Localities in the Warren House Formation (Broad Down)

[SO 395 765]

Introduction

Broad Down lies on the Malverns ridge, 4 km from its southern end (Figure 4.1). Along with Tinker's Hill to the north and Hangman's Hill to the south, it is underlain by volcanic rocks of the Warren House Formation. This comprises spilitic basalt lavas, locally displaying pillow structure, altered intermediate lavas (keratophyres), altered rhyolitic lavas and felsic pyroclastic rocks. According to French and Winchester (pers. comm. to Lambert and Holland, 1971), the formation occurs in an easterly plunging syncline with mafic rocks to the west overlain by felsic rocks to the east. Excavations at the reservoir [SO 765 399] at the time of its construction (Acland, 1898; Green, 1895) revealed that the situation is more complex, with a sequence of interbedded basalts, rhyolites and tuffs and an easterly dip ranging from 45° to near vertical (Worssam *et al.,* 1989).

Penn and French (1971), Worssam *et al.* (1989), Bullard (1989) and Barclay *et al.* (1997) give details of this area, and the petrography of the various rock types was described by Platt (1933). The preservation of pillow structures and other primary textures, and the weakness of the greenschist facies foliation contrasts strongly with the much more intense deformation and metamorphism of the Malverns Complex. The contact between the two units is tectonic, postdating eruption of the Warren House lavas, and was attributed by Barclay *et al.* (1997) to late Avalonian tectonism at the end of the Proterozoic, possibly the same event during which the Longmyndian Supergroup was folded (see Chapter 5, Introduction).

Pharaoh *et al.* (1987b) studied the trace element geochemistry of the lavas. They demonstrated a strong enrichment in large ion lithophile (LIL) elements such as Ba, and Th, whereas the content of High Field Strength (HFS) elements such as Ti, Y and Zr lies close to or just below that of mid-ocean-ridge basalts (MORB). The geochemical characteristics are most similar to those of basalts from primitive volcanic arc and oceanic marginal basin complexes in the western Pacific (Saunders and Tarney, 1984), and to Pan-African ophiolites (proposed marginal basin crust) of the Arabian Shield (e.g. Klemenic, 1987). The geochemical patterns of the Warren House intermediate and felsic lavas parallel those of the basaltic rocks, and suggest that they may be derived from the latter by differentiation. The Warren House rocks do not compare chemically with the Malverns Complex, nor with the extrusive lithologies of the Uriconian Group (Chapter 5) elsewhere in the Wrekin Terrane. Pharaoh *et al.* (1987b) concluded that they were probably erupted in an oceanic marginal basin (Figure 1.4), and were subsequently preserved as a tectonic sliver along a late Precambrian suture (the Malvern line) between the Wrekin and Charnwood terranes (Barclay *et al.,* 1997, and (Figure 1.1)). On the other hand, Strachan *et al.* (1996) argued that there was no evidence from ductile fabric orientations in the Malverns Complex that the Malvern line acted as a major terrane boundary.

The Warren House lavas were dated using the U-Pb isotope system (Tucker and Pharaoh, 1991). Zircon fractions from a crystal-lithic tuff of rhyolitic composition on Broad Down [SO 7655 3960] yielded an eruption age of 566 ± 2 Ma, identical to that obtained for the Uriconian Group of Shropshire (Tucker and Pharaoh, 1991); however, as previously discussed, the two are not chemically identical.

Description

Clutter's Cave

[SO 7628 3935]

This small, man-made cave is also known as Giant's Cave. The rocks are closely jointed and fractured, grey-weathering, purple-blue, spilitic (sodium-rich) basalt. (Bullard, 1989; Penn and French, 1971; Worssam *et al.,* 1989). Bun-size and loaf-size pillow structures are visible at the cave entrance (Figure 4.6) and larger ones 0.8 m across are present above

and to the north of the cave. The lavas are vesicular locally, with green epidote and altered glass filling the vesicles. Joints are filled with haematite, calcite and epidote. These secondary minerals are typical alteration products of tholeiitic lavas erupted under the sea. A few metres north of the cave, a small gully is eroded down the course of a narrow (0.2–0.3 m) breccia layer striking at about 40 to 45°. This may be a tectonically modified breccia between two lava flows. Immediately south of the cave, planes striking at 60° and dipping 60° north-west may be depositional surfaces of the lava sequence.

Reservoir Quarry

[SO 766 397]

Platt (1933), Penn and French (1971) and Bullard (1989) gave descriptions of this quarry. It exposes pink and blue massive, uniform crystal-lithic tuffs that are mainly non-welded, but with some welding evident. Sheared microdior-ite apparently intrudes the tuffs, although there appears to be rather lower proportions of doleritic rock than indicated by Bullard (1989). The quarry is divided into two parts separated by a NE-trending ridge. The freshest rocks exposed at the lowest level of the north wall of the northern sector are felsic, rhyolitic fragmental tuffs with rounded quartz xenocrysts. Fragmental rocks of intermediate composition are present in both sectors. In the southern sector, for example, a 0.3 m-thick pale pink to yellow-brown felsic tuff is overlain by finer-grained, greyish purple tuff of more intermediate composition, indicating the presence of compositional and grain size banding. The junction between the tuffs dips about 20° to the south-east. The intermediate tuffs are veined with epidote and the top of the upper face in the southern sector is strongly tectonized along east-dipping (? Variscan) shear planes.

Interpretation

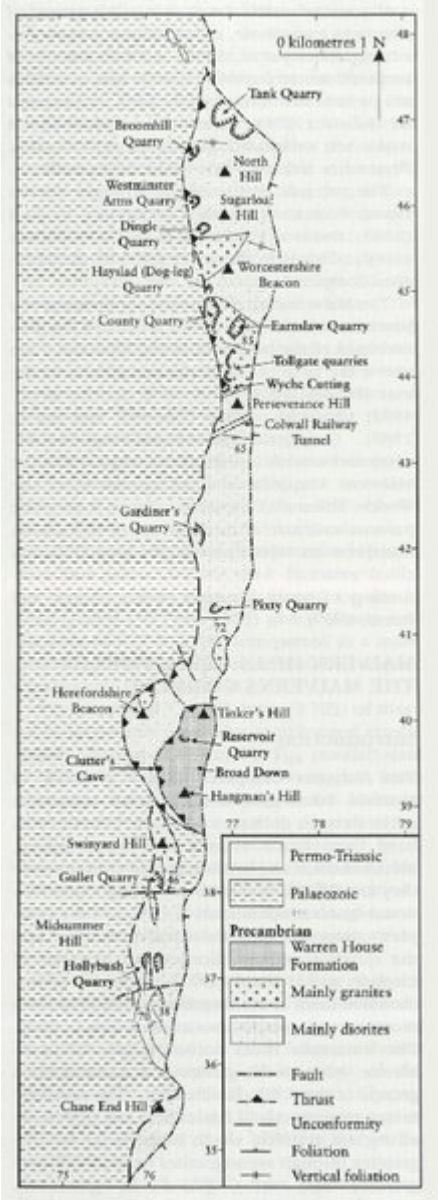
The eruption age of 566 ± 2 Ma, determined on a tuff from Broad Down, indicates that the Warren House Formation was formed late in the history of the Precambrian Avalonian arc system. Its age is identical to that obtained for the Uriconian Group of Shropshire (Tucker and Pharaoh, 1991), and indeed the formation was correlated with the Uriconian lavas, described in Chapter 5, on lithological criteria (Callaway, 1880; Earp and Hains, 1971). Geochemical contrasts between the two suites discussed earlier suggest, however, that the Warren House Formation formed in an intra-oceanic marginal basin setting, whereas the Uriconian Group is representative of eruption within an ensialic marginal basin (Figure 1.4). These findings indicate that the Wrekin Terrane was affected by variable degrees of crustal extension during the main phase of magmatism. Thorpe (1972a, 1974) concluded that the Warren House basalts were originally tholeiitic lavas of possible ocean-floor affinity, although the presence of felsic tuffs, some of which could be the deposits of pyroclastic ash flows, or have been interpreted as ignimbrites (Bullard, 1989), causes some problems with such an origin.

The relationship between the Malverns Complex and the Warren House Formation has generated much discussion. That the latter is about 100 Ma younger is confirmed by recent age dating (Tucker and Pharaoh, 1991). However, several authors have proposed an unconformable relationship, whilst others have proposed a faulted contact. Worssam *et al.* (1989) concluded that the contact between the two units is a tectonic surface, formed after the eruption of the Warren House lavas. Barclay *et al.* (1997) attributed this to deformation that resulted from late Avalonian terrane amalgamation, in very latest Precambrian time; possibly this was the same event that folded the Longmyndian Supergroup of Shropshire (Chapter 5).

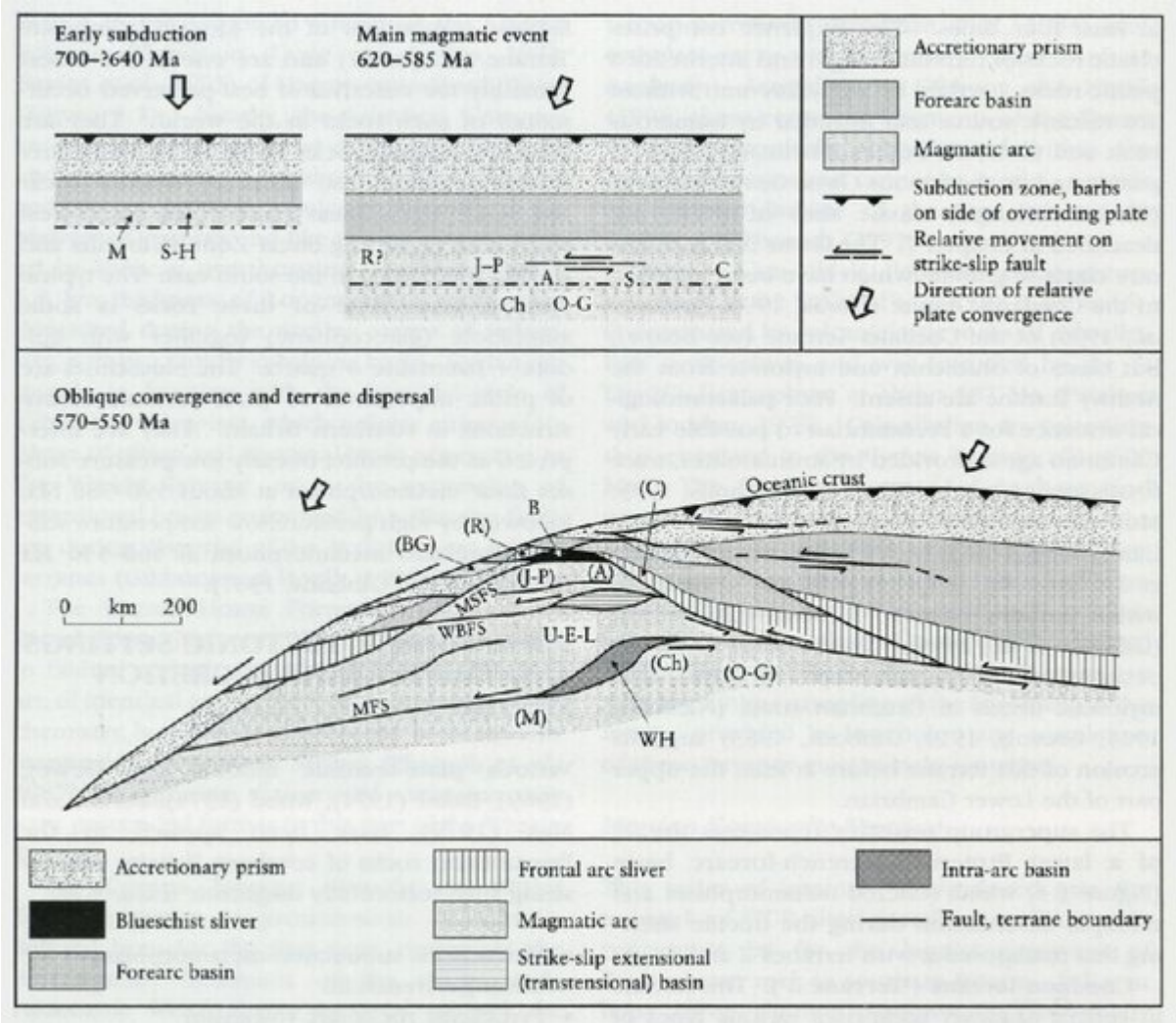
Conclusions

Broad Down provides excellent exposures of the late Precambrian volcanic and volcaniclastic rocks of the Warren House Formation. The diverse succession includes spilitized, basic pillow lavas, altered intermediate lavas (keratophyres) and rhyolitic, welded and non-welded tuffs, some of which may represent pyroclastic ash flows and ignimbrites. Radiometric analysis has given an eruption age of 566 ± 2 Ma, and although this is identical to the age of the Uriconian Group of Shropshire (Tucker and Pharaoh, 1991) these two major rock suites are dissimilar in their geochemistry. The Warren House Formation was probably erupted in an oceanic marginal basin setting, and then brought into tectonic contact with the Malverns Complex much later in the Precambrian.

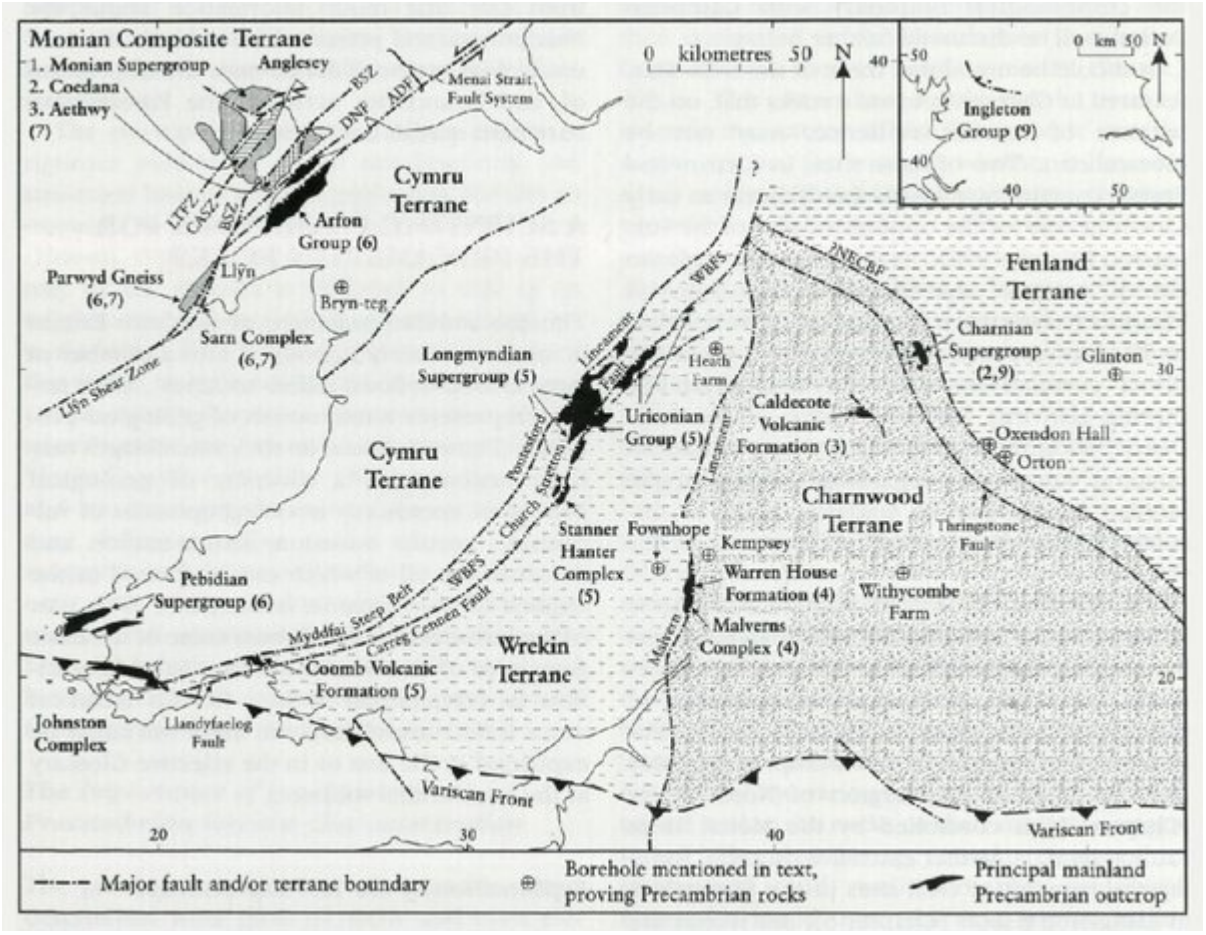
References



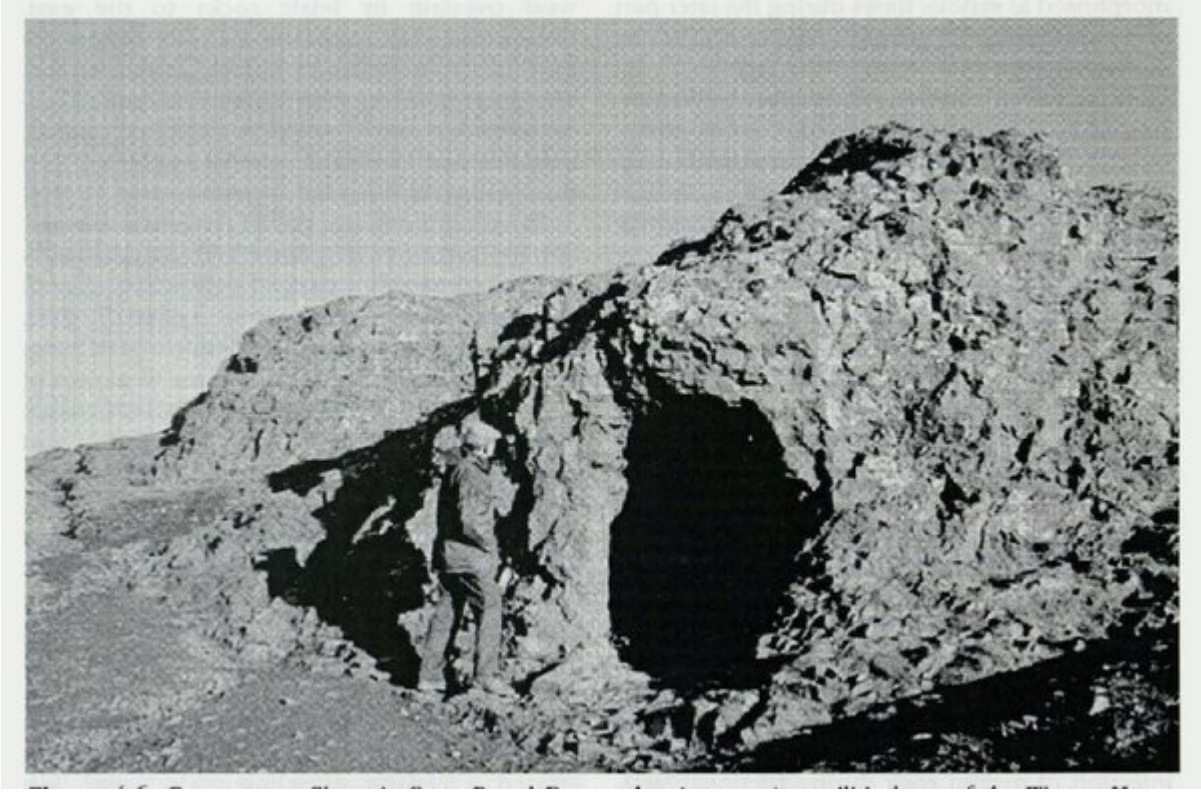
(Figure 4.1) Geological map of the Malvern Hills site, with main localities shown by bold lettering. Note that locally the granites and diorites are strongly foliated with schistose to gneissose fabrics developed. The map includes structural information from R. A. Strachan (pers. comm.) and Bullard (1975).



(Figure 1.4) Model for the late Precambrian evolution of the Avalonian subduction system: episodic Precambrian magmatism (top two cartoons) followed by the dispersal of terranes by transcurrent faulting along the plate margin as convergence became increasingly oblique during the latest Precambrian (modified from Gibbons and Horik, 1996). Note that the presence of the Monian Composite Terrane within this system cannot be proved until Arenig time. A = Arfon Group; B = Anglesey blueschists; BG = Bwlch Gwyn Tuff and related strata (Anglesey); C = Coedana Complex; Ch = Charnian Supergroup; J-P = Johnston Plutonic Complex and Pebidian Supergroup; M = Malverns Complex; MFS = Malverns lineament or fault system; MSFS = Menai Strait fault system; O-G = volcanics in Orton and Glinton boreholes; R = Rosslare Complex; S = Sam Complex; S-H = Stanner-Hanter Complex; U-E-L = Uriconian Group, Ercall Granophyre, Longmyndian Supergroup; WBFS = Welsh Borderland fault system; WH = Warren House Formation. The same letters in brackets (lower cartoon) refer to the relative positions of those volcanic belts that were by then extinct.



(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 4.6) Exposure at Clutter's Cave, Broad Down, showing massive spilitic lavas of the Warren House Formation with pillow structures (e.g. in front of observer). (Photo: T.C. Pharaoh.)