Calton Hill, Derbyshire

[SK 119 715]

C.N. Waters

Introduction

The quarry at the Calton Hill GCR site, about 6 km east of Buxton (Figure 7.3), is noted for the presence of spinel lherzolite and harzburgite nodules within a basanite intrusion. These nodules, brought to the surface during Carboniferous volcanic activity, represent the only known examples in England of mantle-derived material, which provide insight into the petrology and geochemistry of the Earth's mantle. The Golden Hill Quarry GCR site in Wales is the only other location where ultramafic nodules have been found in Great Britain, outside of Scotland.

The intrusion shows a complex relationship with tuffs, agglomerates and lavas of the Upper Miller's Dale Lava, within which it has been intruded. The Upper Miller's Dale Lava is of Brigantian age, equivalent to the lava present at the Litton Mill Railway Cutting GCR site, and younger than the Asbian Lower Miller's Dale Lava seen at the Water Swallows Quarry and Tideswell Dale GCR sites.

The Calton Hill GCR site has been described in detail in numerous publications (Arnold-Bemrose, 1894, 1907, 1910; Tomkeieff, 1928; Aitkenhead *et al.,* 1985), although many of the sections described are no longer exposed. Miller (1988) provided an update on the condition of the site following partial infilling. Recent publications have concentrated on description of the ultramafic nodules (Hamad, 1963; Donaldson, 1978) and mineralization (Ford in Neves and Downie, 1967; Sarjeant, 1967; Curtis, 1976; Walters and Ineson, 1981).

Description

The Calton Hill Volcanic Complex has a broadly circular outcrop with a maximum dimension of about 1000 m across (Figure 7.10). The complex comprises basanite intrusions within tuffs, agglomerates and lavas of the Upper Miller's Dale Lava. The basanite is typically hard, bluish-black and relatively unaltered, whereas the lava is soft, very weathered, brown or green, and highly vesicular with chlorite infills.

The site has been extensively quarried and progressively infilled over a prolonged period, with only two small areas left unfilled. Therefore, all descriptions have been limited to partial exposures with no single comprehensive description of the entire site. The remaining exposures that form the GCR site can be sub-divided into western and southern areas, summarized below.

Western Area [SK 1157 7137]

The south side of this area shows tongues of massive basanite, locally with columnar joints, intruding vesicular and amygdaloidal basalt. Ultra-mafic nodules have been found in the basanite intrusion (Miller, 1988). On the north side there are dolerite dykes up to 3.2 m wide, with good columnar joints, intruded into basalt lava. The lava is soft weathered, highly chloritized, vesicular and amygdaloidal in part with some geodes of quartz, calcite and haematite present at the contact between the two lithologies (Aitkenhead *et al.,* 1985). Oval areas of buff to greenish-grey coarse tuffs and agglomerates, containing limestone fragments up to 13 cm in diameter and basalt bombs up to 10 cm in diameter, project upwards into the lavas (Miller, 1988). A grey, calcareous, lapilli-tug locally bedded and graded, has also been described (Miller, 1988).

Southern Area [SK 1198 7122]

Aitkenhead *et al.* (1985) and Miller (1988) provide descriptions from different phases of quarrying; their combined descriptions provide the succession shown below.

	Thickness (m)
Basalt, very vesicular with irregular and trangressive base	*c.* 6.0
Basanite, spheroidally weathered, crudely columnar jointed with ultramafic nodules (up to 0.11 m diameter) near the base; terminates abruptly to the west at an irregular vertical contact with weathered and mineralized basalt	10.5
Basalt, heavily jointed at base, vesicular in middle and massive with some calcite mineralization at top, intruded by a thin basanite sheet with irregular upper and lower contacts	2.0
Lapilli-tuff, olive-green, calcareous; in places cross-bedded with coarser beds with pumice fragments up to 5 mm and rare bombs up to 60 mm diameter; the coarser beds are more numerous and thicker towards the top	2.5+
Limestone, dome-shaped surface at bottom of excavation	

The intrusive rock is an analcime basanite, variously described as 'analcite-basalt' by Tomkeieff (1928), 'ankaramite lava' by Donaldson (1978), 'dolerite' by Aitkenhead *et al.* (1985) and 'basanite' by Miller (1988). It generally comprises subhedral phenocrysts of olivine ($Fo_{80–85}$) and augite ($Wo_{45}En_{45}Fs_{10}$) in a groundmass of granular augite, plagioclase laths (An_{64}) often showing flow orientation, iron-titanium oxide, analcime and calcite with ultra-mafic xenoliths and xenocrysts. A representative analysis of a clinopyroxene, identified as a salite, has relatively high contents of $A1_2O_3$ (>4%) and TiO_2 (>1.5%) in comparison with clinopyroxenes from the Lower Miller's Dale Lava (Macdonald *et al.,* 1984).

The peridotite xenoliths occur as coarse-grained, spinel-bearing nodules (Figure 7.11) in which marginal re-equilibration of minerals occurs adjacent to the basanite (Hamad, 1963; Donaldson, 1978). Typically, the nodules are dominated by the presence of olivine (64–85%), partially serpentinized and Mg-rich ($Fo_{91–92}$), with subordinate orthopyroxene (8–24%) ($Wo_1En_{91}Fs_8$), minor clinopyroxene (1–2%) ($Wo_{47}En_{49}Fs_4$) and spinel (less than 4%) (Donaldson, 1978). Some nodules have been identified as harzburgites, which contain enstatite (an orthopyroxene) as the second dominant mineral, whereas the majority are lherzolites in which both enstatite and chrome-diopside (a clinopyroxene) are abundant. The nodules show extreme depletion of Ca, Al, Ti and Na relative to undepleted mantle and a high Mg/(Mg + Fe) ratio (Donaldson, 1978).

The tuffs, agglomerates and lavas of the Upper Miller's Dale Lava appear to have been deposited upon an erosion surface on top of the Asbian (D_1) Bee Low Limestones. They are in turn overlain by the Monsal Dale Limestones with faunal assemblages of the Upper *Dibunophyllum* (D_2) Zone, indicative of a Brigantian age (George *et al.,* 1976). The age of the basanite intrusion is, in contrast, poorly constrained. Fitch and Miller (1964) provided a whole-rock K-Ar date of 295 ± 14 Ma (*c.* 301 Ma with new constants) indicative of a Stephanian age of intrusion, at least 26 million years after extrusion of the lavas. This date almost certainly relates to the age of hydrothermal alteration associated with mineralization and not to the age of intrusion.

The site shows extensive development of hydrothermal mineralization. The basanite contains analcime and spherulitic chlorite, commonly filling amygdales (Aitkenhead *et al.,* 1985). Veins, 1–5 cm wide, of a fibrous mineral described by Sarjeant (1967) as chlorite, weather to form a clay mineral identified by Curtis (1976) as the smectite saponite. Ford (in Neves and Downie, 1967) has identified a complex history of mineralization including calcite, chlorite, quartz, haematite, baryte and limonite.

Interpretation

The Calton Hill Volcanic Complex was first discovered by Arnold-Bemrose (1894, 1907, 1910), who recognized an olivine basalt containing ultramafic nodules, and an agglomerate. Quarrying operations gradually revealed further the nature of the north-east part of the complex, described in detail by Tomkeieff (1928). He recognized two distinct components to the basalts: amygdaloidal Upper Miller's Dale Lava and associated stratified tuff with fragments of lava and limestone, intruded by a basanitic sill, with analcime, ultramafic nodules and showing a chilled margin against the lavas. Tomkeieff, and most subsequent workers, considered that the tuffs and amygdaloidal lavas at Calton Hill formed in a vent, which subsequently controlled the emplacement of the intrusion. The sections described by Arnold-Bemrose and Tomkeieff are no longer exposed. Aitkenhead *et al.* (1985) provided additional descriptions, broadly confirming the interpretations of previous workers.

Macdonald *et al.* (1984) provided a radically different interpretation, suggesting that the site displays five discrete lava flows in which the basanite forms the relatively unaltered centres of each flow, whilst the tops and bottoms of the flows have been extensively altered. They interpreted the Calton Hill Volcanic Complex as a phreatic tuff-ring comprising tuffs, agglomerates and flows of subaqueous lavas, which accumulated on the Bee Low Limestones, and which are separated from the overlying Upper Miller's Dale Lava by 15 m of limestone. The exposures used as evidence for this model are no longer visible. They also noted that the nodule-bearing 'lava' is silica-undersaturated, with clinopyroxene compositions consistent with the rock being alkaline. This is distinct from the tholeiitic affinities of the Lower and Upper Miller's Dale lavas.

Miller (1988) provided an update on the condition of the site following partial infilling and stated the evidence for the intrusive nature of the basanites. This includes transgressive and in places vertical contacts, chilling of the basanite margins, restriction of analcime and ultramafic nodules to the basanite, and the mineralization of the lavas. From this evidence he concluded that the basalt lavas and the basanite intrusion are parts of two distinct igneous events. He was also unable to find supporting evidence for the limestone separating the complex from the Upper Miller's Dale Lava.

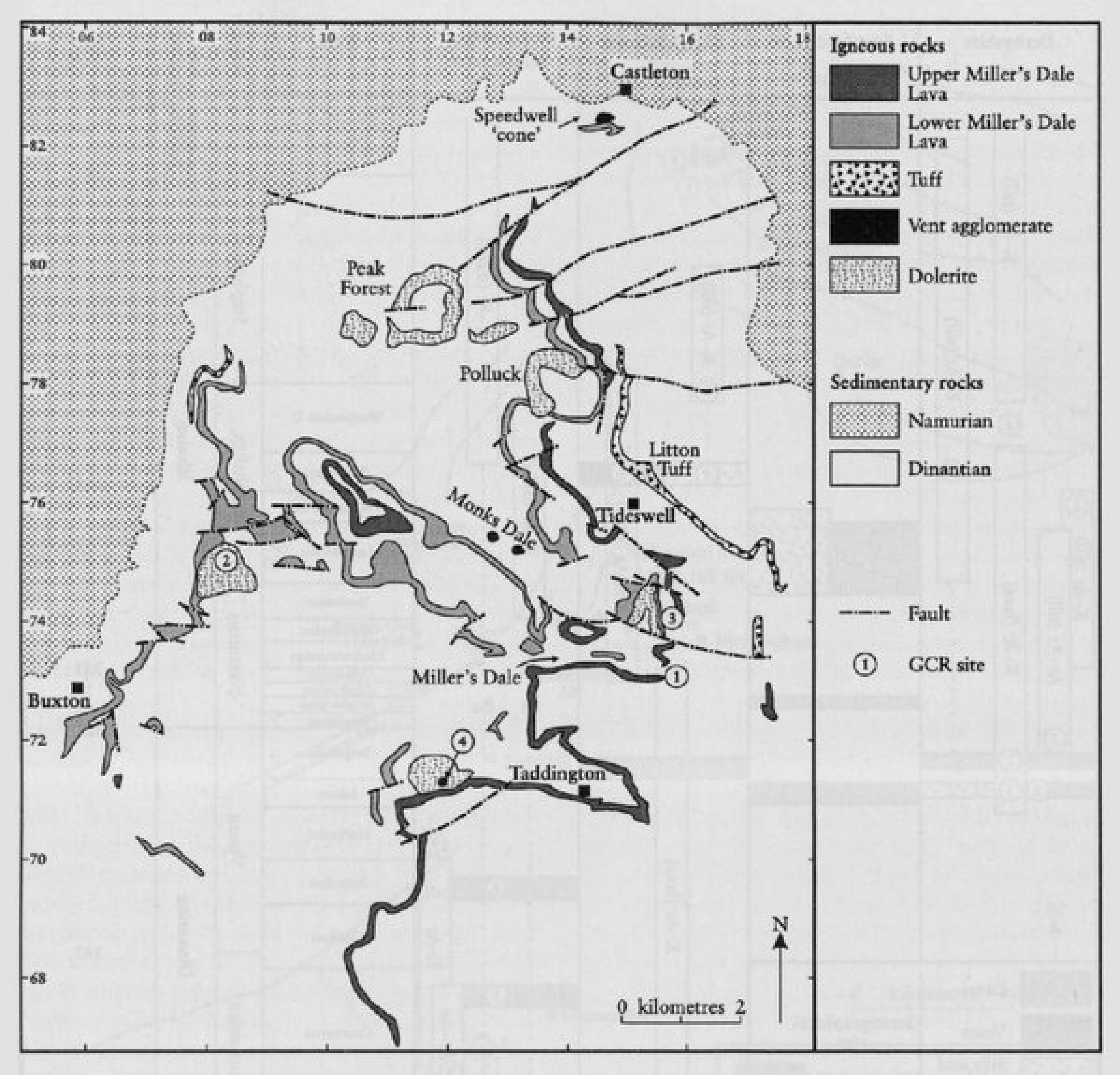
Numerous publications have concentrated on describing the ultramafic nodules (Hamad, 1963; Donaldson, 1978) and mineralization (Ford in Neves and Downie, 1967; Sarjeant, 1967; Curtis, 1976; Walters and Ineson, 1981). The depletion of certain major elements and high Mg/(Mg + Fe) ratios (Donaldson, 1978) suggest that the nodules represent residues from partial melting of the mantle at an approximate depth of 45 km.

Conclusions

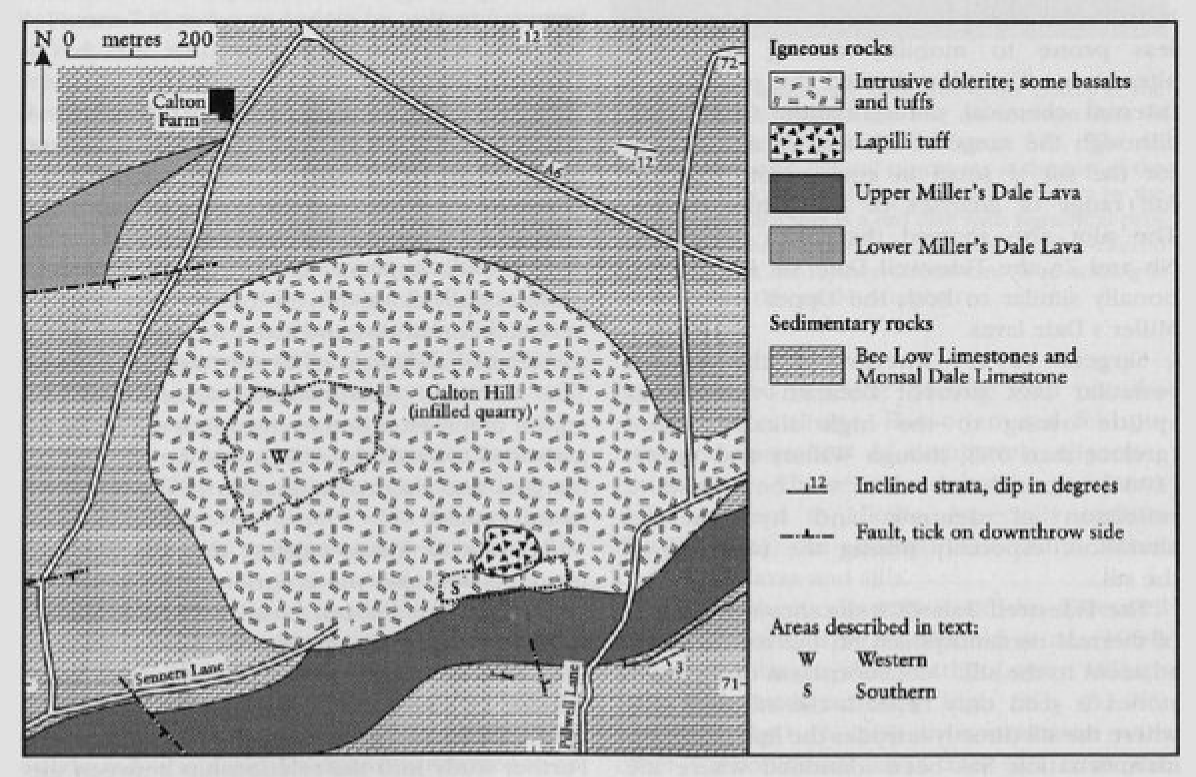
The quarry at Calton Hill is of international importance as the only known locality in England at which material from the Earth's mantle can be found. The material, in the form of nodules composed exclusively of minerals rich in magnesium and iron (olivine, pyroxene and spinel), probably formed in the upper levels of the mantle. Subsequently, during Carboniferous volcanic activity, fragments of this mantle material were brought closer to the surface within basaltic magma.

Around Calton Hill, an early cone of consolidated volcanic ash (tuft) and lavas that were erupted through water-saturated sediments or shallow water, is overlain by more persistent basaltic lavas of tholeiitic geochemical affinities. These Early Carboniferous volcanic rocks are intruded by basaltic sills of alkaline geochemical affinities, which are hosts to the mantle nodules. There are clearly two separate igneous events but currently available radiometric dates suggest an unrealistic time gap between the volcanic rocks and the sills. The site therefore provides opportunities for future research into the timing of these two magmatic phases, with important implications for the understanding of magmatic evolution in the Carboniferous rocks of Derbyshire.

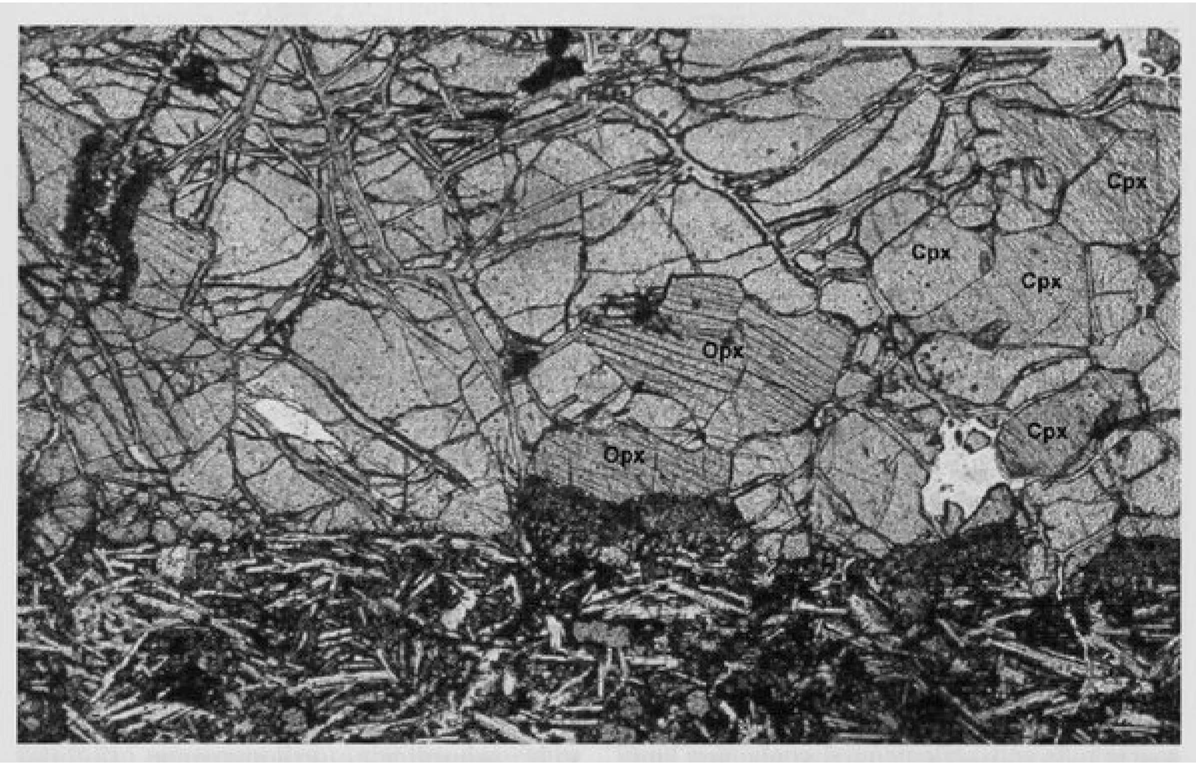
References



(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).



(Figure 7.10) Map of the Calton Hill GCR Site. Based on Geological Survey 1:10 560 Sheet SK 17 SW (1972).



(Figure 7.11) Photomicrograph of a lherzolite nodule from Calton Hill (BGS thin section No. E8340) with coarse-grained olivine, only serpentinized along fractures, subordinate orthopyroxene (Opx) and clinopyroxene (Cpx). The contact with the host basalt (bottom) is very sharp with hardly any visible reaction. Plane-polarized light. The scale bar (top right) is 1 mm. (Photo: British Geological Survey, No. MN39854, reproduced with the permission of the Director, British Geological Survey, © NERC.)