of the Rheic Ocean led to the Variscan or Hercynian Orogeny during late Westphalian and Permian times. South of the Wales–Brabant Massif, compression resulted in thrust faulting and nappe emplacement (Isaac *et al.,* 1982). In northern Britain, inversion of Lower Carboniferous half-graben and subsequent erosion led to the development of a Permian–Carboniferous angular unconformity (Corfield *et al.,* 1996).

Stratigraphy

The framework for the consideration of Lower Carboniferous successions in this volume has been based on the three most commonly used branches of stratigraphical practice: lithostratigraphy — concerned with the subdivision and correlation of rock successions according to their lithological character; biostratigraphy —concerned with the subdivision and correlation of rock successions based on the distribution of fossils; and chronostratigraphy — the true time/rock stratigraphy that attempts to establish the chronology and correlation of rock successions around the world against a globally accepted timescale based on isochronous (time equivalent) units, the boundaries between which are defined at internationally agreed stratotype sections and points.

The chronostratigraphical scheme for the Lower Carboniferous succession derives from the Heerlen Classification of the Carboniferous System, the essential elements of which are illustrated in (Figure 1.2). The development of this scheme is outlined by Wagner (1989) and Wagner and Winkler Prins (1991, 1994). The Lower Carboniferous sequence is divided into eight regional stages, six in the Dinantian Subsystem (Courceyan, Chadian, Arundian, Holkerian, Asbian and Brigantian — see George *et al.,* 1976) and two in the Silesian Subsystem (Pendleian and Arnsbergian — see Hudson and Cotton, 1943; Ramsbottom, 1969; Ramsbottom *et al.,* 1978). Despite assurances to the contrary (George, 1978a), the establishment of these stages does appear to have been based upon the earlier recognition of eustatically controlled cycles (mesothems) in Lower Carboniferous successions by Ramsbottom (1973, 1977a) (see Riley, 1993). The majority of stages are defined at stratotype sections, either in northern England, South Wales or southern Ireland (see George *et al.,* 1976; Ramsbottom, 1981), but a stratotype section for the Arnsbergian Stage has yet to be established. Furthermore, although the status of the British Dinantian stages and their stratotypes has been questioned by Riley (1993, 1995), most notably for the Chadian Stage but also for the Holkerian and Brigantian stages, appropriate replacement sections have yet to be formally recognized.

Since Vaughan (1905) and Garwood (1913) established the first coral–brachiopod zonation schemes for the British Lower Carboniferous sequence, a proliferation of biostratigraphical schemes for the Lower Carboniferous successions of north-west Europe has evolved based principally on the distribution of miospores (Sullivan, 1964a,b, 1968; Butterworth and Spinner, 1967; Hibbert and Lacey, 1969; Llewellyn *et al.,* 1969; Mortimer *et al.,* 1970; Johnson and Marshall, 1971; Marshall and Williams, 1971; Neves *et al.,* 1972, 1973; Neves and Ioannides, 1974; Clayton *et al.,* 1977, 1978; Welsh, 1980; Welsh and Owens, 1983; Higgs, 1984; Higgs and Clayton, 1984; Clayton, 1985; Higgs *et al.,* 1988a,b; Oliathain, 1993), conodonts (Higgins, 1961, 1975, 1985; Matthews, 1961, 1969; Varker, 1968; Rhodes *et al.,* 1969; Morris, 1970a; Butler, 1973; Matthews and Thomas, 1974; Groessens, 1975; Metcalfe, 1976, 1980, 1981; Varker and Higgins, 1979; Stewart, 1981; Higgins and Varker, 1982; Be■ka, 1985; Varker and Sevastopulo, 1985; von Bitter *et al.,* 1986; Armstrong and Purnell, 1987; Austin, 1987; Purnell, 1989, 1992; Strogen *et al.,* 1990; Conil *et al.,* 1991; Stone, 1991), foraminifera (Cummings, 1961; Fewtrell and Smith, 1978; Conil *et al.,* 1980, 1981; Fewtrell *et al.,* 1981a; Strank, 1981, 1982a,b, 1983, 1985, 1986; Athersuch and Strank, 1989; Riley in Davies *et al.,* 1989; Riley, 1990a, 1995; White, 1992) and ammonoids (Bisat, 1924, 1928, 1934, 1952, 1955, 1957; Moore, 1930, 1936, 1939, 1941, 1946, 1950, 1952, 1958; Moore and Hodson, 1958; and see Butcher and Hodson, 1960; Ramsbottom in Earp *et al.,* 1961; Matthews, 1970; Ramsbottom and Saunders, 1985; Riley, 1985, 1990b, 1991, 1996; Korn, 1986, 1988; Kullman *et al.,* 1991; Brandon *et al.,* 1995, 1998).

Additional work by Hill (1938–1941), Mitchell and Green (1965), Nudds (1975, 1977, 1980, 1981, 1993, 1999), Ramsbottom and Mitchell (1980), Sutherland and Mitchell (1980), Mitchell (1981, 1989), Somerville and Strank (1984a,b), Somerville and Jones (1985), Mitchell *et al.* (1986), Somerville *et al.* (1986, 1989) Nudds and Somerville (1987), Sevastopulo and Nudds (1987) and Mitchell and Somerville (1988) has led to significant improvements in our understanding of the distribution of coral taxa and to the refinement of the Vaughanian coral–brachiopod scheme.

Biostratigraphical schemes for selected parts of the Lower Carboniferous sequence based on the distribution of trilobites (Riley, 1982a) and ostracodes (Robinson, 1978; Gooday, 1983) have also been proposed. Additional information on the distribution of Lower Carboniferous trilobite taxa is presented by Osmolska (1970), Miller (1973), Tilsley (1977, 1988), Owens (1984, 1986), Riley (1984, 1990a) and Owens and Tilsley (1995).

Recent developments in stratigraphical practice have witnessed the introduction of seismic sequence stratigraphy as a method of evaluating successions, and a seismic sequence stratigraphical scheme for the Carboniferous System has been proposed by Ebdon *et al.* (1990), Fraser and Gawthorpe (1990) and Fraser *et al.* (1990). Sequences for the Dinantian Subsystem were originally based on seismic evidence from the East Midlands, and Ebdon *et al.* (1990) considered that their scheme might form the basis of a chronostratigraphical division of the Lower Carboniferous sequence. However, Riley (1993) showed that seismic stratigraphy is unable to provide sufficient stratigraphical resolution and is inferior to biostratigraphical techniques in recognizing some sequence boundaries.

For further information on the development and application of these stratigraphical schemes the reader is referred to the detailed and comprehensive review paper on British Dinantian stratigraphy by Riley (1993), in which a table (fig. 1) of the most commonly used biostratigraphical zonation schemes is presented alongside the currently accepted chronostratigraphical framework for the Dinantian Subsystem. An updated and extended version of this figure, incorporating biozones from the Pendleian and Arnsbergian stages (in keeping with the concept of the Lower Carboniferous Subsystem used in this volume — see 'Scope of this volume', this chapter) is presented in (Figure 1.4). It is to this figure that the reader is referred when cross-referencing between chronostratigraphical stage names and biostratigraphical zonal subdivisions mentioned in the text. A correlation chart illustrating the varied lithostratigraphy of each palaeogeographical area considered in this volume is presented towards the beginning of each chapter. Note that in each of these charts, the illustrated stratigraphy shows only representative sections of the strata present in each of the areas shown and that the majority of those stratigraphical units recorded are, unless otherwise stated, of formation status.

For further information relating to the geochronometric (radiometric) age data presented in (Figure 1.4), the reader is referred to the recently published review paper by Menning *et al.* (2001).

Rationale for GCR site selection

The Lower Carboniferous GCR sites documented in this volume have been selected in general accordance with the principles of the Geological Conservation Review as outlined by Ellis *et al.* (1996). They therefore include: sites of importance to the international community of Earth scientists (e.g. time interval/boundary stratotypes, type localities for a variety of other geological phenomena, such as rocks and fossils, and historically important sites where, for example, particular geological theories were first established); sites containing exceptional features (e.g. a unique fossil assemblage, reef, deep-water carbonate buildup, palaeokarst, sedimentary structure); and sites of national significance that are representative of a particular geological process, event or feature regarded as fundamental to the understanding of Britain's Earth history (e.g. glacio-eustatic sea-level changes, depositional events, tectonic episodes). An additional and important factor in the site selection process was to choose the minimum number of sites that adequately represent the chronostratigraphical and sedimentary evolution of those clearly defined palaeogeographical areas (sedimentary basins) recognized in the British Lower Carboniferous Subsystem. It is this palaeogeographical framework that provides the structure to this volume. To understand more about how these site selection criteria influenced the choice of sites in each area the reader is referred to the 'GCR site coverage' section in each of the 'Introductions' to the chapters that follow.

The Lower Carboniferous GCR sites were assessed and selected after widespread consultation with subject specialists and after consideration of a list of existing and potential Lower Carboniferous SSSIs compiled by the former Nature Conservancy Council in the late 1970s and the 1980s. The results of this initial review were consolidated by M.A. Whyte (Dinantian of Scotland), P.J. Cossey (Dinantian of northern England and North Wales), M.J. Weedon and V.P. Wright (Dinantian of southern England and South Wales), M.J. Whiteley (Dinantian of Devon and Cornwall) and D. Owen-Roberts (Pendleian and Arnsbergian stages of the Namurian Series).

The documentation and justification relating to the selected sites recorded in this volume has therefore been compiled retrospectively and this has caused some problems. For example, some sites may have deteriorated and features originally used to justify their selection may not be visible at present. In such cases, provided those original features of interest still exist (i.e. the site has not been totally lost) and the site is deemed conservable, the original justification for selection still holds and the site will have been retained. Inevitably, however, there has been some change to the Lower Carboniferous GCR site network as information from new sites of national and/or international significance has come to light, the details of which are documented in the pages that follow.

In this volume, the GCR sites are divided between nine chapters arranged palaeogeographically from north to south. The GCR blocks that are represented are organized into these chapters as follows:

- Dinantian of Scotland — Chapter 2 (Midland Valley Basin);
- Dinantian of northern England and North Wales — Chapter 3 (Northumberland Trough), Chapter 4 (Lake District Block and Alston Block), Chapter 5 (Stainmore Basin and Askrigg Block), Chapter 6 (Craven Basin), Chapter 7 (Derbyshire Platform, North Staffordshire Basin and the Hathern Shelf) and Chapter 8 (North Wales Shelf);
- Dinantian of southern England and South Wales — Chapter 9 (South Wales–Mendip Shelf);
- Dinantian of Devon and Cornwall — Chapter 10 (Culm Trough);
- Namurian (lower part, i.e. Pendleian and Arnsbergian stages only) — spread between all chapters.

Invertebrate fossils in the GCR

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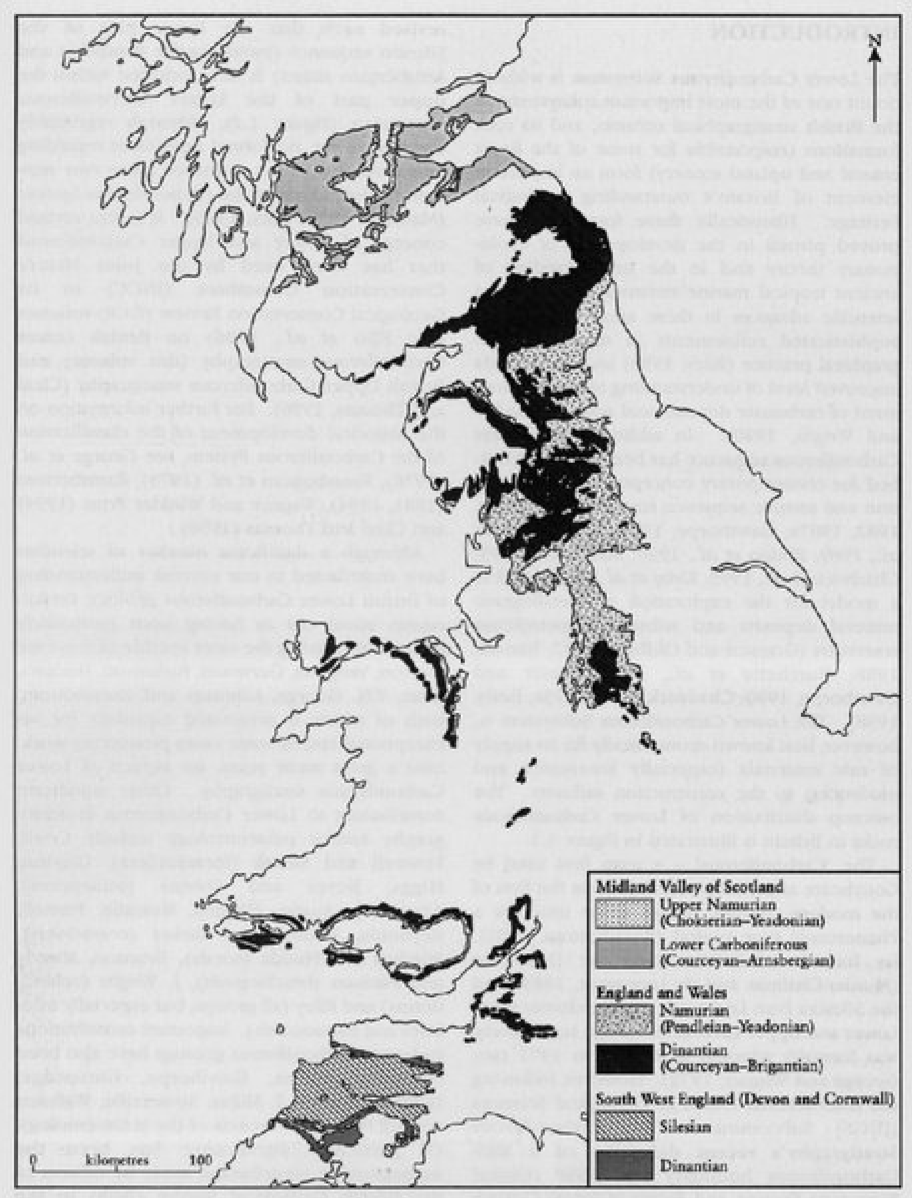
Although the relatively common invertebrate fossils do not have a separate selection category in the GCR in their own right, the scientific importance of many stratigraphy sites lies in their fossil content. Invertebrate fossils are important in stratigraphy because they help to characterize stratal units. In practice, stratigraphy is at its most secure where adequate fossils are found. One of the main tasks of stratigraphers is to determine the relative ages of strata and to compare or correlate them with strata of the same age elsewhere. Fossils have long provided one of the most reliable and accurate means of approaching these problems.

Therefore, some 'stratigraphy' GCR sites are selected specifically for their faunal content, which facilitates stratal correlation and enables the interpretation of the environments in which the animals lived. Other 'stratigraphy' GCR sites are of crucial importance palaeontologically and palaeobiologically, because they yield significant assemblages of invertebrates that provide evidence for past ecosystems and the evolution of life. Moreover, some sites have international significance because they have yielded fossils that are the 'type' material for a species.

In contrast to the manner in which most invertebrate fossils are represented in the GCR, fossils of vertebrates (Benton and Spencer, 1995; Dineley and Metcalf, 1999; Benton *et al.,* in prep.), arthropods (except trilobites) (Palmer *et al*., in prep.) and terrestrial plants (Oeal *et al.,* 2001) do have their own dedicated selection categories, owing to the relative rarity of the fossil material.

References

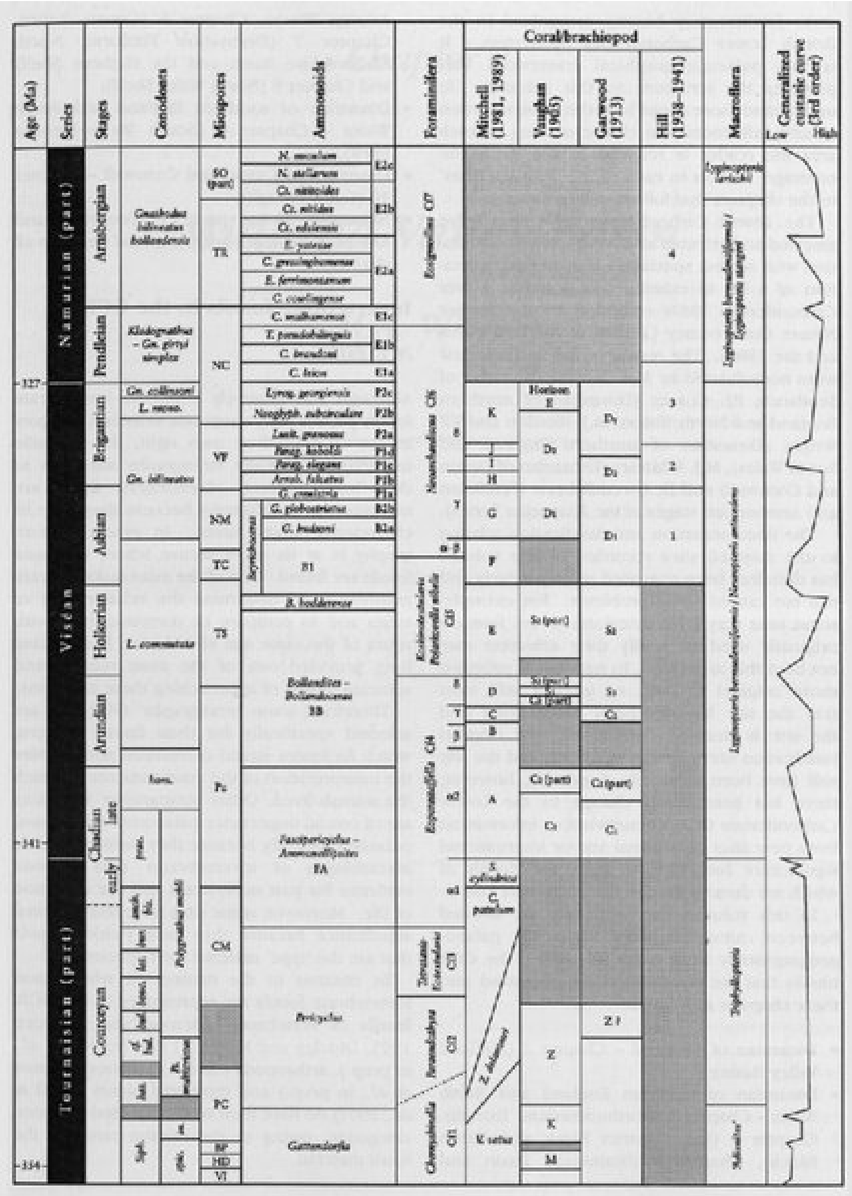


(Figure 1.1) Outcrop map illustrating the distribution of Lower Carboniferous (Dinantian and early Namurian) rocks in Britain. Note that in most areas the position of the Mid-Carboniferous boundary, close to the base of the Chokierian Stage, remains ill-defined and falls within the limits of the Namurian outcrop area. In southwest England, for similar reasons, this boundary falls within the limits of the Silesian outcrop area. Based on various sources and including information from [British] Geological Survey maps of the area (mainly Institute of Geological Sciences, 1979a,b).

System	Subsystem (1972)	Subsystem (proposed)	Series		Stages	Stages (British)
Carboniferous (part)	Silesian (part)	Upper Carboniferous or Pennsylvanian (part)	Bashkirian	Namurian	Chokierian	Chokierian
Carboniferous (part)	Silesian (part)	Lower Carboniferous or Mississippian	Serpukhovian	Namurian	Arnsbergian	Arnsbergian
Carboniferous (part)	Silesian (part)	Lower Carboniferous or Mississippian	Serpukhovian	Namurian	Pendleian	Pendleian
Carboniferous (part)	Dinantian	Lower Carboniferous or Mississippian	Viséan		Warnantian	Brigantian
Carboniferous (part)	Dinantian	Lower Carboniferous or Mississippian	Viséan		Warnantian	Asbian
Carboniferous (part)	Dinantian	Lower Carboniferous or Mississippian	Viséan		Livian	Holkerian
Carboniferous (part)	Dinantian	Lower Carboniferous or Mississippian	Viséan		Moliniacian	Arundian
Carboniferous (part)	Dinantian	Lower Carboniferous or Mississippian	Viséan / Tournaisian		Ivorian	Chadian
Carboniferous (part)	Dinantian	Lower Carboniferous or Mississippian	Tournaisian		Hastarian	Courceyan

(Figure 1.2) Lower Carboniferous chronostratigraphy — the Heerlen Classification. After Metcalfe (1997).

(Figure 1.3) The main structural elements controlling the palaeogeography of Britain during Early Carboniferous times. Note the distribution of the Tweed Basin, Solway Basin and Northumberland Basin which together constitute the Northumberland Trough area as considered in Chapter 3 of this volume. Based, in part, on Johnson (1984), Gawthorpe et al. (1989), Ebdon et al. (1990), Fraser and Gawthorpe (1990), Armstrong and Purnell (1993) and Corfield et al. (1996).



(Figure 1.4) Chronostratigraphical and biostratigraphical classification schemes for the Lower Carboniferous Subsystem. After Riley (1993, fig. 1) with additional information for the Pendleian and Arnsbergian stages supplied by the same author. Absolute age data from Guion et al. (2000) based mainly on information by Lippolt et al. (1984), Hess and Lippolt (1986), Leeder and McMahon (1988) and Claoue-Long et al. (1995). Ammonoid abbreviations used in this figure: N. — Nuculoceras; Ct. — Cravenoceratoides; E. — Eumorphoceras; C. — Cravenoceras; T. — Tumulites; Lyrog. — Lyrogoniatites; Neoglyph. — Neoglyphioceras; Lusit. — Lusitanoceras; Parag. — Paraglyphioceras; Arnsb. — Arnsbergites; G. — Goniatites; B. — Bollandoceras. Conodont abbreviations used: Gn. — Gnathodus; Gn. collinsoni — Gnathodus girtyi collinsoni; L. mono. — Lochriea mononodosa; L. — Lochriea; horn. — Gnathodus homopunctatus; prae. — Mestognathus praebeckmanni; and,. — Scaliognathus anchoralis; bis. — Polygnathus bischoffi; bur. — Eotaphrus burlingtonensis; lat. — Doliognathus latus; bout. — Dollymae. bouckaerti; bul. — Eotaphrus bultyncki; has. — Dollymae bassi; siph. — Siphonodella; Ps. — Pseudopolygnathus; in. — Polygnathus inornatus; spit. — Polygnathus spicatus. Stipple ornament shows interzones (conodonts and miospores) or non-sequences (brachiopods).