Chapter 2 Charnwood Forest

Introduction

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The scattered Precambrian inliers of Charnwood Forest together constitute one of the larger basement occurrences in England. The simple structure, involving broad anticlinal folding of the sequence, has brought to crop about 3.5 km of strata and revealed what is arguably one of the most extensive and continuous sequences through a subaqueous volcaniclastic succession to be found anywhere in Britain. Although this region has long been a classic area for Precambrian geology, its importance for regional stratigraphical studies has been underlined by recent advances showing that part of the succession may be Cambrian in age.

Previous workers recognized that the complex Precambrian outcrop patterns ((Figure 2.1), inset) are due to the partial exhumation of a buried mountainous topography dating to early Triassic times (Watts, 1903; Bosworth, 1912). This process has contributed to the distinctive modern landscape of Charnwood Forest and produced many spectacular sections through the Precambrian–Triassic unconformity in quarries, but its unfortunate legacy is that natural Precambrian rock exposure has been restricted to small craggy knolls. Despite these problems, and a widespread Quaternary cover, geological mapping over the years (e.g. Watts, 1947; Moseley, 1979; Worssam and Old, 1988; Carney, 1994) has resulted in a detailed subdivision of the Precambrian rocks and structures affecting them, as portrayed in (Figure 2.1).

Publications on the basement rocks of Charnwood Forest extend back over two centuries, and the region has long been important to the development of many scientific issues related to English basement geology and the recognition of ancient volcanic sequences, as summarized by Watts (1947) and Ford (1979). The culmination of this research is a stratigraphical hierarchy formalized by Moseley (1979) and Moseley and Ford (1985). In their scheme the bedded volcaniclastic rocks are collectively termed the Charnian Supergroup and this in turn is subdivided into the major groupings shown in (Figure 2.1).

The eight stratigraphical GCR sites, featured in (Figure 2.1), are chosen to represent as much of the Charnian succession as possible, and to show the wide variety of lithologies and environments involved in its evolution. It should be noted that the Brand Group, at the top of the sequence, is now considered to be at least in part Lower Cambrian. Consequently the GCR sites that mainly portray it (Stable Pit and 'The Brand') have been placed within a separate chapter (9) devoted to rocks of probable Lower Palaeozoic age. One of the outstanding features contributing to the international geological importance of Charnwood Forest is the preservation on bedding planes of Precambrian fossil impressions; six palaeontological localities have been discovered, and are described in Chapter 8.

Clues to the ultimate origin of the magmas that built up the Charnian sequence are provided by major and trace element geochemical data for the Charnian Supergroup and its associated volcanic complexes, as summarized by Pharaoh *et al.* (1987b). The rocks are characterized by high contents of Large Ion Lithophile (LIL) trace elements (e.g. K, Rb and Ba) combined with High Field Strength (HFS) element abundances (e.g. Zr, Hf, Y and Yb) that are well below values for mid-ocean-ridge basalt (MORB). They therefore have calc-alkaline attributes, as previously recognized by Thorpe (1974) and Le Bas (1982), which in turn indicates that the parental magmas were of volcanic arc type, generated in a subduction zone setting. Similar values for the HFS elements characterize magmas supplying modern volcanic arcs of very primitive type, suggesting that the Charnian Supergroup was originally founded upon oceanic crust or highly attenuated continental crust.

Cessation of Charnian volcanism was followed by two intrusive episodes. The first of these involved the emplacement of the North Charnwood Diorites and the second and final phase, the South Charnwood Diorites (terminology of Worssam and Old, 1988). The former intrusions are geochemically indistinguishable from the extrusive Charnian rocks, although they are generally of more basic composition. By contrast, the South Charnwood Diorites, locally known as 'markfieldite', are distinctive on account of their granophyric textures and geochemistry. Pharaoh *et al.* (1987b) note that in comparison with the earlier Charnian rocks, the South Charnwood Diorites are highly enriched in LIL elements, particularly K, plus Ce and P. However, Nb, Ta and other HFS elements remain below MORB values except in the most evolved samples. Such features indicate that the diorite magmas belong to the high-K calc-alkaline series and were emplaced at a time when the Charnian arc had achieved greater maturity and was floored by thickened crust (Pharaoh *et al.,* 1987b).

The distinctive geochemical signature of the Charnwood basement rocks is one of the principal reasons for equating them with the Precambrian occurrences of the Nuneaton inlier, described in Chapter 3 (Carney and Pharaoh, 1993; Bridge *et at.,* 1998). The relevant geochemical comparisons that can be drawn between the two occurrences have considerable implications for regional geology They extend the distribution of 'Charnian' type rocks for at least 20 km to the south-west, and support the hypothesis of a 'Charnwood Terrane' (Chapter 1), whose distribution is shown in (Figure 1.1). This forms one element of the collage of diverse volcanic and metamorphic terranes that comprises the Precambrian basement of England and Wales (see Chapter 1).

Chemical comparisons that have been made between the South Charnwood Diorites and the granophyric diorite intrusion exposed at the Judkins' Quarry GCR site, Nuneaton (Chapter 3), are especially significant to the age of Charnian magmatism since they are supported by ϵNd(t) isotope evidence that the Nuneaton granophyric diorite and South Charnwood Diorites were both generated at the same point in time (McIlroy *et al.,* 1998). This is a critical observation because the Nuneaton granophyric diorite, with a U-Pb age of 603 ± 2 Ma (Tucker and Pharaoh, 1991) is the only outcropping Precambrian rock that has been precisely dated in this part of England.

Direct radiometric age determinations have been conducted on Charnwood Forest rocks but the techniques so far used have yielded ambiguous results (see reviews in Worssam and Old, 1988; Moseley and Ford, 1985; Sutherland *et al.,* 1994). A suite of K-Ar determinations (Meneisy and Miller, 1963) has given values ranging widely between 684 ± 29 and 260 ± 15 Ma, which must in part reflect the complex Palaeozoic deformational history of this region. A late Neoproterozoic Rb-Sr age of 552 Ma was obtained on a sample from the South Charnwood Diorites, but had a large error range of ± 58 Ma rendering the result uninterpretable (Cribb, 1975). Other criteria normally regarded as reliable for determining age are currently controversial. For example, the Charnian Precambrian fossil assemblage has been equated with Ediacara-type faunas that in other parts of the world are considered to be no older than 580 Ma (e.g. Bowring *et al.,* 1993; McIlroy *et al.,* 1998). At the Cliffe Hill GCR site, fossil-bearing Charnian strata are intruded by the South Charnwood Diorites, but if these intrusions are indeed equivalents of the Nuneaton granophyric diorite (see above) the latter's radiometric age would make the Charnian faunas older than the Ediacaran by at least 20 million years.

Within the Caledonide orogenic belt to the north-east of Charnwood Forest, concealed Precambrian volcanic rocks were proved in the Orton and Glinton boreholes, between Leicestershire and Norfolk. These rocks were dated by the U-Pb method at 612 and 616 Ma by Noble *et al.* (1993, and (Figure 1.2)). Their chemical compositions suggest they may not be precise equivalents of the Charnian Supergroup, but may instead constitute part of a separate Precambrian volcanic arc system, the Fenland Terrane shown in (Figure 1.1), to the east of the Charnwood Terrane.

An episode of Precambrian folding has been detected at the Cliffe Hill Quarry GCR site, intervening between deposition of the Charnian Supergroup and intrusion of the South Charnwood Diorites. An entirely unrelated deformation was responsible for the anticlinal structure of the Charnian Supergroup (Figure 2.1) and the penetrative cleavage that affects it. This cleavage is steeply dipping, with NW–SE to WNW–ESE orientations, and is an essential fabric element accentuated in the finer-grained rocks of the Charnian Supergroup but also present in many of the massive pyroclastic rocks and intrusions. The possibility that this cleavage is structurally related to the main Charnian anticline has been hotly debated in the past. Watts (1947) believed that the cleavage was Precambrian (Neoproterozoic), although formed after the anticlinal fold. On the other hand, Jones (1927) suggested a Caledonian age for the cleavage, implying that it was not related to Charnian folding. Evans (1963) disagreed, observing that even though the cleavage apparently cuts across the main Charnian fold axis, this did not rule out contemporaneity between the two types of structure. Nowadays such a relationship is referred to as cleavage-fold transection, and is commonly observed in orogenic terranes where lateral movements have accompanied compression (e.g. Soper *et al.,* 1987). The anticlockwise-transecting cleavage geometry of Charnwood Forest was described in some detail by Moseley (1979) and has been recognized by measurements taken on outcrops at the Bradgate Park GCR site. To determine the cleavage age, tectonic mica fabrics were sampled from several exposures, including those at 'The Brand' GCR site, and analysed for their $^{40}Ar/^{39}Ar$ ratios. The results have been combined statistically to give an age indicating that the deformation occurred during the Acadian (Siluro-Devonian) orogenic event that affected much of the basement of central England (BGS, unpublished data).

The metamorphic grade of the cleavage-forming recrystallization event has been estimated from XRD techniques used to determine the Kubler indices of white mica (illite) crystallinity; the values obtained, mainly grouped between 0.15 and 0.24, are indicative of epizonal (greenschist facies) metamorphic conditions (Merriman and Kemp, 1997). In thin sections of finer-grained rocks, this fabric consists of well-crystallized, oriented intergrowths of white mica and chlorite that are largely of tectonic origin. Because of this metamorphism, most Charnian lithologies should be prefixed with the term 'meta'. To prevent tiresome repetition of the same letter strings, however, this practice will not be followed here.

Charnian Supergroup

The Charnian Supergroup currently includes the three main groupings established by Moseley and Ford (1985), as shown in (Figure 2.1). However, the Precambrian affinity of the youngest division, the Brand Group, is now doubted and it may possibly be Lower Cambrian in age (Bland, 1994; Bland and Goldring, 1995). The ramifications for Charnian stratigraphy are that parts of the Brand Group, perhaps even the whole of this division, may eventually be excluded from the Charnian Supergroup, if this term is to be restricted only to the Precambrian part of the sequence. In this volume, two of the former Charnwood GCR sites (Stable Pit and Brand Hills), now possibly containing Lower Cambrian rocks, are described in a separate chapter (9). Their stratigraphical context is discussed further in the *British Cambrian to Ordovician Stratigraphy* GCR volume (Rushton *et al.,* 1999).

The mode of formation of the Charnian rocks, and their tectonic setting, can be partly deduced from their geochemical attributes, which have already been summarized. These show that the parental magmas were calc-alkaline and similar to those of modern evolved volcanic arcs founded upon oceanic or attenuated continental crust. Many modern intra-oceanic arc systems are largely submerged, and consequently it is the fragmental material, either eroded or ejected from the volcanic axis, that is the most likely to be preserved in the depositional basins that surround the arc. This explains why the Charnian Supergroup is mainly composed of well-stratified volcaniclastic lithologies (terminology of Fisher and Schmincke, 1984; see (Table 1) in the Glossary, in the present volume), as exemplified, for example, at the Morley Quarry, Outwoods–Hangingstone Hills and Bradgate Park GCR sites. Such strata contain varying proportions of epiclastic material (derived from erosion) and pyroclastic constituents (derived directly from volcanic eruptions), with an important pyroclastic component in the Maplewell Group (Moseley and Ford, 1989), particularly the Beacon Hill Formation exposed at the Beacon Hill GCR site. The Beacon Hill Formation is replaced to the north-west by the Charnwood Lodge Volcanic Formation (Figure 2.1); that unit is dominated by coarse-grained, block-rich lithologies, seen at the Warren Hills and Charnwood Lodge GCR site, and is interpreted as part of a volcaniclastic apron to local volcanic centres (Carney, 2000). Magmatic source regions in this north western part of the Charnian Supergroup are represented by lithologies interpreted as shallow-level intrusions occurring in close proximity to the Charnwood Lodge Formation. These assemblages cannot be subdivided lithostratigraphically and are known as the Bardon and Whitwick volcanic complexes (Moseley and Ford, 1985; Carney, 1999), the former exposed at the Bardon Hill GCR site.

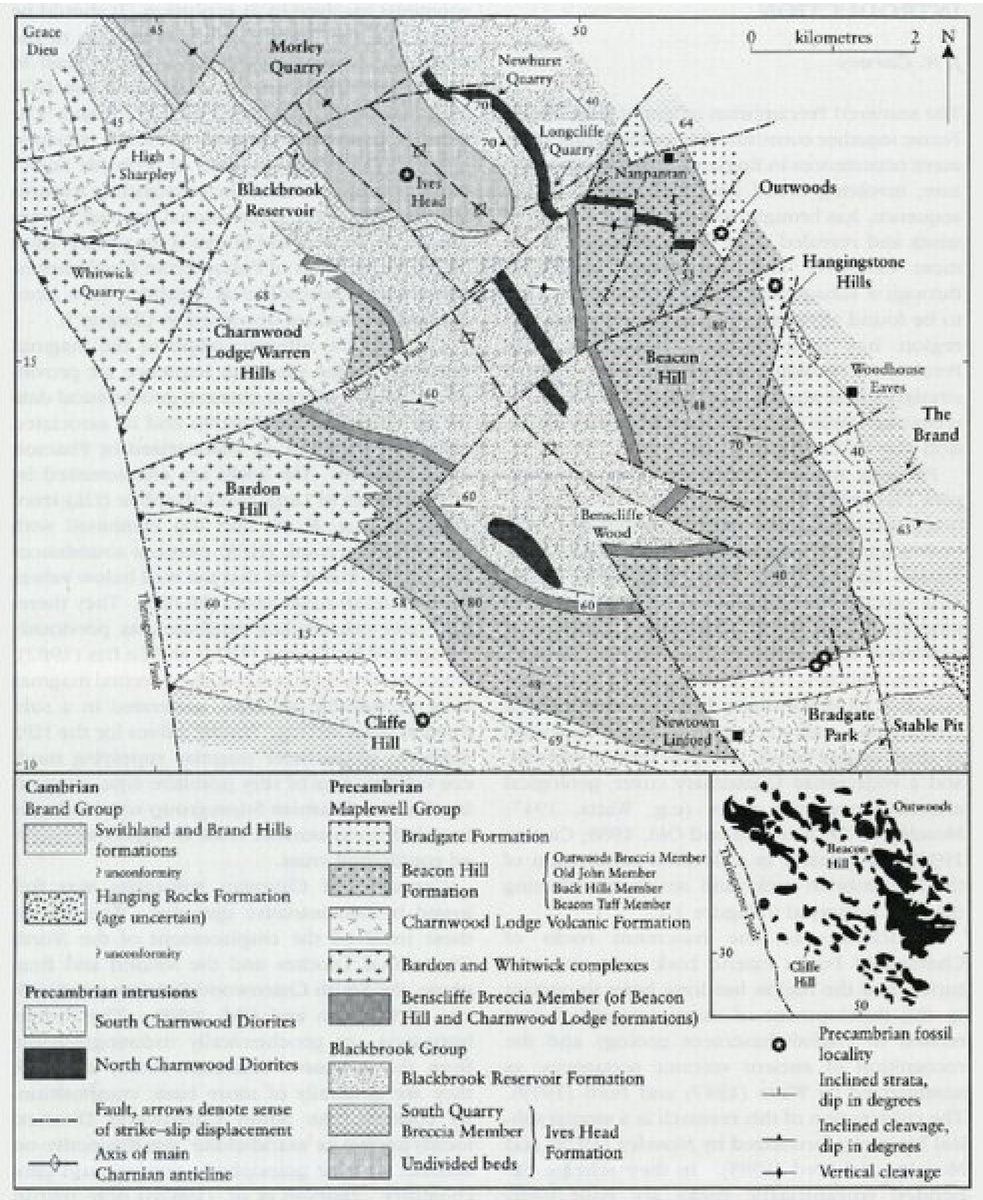
The volcaniclastic beds of the Charnian Supergroup show a general absence of well-organized sedimentary structures, such as cross-bedding, which may be indicative of tidal reworking at shallow depths. Wave ripples, tentatively identified only at the Beacon Hill GCR site, could nevertheless suggest rare episodes of shoaling to depths above those appropriate to the limit of wave influence (i.e. above storm-wave base). It is further possible that some of the parallel-laminated sandy strata were storm-deposited, again suggesting the possiblity of a nearshore influence. On the other hand, relatively deep-water, offshore environments are more in keeping with sedimentary structures such as grading, slump-folding and various other types of soft-sediment deformation. These features suggest deposition from debris flows, pyroclastic flows and turbidity currents triggered by instability on the more distant, and shallower, flanks of basins marginal to the active volcanoes. In such environments the Charnian Ediacaran fauna evidently thrived and was at times preserved on the bedding planes of the finer-grained lithologies (Chapter 8).

North and South Charnwood Diorites

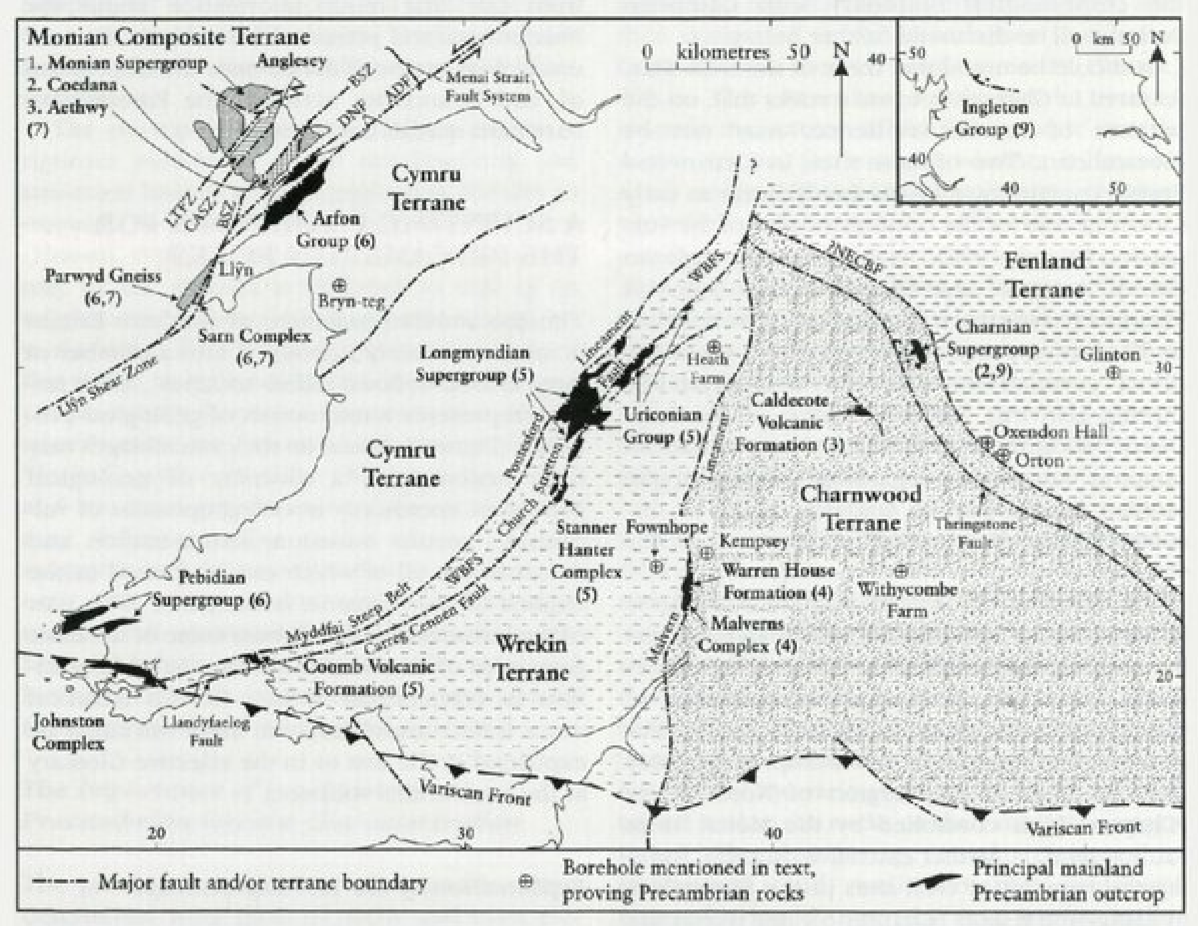
Two suites of intrusions (Figure 2.1), distinct from each other in petrography and chemistry, represent the final Charnian magmatic phases. The North Charnwood Diorites form sub-vertical sheets up to 60 m thick consisting of medium- to coarse-grained diorite with subordinately developed granophyric textures. They are not represented at any of the GCR sites, but are geochemically equivalent to the narrower and finer-grained sheets of basaltic-andesite described in Boon's and Judkins' quarries at Nuneaton (Bridge *et al.,* 1998).

The coarser-grained, granophyric-textured diorites of southern Charnwood Forest were termed 'markfieldite' by Hatch (1909) but Wills and Shotton (1934) preferred 'granophyric diorite' as the more accurate name. Nowadays they are placed within a 'South Charnwood Diorite' association of intrusions, which are more leucocratic, contain visible quartz, and are less sheared than the North Charnwood Diorites (Worssam and Old, 1988). The South Charnwood Diorites represent the youngest magmatic phase and, as discussed above, they are geochemically comparable to the granophyric diorite at Nuneaton that has been dated at 603 ± 2 Ma. It has commonly been assumed that these intrusions were emplaced into all parts of the Charnian Supergroup. However, the youngest definite intrusive contacts are against strata equated with the Bradgate Formation of the Maplewell Group, as described at the Cliffe Hill Quarry GCR site. The South Charnwood Diorites have not been proved to cut the stratigraphically highest beds of the Charnian Supergroup, and as noted by McIlroy *et al.* (1998), the Brand Group strata contain granophyre pebbles that are geochemically and petrographically identical to the South Charnwood Diorites (see Chapter 9). Erosional unroofing of these intrusions prior to deposition of the Brand Hills and Swithland formations would be compatible with the Lower Cambrian age recently proposed for those units.

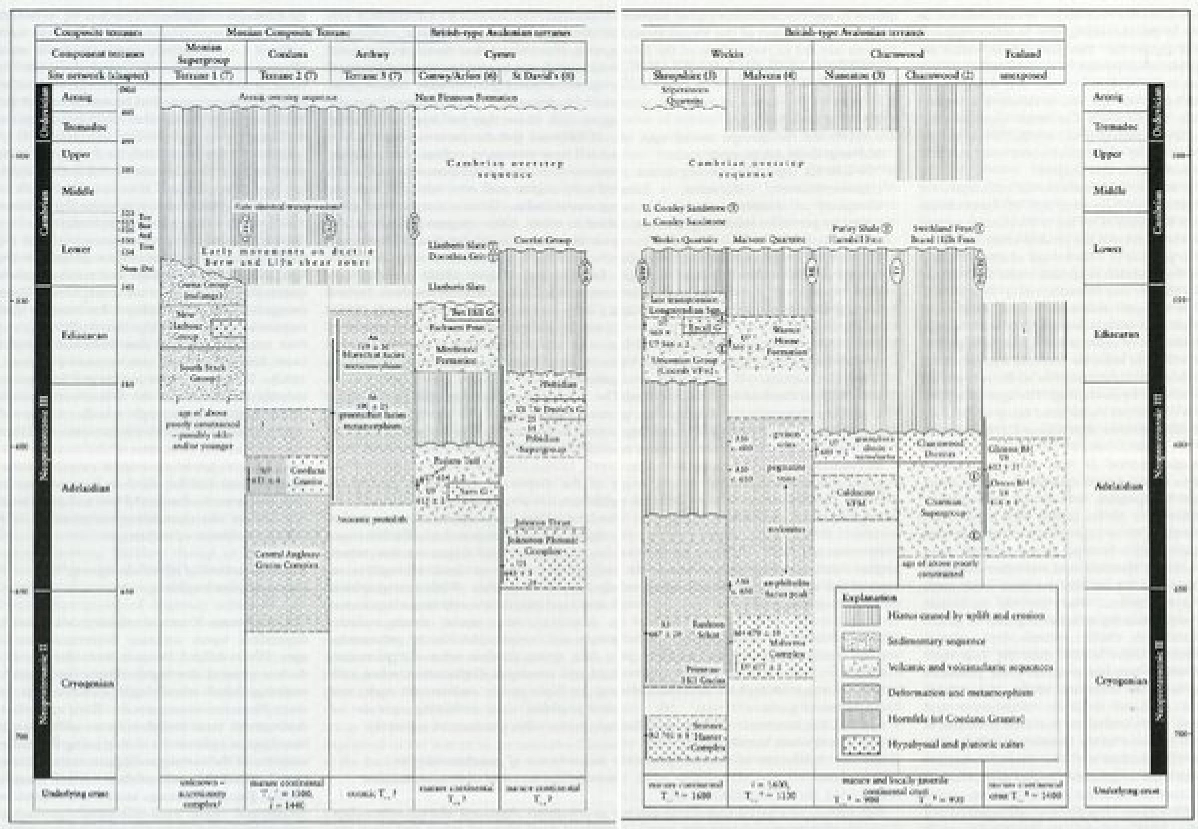
References



(Figure 2.1) Geological map of Precambrian and Cambrian rocks in Charnwood Forest, showing the locations of the GCR sites (in bold lettering). Note that younger rocks are omitted for clarity. The inset shows the actual extent of the 'basement' inliers (dark shading) between this younger cover. The latter mainly consists of Triassic strata, with Coal Measures included to the west of the Thringstone Fault; extensive veneers of Quaternary drift are also present (modified from Worssam and Old, 1988).



(Figure 1.1) Sketch map showing the distribution of Precambrian outcrop, and boreholes proving Precambrian rocks, in southern Britain. Note that the outcrops are labelled with the names of the principal geological units, followed by numbers (in brackets) of the chapters for the relevant GCR sites. Terrane boundaries are slightly modified after British Geological Survey (1996); Myddfai Steep Belt after Woodcock (1984a); Monian Composite Terrane after Gibbons and Horák (1990). Key: ADF, Aber-Dinlle Fault; BSZ, Berw Shear Zone; CASZ, Central Anglesey Shear Zone; DNF, Dinorwic Fault; LTFZ, Llyn Traffwll Fault Zone; ?NECBF, postulated NE Charnwood Boundary Fault. The boundary of the Midlands Microcraton basement domain is outlined by the NECBF and Pontesford-Myddfai lineament systems; WBFS, Welsh Borderland Fault System.



(Figure 1.2) Correlation chart for the late Neoproterozoic history of southern Britain. Key: A, ^{40}Ar–^{39}Ar age; M, U-Pb monazite age; R, Rb-Sr whole-rock isochron age; U, U-Pb zircon age; T_{DM}, Depleted mantle Sm-Nd age; i, inherited zircons. Key to faunas; (E) Ediacaran fossils; (T) Teichichnus trace fossils. Key to horizontal boundaries; continuous line, conformable stratigraphy; wavy line, unconformity; dashed T line, tectonic contact; dashed line, nature of contact uncertain. Terrane boundaries: BSZ, Berw Shear Zone; CASZ, Central Anglesey Shear Zone; LTFZ, Ll■n Traffwll Fault Zone; ML, Malvern Lineament; MSFS, Menai Strait Fault System; ?NECBF, postulated NE Charnwood Boundary Fault; TF, Thringstone Fault;WBFS, Pontesford Lineament of Welsh Borderland Fault System. Literature sources: 1, Patchett and Jocelyn (1979); 2, Patchett et al., (1980); 3, Beckinsale et al., (1984); 4, Thorpe et al., (1984); 5, Davies et al., (1985); 6, Dallmeyer and Gibbons (1987); 7, Tucker and Pharaoh (1991); 8, Noble et al., (1993); 9, Horák et al., (1996); 10, Strachan et al., (1996). Stratigraphical data for Lower Cambrian sequence, and fossil occurrences after McIlroy et al., (1998): nem-Dal, Nemakit-Daldynian; Tom, Tommotian; Atd, Atdabanian; Bot, Botomian; Toy, Toyonian.

Grain size (mm)	SEDIMENTARY ROCKS		VOLCANICLASTIC ROCKS Epiclastic (25-75% pyroclasts)	Pyroclastic (>75% pyroclasts)		IGNEOUS ROCKS
256	*CONGLOMERATE* And *BRECCIA*		*VOLCANICLASTIC CONGLOMERATE, BRECCIA, GRANULESTONE* etc.	Bombs … *AGGLOMERATE* Blocks… *VOLCANIC BRECCIA*		Very coarse-grained
64						
16				*LAPILLI TUFF*		
2	*GRANULESTONE*					Coarse-grained
1-2	Very coarse-					
1-0.5	Coarse-					Medium-grained
0.25-0.5	Medium-	*SANDSTONE*	*TUFFACEOUS SANDSTONE*			
0.125-0.25	Fine-		(coarse, medium, fine etc)	Coarse	*TUFF*	
0.032-0.125	Very fine- grained					Fine-grained
0.004-0.032	*SILTSTONE*		*TUFFACEOUS SILTSTONE*			Very fine-grained
<0.004	*MUDSTONE*		*TUFFACEOUS MUDSTONE*	Fine		Cryptocrystalline

(Table 1) A simplified comparative grain-size and grain-compositional chart for sedimentary, volcaniclastic and igneous rock types. The volcaniclastic rock classification is modified from Fisher (1961) and Fisher and Schmincke (1984).