

South coast of Arran

OS Grid Reference: NR952208

Highlights

The site contains the best-exposed dyke swarm in the British Tertiary Volcanic Province and arguably one of the best examples in the world. The nearby Bennan Head composite sill has an exceptionally thick lower margin, and both its margins contain excellent examples of xenocrysts derived from granitic magma.

Introduction

The site encompasses the littoral shore zone from Cleitheadh Buidh east for about 5 km to Kildonan Castle, and the cliff at and immediately west of Bennan Head. The section cuts across the south Arran dyke swarm (consisting here of about 200 basalt and dolerite dykes), forming one of the best-exposed sections through a Tertiary dyke swarm (Figs 6.8 and 6.9). The adjoining Bennan Head composite sill is extremely well exposed around the base of the headland and in the Struey Water to the west; the upper basic member is highly xenocrystic and the lower part of the central quartz porphyry shows signs of hybridization. Baked Triassic sandstones are the country rocks in this area.



Figure 6.8: Dyke swarm on the foreshore at Kildonan. The dykes weather out to form reefs; the softer Triassic sandstone in between has been eroded back. South Coast of Arran site, Arran. (Photo: C.H. Emeleus.)



Figure 6.9: Dolerite dykes forming part of the Arran dyke swarm on the shore below Kildonan Castle (NS 037 209). South coast of Arran site, Arran. (Photo: C.J. MacFadyen.)

The dyke swarm of southern Arran has been recognized for many years, one of the earliest studies being that of Necker de Saussure (1840). Knapp (1973) has studied the form and structure of the dykes and Halsall (1978) has investigated the emplacement and compositional variation of the dykes within this site along the Kildonan shore. A palaeomagnetic study of the swarm has been carried out by Dagley *et al.* (1978).

Description

The site comprises a 10-km-long coastal section from Cleitheadh Buidh (NR 956 208) to Kildonan (NS 037 208), including the sea cliffs near Bennan Head. The exposures of the dyke swarm are principally on the shore (Figs 6.8 and 6.9); the composite sill is seen in the cliffs at Bennan Head and in small quarries to the north.

The southern Arran dyke swarm in this area has a dominant NW–SE trend, although north–south dykes are also abundant and there are subsidiary NE–SW-orientated dykes. Generally, the dykes are subvertical, but some have inclinations of between 60° and 70° to the north-east. Thicknesses vary from a few centimetres up to 30 m. The entire section contains about 200 dykes, representing a crustal dilation of about 10%. Some of the dykes bifurcate and, in several instances, dykes intersect. The shore section reveals clear, 'textbook' examples of features associated with dyke intrusion, such as prominent chilled margins, bedding offsets across dykes, flow-banding, vesicles and amygdalae, jointing and dyke offsets.

Various rock types are represented by the dyke swarm, the commonest being: transitional alkaline olivine dolerite, alkali olivine dolerite (crinanite and teschenite), tholeiitic olivine dolerite and quartz dolerite.

Red and white Triassic sandstones and coarser clastic rocks are the country rocks; they are often bleached and even occasionally metamorphosed to form tough, grey hornfelses which may contain quartz paramorphs after tridymite. The baked margins sometimes stand up as low walls along the dyke margins.

The major, thick composite sill of Brennan Head, with a central quartz–feldspar porphyry component, is flanked above and below by tholeiite. The sill is similar in many respects to the Drumadoon Sill. The base of the intrusion contains some large xenoliths, or rafts, of sandstone and, in the lower part of the porphyry, dark xenolithic bands of dolerite occur near to a small waterfall above the main Struey Falls (NR 993 203). The sections in and near Struey Burn (NR

994 205) show the acidic component to be more melanocratic than normal, and there is evidence for hybridization both by magma mixing and assimilation of xenolithic material. The marginal tholeiitic members, particularly the upper one, carry abundant quartz and alkali-feldspar xenocrysts (cf. Drumadoon Sill) and also scattered hypersthene crystals; the lower marginal tholeiite is exceptionally thick (>10 m).

Interpretation

The site contains the best example of a dyke swarm in the BTVP, including many of the 'textbook' features of dykes and a considerable range in compositions. Consequently, it is a classic section, with international status, and is frequently visited for educational purposes.

Halsall (1978) distinguished ten episodes of dyke and sill emplacement, based on successive, cross-cutting phases of intrusion. He showed that there was a general trend from alkali-basaltic to tholeiitic magmas with time, possibly attributable to increased partial melting of a mantle source as the swarm was intruded. However, superimposed on this simple pattern there was also random intrusion of olivine dolerite, tholeiitic olivine dolerite and tholeiitic dolerite dykes throughout the entire period, suggesting crustal magmatic plumbing similar to that envisaged for the Mull and Skye lavas (Chapter 1).

A palaeomagnetic study of the dykes (Dagley *et al.*, 1978) showed the majority to have reversed magnetization (>75%) and that the proportion showing reversed polarity increased from west to east. There is no simple correlation between polarity and petrography and neither is there a significant difference between mean pole directions of the alkali-basalt and tholeiitic intrusions. Overall, it appears that the dykes span three or four magnetic polarity episodes, reversed–normal–reversed or (more probably) reversed–normal–reversed–normal (Dagley *et al.*, 1978), during a period of about three million years, or four if four polarity periods were involved. Reliable radiometric age determinations are not as yet available for the dykes, but they pre-date the Holy Island trachyte which has been dated at about 58.5 Ma (Macintyre, 1973).

The high percentage of crustal dilation represented by the dykes indicates that Arran lay on a zone of crustal extension and possible thinning during the Palaeocene. Speight *et al.* (1982) consider that the dyke swarms formed above ridge-like, basaltic, magma chambers situated in the lower crust and extending into the mantle. They regard the ridges as fundamental structures in the BTVP, forming in the crust beneath the region in response to shearing stresses associated with the opening of the North Atlantic, and they compare the pattern of dyke swarms in the BTVP with similar, but smaller-scale patterns formed by quartz-filled tension gashes (cf. Speight *et al.*, 1982, Fig. 33.5).

The Bennan Head composite sill intrusion has many features in common with the composite intrusions of the Drumadoon–Tormore site. The principal differences are the thick, lower basaltic and doleritic member at Bennan and the occurrence of fairly numerous baked sedimentary xenoliths near the floor of the intrusion. Intrusion of the mafic rocks appears to have disturbed the country rocks to a much greater extent than at Drumadoon–Tormore. Although no quantitative modal data are available, the Bennan Head sill contains many more obvious examples of quartz and feldspar xenocrysts in its mafic members than are found at Drumadoon–Tormore, particularly towards the top, suggesting mixing with greater amounts of porphyritic acid magma.

Conclusions

The large number of well-exposed dykes and the wealth of intrusive features which they show, make the dyke swarm exposed on the south Arran shore the best example to be found within the Province. The site was thus selected as the type section of a dyke swarm. The intrusion of the dykes has extended the crust by about 10%: this was achieved during the course of as many as ten phases of dyke injection.

Measurements of the remanent magnetization of the dykes show that the swarm was probably emplaced over a period of between three and four million years, spanning three or four episodes of magnetic polarity.

The Bennan Head composite sill provides additional evidence from Arran for the coexistence of basic and acid magmas and that mingling between these occurred both before intrusion and after emplacement of the intrusion.

Reference list

- Dagley, P., Mussett, A.E., Wilson, R.L. et al. (1978) The British Tertiary igneous province: palaeomagnetism of the Arran dykes. *Geophysical Journal of the Royal Astronomical Society*, **54**, 75–91.
- Halsall, T.J. (1978) The emplacement of the Tertiary dykes of the Kildonan shore, south Arran. *Journal of the Geological Society of London*, **135**, p. 462 (abstract).
- Knapp, R.J. (1973) The form and structure of the Islay, Jura and Arran Tertiary basic dyke swarms. Unpublished Ph.D. Thesis, University of London.
- Macintyre, R.M. (1973) Lower Tertiary geochronology of the North Atlantic continental margins. In *Geochronology and Isotope Geology of Scotland* Field guide and reference.
- Necker de Saussure, L.A. (1840) Documents sur les Dykes de Trap d'une Partie de l'île d'Arran. *Transactions of the Royal Society of Edinburgh*, **14**, 677–98.
- Speight, J.M., Skelhorn, R.R., Sloan, T., et al. (1982) The dyke swarms of Scotland. In *Igneous Rocks of the British Isles*. (ed. D.S. Sutherland), Wiley, Chichester, pp. 449–59.