Benbeoch, East Ayrshire

[NS 484 085]–[NS 498 081]

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Introduction

A suite of basic alkaline intrusions was intruded into the sedimentary basins that now comprise much of the Midland Valley of Scotland (Cameron and Stephenson, 1985). In the west of the Midland Valley, where the intrusions are mostly of Late Carboniferous to Early Permian age, they include the Saltcoats and Lugar sills (see Ardrossan to Saltcoats Coast and Lugar GCR site reports) and many others in the area between Patna and Dalmellington. These sills are typically olivine bearing and contain a variety of rock-types, with varying proportions of olivine or augite enrichment in the main parts of the intrusion.

The sill of dolerite and picrodolerite that forms Chalmerston Hill, 3 km north-east of Dalmellington (Figure 5.17), provides a good example of a type in which the petrography is dominated by olivine enrichment. The columnar-jointed crags of very fresh dolerite at Benbeoch, which form a distinctive feature at the eastern extremity of the hill, provide a continuous section, about 65 m in vertical thickness, through the greater part of the intrusion (Figure 5.18). Most of the western part of Chalmerston Hill has been excavated as part of a vast opencast coal development and the original land surface no longer exists. However, the opencast working has exposed the base of the sill, which was previously unseen, and a section through the lowest 30 m of sill is to be preserved and landscaped.

The rocks of the Benbeoch Sill are typically 'theralitic', in that they contain significant nepheline, with lesser amounts of analcime, and hence should be classed as nepheline-dolerites. They are also rich in fresh olivine and the sill was selected by Tyrrell (1912) as the type example of a rock-type he termed 'kylite', which is well developed in this part of south Ayrshire. The term was adopted as part of the classification used by the Geological Survey (Eyles *et al.,* 1929, 1949) and hence is of historical significance, but it is no longer used. The most detailed study of the sill was that of Dreyer and MacDonald (1967), who documented the extent of internal modal, mineralogical and chemical variation.

Description

The Benbeoch Sill is intruded into strata of the Upper Coal Measures at the local base of the Barren Red Measures. It forms the main mass of Chalmerston Hill, the highest part of which, Benbeoch (463 m), is bound to the south-east by Benbeoch Crags [NS 496 082] where columnar-jointed picrodolerite occurs in a 40 m-high cliff (Figure 5.18). Here, the top part of the sill has been removed by glacial erosion. The base at Benbeoch Crags is concealed by scree and boulders but some detached slabs, one notably 3 m long, contain a decreasing amount of olivine along their length, passing into what was most likely a chilled margin and hence the base of the intrusion. One such boulder occurs only 12 m below the foot of the cliff, and hence provides a maximum for the amount of the sill that is unexposed at this locality.

Opencast coal workings on the western flank of Chalmerston Hill have exposed a good section of the basal part of the sill around [NS 485 084]. Other sills have been encountered below the main sill and many of the coals close to these sills have reduced amounts of volatiles, enhancing their value. As the bottom contact and the contact zone in the underlying sedimentary rocks is not seen anywhere else, a representative part of the section has been preserved to allow future study. The sedimentary rocks consist of pale-green mudstone resting on laminated sandstones of shallow-water fluvial origin. Obvious baking fades away from the contact within a few metres and there is localized brecciation of the country rocks. The chilled margin of the sill contains sparse small vesicles. Over a distance of less than 1 m above the contact, the rock increases in grain size to a very fresh bluish dolerite in which faint layering can be discerned on weathered surfaces, possibly reflecting very slight modal variations. The coarser-grained gabbro above this is intersected in places by white veins (up to 50 mm in width), containing dark needle-shaped crystals of amphibole. The veins emanate from coalescing patchy areas, have gradational margins and hence are most likely derived from late-stage concentrations of

alkali- and volatile-rich residual liquids from the magma. Similar veins, containing large acicular crystals of the titanium-rich amphibole kaersutite, occur as late differentiates of the Lugar Sill (see Lugar GCR site report). Although some good columnar jointing occurs, the outcrop is dominated by a set of closely spaced, planar, vertical joints trending around 110°. These joints are invariably filled by apparently later zoned veins, dominated by clay minerals and chlorite and containing prehnite, but exhibiting pseudomorphs after plagioclase, clinopyroxene and rare olivine. They have sharp but irregular margins but seem to be due to hydrothermal replacement.

Near the top of Chalmerston Hill, at [NS 490 083], a variety of picrite, exceptionally rich in olivine occurs in a small knoll. It was named 'kylite-picrite' by Tyrrell (1912).

The chilled margin exposed in the large slab below Benbeoch Crags contains equant micro-phenocrysts of carbonated and serpentinized olivine set in a dark turbid groundmass with a few small fresh feldspar laths. About 0.5 m above the margin the rock, although still fine grained, is little altered and contains abundant olivine with peripheral zoning, along with small euhedral zoned pink augites in a sub-ophitic relationship with zoned plagioclase laths. Magnetite and analcime are also present. Both olivine and augite increase in grain size away from the chilled margin but while the augite decreases in abundance there is a corresponding increase in modal olivine (Figure 5.19).

The proportion of olivine in the main part of the Benbeoch Crags section varies only slightly from an average value of 35.5%, except at the top of the section where a decrease in olivine content and a corresponding increase in augite suggest a position only a few metres below the top contact prior to erosion. The olivine (Fo_{75}) is unzoned and occurs as rounded or subhedral crystals, in a few cases enclosed by augite. The strongly zoned, faintly pleochroic augite commonly displays hour-glass twinning. It is rich in titanium and appears to have commenced its crystallization prior to that of plagioclase in view of their sub-ophitic or intersertal relationship. The strongly zoned feldspar has cores of calcium-rich bytownite but grades to andesine at the margins. There is a small amount of fresh nepheline, and analcime and biotite occur as minor components. Tiny needles of apatite occur in the groundmass and as inclusions in the augite. The Chalmerston Hill picrite, estimated to be positioned about 15 m below the top of the sill, contains almost 55% olivine but both the olivine and the plagioclase have the same composition as in the rest of the sill although the augite is not so strongly zoned.

Whole-rock analyses of the Benbeoch and Chalmerston Hill picrodolerites and picrites, together with other 'Icylitic' intrusions of Ayrshire, indicate a trend of high alkalinity and only moderate iron enrichment, relative to analcime-bearing olivine-dolerites such as those that are common in Palaeogene sill-complexes of Scotland (Dreyer and MacDonald, 1967). This could help to distinguish them from sills of Palaeogene age that crop out in adjacent areas of south Ayrshire (e.g. see Howford Bridge GCR site report).

Interpretation

In the Benbeoch Crags section, there is only minor inhomogeneity in the modal proportions of olivine and augite (Figure 5.19). This is matched by small variations in chemical composition. The apparent lack of internal chilled margins, or indeed any sudden discontinuities, suggests that the magma was emplaced in a single pulse. The observed variations in mode near the top and bottom of the sill make it clear, however, that the first intruded magma, as represented by the chilled margins, was significantly less enriched in olivine crystals than that which formed the main part of the sill. There is no evidence here of any measurable concentration of olivine by post-intrusive crystal settling, so such variation in olivine content as has been observed most likely arose in the magma prior to intrusion. The much greater abundance of olivine in the picrite at Chalmerston Hill at a level 'at or a little below the centre of the sill' (Tyrrell, 1912) could be evidence of a separate but contemporary pulse of magma, or an extreme of gradation, in either case representing the last part of the magma to be intruded. The former explanation would resemble the relationships observed in the Lugar and Saltcoats sills, where the most olivine-enriched portions are emplaced last, without chilling.

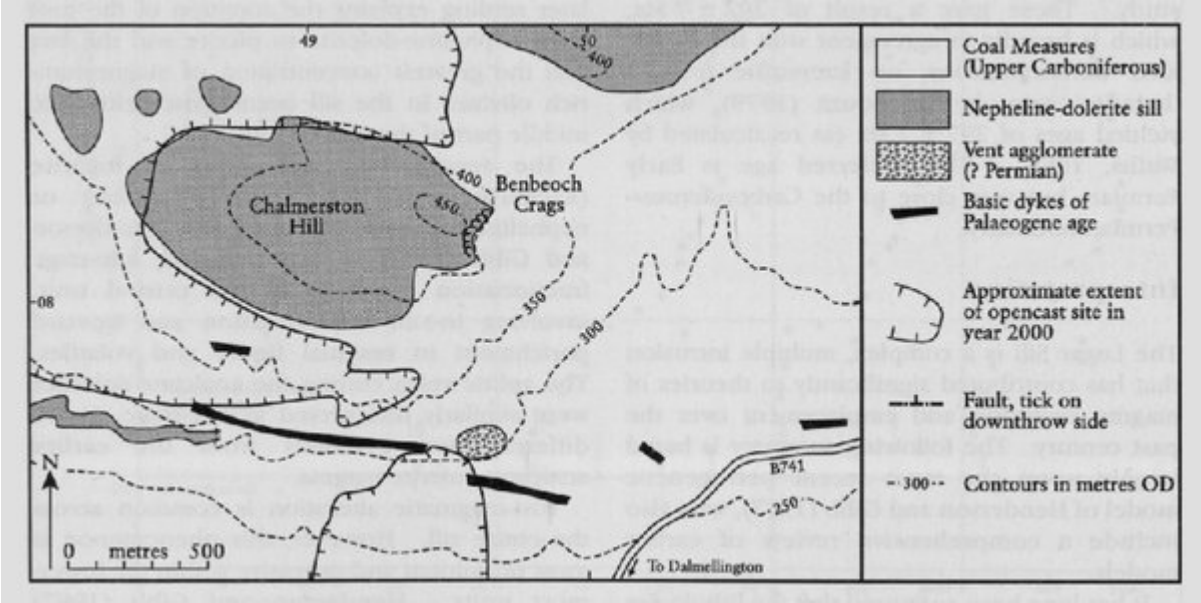
The lack of zoning of the olivine crystals suggests slow growth under conditions approaching stable chemical equilibrium. The similarity in composition of the olivine in both the picrite and the picrodolerite suggests that both rocks originated from the same batch of differentiated magma. If there had been any significant differentiation *in situ* it would have been reflected by a higher magnesium content in the olivine of the picrite. This points to olivine enrichment by some process

prior to intrusion or associated with the movement of the magma in the conduit during emplacement. However, lack of exposure renders the precise relationship of the picrite to the rest of the intrusion uncertain.

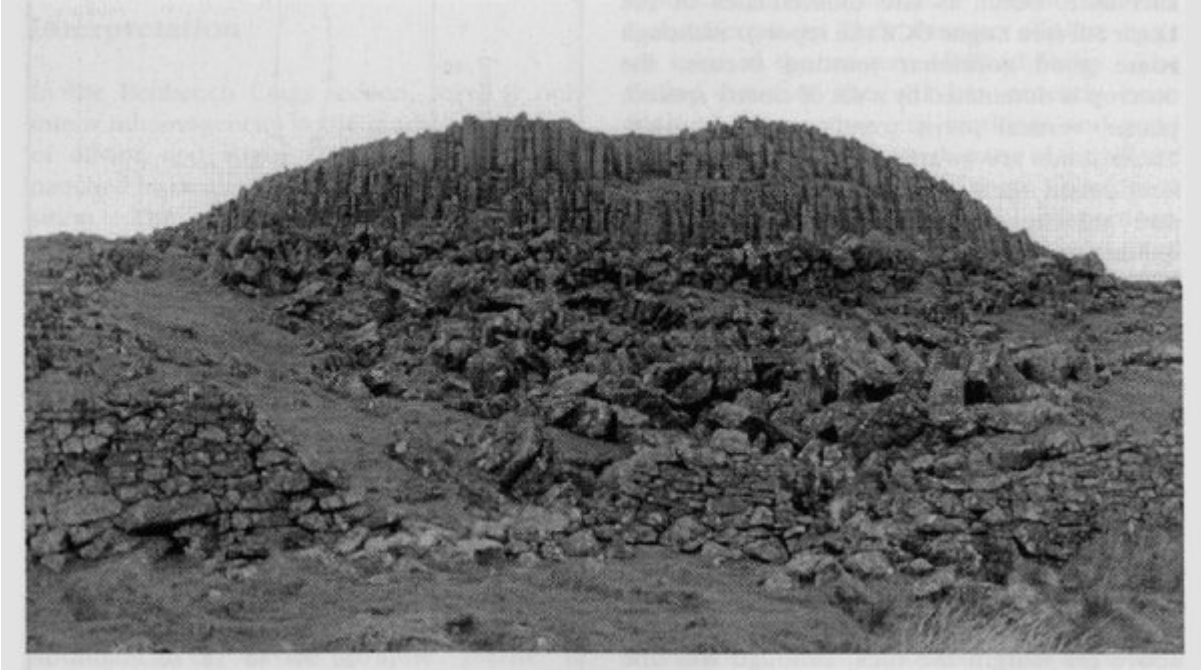
Conclusions

The Benbeoch Sill comprises distinctive olivine-rich varieties of nepheline-dolerite and nepheline-gabbro ('theralites) within the Late Carboniferous to Early Permian alkaline basic sill suite of the western Midland Valley. The chilled base of the sill has recently been exposed in opencast coal workings and good continuous sections through parts of the sill are exhibited here and in natural crags. In addition to vertical variations in mineral proportions, late-stage alkali-rich patches and veins and various types of jointing are well exhibited. The exceptionally fresh condition of the rocks affords the opportunity to expand knowledge of their whole-rock and mineral geochemistry, and hence gain a valuable insight into the origin of the magma and its subsequent evolution prior to, during and following emplacement and crystallization. When linked with detailed studies of similar but subtly different sills, such as that at Lugar, such studies could significantly increase our understanding of Carboniferous–Permian magmatism in northern Britain and also contribute to a wider understanding of the petrogenesis of alkali-rich basic rocks. A continuous drill core through the sill on this site would be particularly useful.

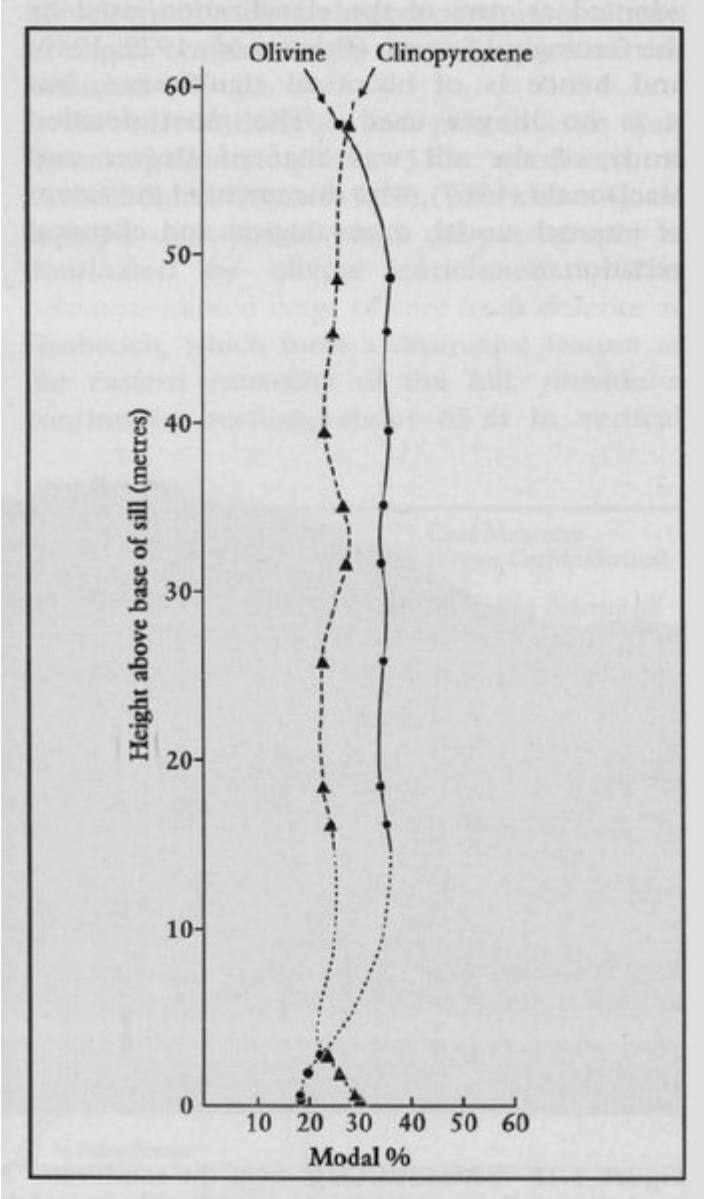
References



(Figure 5.17) Map of the area around the Benbeoch GCR site. Based on Geological Survey 1:10 560 Ayrshire sheets 67NW; and 66NE (both 1910); and 1:63 360 Sheet 14, Ayr (1933).



(Figure 5.18) Benbeoch Crags from the south-east. Note the strongly developed columnar jointing in the nepheline-dolerite of the Benbeoch Sill. The top of the sill has been removed by erosion and up to 12 m at the base is covered by scree and boulders, but a 40 m-thick section is exposed. (Photo: Scottish Natural Heritage.)



(Figure 5.19) Variation in modal olivine and augite through the Benbeoch Sill.