Howford Bridge, East Ayrshire

[NS 512 254]–[NS 516 255]

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Introduction

The River Ayr at Howford Bridge, 1 km west of Catrine, East Ayrshire, affords a representative section through some of the youngest volcanic rocks in the Carboniferous–Permian Igneous Province of northern Britain (Figure 4.11). The lavas and tuffs of this GCR site form part of the Mauchline Volcanic Formation, which comprises the lower part of the Permian succession in the Mauchline Basin. The upper part comprises continental red bed sandstones of the Mauchline Sandstone Formation and the whole succession is 610 m thick at its maximum.

The Mauchline Basin has a simple form in which the more resistant, volcanic rocks form a low ridge surrounding a broad, shallow topographical depression. The volcanic rocks thicken eastwards from 100 m to 238 m and are probably part of a more extensive volcanic field that extended originally to the south-east, across the Southern Upland Fault, to include the Carron Basalt Formation of the Sanquhar and Thornhill basins (see Carron Water GCR site report).

Regionally, the Mauchline Volcanic Formation rests unconformably, but with no marked discordance, upon reddened Upper Coal Measures sedimentary rocks. Fossil plant remains from intercalated sedimentary beds elsewhere in the basin suggest an earliest Permian age (Wagner, 1983), and hence the volcanic rocks have considerable potential importance for dating the Carboniferous-Permian boundary. K-Ar whole-rock dates of around 286 ± 7 Ma were obtained from the lavas by De Souza (1979, 1982), and Wallis (1989) reported a K-Ar date of 291 ± 6 Ma from an associated neck intrusion. Palaeomagnetic measurements support an age of emplacement close to the Carboniferous-Permian boundary (Du Bois, 1957; Harcombe-Smee *et al.,* 1996).

The section was first described by Geikie (1866) (his Ballochmyle section) and subsequently by Eyles *et al.* (1949) in the Geological Survey memoir and by Mykura (1967). Excursion guides for the Glasgow district have included this key section (e.g. Weedon and Mykura in Lawson and Weedon, 1992). Detailed petrographical descriptions of the formation were given by Tyrrell (1928a), and analyses of the lavas were included in studies of Silesian and Permian magmatism of northern Britain by Macdonald *et al.* (1977) and Wallis (1989). A stream-sediment survey of the Mauchline Basin has revealed significant amounts of gold, possibly derived from the volcanic rocks and precipitated from hydrothermal solutions in the red beds (Leake *et al.,* 1997).

Description

The Mauchline Volcanic Formation is extremely variable in lithology, but comprises mainly lenticular basic lavas, with intercalated beds of tuff, tuff-breccia, agglomerate, aeolian sandstone and mudstone. The lavas are mainly olivine-microphyric and olivine-clinopyroxene-microphyric basalts with some nepheline basanites, analcime basanites and olivine nephelinites (Eyles *et al.,* 1949), though whole-rock analyses reveal many basaltic hawaiites and hawaiites (Wallis, 1989). There is a variable, localized basal unit of tuffs and volcaniclastic sandstones. The overlying Mauchline Sandstone Formation comprises brick-red sandstones with large-scale, dune cross-bedding and is characterized by the presence of wind-rounded grains.

Lavas and interbedded sedimentary rocks are exposed in the river bed and on the south bank upstream (east) of the new road bridge. The dip here is about 10° to the west. Lavas on the north bank, beneath the new bridge, are difficult to access. The best section of the upper part of the volcanic formation is seen in the cliff below the old road, downstream (west) from [NS 512 254] (Figure 4.12). Here tuffs, some containing wind-rounded sand grains, are interleaved with and overlain by the Mauchline Sandstone Formation. The latter is very well exposed in old quarries and cliffs around [NS 511 254], where the large-scale dune bedding can be seen.

Most flows appear to be altered to a greater or lesser degree, and colour varies between grey and a purplish-red, although some very fresh material is preserved. Pseudomorphed olivines are a common feature on weathered surfaces, giving the rocks a characteristic speckled appearance. The lavas are fine grained, usually highly scoriaceous and amygdaloidal with mainly calcite and zeolite infills. Some flows contain larger cavities and preserve fossilized surface cracks infilled with reddish-brown sandstone. The fragmental volcanic rocks are predominantly lithic tuffs and volcaniclastic breccias. They usually comprise sub-angular to angular lapilli and blocks of olivine basalt, which are commonly amygdaloidal, in a matrix of finer material derived from weathered ash and lava. Some crystal-lithic tuffs may be present. Sedimentary rocks interbedded with the lavas are orange-red or brick-red, generally fine- to medium-grained, commonly pebbly, sandstones and less commonly siltstones and mudstones. Clasts in the sandstones are mostly basalt, reflecting weathering of contemporaneous lavas, tuffs and vent agglomerates. Some, but not all, sandstones also contain wind-rounded quartz grains.

The geochemical studies by Macdonald *et al.* (1977) and Wallis (1989) have provided many whole-rock analyses of the Mauchline lavas, 28 of which are from the Howford Bridge area. All of the latter are basalts or basanites. In contrast to the majority of lavas from earlier Carboniferous volcanism in the Midland Valley, these lavas have strongly alkaline characteristics and are mainly strongly silica-undersaturated (nepheline-normative), although Macdonald *et al.* (1977) and Wallis (1989) also identified some mildly alkaline, transitional (hypersthene-normative) types. They have distinctive isotopic and trace-element signatures (see 'Introduction' to this chapter).

Also notable at this site is an irregular sill of analcime-bearing olivine-dolerite that cuts the lavas (Geikie, 1897; Tyrrell, 1912, 1928b). It forms a cliff on the north bank of the river, between the old and new bridges, and is probably between 25 m and 30 m thick. It appears to have been intruded partly along the plane of relative weakness afforded by an intercalation of fissile sandstone and has chilled upper and lower margins. Xenolithic bodies of sandstone and basalt lava occur close to the sill's margins and pale-coloured segregation veins of analcime-syenite are well seen. Although this sill was formerly assumed to be contemporaneous with the Lugar Sill and hence only slightly younger than the lavas, it is now considered to be part of the Prestwick–Mauchline Sill-complex, of Palaeogene age (Mykura, 1967). A K-Ar mineral date of 58.4 ± 1.4 Ma from Howford Bridge (De Souza, 1979, recalculated by Wallis, 1989) is the main evidence for the age of this complex, although earlier studies of palaeomagnetism from several localities had reached the same conclusion (Armstrong, 1957).

Interpretation

The Early Permian volcanic activity appears to have been a mixture of effusive and explosive events, interrupted by periods of relative quiescence during which sediments were deposited. Various features of the lavas, for example the scoriaceous surfaces and the presence of surface fissures infiltrated by sandstone, suggest that they were emplaced subaerially and no pillow lavas or hyaloclastites have been reported.

Lateral variations in thickness, lithology and facies are a feature of the Mauchline Volcanic Formation. This strongly suggests that lavas were probably erupted as localized events from a number of separate centres. Some 60 or so volcanic necks, many with intrusions of highly silica-undersaturated rock-types, including olivine analcimite and monchiquite, occur within a radius of 30 km and these may well have been the sources of both the lavas and the pyroclastic rocks. Many basic alkaline sills and dykes in the western Midland Valley are also thought to be contemporaneous with this volcanism (e.g. see Lugar GCR site report).

The composition, irregular lithofacies alternation, and sedimentary structures of the sedimentary rocks point to a mixture of aeolian and subaqueous deposition. Hence the overall palaeoenvironment appears to have been one of a spas-modienlly active volcanic field combined with increasingly arid, desert conditions, punctuated by seasonal periods of rainfall giving rise to sheet-floods and local lakes. Topography is thought to have been subdued with the lavas erupted on to a floodplain.

The strongly silica-undersaturated nature of these lavas was one line of evidence that led MacGregor (1948) to propose that volcanism in the Scottish sector of the Carboniferous-Permian Igneous Province of northern Britain became increasingly silica-understaurated with time. This was refined by Macdonald *et al.* (1977), who identified two magmatic or thermal cycles, each beginning with the production of hypersthene-normative magmas which then gave way to increasingly nepheline-normative types. The Mauchline lavas are part of the second of these cycles, but more recent work has suggested that this model is over-simplified (see Chapter 1).

Analyses of these lavas have contributed greatly to the overall model for the generation and evolution of Silesian and Early Permian magmas proposed by Wallis (1989) and summarized in Chapter 1. More specifically, they exhibit reduced levels of the most incompatible trace elements, because the lithospheric mantle, the usual source of such elements in the Midland Valley igneous rocks, had already been depleted by partial melting in late Namurian times which had resulted in the Troon Volcanic Member. However, Sr and Nd isotope ratios do still indicate some lithospheric interaction, in marked contrast to late Stephanian–Early Permian igneous rocks in areas such as Fife and East Lothian, which had been affected by partial melting responsible for the Stephanian tholeiitic intrusions (see Chapter 6).

A north-west-south-east to WNW–ESE structural control for both volcanism and sedimentation in the Permian basins of south-west Scotland was inferred by MacGregor (1948) and Mykura (1967) respectively and this has generally been interpreted as being a reflection of north-west-south-east and north-south rifting (McLean, 1978). More recent interpretations have related the basin development to the presence and reactivation of Caledonian structures in the underlying basement rocks (Anderson *et al.,* 1995; Coward, 1990, 1993, 1995). Coward's (1993) model of the tectonic evolution of the Midland Valley envisaged sinistral strike-slip movement on the Highland Boundary and Southern Upland faults continuing throughout the Carboniferous Period but being replaced by dextral strike-slip movement during end-Carboniferous and Early Permian times. The Mauchline Basin is situated between the ENE- to NE-trending Inchgotrick Fault in the north and the NE-trending Kerse Loch Fault to the south, and Rippon *et al.* (1996), whilst generally supporting Coward's model, suggested that these faults may have acted as extensional structures controlling basin formation and volcanism. However, they pointed out that, as dykes with petrological affinities to the Mauchline lavas and also the Late Carboniferous tholeiitic dykes have east-west trends, the extension may have been north-south.

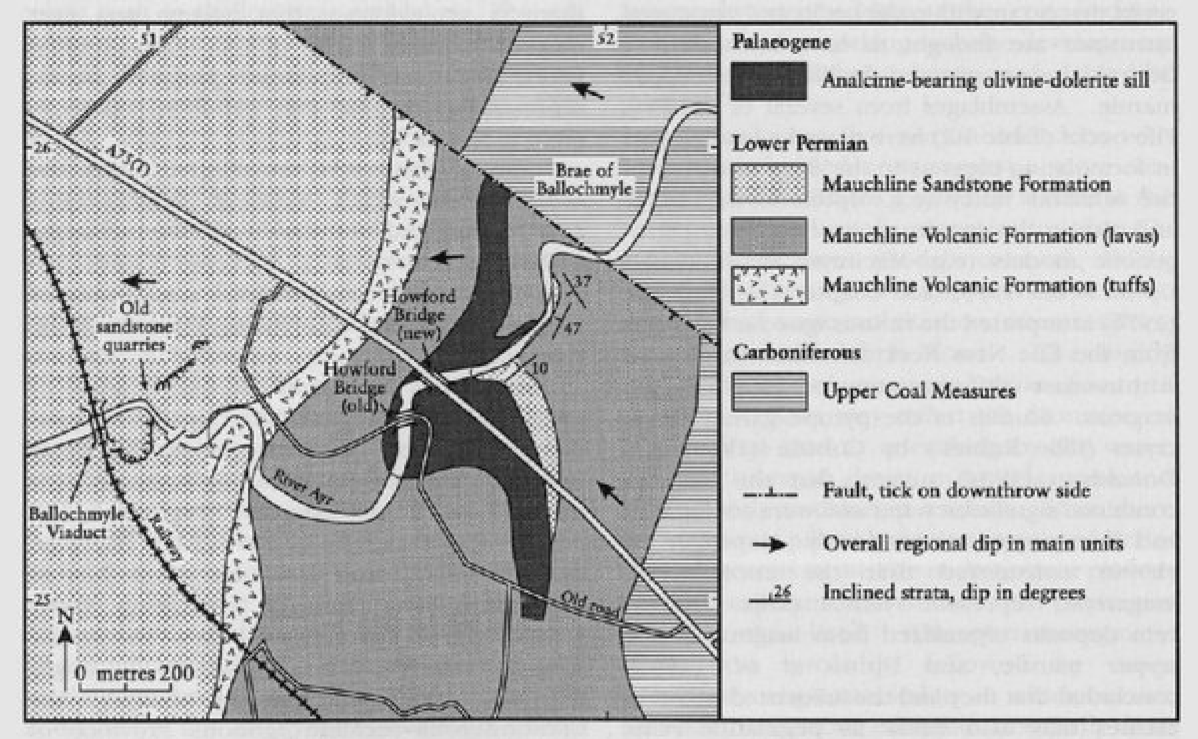
Conclusions

The volcanic rocks that crop out at the Howford Bridge GCR site are representative of the Mauchline Volcanic Formation, the extrusive product of one of the youngest magmatic events in the Carboniferous-Permian Igneous Province of northern Britain. Many volcanic necks, plugs and sills in and around the Mauchline Basin are related to these rocks and they may have formed part of a larger volcanic field that included the comparable sequences of the Thornhill and Sanquhar basins to the south-east.

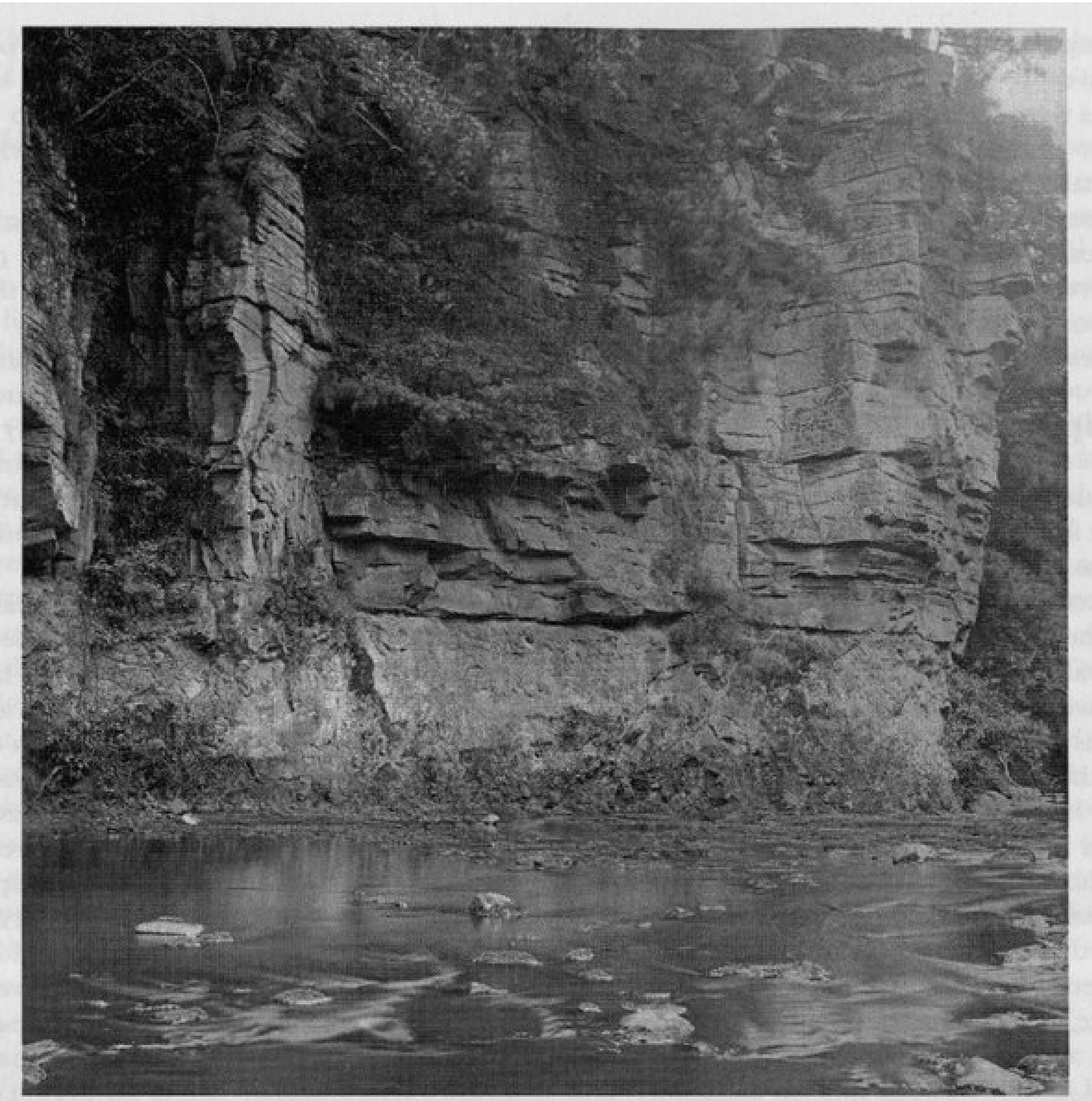
Old quarries that expose wind-deposited, dune-bedded, red sandstones of the overlying Mauchline Sandstone Formation are an added attraction at this site. The intimate association of these continental red beds with the volcanic rocks was a factor that first led geologists to suggest a Permian age for the volcanism, and plant remains have subsequently been found elsewhere in the Mauchline Basin that confirm an Early Permian age. Since both lithological and palaeontological evidence suggests that the volcanic rocks were erupted close to the Carboniferous-Permian boundary, they have international importance as a source of material for radiometric dating, and recently obtained dates have contributed to the currently accepted boundary age of 290 million years.

The lavas and tuffs at this site are mainly basaltic and some are very deficient in silica (basanites). They are some of the most silica-undersaturated and alkaline in the whole igneous province and hence are of considerable interest. They play an important role in developing a consistent model for the magmatic origin and development of the province, which in turn is of great relevance to the broader aspects of magmatism and basin development in Britain and north-west Europe during Late Palaeozoic times. An alkali dolerite sill in the eastern part of the site is of much younger, Palaeogene age and is related to similar sills on the Isle of Arran.

References



(Figure 4.11) Map of the area around the Howford Bridge GCR site. Based on Geological Survey 1:10 560 sheets NS 52 NW (1966); and NS 52 SW (1964).



(Figure 4.12) Cliffs of the River Ayr near Howford Bridge, showing aeolian sandstones of the Mauchline Sandstone Formation, overlying poorly bedded tuffs of the Mauchline Volcanic Formation. (Photo: British Geological Survey, No. C2917, reproduced with the permission of the Director, British Geological Survey, © NERC.)