Dumbarton Rock, West Dunbartonshire

[NS 400 745]

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Introduction

The prominent landmark of Dumbarton Rock, on the north bank of the River Clyde at its confluence with the River Leven, has been a fortified site since the 5th century AD or earlier. Its situation, visual impact and state of preservation make it particularly significant as an example of a volcanic plug. It is the westernmost of a series of basaltic plugs and necks, extending in a broad belt for more than 25 km in an ENE direction as far as the Campsie Fells, that define the Dumbarton–Fintry volcanotectonic line (Whyte and MacDonald, 1974; Craig and Hall, 1975; (Figure 2.3); see Campsie Fells GCR site report). The plug cuts Tournaisian sedimentary rocks of the Inverclyde Group, and the nearest outcrops of possible associated lavas (the Visean Clyde Plateau Volcanic Formation) occur about 2.5 km to the north-east in the Kilpatrick Hills, and 1.5 km to the south, on the opposite bank of the River Clyde.

Despite its easy accessibility, the excellent exposures of fresh glacially smoothed rock and the well-exposed relationships of the intrusive basalt with adjacent tuffs, agglomerate and sandstone, very little was published on Dumbarton Rock prior to a detailed investigation by Whyte (1966). Its popularity as a geological excursion locality is reflected by descriptions in field guides, based largely upon Whyte's account (Whyte and Weedon in Lawson and Weedon, 1992). Further geochemical aspects were discussed by Whyte (1980) and a single K-Ar whole-rock age determination of 302 ± 8 Ma (*c.* 308 Ma using new constants) was reported by De Souza (1979).

Description

Dumbarton Rock rises to a height of 73 m above the reclaimed intertidal mudflats at the mouth of the River Leven (Figure 2.30). It is roughly oval in plan having an east–west elongation of 275 m and a north–south width of 200 m. A NW-trending gully divides the summit area. There is a distinctive pattern of columnar jointing. The columns, averaging about 60 cm in diameter, fan downwards and outwards at steep angles, with a tendency in some places for the inclination to become shallower near the base of the Rock (Figure 2.31).

The relationship between the intrusive basalt, adjacent pyroclastic rocks and associated sedimentary rocks is seen only on the north-west side of the plug [NS 399 746] where bedrock is exposed along about 80 m of shoreline. At the southern end of the section, sandstone, beds of fissile mudrock and carbonate rocks ('cementstones) of the (Tournaisian) Ballagan Formation dip steeply towards the contact. The sedimentary rocks are in the form of isolated blocks up to about 20 m in length, which are either faulted against tuffs and agglomerates or have fallen into them in the volcanic vent (Whyte, 1966).

There is a narrow zone of contact alteration, up to 15 cm wide, in the sandstones and 'cementstones' adjacent to the plug, and sandstone xenoliths up to about 30 cm in diameter have been incorporated in the basalt. In the xenoliths, quartz may have been altered to tridymite in reaction rims. The basalt close to the contact is chilled and highly altered. The groundmass olivine and augite are completely altered to chlorite and the feldspar to albite; abundant amygdales are also present, containing spherulitic green chlorite and in some cases a little calcite. Chemical analyses indicate the incorporation of a significant amount of water into the basalt at, or closely following, the time of intrusion. This effect decreases away from the contact and is hardly discernible a metre or so into the plug. Within this 1 m zone, barium and strontium decrease in concentration towards the margin of the basalt and there is a corresponding increase in concentration of barium and, to a lesser extent, strontium in the immediately adjacent sedimentary rocks, especially in sandstone (Whyte, 1980).

Away from the contact zone the basalt of the plug is fine grained and has a uniform micro-porphyritic texture with microphenocrysts of labradoritic plagioclase and olivine (Fa_{31}) set in a fine-grained groundmass of plagioclase, generally granular augite and opaque iron oxides. Accessory minerals include chlorite, analcime and apatite. In addition to the xenoliths of country rock incorporated in the margins, a few dunitic xenoliths have been found. Although no mineral layering has been detected, flow texture of microphenocrysts and groundmass feldspar laths is common. There is an apparent increase in the ratio of plagioclase to augite from an average of 2.3:1 at the base of the rock to 4.2:1 at the summit. Such variations in mode are common within lavas and plugs of basaltic affinity in the Clyde Plateau Volcanic Formation.

Compositions of fresh basalts from Dumbarton Rock (Whyte, 1966, table 2) are similar in most respects to those found in lavas and plugs of Visean age in the nearby Kilpatrick Hills. The magnesium content, although unusually low, is within the range of variation found within the Clyde Plateau Volcanic Formation (MacDonald and Whyte, 1981). The fresh rock is nepheline-normative and De Souza (1979) suggested that it should therefore be regarded as basanitic. However, no modal nepheline and only accessory amounts of analcime have been identified. On these grounds the rock should be termed an alkali olivine basalt. It differs petrographically from many lavas of the Kilpatrick Hills and other parts of the Clyde Plateau Volcanic Formation only in the freshness of the olivine. The freshness is reflected by relatively high FeO/Fe_2O_3 ratios, a feature that it shares with other plugs associated with the formation. This contrasts with the lavas, in which late-stage alteration, attributable to autometasomatism, increases the proportion of ferric iron. In turn this affects the norm calculation in such a way that the lavas often appear to be more silica-saturated than the plugs.

Interpretation

It has commonly been assumed that Dumbarton Rock was emplaced as a vent intrusion at or near the top of the conduit of a volcano that was active during the time of eruption of the lavas of the Kilpatrick Hills (Whyte, 1966). However, whereas the northern outcrops of the Clyde Plateau Volcanic Formation appear to have been erupted between about 330 Ma and 320 Ma (*c.* 337–327 Ma with new constants), a single K-Ar determination of a sample of fresh basalt from Dumbarton Rock yielded a date of *c.* 308 Ma with new constants (De Souza, 1979). This, together with the perceived basanitic nature of the plug, led De Souza to suggest that the emplacement of the plug took place in Late Carboniferous time and hence that it was not related directly to the Visean volcanism. There is nothing particularly distinctive about Dumbarton Rock in its geographical setting that would set it apart from other vent intrusions in the northern Clyde Plateau and, given the apparent petrographical affinities with the adjacent lavas and plugs, it seems appropriate, for now, to regard the single Late Carboniferous K-Ar date as an anomaly. This fresh intrusion would, however, be a good subject for further dating by the Ar-Ar method, not only to clarify its own association but also to date the age of volcanism in this part of the Midland Valley more accurately.

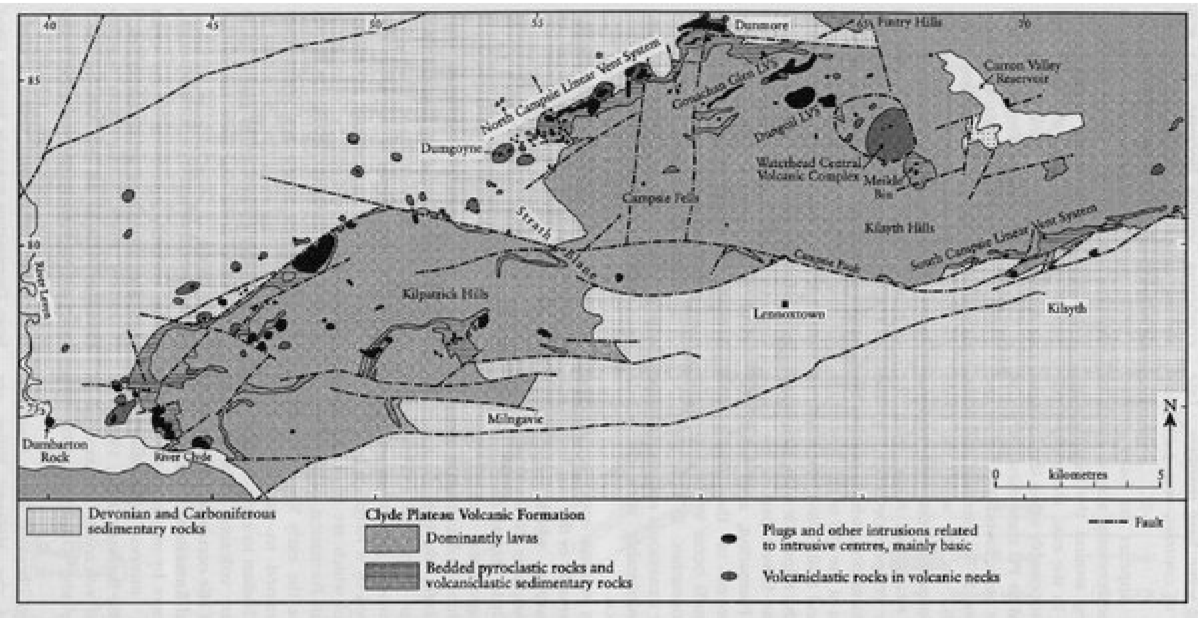
The joint pattern of Dumbarton Rock is consistent with the base of the cooling body of intruded basalt liquid having the form of an inverted cone. Hence Whyte (1966) deduced that the form of the base of the intrusion could have been determined by the shape of the volcanic crater into which it was emplaced. The basalt of the plug contains abundant amygdales in the contact zone but these become much less common away from the contacts. The presence of amygdales is a clear indication that the basalt was emplaced at low pressure and most likely at a time when there was a connection with the surface. From this it can be inferred that the plug infilled the vent of an active volcano and might indeed represent the lower part of a lava lake that formed in the active crater. Lava lakes formed in such conditions can remain liquid for sufficient time to allow degassing to take place; hence the paucity of amygdales in all but the chilled margins of the plug. The degassing of the magma could account for the freshness of the olivine, which in Visean volcanic rocks is almost invariably replaced by secondary minerals. Mineralogical and geochemical evidence also suggests the subsequent outward migration of volatiles, resulting in chloritization, albitization and some leaching of trace elements from the basalt into the immediately adjacent country rock (Whyte, 1980).

The marginal ring of pyroclastic rocks contains tilted blocks of the Ballagan Formation that are at a structural level below its inferred base in this area. Hence the Ballagan Formation beds most likely collapsed into the open vent, along with parts of the cone, during an interval of decreased eruptive intensity, and are preserved in a subsided cylindrical block within an inferred ring-fault (Figure 2.31) and (Figure 2.32). From the above it appears highly probable that the plug was emplaced at a time when the crater of the volcano was open. The lava lake so formed could well have been overflowing to produce a lava flow, now removed by erosion. Similar historical monogenetic volcanoes commonly erupt continuously for periods of many weeks or months and so there would have been adequate time to supply the fluids, and maintain the temperatures needed to account for the observed contact phenomena.

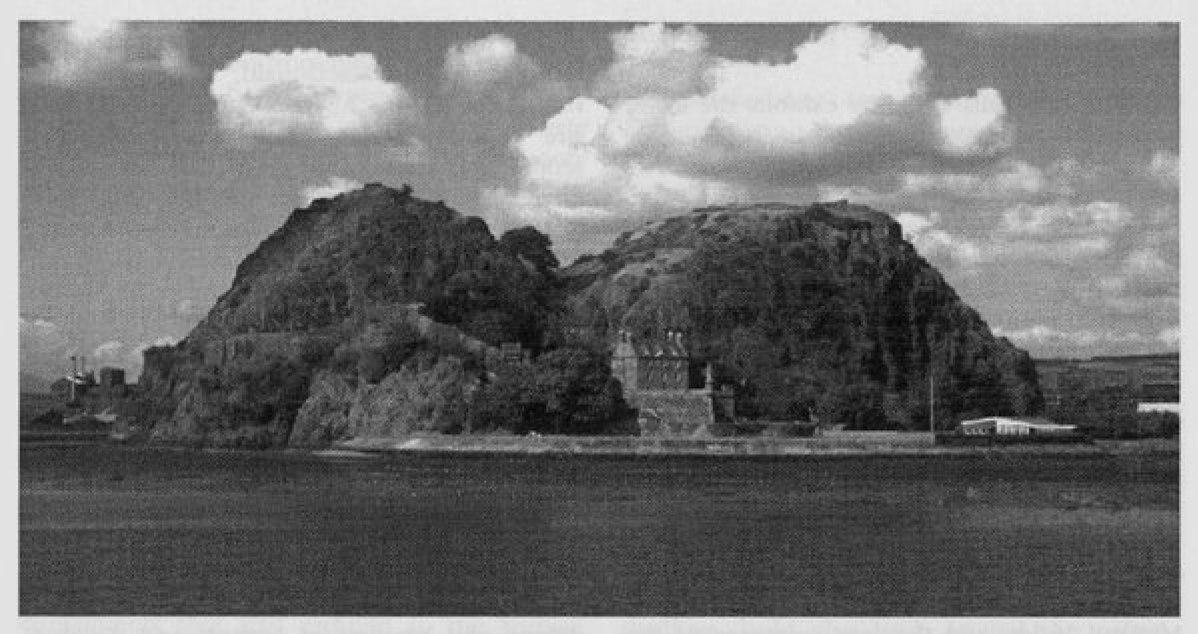
Conclusions

The Dumbarton Rock GCR site combines historical significance as a fortified site with geological importance as the remnant of a mass of lava that solidified in the crater of an Early Carboniferous volcano. It is composed of alkali olivine basalt and has close petrographical and geochemical affinities with the Visean volcanic rocks of the Clyde Plateau Volcanic Formation in the adjacent Kilpatrick Hills. It has special significance as an example of a volcanic plug. Its isolated position, standing above the mudflats of the Clyde estuary, provides a three-dimensional view of the columnar joint pattern that is unrivalled in the west of Scotland. The level of erosion also exhibits the relationships between the basalt plug, remnants of the volcanic cone and country rocks that are seldom seen in the remains of Palaeozoic volcanoes. A single K-Ar radiometric date that suggests a Late Carboniferous age appears to be anomalous in the light of the other evidence and highlights the need for further dating using more accurate modern methods.

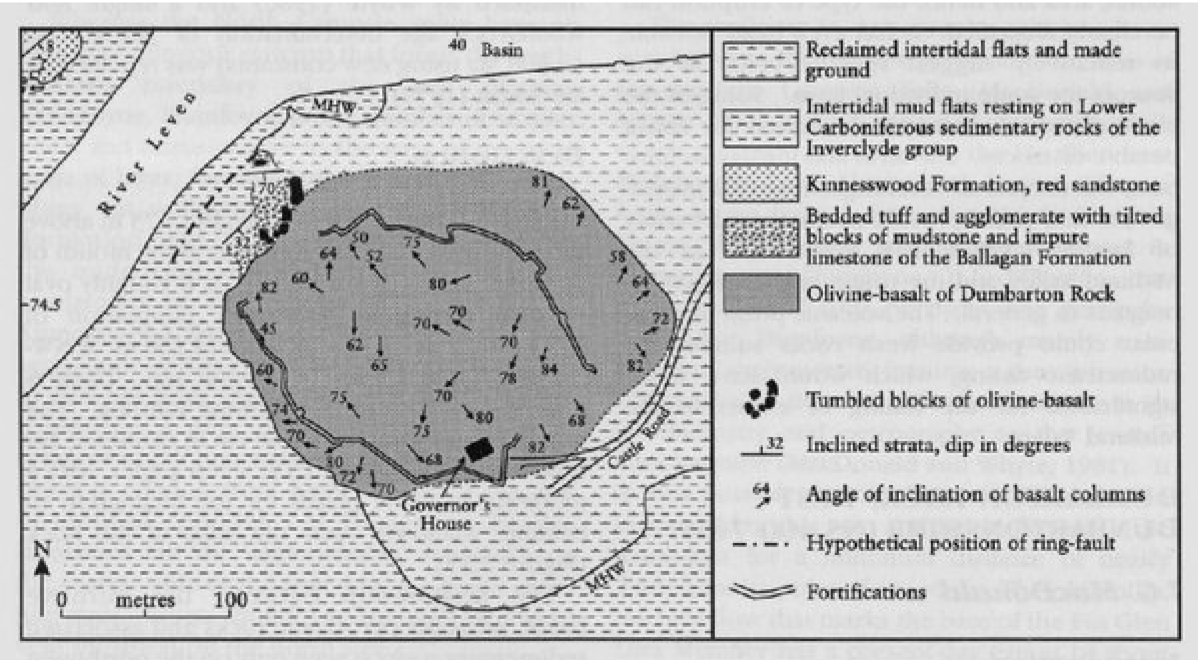
References



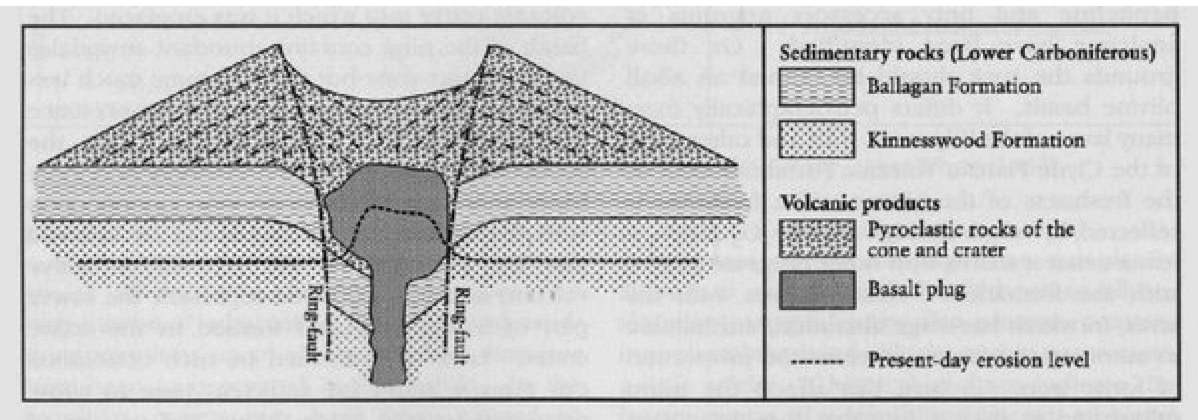
(Figure 2.3) Map of the Kilpatrick Hills and Campsie Fells, showing outcrops of the Clyde Plateau Volcanic Formation and volcanotectonic lineaments defined by plugs, necks and proximal volcaniclastic beds. The most prominent lineament, along the north-west edge of the volcanic outcrops, is the Dumbarton–Fintry Line of Whyte and MacDonald (1974). Based on British Geological Survey 1:50 000 sheets 30W, Greenock (1990); 30E, Glasgow (1993); and 31W, Airdrie (1992).



(Figure 2.30) Dumbarton Rock, a plug of olivine basalt, from the River Clyde. (Photo: J.G. MacDonald.)



(Figure 2.31) Map of the area around the Dumbarton Rock GCR site. After Whyte (1966).



(Figure 2.32) Diagrammatic cross-section illustrating possible structures associated with the Dumbarton Rock volcano. After Whyte (1966, fig. 4). where in the Clyde Plateau Volcanic Formation. They also occur in the Paleocene lava sequence of the Isle of Skye, where they are represented by the Roineval GCR site in the British Tertiary Volcanic

Province GCR Volume (Emeleus and Gyopari, 1992).