Chapter 7 Carboniferous and Permian igneous rocks of central England and the Welsh Borderland

Introduction

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Carboniferous intrusive and extrusive rocks crop out in a number of relatively small and isolated centres in the Derbyshire Peak District, the Black Country of the West Midlands, the Welsh Borderlands and the Bristol area (Figure 7.1). Boreholes for oil and coal exploration in the East Midlands, Oxfordshire and Berkshire have proved additional Carboniferous igneous rocks at depth, showing a more extensive distribution than the surface exposures. Igneous rocks of Carboniferous and Permian age, south of the Variscan Front, are described fully in the *Igneous Rocks of South-West England* GCR Volume (Floyd *et al.,* 1993). These include Dinantian and Early Permian alkaline lavas and pyroclastic rocks, and the calc-alkaline granite batholith that was intruded during Late Carboniferous to Early Permian times.

The igneous rocks of central England were of importance in the early development of the understanding of geological processes when Hutton (1788) recognized that the 'ragstones' of south Staffordshire and 'toadstones' of Derbyshire are comparable to lavas erupted from active volcanoes and that these areas had formerly seen volcanic activity. Subsequent research has provided information on field relations and petrography, and more recently work on the geochemistry has contributed to the development of understanding of the tectonic evolution of the UK during the Carboniferous Period.

Carboniferous igneous activity in this area is all considered to have occurred in a within-plate environment on the Laurussian continent (see Chapter 1). There is no evidence of direct input from the subduction-related magmatism prevalent in south-west England at the time (Upton, 1982; Macdonald *et al.,* 1984). The nature of the igneous activity in this region evolved in response to changes in tectonic processes and can be broadly sub-divided into events of Dinantian and Silesian age (Figure 7.2). The products of all these events show a typical lack of differentiation in comparison with their Scottish equivalents, probably because only small volumes of magma were produced and the eruptive activity was short-lived (Francis, 1970a).

Dinantian igneous activity

The main control on development of Dinantian volcanicity throughout England and Wales was north-south lithospheric stretching and thinning associated with the formation of blocks and basins (Leeder, 1982). Much of the activity occurred along lines of pre-existing basement lineaments which commonly bound the main blocks and basins (Francis, 1970a). The main centre of igneous activity at this time was in the Derbyshire Dome, with minor volcanism in the Bristol and Wenlock areas and in the East Midlands.

In Derbyshire, basaltic lavas, pyroclastic rocks and sills occur within a Dinantian carbonate succession. The extrusive rocks are associated with Visean sedimentary rocks, which can be determined biostratigraphically to be late Holkerian to late Brigantian in age, although the majority of activity occurred during early Brigantian times (Walters and Ineson, 1981). The sills appear to be genetically related to the extrusive rocks and are probably also of late Dinantian age, although whole-rock K-Ar and Ar-Ar dates on the sills suggest they are considerably younger than the lavas (Fitch *et al., 1970;* M. Timmerman, pers. comm., 2002); the discrepancy may be a function of hydrothermal alteration.

In general, the igneous bodies are poorly exposed, with active or former quarrying operations providing most of the important exposures. Arnold-Bemrose (1894, 1907) identified two major centres of igneous activity at Matlock and Miller's Dale, covering areas of about 200 km^2 and 145 km^2 respectively (Francis, 1970a). The GCR sites of Litton Mill, Water Swallows Quarry, Tideswell Dale and Calton Hill are all located in the more northerly Miller's Dale Centre (Figure 7.3). Francis (1970a) identified at least 14 agglomerate vents, and Walters and Ineson (1981) recognized 30 distinct lavas and beds of pyroclastic rock. Stevenson and Gaunt (1971) noted a lack of any relationship between the flows and the vents and suggested an origin through fissure eruptions. However, Walters and Ineson (1981) suggested that the volcanic

rocks were the product of small, short-lived central vent volcanoes and proposed some correlations based on the more laterally extensive pyroclastic rocks. Aitkenhead *et al.* (1985) identified two further local eruptive centres, largely from subsurface occurrences, and renamed the Matlock and Miller's Dale centres 'Bonsall' and 'Tunstead' respectively. They noted that the eruptions from the four centres were not contemporaneous and that lavas cannot be correlated from one centre to another. Wilkinson (in Neves and Downie, 1967) has proposed that intrusions and volcanic vents tend to coincide with WNW-trending anticlinal axes or occur along the margins of structural blocks.

The lavas are typically only a few tens of metres in thickness, but with some discrete flows up to 42 m thick (Francis, 1970a) and composite or compound flows in places (Walters and Ineson, 1981; Ineson and Walters, 1983; Macdonald *et al.,* 1984). The two main lava units exposed at GCR sites in Derbyshire are the Upper Miller's Dale Lava and the Lower Miller's Dale Lava (note that the lithostratigraphical name refers to them in the singular despite the common presence of multiple lava flows). They are usually highly altered, fine-grained, olivine-phyric and aphyric basalts. The lavas are commonly vesicular with amygdales of carbonate, chlorite, chalcedony or albite (Macdonald *et al.,* 1984). Many of the lavas are thought to have been subaerial eruptions upon an emergent platform, and interdigitated breccias are characteristic of subaerial autobrecciation, formed in response to friction or internal disruption of flows (meson and Walters, 1983). However, it has been suggested that some lavas flowed across wet sediments, terminating locally in shallow water (Cheshire and Bell, 1977; Walkden, 1977; Macdonald *et al.,* 1984), and pillow lavas are recorded in marine basinal facies marginal to the platform. Tuffs are typically subordinate to the lavas, commonly preceding and/ or following lava eruption (meson and Walters, 1983). However, K-bentonites are widespread, most notably in the Bee Low Limestones of Asbian age, which contain 30–40 beds, generally less than 3 cm thick, though locally up to 1.25 m thick (Walkden, 1972, 1977; Aitkenhead *et al.,* 1985). Tuff-cones have been inferred or recognized at numerous localities and typically contain vitric and devitrified lapilli-tuffs, interpreted as the products of phreatomagmatic activity due to the interaction of magma and groundwater in the vent (meson and Walters, 1983).

The sills are dominantly medium- to coarse-grained olivine-dolerites, distinguished by the presence of altered olivine phenocrysts, ophitic intergrowths of clinopyroxene and plagioclase, and the absence or rarity of vesicles and amygdales (Macdonald *et al.,* 1984). The majority of these dolerite intrusions were emplaced along planes of weakness between lavas and limestones.

Small outcrops of volcanic rocks of late Tournaisian to early Visean age occur in the Bristol area, close to the final position of the Variscan Front (Figure 7.1). However, at the time of their eruption this area was within the extensional back-arc basin to the north of the front. The olivine basalt lavas and tuffs, some of which were submarine, are represented by the GCR sites at Spring Cove and Middle Hope. The Little Wenlock Lava of the Welsh Borderlands is a vesicular, microporphyritic, olivine basalt, up to 30 m thick, of Brigantian age (Francis, 1970a). Three minor dykes in the Welsh Borderlands cut strata of Devonian age, and are considered to have been intruded during Carboniferous time (Francis, 1970a). These are the Brockhill Dyke of analcime-gabbro (formerly 'teschenite), the olivine-dolerite Bartestree Dyke and the monchiquitic Llanllywel Dyke, the last of these being associated lithologically and geographically with the monchiquite intrusion and volcanic pipe at the Golden Hill Quarry GCR site.

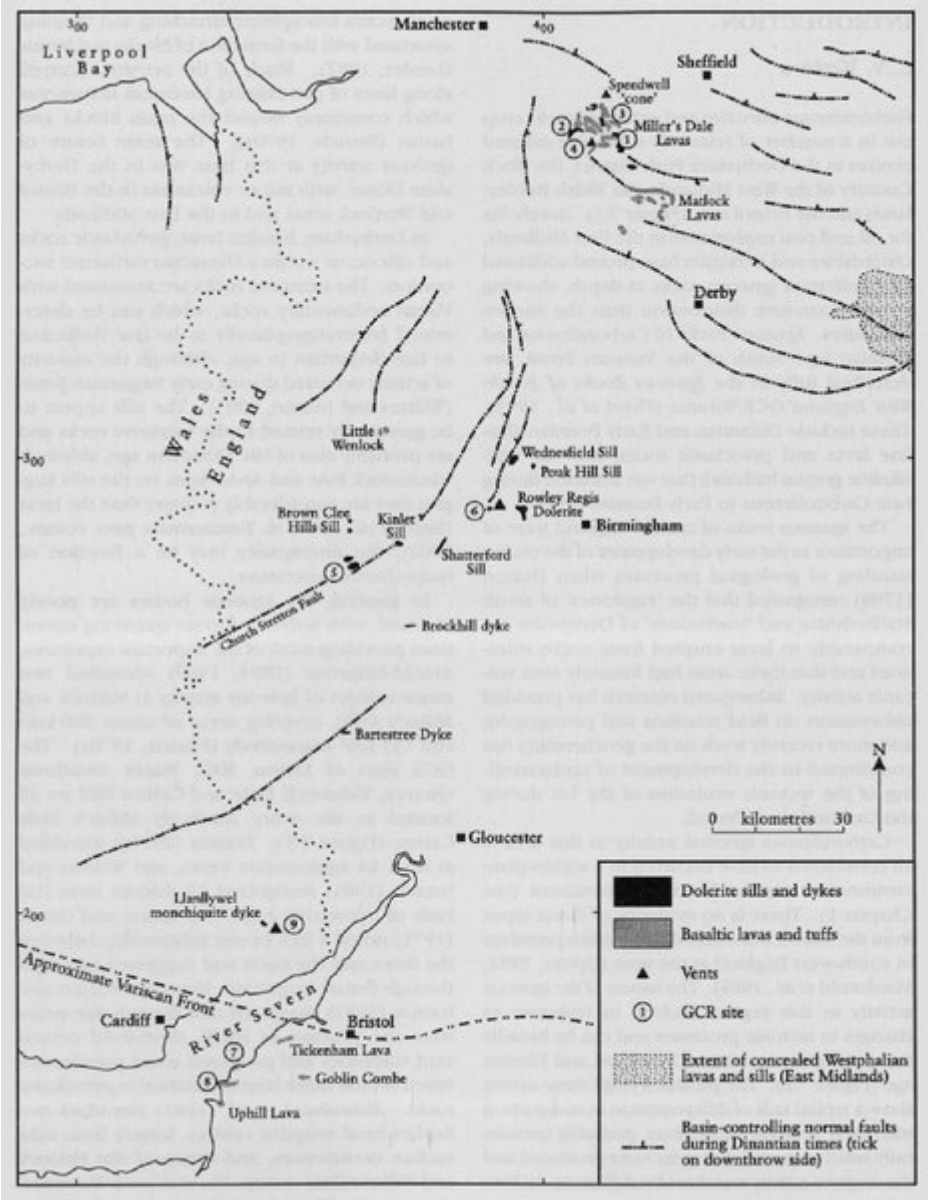
Silesian igneous rocks

During Namurian and early Westphalian times, north–south tectonic extension was largely replaced by a period of thermal crustal sagging caused by cooling of the asthenosphere beneath the thinned lithosphere. This process is not normally associated with the generation of igneous activity (Leeder, 1982). However, volcanic activity continued, although less abundantly and with relatively few lavas. Volcanicity became more explosive with production of tuffs and thin ash-fall clays, referred to as bentonites or tonsteins, typically a few millimetres to centimetres thick (Trewin, 1968; Francis, 1969; Price and Duff, 1969; Spears, 1970). Acidic ash-fall deposits generally cover very large areas and have been associated with Variscan volcanic activity at a destructive plate margin present to the south of Britain (Spears and Kanaris-Sotiriou, 1979). Basic bentonites are more locally developed and may relate to the alkaline igneous activity that produced the dolerite sills and lavas of the East Midlands and sills of the West Midlands during Langsettian (Westphalian A) and Bolsovian (Westphalian C) times, respectively.

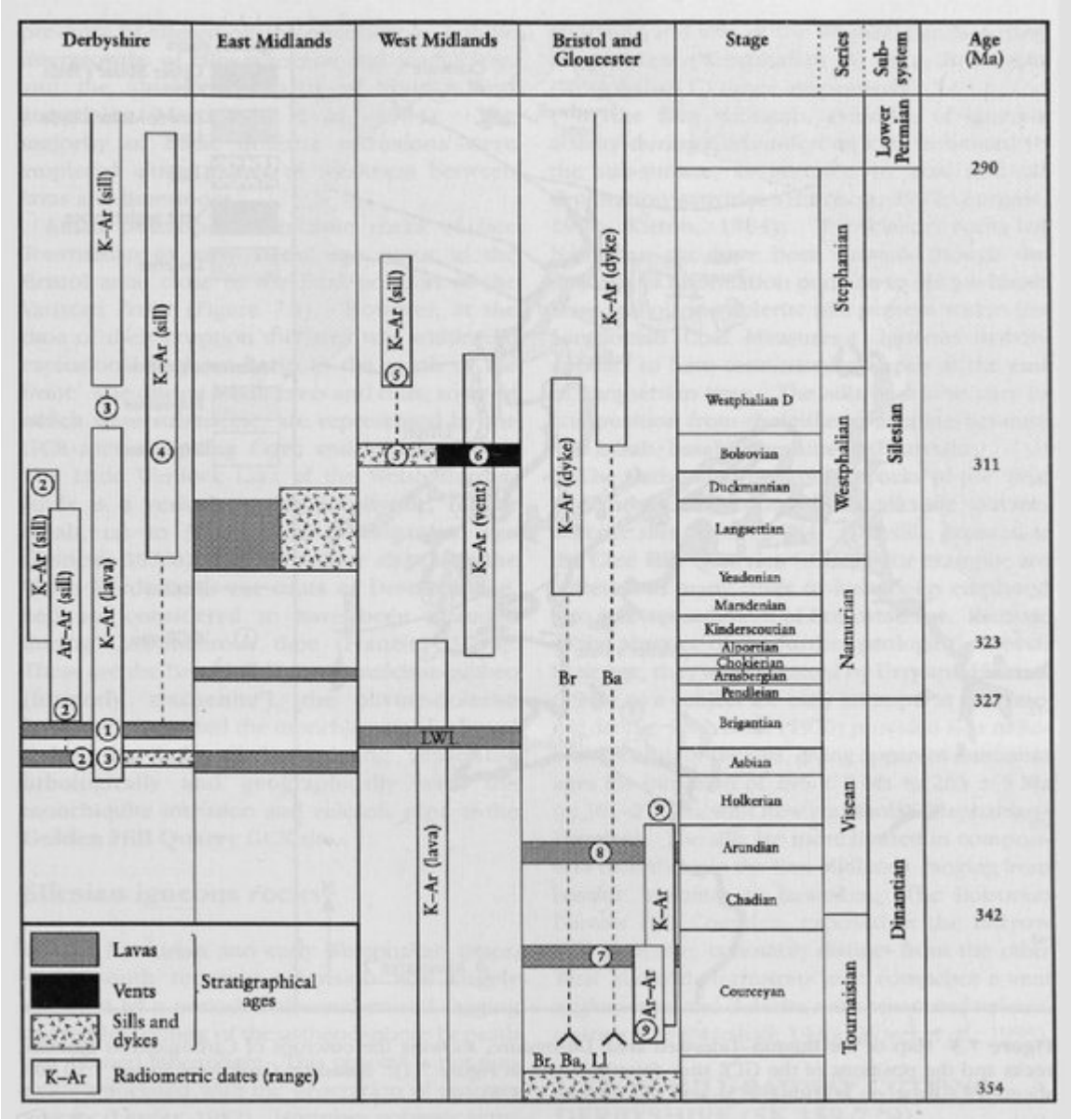
In the East Midlands, evidence of igneous activity during Carboniferous time is limited to the sub-surface, as revealed by coal and oil exploration activities (Harrison, 1977; Burgess, 1982; Kirton, 1984). Pyroclastic rocks of Namurian age have been proved, though the majority of information pertains to olivine basalt lavas and olivine-dolerite sills present within the Langsettian Coal Measures. Igneous activity appears to have terminated abruptly at the end of Langsettian time. The sills and lavas vary in composition from tholeiitic to alkaline basanite and basalt, basaltic hawaiite and hawaiite.

The Carboniferous igneous rocks of the West Midlands are predominantly alkaline olivine-dolerite sills (Kirton, 1984). The sills, exposed at the Clee Hill Quarries GCR site for example, are believed in many cases to have been emplaced into still-wet sediment of Bolsovian age. Because of the absence of any further geological clues to their age, they were selected by Urry and Holmes (1941) as a subject for early attempts at radiometric dating. Fitch *et al.* (1970) provided K-Ar radiometric dates for the sills, giving apparent minimum ages for intrusion of 295 ± 5 Ma to 265 ± 5 Ma (*c.* 301–271 Ma with new constants) (Stephanian–Permian). The sills are more limited in composition than those in the East Midlands, ranging from basaltic hawaiites to hawaiites. The Bolsovian Barrow Hill Complex, exposed at the Barrow Hill GCR site, is notably distinct from the other West Midlands intrusions as it comprises a vent agglomerate and dolerite, with associated volcaniclastic rocks (Marshall, 1946; Glover *et al.,* 1993).

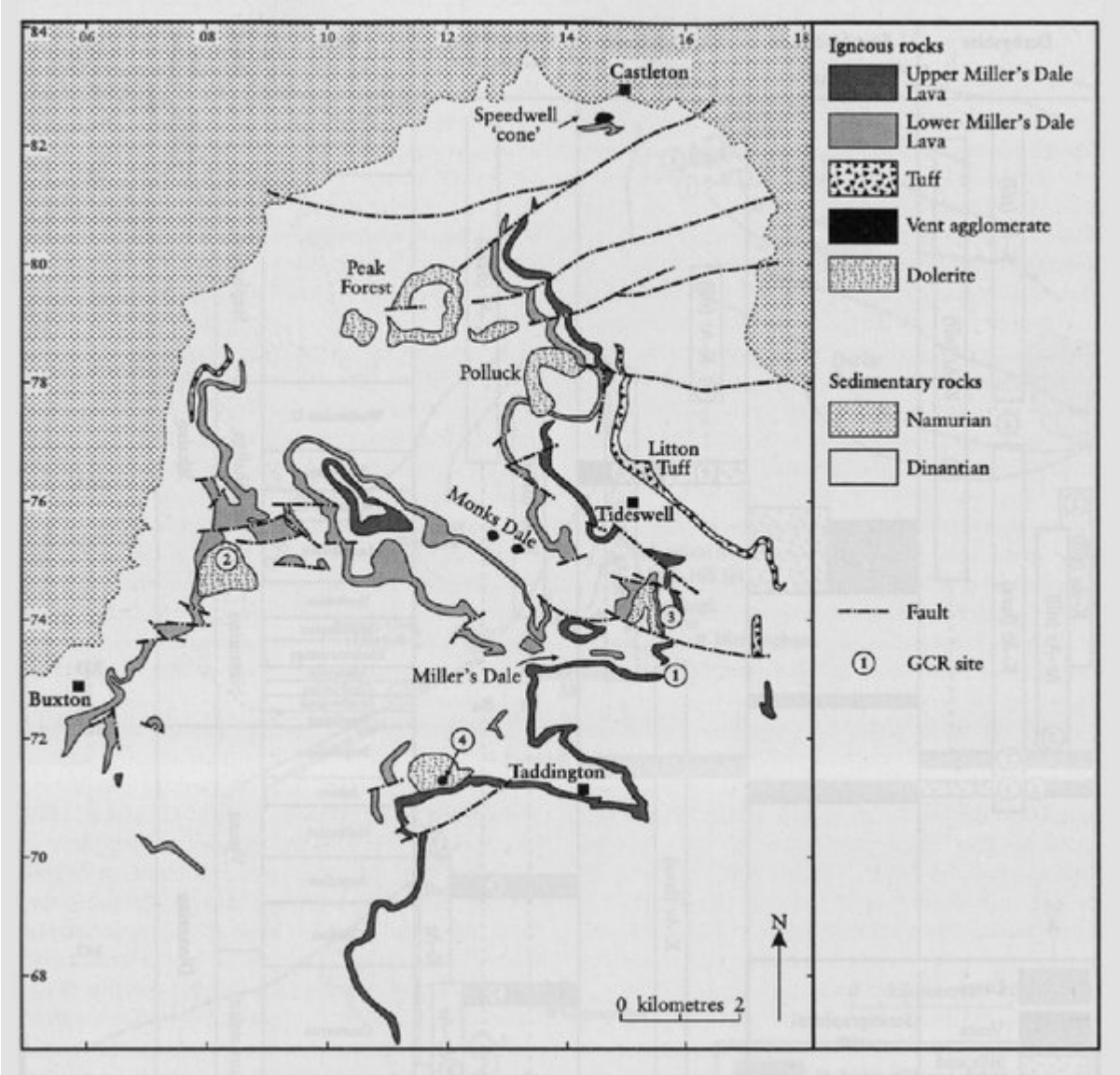
References



(Figure 7.1) Map of central England and the Welsh Borderlands showing locations of Carboniferous igneous rocks and the GCR sites. GCR sites: 1 = Litton Mill Railway Cutting; 2 = Water Swallows Quarry; 3 = Tideswell Dale; 4 = Calton Hill; 5 = Clee Hill Quarries 6 = Barrow Hill; 7 = Middle Hope; 8 = Spring Cove; 9 = Golden Hill Quarry. Based on Geological Survey 1:625 000 Geological map of the UK South (1979).



(Figure 7.2) Approximate ages and stratigraphical distribution of selected igneous rocks from central England and the Welsh Borderlands. The GCR sites are numbered as for (Figure 7.1). (Ba = Bartestree Dyke; Br = Brockhill Dyke; Ll = Llanllywel Monchiquite Dyke; LWL = Little Wenlock Lavas.) After Francis (1970a); and Kirton (1984). The timescale is that of Gradstein and Ogg (1996).



(Figure 7.3) Map of the Buxton-Tideswell area, Derbyshire, showing the outcrops of Carboniferous igneous rocks and the positions of the GCR sites (numbered as in (Figure 7.1)). Based on Geological Survey 1:50 000 sheets 99, Chapel en le Frith (1975); and 111, Buxton (1978).