Dunrod Hill, Inverclyde

[NS 236 741]–[NS 246 721]

D. Stephenson

Introduction

Dunrod Hill, 5 km south of Gourock, is part of the Renfrewshire Hills succession of the Clyde Plateau Volcanic Formation, of Dinantian age. The lavas are typical representatives of the Strathgryfe Lava Member, which comprises the thickest part of the formation and dominates the northern part of the Renfrewshire Hills. It has been selected for the GCR because of excellent exposures of composite lava flows of hawaiite composition, first described by W.Q. Kennedy in 1931. Such flows, comprising a markedly feldspar-phyric upper part overlying an aphyric base, are fairly common in the Strathgryfe Lava Member and have also been described elsewhere 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).

The Renfrewshire Hills succession is typical of the Clyde Plateau Volcanic Formation in that it comprises mainly lavas of a mildly alkaline to transitional, alkali-basalt series, dominated by olivine basalts, hawaiites and mugearites, but ranging locally through to trachyandesites, trachytes and rhyolites (Johnstone, 1965; Paterson *et al.,* 1990; Monro, 1999). The whole succession may be up to 1000 m thick in the north of the hills, of which up to 750 m are the Strathgryfe Lava Member. This member is characterized by feldspar-phyric flows ('Markle' type in the local classification), mostly of hawaiitic composition, and aphyric mugearites in approximately equal proportions; there are few basalts. The eruptions were entirely subaerial and the presence of reddened flow tops and lateritic beds are indicators of tropical weathering between eruptions. Pyroclastic rocks are rare in the main basalt–hawaiite–mugearite sequences and there are no features to suggest a central volcano. The lower parts of the lava pile are cut by numerous dykes with a predominant northeastward trend, particularly along the projected continuation of the Dumbarton–Fintry Line (see 'Introduction' to this chapter), which may mark the site of fissure eruptions.

A general description of the volcanic succession in the northern part of the Renfrewshire Hills is given in the British Geological Survey memoir (Paterson *et al.,* 1990), and many analyses from the district have been included in a geochemical and petrological study of Dinantian lavas of the Midland Valley by Smedley (1986a,b, 1988a). Subsequent to the description by Kennedy (1931), the composite lavas were included in a general study of composite bodies by Boyd (1974), who included 18 analyses from this GCR site. The radiometric age of the Clyde Plateau Volcanic Formation as a whole has been suggested as 335 Ma to 325 Ma, based upon K-Ar whole-rock and mineral dates of the freshest lavas and associated intrusions (De Souza, 1982). This is broadly compatible with its lithostratigraphical position (within the Strathclyde Group), which, in the absence of any reliable biostratigraphical data, suggests a Visean age.

Description

The area between Dunrod Hill and Greenock is a fault-bound block of lavas, separated from the main outcrop of the Clyde Plateau Volcanic Formation in the northern Renfrewshire Hills by the Largs Fault Zone. This structure is a major NNE-trending splay off the Highland Boundary Fault and has a complex history of movement, mainly prior to the eruption of the lavas, but with some post-lava movement (Paterson *et al.,* 1990). To the north-west, the lava outcrop is cut by the Spango Valley along the line of the NE-trending Inverkip faults, which are also probably related to the Highland Boundary Fault. The south-western flank of Dunrod Hill is controlled by the Dunrod Fault, juxtaposing the lava sequence against the strati-graphically lower Clyde Sandstone Formation which forms slightly lower hills to the southwest.

The name 'Dunrod Hill' was formerly applied to the whole of the hill above and to the northeast of Shielhill Glen (cf. Kennedy, 1931), whereas on modern maps it is restricted to the 298 m hilltop with a triangulation pillar [NS 240 726]. The GCR site is centred upon the hilltop now known as 'Cauldron Hill' [NS 236 729] and is bound to the south-west and north-west by the aqueduct that takes water from Loch Thom to Greenock (Figure 2.33).

Within this area the volcanic succession dips gently to the north or NNE and consists entirely of hawaiite and mugearite lavas. The former are notably feldspar-macrophyric with a dark-purple matrix. The central parts of flows are generally massive and these tend to form low crags and the more obvious topographical features of the area. The mugearites are pale grey, fine grained and aphyric. Their exposures are characterized by closely spaced jointing broadly parallel to the flow surfaces, and some weathered surfaces have lines etched in a similar orientation. In thin section these planar features are seen to reflect an orientation of the ground-mass feldspars, which is almost certainly due to flow foliation. Both types of lava have amygdaloidal zones, most notably, but not exclusively, at the top and bottom of the flow, where they are commonly associated with autobrecciation and hydrothermal alteration. Such zones weather more easily than the more massive central parts of flows and are exposed mainly in stream sections.

The composite lavas that are the main feature of this site are best exposed high on the western flank of Cauldron Hill, where they form conspicuous crag features (Figure 2.34). Kennedy (1931) identified two such flows on Cauldron Hill and a further one around the headwaters of the Hole of Spango. The current 1:10 000 scale British Geological Survey map (NS 27 SW, 1987) shows far more faults than the original (Kennedy) mapping, so that the correlation of flows between fault blocks is less certain, but there are certainly at least two composite flows in this area. Similar flows also occur a short distance to the north of the site.

The lower part of each composite flow is aphyric and usually exhibits the platy jointing and foliation that is characteristic of mugearite flows. This is overlain by macroporphyritic lava with abundant (15 to 22%) feldspar phenocrysts up to 15 mm in diameter and rare (less than 1%) microphenocrysts of clinopyroxene and titano-magnetite. The relative proportions of the two facies vary, but the flows are always asymmetrical with typical thicknesses of about 1 m for the lower facies and 5 m for the upper. The junction between the facies is gradational in places, but more commonly it occurs abruptly over a distance of only a few centimeters. There is no sharp contact and neither facies is chilled. The fine-grained groundmass of the upper facies is indistinguishable from the lower facies and seems to be in continuity with it. In some places, rare macrophenocrysts of feldspar, similar to those of the porphyritic facies, are observed in the upper 80 cm of the aphyric facies. The junction occurs within the massive, central part of the flow and there is never any intervening amygdaloidal or slaggy, brecciated zone, such as is usually seen at flow margins. In most exposures the junction is planar and parallel to the flow surface, with only minor irregularities. However, Kennedy (1931) recorded interfingering in places and cites several instances where one or other of the facies is pinched out. In most cases, this absence of one facies is based on correlation of flows between exposures and is difficult to substantiate. However, at one place the aphyric lower facies is seen to cut up through the porphyritic upper facies, with platy jointing parallel to the junction and clearly dipping at a higher angle than is usual (Kennedy, 1931, locality B; [NS 2333 7316]). Junctions with underlying and overlying flows, where seen, exhibit the slaggy, brecciated and amygdaloidal zones that are typical of the lava sequence and leave its extrusive nature in no doubt.

Almost all analyses from the composite flows (Kennedy, 1931; Boyd, 1974) fall within the field of hawaiite, whether in the classification based on normative composition (as used for Scottish Dinantian lavas by Macdonald, 1975; Smedley, 1986a; Paterson *et al.,* 1990; Monro, 1999), or in the TAS (total alkalis/silica) system based on oxide percentages (as favoured by Boyd, 1974, and the IUGS classification of Le Maitre, 2002). In the normative classification the more basic compositions could be classed as 'basaltic hawaiites'. Boyd (1974) analysed both whole-rock and groundmass from several samples, confirming field and petrographical observations that the groundmass of the porphyritic facies is very similar to analyses of aphyric rocks close to the junction of the facies. Slightly more fractionated aphyric rocks occur in the lowest parts of the flows, farthest from the junction; these fall just within the mugearite field in the TAS classification. In common with most lavas of the Clyde Plateau Volcanic Formation, the rocks are transitional alkaline and are mostly olivine-hypersthene-normative.

The petrography of the two facies has been described in detail by Kennedy (1931). Feldspar compositions are particularly instructive and have been studied by Boyd (1974). Despite the hawaiitic whole-rock compositions, the plagioclase macrophenocrysts in both facies are very calcic. In the porphyritic facies, complexly zoned cores of bytownite ranging from An_{78-68} are surrounded by normally zoned rims of labradorite, An_{70-58}. The rare macrophenocrysts in the top of the aphyric facies have compositions of An_{76-70}, identical to the cores in the porphy-ritic rock. Scattered microphenocrysts in the aphyric facies ($An_{55–28}$) are andesine, identical in composition to the groundmass feldspars of the porphyritic facies ($An_{55–30}$). Groundmass feldspars in the aphyric rocks are strongly zoned in the andesine range, $An_{40–28}$. Normative feldspar compositions suggest that significant alkali feldspar (?anorthoclase) may be present in the groundmass.

Interpretation

There can be little doubt that where the two rock-types at Dunrod Hill are juxtaposed as described above, they are parts of a single composite body. The massive, fresh exposures pass upwards and downwards into typically rubbly and amygdaloidal marginal zones, but the internal junction is near planar, undisturbed, unaltered and the aphyric facies seems to be continuous with the groundmass of the porphyritic facies. The two facies cannot have originated as separate flows. Although the transition from porphyritic to non-porphyritic is abrupt, there is no sign of a chill or any other manifestation of a sharp intrusive contact. Nor are any other sharp contacts observed within the bodies, so the possibility of either (or both) of the components having been intruded as sills into a pre-existing lava is unlikely.

The mechanisms whereby composite lava flows may be generated and preserved are more difficult to envisage than those responsible for composite intrusions, in which pulses of magma from either the same or from various sources are channelled up a common conduit. Kennedy (1931) discussed the possibility of some form of in-situ separation of crystals that were suspended in the magma on extrusion. He dismissed gravitative differentiation on the grounds that plagioclase crystals should sink, rather than float, in a magma of hawaiitic composition. He also reasoned that complete separation would be unlikely in the short time between eruption and the cooling magma becoming too viscous to allow movement of crystals. Separation due to liquid or viscous flow also seems unlikely to have produced such clear and complete separation without any sign of turbulent flow patterns, however slight, or of intermingling at the junction of facies.

Kennedy (1931) concluded that the differentiation must have occurred prior to extrusion and that the eruption involved two types of magma from 'separate bodies within the magma basin'. Although near-simultaneous eruption and intermingling of two distinct magmas can be inferred at Craigmarloch Wood [NS 345 719], from another composite flow in the Renfrewshire Hills described by Kennedy (1933), it does not seem necessary to invoke such a complex and coincidental event for the Cauldron Hill flows. The detailed geochemical and mineralogical data of Boyd (1974) confirm the impression gained from field relationships and petrography that the two rock-types are not only close in whole-rock composition, but also show evidence of a close genetic inter-relationship. The distribution of trace elements, particularly Sr, Ba and Rb, strongly suggests plagioclase fractionation, and numerical modelling is able to predict the observed compositional range simply by fractionation of the observed phenocryst phases. In this respect the Cauldron Hill composite flows differ from others studied by Boyd, which require more complex processes.

So, it is likely that the flows were erupted from magma chambers in which the crystallization and settling of plagioclase and, to a much lesser extent, clinopyroxene and titano-magnetite had resulted in zoning in terms of both mineral proportions and bulk magma composition. The upper, phenocryst-free portion was erupted first, followed by phenocryst-bearing magma, possibly as the phenocryst-free magma became exhausted. The continuous nature of the groundmass at the junction between the two phases suggests that full crystallization of the first pulse had not occurred when it was overridden by the second, possibly within a few hours by analogy with modern flows. Kennedy (1931) cited localities where the later pulse completely overran the earlier pulse to rest directly on the underlying flow, and other localities where only the earlier pulse reached. Such occurrences are highly likely, but are difficult to recognize and substantiate on the ground.

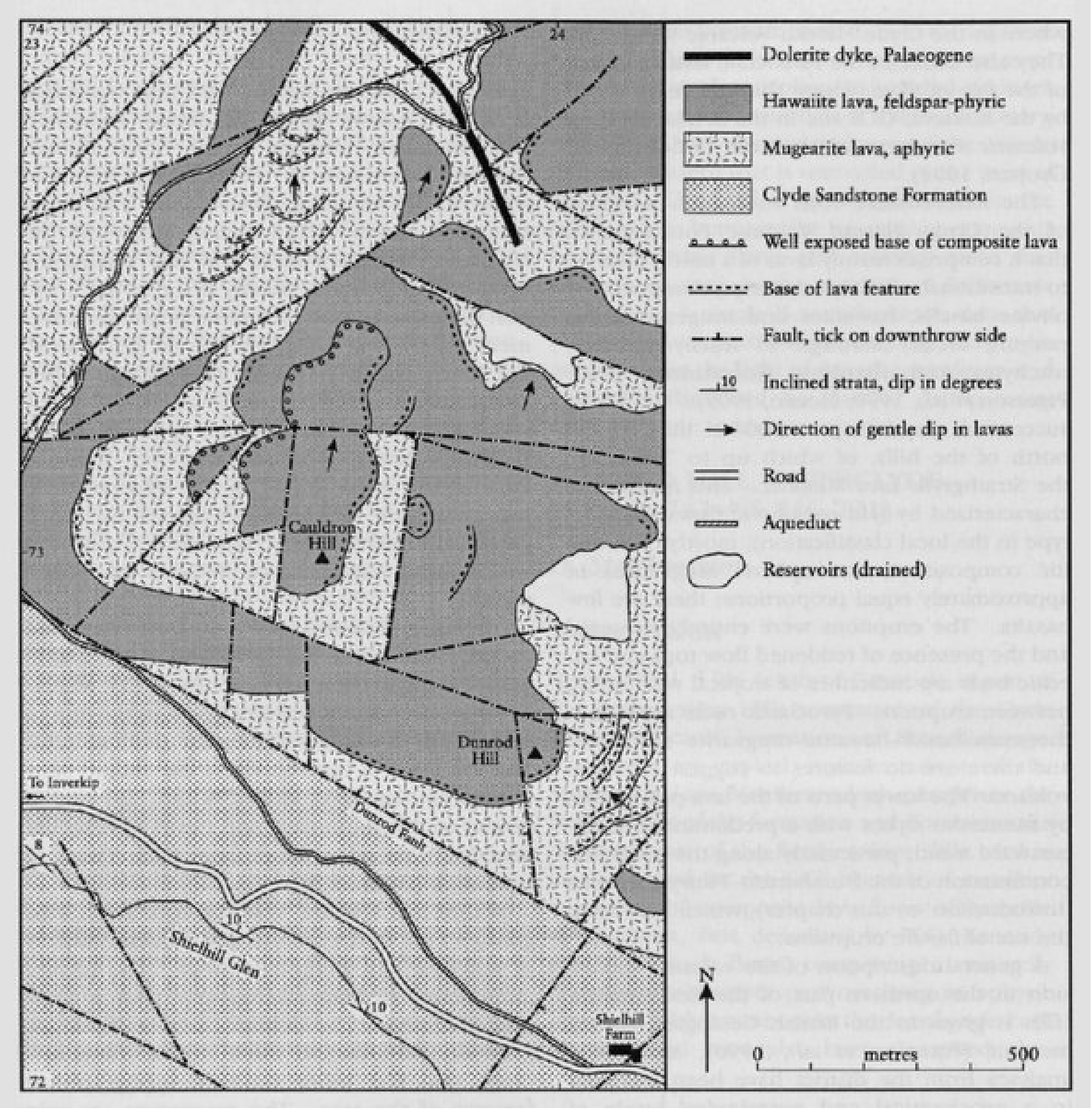
Given the limited variation in whole-rock composition seen in the composite flows and the inferred rapid sequential changes during the eruptions, it is probable that the magma chambers were small local developments, quite close to the surface. Maybe they were similar in form to compositionally zoned dykes that are exposed elsewhere in the world (e.g. South Greenland; Bridgwater and Harry, 1968). These in turn were probably fed from deeper magma chambers where the hawaiitic magmas were produced by higher pressure fractionation of mantle-derived alkali olivine basalts; the bytownite cores to the macrophenocrysts may be relics of this early stage. The compositional range throughout most of the Strathgryfe Lava Member is not much greater than that seen in the composite flows, which may therefore provide a model for magmatic differentiation in the whole lava field and possibly even for similar fields worldwide.

Conclusions

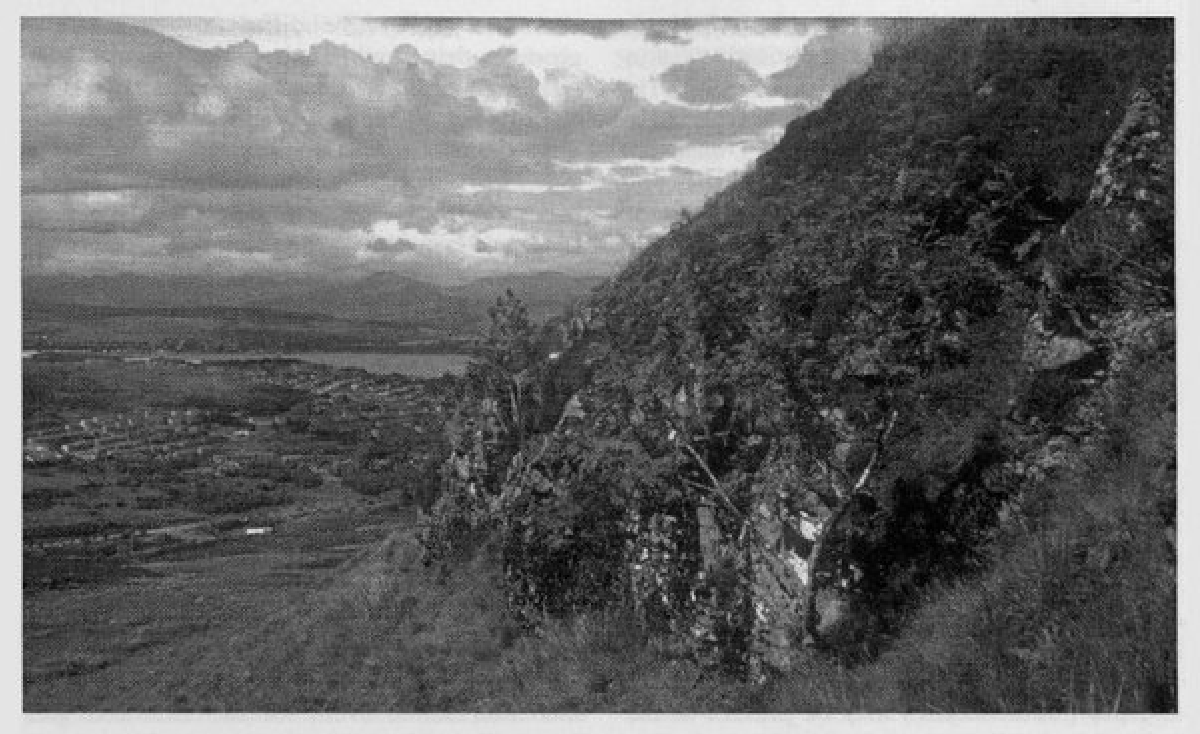
The lava sequence exposed in the area around Dunrod Hill is typical of the Strathgryfe Lava Member, which comprises by far the greatest part of the Visean Clyde Plateau Volcanic Formation in the Renfrewshire Hills. The member is characterized by a restricted range of lavas which are almost all either hawaiites, with phenocrysts (large crystals) of plagioclase feldspar, or slightly more evolved mugearites, which have no crystals visible to the naked eye.

On Cauldron Hill both rock-types can be seen, one above the other, in the same 'composite' lava flows. The relatively sharp but uninterrupted transition between the two rock-types and the close geochemical and mineralogical relationships between them suggest that they were emplaced in rapid succession as pulses of the same eruption. It is likely that the pulses tapped different levels of a near-surface magma chamber that had become compositionally zoned as some of the earliest minerals to crystallize (mainly feldspars) settled out. The Cauldron Hill composite flows are some of the best in Britain and have potential international importance for further studies on the evolution of magmas in high-level magma chambers that feed surface eruptions.

References



(Figure 2.33) Map of the area around the Dunrod Hill GCR site. Based on British Geological Survey 1:10 000 Sheet NS 27 SW (1987).



(Figure 2.34) View from the north-west flank of Cauldron Hill, towards Gourock and the River Clyde. The low crag is typical of the composite hawaiitic lavas in the Dunrod Hill GCR site. (Photo: D. Stephenson.)