Pendle Hill, Lancashire

[SD 781 414]–[SD 774 409], [SD 786 411] and [SD 751 377]

Introduction

The Pendle Hill GCR site report is a composite account of the geology at three GCR sites situated on the western flank of the Pendle Monocline (Figure 6.1), namely Little Mearley-Limekiln, Dinantian [SD 781 414]–[SD 774 409], Little Mearley Clough, Namurian [SD 786 411] and Light Clough, Namurian [SD 751 377]. Together, these sites expose deep-water mudstones, limestones and sandstones spanning an interval that extends from the upper part of the Hodder Mudstone Formation through to the Pendle Grit Formation (Figure 6.2). Along with other sections in the area they formed the basis for Phillips' (1836) terms 'Bolland' and 'Craven Shales'. Later, Hind and Howe (1901) recognized the special importance of these sections, which formed the basis for their now-disused 'Pendleside Series', erected to try to accommodate strata transitional between the 'Mountain Limestone' of Phillips (1836) and the Millstone Grit. The Pendle Hill area provides the type sections for the Pendleside Limestone, Lower Bowland Shale, Upper Bowland Shale and Pendle Grit formations as well as the Pendleside Sandstones Member. It includes some of the classic sections from which Bisat (1928, 1930, 1934, 1950, 1952) and Moore (1930, 1936, 1939, 1946) developed late Viséan and early Namurian ammonoid (goniatite) biostratigraphical schemes. It is also the type area for the Pendleian Stage and includes the stratotypic base and type locality (Light Clough) for the base of the Namurian Series, defined at the first entry point of the ammonoid *Cravenoceras leion* ((Figure 1.4), Chapter 1). Excellent field descriptions relating to the stream and quarry sections represented by the GCR sites in this area are given in the [British] Geological Survey memoir for the area (Earp *et al.,* 1961).

Description

At the base of the succession the Hodderense Limestone Formation (= '*Bollandoceras hodderense* Beds' of Earp *et al.,* 1961) is a widespread and regionally important pelagic cephalopod limestone-shale interval of Holkerian age (Riley, 1990a). The formation averages about 6 m in thickness and comprises limestone beds, typically wackestones and floatstones, with diagenetic nodules giving a blotchy appearance. Nautiloid shells and ammonoids, including the zonal form *B. hodderense,* are typical macrofossils, and these are commonly corroded on their upper surfaces. Trilobites (*Latibole*)*,* bellerophontid gastropods, smooth spiriferoids and the cool-water coral *Rotiphyllum* also occur. Micro-crinoids, ophiuroids and conodonts are abundant in microfossil preparations in some of the interbedded mudstones.

The overlying Pendleside Limestone Formation (early Asbian) has a shaly lower unit termed the 'Rad Brook Mudstone Member', which can be up to 100 m thick. In the lowest 5 m of this unit a widespread marker band contains the dendroid graptolite *Callograptus carboniferus.* The main limestone-dominated interval that forms the upper part of the Pendleside Limestone Formation is about 200 m thick and comprises limestone turbidites and carbonate gravity-flow units, slumps and channels. Limestones in this unit are composed entirely of carbonate debris (e.g. brachiopod and crinoid debris, peloids, ooids, foraminifera and algal fragments), and 'Bouma-type' sequences are well developed in this part of the succession.

The Lower Bowland Shale Formation (late Asbian–Brigantian) overlies the Pendleside Limestone Formation. The best overall section of the Bowland Shales is at Little Mearley Clough (Figure 6.16). This formation, approximately 85 m thick in the Pendle Hill area, comprises dark-grey to black pyritic, organic-rich shales. Another feature of the Bowland Shales is the appearance of several fossil bands or condensate horizons, comprising shell debris of cephalopods and hemipelagic bivalves (*Posidonta*)*,* separated by poorly fossiliferous mudstone intervals. An unusual fossil condensate level (about 10 cm thick), which occurs near the base of the formation, in the *Goniatites hudsoni* Zone (B_{2a}), contains well-preserved examples of the trilobite *Phillibole aprathensis* at all growth stages. A similar bed occurs at this level in Germany (Nicolaus, 1963).

Within the middle of the Lower Bowland Shale Formation is a widespread sandstone, the Pendleside Sandstones Member. Like the Pendleside Limestone Formation, mapping along the Pendle Monocline shows laterally discontinuous packages of decimetre-thick sandstone beds several kilometres wide in this member, separated by ammonoid–bivalve-bearing hemipelagic mudstones. The member thins from approximately 200 m in the northeast of the area to less than 50 m in the southwest. Each sandstone package shows upward bed thickening from centimetre- to metre-scale and the interbedded shales within these packages become increasingly silty and micaceous. In the lower part, 'Bouma-type' structures, soft-sediment deformation, slumps and sole and prod marks are common. These appear to be largely unconfined turbidite deposits. Younger beds are thicker and internally structureless, suggesting more confined mass grain flow. Rare examples of hummocky cross-stratification indicate that storm wave-base had been reached (the first such evidence for significant shallowing in the Clitheroe area since late Tournaisian times). The sand grains are normally fine- to medium-grained in the Pendleside Sandstones Member; however, mudstone rip-up clasts and occasional siderite pebbles demonstrate that the sand grains reflect the sorting of the source supply rather than grain sorting during transport in the turbidite system. Some beds contain crinoid sand and rhynchonellid brachiopod debris, but the dominant fossil content in most beds is plant debris, particularly calamitids. Approximately 27 m stratigraphically above the Pendleside Sandstones Member, the highest Viséan ammonoid band, that of *Lyrogontatites georgiensis* (P_{2c}), of typical 'Namurian style' is separated from the basal Namurian, Cravenoceras lelon Marine Band (E_{la}l) by fissile pyritic mudstones (*c.* 3 m) which lack a marine macro-fauna.

The section at Little Mearley Clough (Figure 6.16) shows a virtually continuous and well-exposed section through the lower part of the Pendleian Stage from the Upper Bowland Shale Formation to the Pendle Grit Formation, but a small normal fault cuts out the basal Namurian sequence, hence the basal boundary stratotype for the Namurian Series is defined at Light Clough, the type locality of *C. leion.* This section also extends into the Pendle Grit Formation. The Upper Bowiand Shale Formation is more fissile and platy than the Lower Bowland Shale Formation. Several closely spaced ammonoid bands occur through the E_{1a} and E_{1b} ammonoid zones, with the bivalve *Posidonia membranacea* being typically most conspicuous in scree. Only one marine band (*C. malhamense*)is present in the E_{1c} Zone, above which sandstone turbidites of the Pendle Grit Formation resume, starting with centimetre-scale graded beds with 'Bouma-type' internal bedding and basal-bed prod (mainly from plant 'bounces') and scour marks. These beds thicken upwards from centimetre- to metre-scale bed thicknesses at the expense of hemipelagic mudstone. Unlike the Pendleside Sandstones Member, the Pendle Grit Formation becomes increasingly pebbly upwards, with quartz and feldspar pebbles in excess of 1 cm diameter commonly present in scour and channel bases, denoting erosion from a metamorphic-granitic hinterland. This is typical of the Millstone Grit and a feature of many sandstones in the Namurian Series. At the top of the Pendle Grit is a sandstone silcrete palaeosol (ganister), clasts of which, containing rootlets, can be found loose in the brash underlying peat between the head of Little Mearley Clough and Ogden Clough. The highest beds of the Pendle Grit are fluvial in origin.

Interpretation

The Hodderense Limestone Formation formed during Holkerian times when sea levels were high and the Craven Basin was starved of terrigenous sediment (Riley, 1990a). It represents a classic example of a pelagic limestone; a lithofacies well known from Palaeozoic to mid-Mesozoic deep-water sequences, prior to the evolutionary appearance of calcareous plankton in mid-Jurassic times.

The Pendleside Limestone Formation represents one of the best examples of a deep-water carbonate turbidite system in Britain. Channel and fan morphologies can be recognized at several scales, from kilometre-scale fan systems seen along the Pendle Monocline (as illustrated on [British] Geological Survey maps of the area; Institute of Geological Sciences, 1975a) shaling out from north-east to southwest, to small-scale channels (e.g. at Limekiln Clough). The carbonate debris in these beds is derived from a variety of platform environments developed during late Holkerian and Asbian times at the basin margins (Askrigg Block and Central Lancashire High). The lack of accommodation space on these platforms caused their carbonate production to be exported into the basin. Frequent glacio-eustatic sea-level change was the main cause of the transition from ramps (with ample accommodation space) in Holkerian times, to platforms (with limited accommodation space) in Asbian times.

The onset of the deposition of the Bowland Shales (late Asbian–Pendleian) marked a significant change in marine chemistry, and specifically the change from mainly dysoxic to predominantly anoxic conditions at the sediment surface.

Consequently these beds are less bioturbated and more organic rich than the underlying formations (i.e. the Bowland Shales are oil shales). This is in common with some other deep-water sections at this time (e.g. Antler Foreland Basin, Utah, USA; Titus and Riley, 1997). Their development denotes intense stratification of the water column and isolation of the deep basinal water. This was probably a response to climate and ocean circulation change as the Carboniferous glaciation intensified, and was further enhanced in the Craven Basin by the appearance of microbial reefs during Asbian and early Brigantian times, which fringed the surrounding carbonate platforms and restricted the gravitational flow of oxygenated water and carbonate detritus into the basin from the platform interiors. The fossil bands of the Bowland Shales are the forerunners of the marine bands so typical of Namurian rocks and represent marine highstand deposits formed during interglacial periods.

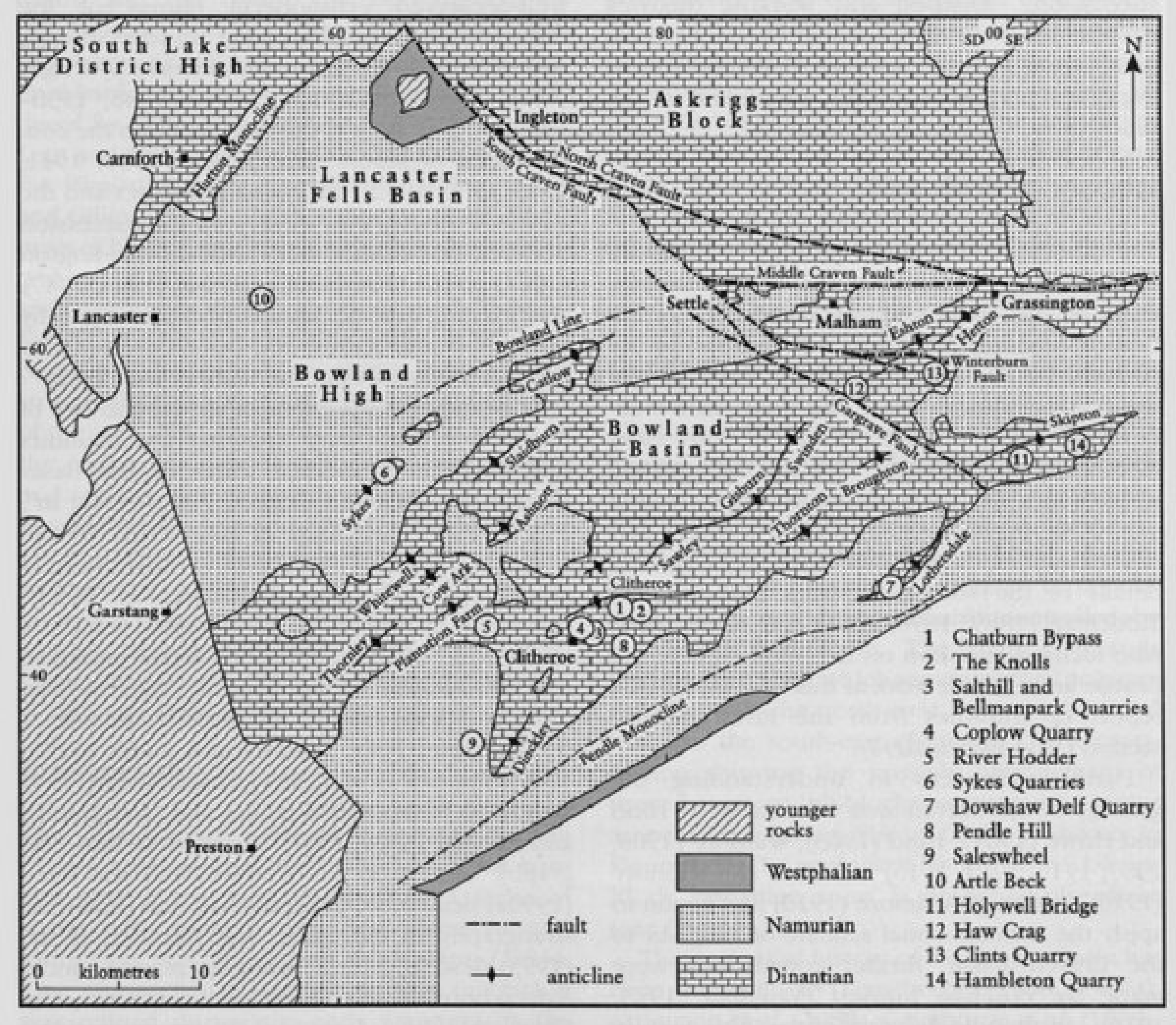
The Pendleside Sandstones Member (mainly mid-Brigantian) most probably represents a series of vertically and laterally stacked, lowstand, forced regression, turbidite lobes fed by fluvial and coastal processes associated with the Askrigg Block and South Lake District High during lowstand emergence; the hemipelagic mudstones, present between the sandstone packages, representing highstand. By late Brigantian times (P_{2b} ammonoid zone) sandstone supply had largely ceased allowing further deposition of hemipelagic mudstones (Lower Bowland Shale and Upper Bowland Shale formations) into Pendleian times.

The Pendle Grit Formation represents the first major influx of 'Millstone Grit' into the Central Pennine Basin. It represents a turbidite-fronted delta system. Brandon *et* al. (1995) demonstrated that the Pendle Grit was fed by a fluvial system preserved on the Askrigg Block as the Bearing Grit. Hitherto this source was unrecognized, within a broader definition of the Grassington Grit. The presence of a palaeosol at the top of the formation provides the first evidence of subaerial emergence in the region since Tournaisian times and represents temporary filling of the basin to base level during eustatic fall and copious sediment supply in mid-E_{1c} times.

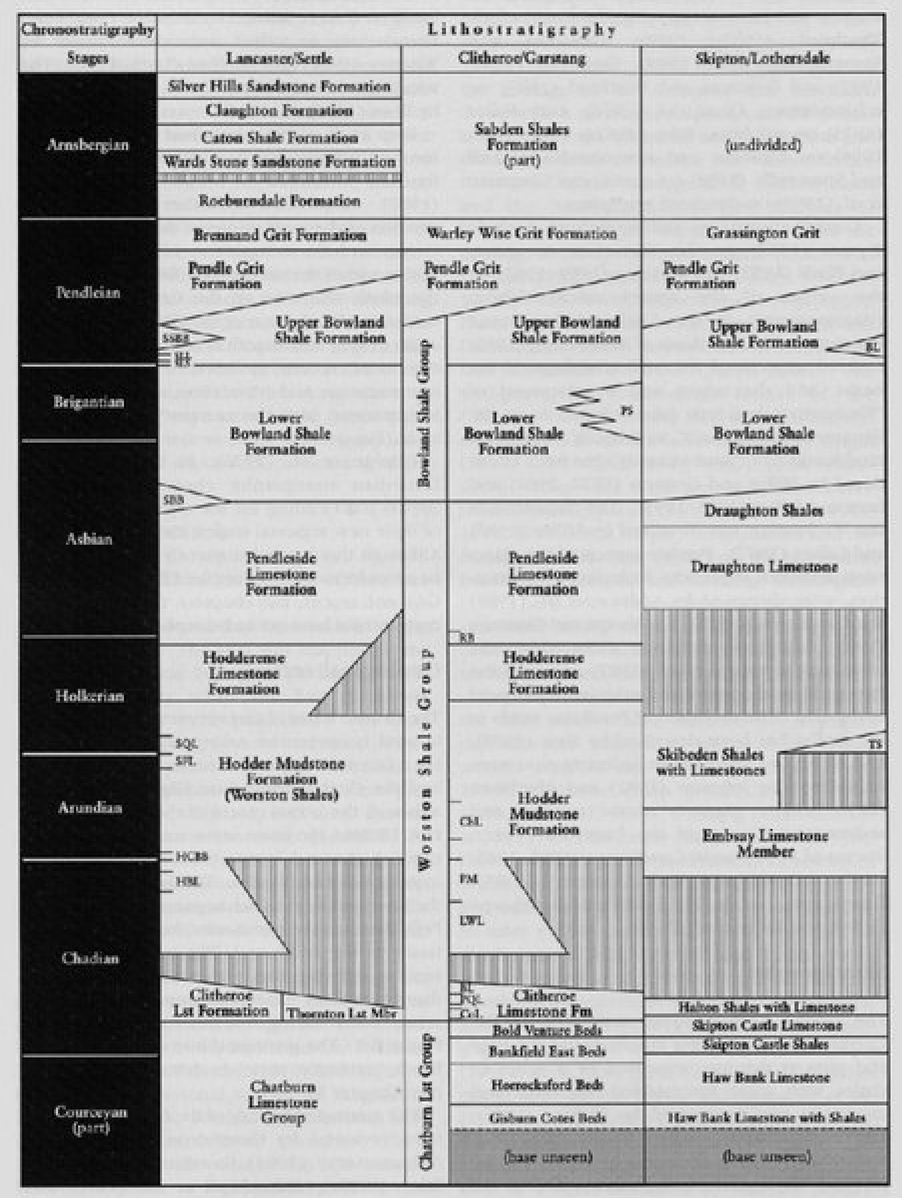
Conclusions

Pendle Hill is of international importance as it provides the type ammonoid biostratigraphy of western Europe for late Viséan and early Namurian times, with many ammonoid type specimens described from stream sections along the flanks of the hill. It is also the type area in which the base of the Namurian Series is defined. The site also shows a variety of turbidite systems, fed from both limestone and clastic environments. The effects of glacially controlled sea-level changes on the sedimentary environments and faunas in equatorial deep-water marine basins can also be seen. The appearance of Millstone Grit is earlier than farther south, such as in Derbyshire, demonstrating that this facies was fed by rivers to the north. The Bowland Shales are excellent source rocks for hydrocarbons, which have accumulated in oil and gas fields to the west, under the Irish Sea.

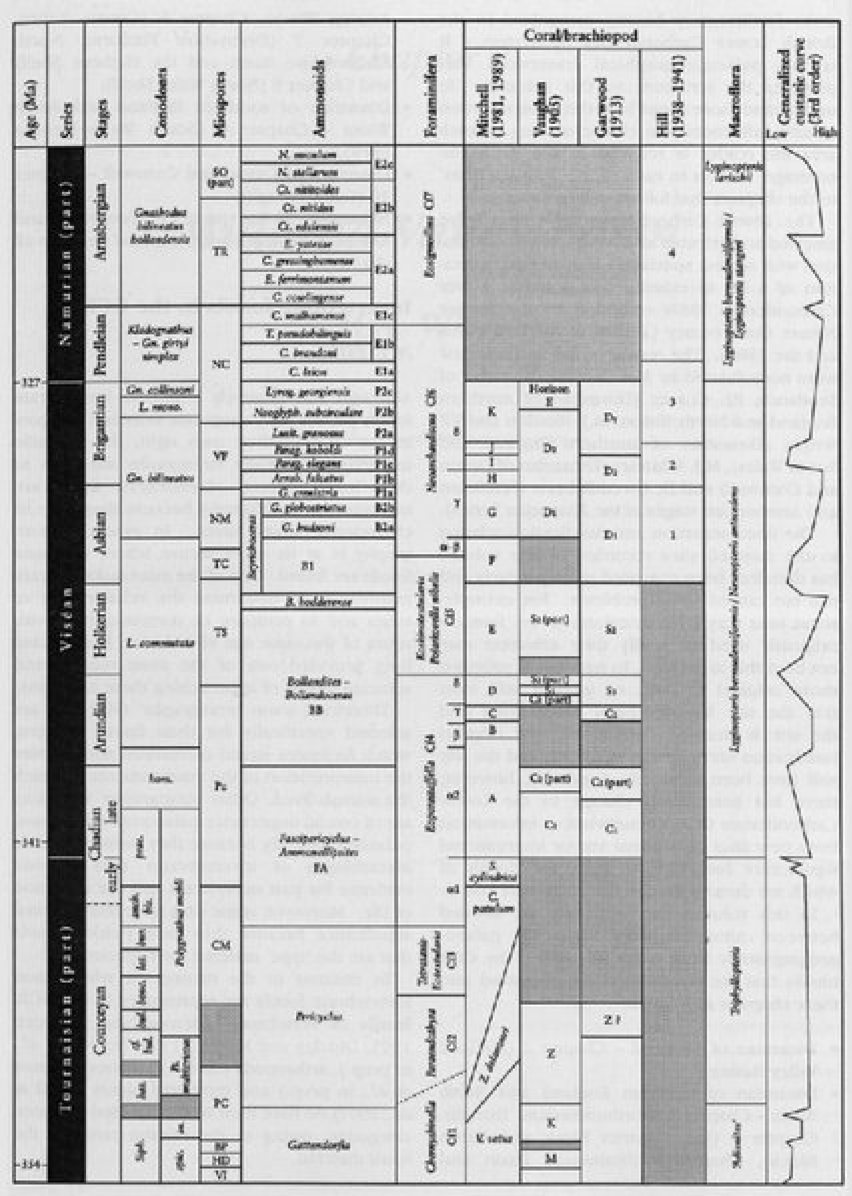
References



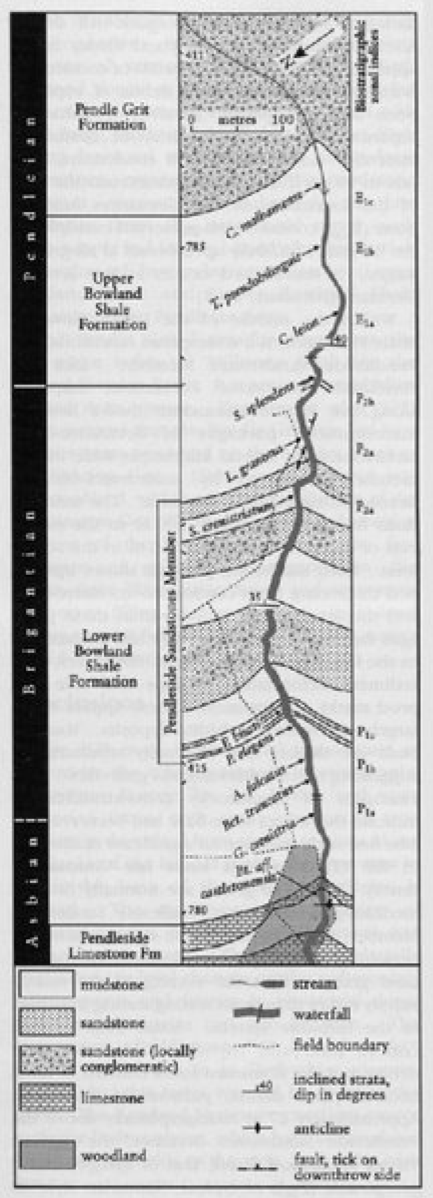
(Figure 6.1) Geological map of the Craven Basin illustrating the distribution of Carboniferous outcrops and the locations of GCR sites described in the text. Note that in the Bowland Basin area, the hinge traces of major folds within the Ribblesdale Fold Belt are also shown. The Central Lancashire High lies to the south of the Pendle Monocline beneath the area obscured by the key. Based on Riley (1990a) and Brandon et al. (1998).



(Figure 6.2) Simplified stratigraphical chart for the Lower Carboniferous succession of the Craven Basin. (HBL — Hetton Beck Limestone Member; HCBB Haw Crag Boulder Bed; SFL — Scaleber Force Limestone Member; SQL — Scaleber Quarry Limestone Member; SBB — Scaleber Boulder Bed; SLS — Sugar Loaf Shales; SLL — Sugar Loaf Limestone; SSBB School Share Boulder Bed; CoL — Coplow Limestone Member; PQL — Peach Quarry Limestone Member; BL — Bellman Limestone Member; LWL — Limekiln Wood Limestone Member; PM — Phynis Mudstone Member; ChL — Chaigley Limestone Member; FIB — Rad Brook Mudstone Member; PS — Pendleside Sandstones Member; TS — Twiston Sandstone Member; BL — Berwick Limestone.) Areas of vertical ruling indicate non-sequences. Not to scale. Compilation based on Hudson and Mitchell (1937), Metcalfe (1981), Arthurton et al. (1988), British Geological Survey (1989), Riley (1990a, 1995), Aitkenhead et al. (1992), Brandon et al. (1995, 1998).



(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).



(Figure 6.16) Geological map and stratigraphy of Lower Carboniferous (Asbian–Pendleian) strata at Little Mearley Clough showing the position of key ammonoid horizons referred to in the text. After Earp et al. (1961). C. — Cravenoceras; T. — Tumilites; S. — Sudeticeras; L. — Lusitanoceras; P. — Paragoniatites; A. — Arnsbergites; Bct. — Beyrichoceratoides; G. — Goniatites; Bt. — Bollandites.