Heads of Ayr, South Ayrshire

[NS 279 183]–[NS 296 186]

I.T. Williamson and A.A. Monaghan (nee Sowerbutts)

Introduction

The Heads of Ayr, a prominent headland and coastal cliffs, is situated on the Ayrshire coast 5 km south-west of the town of Ayr (Figure 2.37)a and (Figure 2.38). It is formed of a succession of volcaniclastic rocks and minor basalt intrusions, interpreted as a volcanic neck and believed to be related to the growth of a moderately sized volcano in Dinantian times. The rocks exposed at the GCR site allow the internal structure of the neck and its lithologies to be investigated in some detail. Some of the included rock fragments are probably derived from the mantle and hence provide an insight into the source region of the magma responsible for the volcanism.

Early, brief accounts of the geology of the area were by Geikie *et al.* (1869) and Geikie (1897). However, the first detailed observations were made by Tyrrell (1920) and these were added to by Eyles *et al.* (1929). Many of their observations were confirmed by Whyte (1963b) in his comprehensive study of the neck. The area has been re-described recently by Sowerbutts (1999) as part of a re-survey of the area by the British Geological Survey. The Heads of Ayr GCR site is frequently used for educational purposes and features in field guides to the region (e.g. Whyte in Lawson and Weedon, 1992).

Description

The volcaniclastic rocks at the Heads of Ayr are well exposed along 850 m of foreshore (NS 284 187–NS 295 188), on a wavecut platform and in the adjacent sea cliffs. The cliffs reach a maximum height of 75 m and form a double headland separated by a central embayment (Figure 2.37)b and (Figure 2.38). The volcaniclastic rocks are juxtaposed against sedimentary rocks of the Dinantian Ballagan Formation (Inverclyde Group) (Sowerbutts, 1999). These generally gently dipping strata comprise interbedded micaceous sandstone, calcareous siltstone and dolomitic limestone ('cementstone'). The contact between the volcaniclastic and sedimentary rocks appears to be nearly vertical, though there are small-scale irregularities where the contact becomes sub-parallel to bedding in the sedimentary rocks. Close to the contact with the volcaniclastic rocks, the sedimentary rocks have been deformed; on the west side of the Heads of Ayr, there is a noticeable increase in dip from about 5° to 28° towards the margin, and rocks on the east side are folded and faulted. Faults are both parallel and radial to the contact, the throws of the latter decreasing abruptly away from it. Sedimentary rocks on the foreshore beyond the eastern margins of the vent are folded into small basin-like structures a few tens of metres across and are intruded by a small boss-shaped mass of lithic tuff (Figure 2.37)b.

The volcaniclastic rocks are interpreted to be pyroclastic, and comprise mainly coarse-tuff, lapilli-tuff, and tuff-breccia, with thin beds of fine-tuff. They vary in colour from green to blue-grey to purplish, generally reflecting the colour of the dominant basaltic clast-type and the degree of alteration of the finer-grained constituents. Most pyroclasts are igneous in origin, but there is also a proportion of sedimentary rock. According to Whyte (1963b), bedded tuff in the western part of the outcrop comprises 96.1% volcanic fragments, commonly cemented by carbonate, whereas rocks in the eastern part contain 97.6% volcanic clasts in a matrix of fine-tuff and crystals. There is a small population of dark-green clasts of serpentinized lherzolite up to 30 cm across. Other clasts include baked 'cementstone', 'cementstone' conglomerate and calcareous sandstone derived from the Ballagan Formation, Devonian pebbly and siliceous sandstones, and Lower Palaeozoic chert and silt-stone. Also found are carbonized fragments of wood.

Sowerbutts (1999) identified several volcaniclastic lithofacies within the Heads of Ayr GCR site:

- *Coarse lithic lapilli-tuff and tuff-breccia is* most common and comprises massive and crudely bedded, poorly sorted rocks. On the western side of the Heads of Ayr are metre-thick massive beds of this lithofacies. On the eastern side, some larger slabs of disrupted Ballagan Formation rocks also occur, including one up to 20 m across (Whyte, 1963b). Clasts in this lithofacies are dominantly of vesicular basalt, rounded to sub-angular and commonly up to 40 cm across. Under the microscope, some very irregular basalt clasts have altered haloes, indicative perhaps of their emplacement as hot pyroclasts. The matrix is poorly sorted fine-tuff.

- *Fine lithic lapilli-tuff* is found on the westernmost side of the neck, consisting of poorly sorted lapilli-tuff in which clasts are generally less than 2 cm across. These rocks are bedded, and normal and reverse grading are common. Some poorly defined, low-angle erosional trough- and cross-bedded structures are present. Locally, strings of larger volcanic clasts also define bedding and some rare, large, almost spherical volcanic blocks of cobble size have sags in the bedding beneath them. The finer fraction comprises lithic volcaniclastic debris and quartz grains.
- *Laminated tuff is* intimately and discontinuously interbedded with the fine lithic lapilli-tuff. In places these beds contain weakly developed troughs and erosion surfaces.

Between the high- and low-tide mark in the central embayment at Heads of Ayr, Whyte (1963b) described mudstone and 'cementstone' country rocks that are cut by an irregular mass of intrusive breccia, and irregular small intrusions of basalt (Figure 2.37)b. The outcrop of sedimentary strata and its intrusive mass is constrained between two NW-trending faults along which dykes have been emplaced *en échelon.* The western marginal dyke is an analcime-basalt considered to be Carboniferous in age, whereas the larger eastern dyke is a composite body with a marginal facies of tholeiitic basalt intruded by olivine-dolerite and probably of Palaeogene age.

Whyte (1963b) described the intrusive breccia as consisting mainly of angular clasts of igneous and much sedimentary rock in a highly chloritized groundmass. Cutting these rocks are small, irregular masses of olivine-augite-phyric 'monchiquitic basalt' (probably a basanite) with fresh nepheline in some samples; clusters of olivine and augite crystals may be derived from ultramafic xenoliths. The margins of these masses are fragmented and grade into the breccia, forming an igneous matrix to the clasts.

Interpretation

Volcaniclastic lithofacies such as those at the Heads of Ayr are difficult to interpret because many of the bedforms, and lithological and sorting characteristics are compatible with deposition in both sedimentary and volcanic regimes. Nevertheless, a volcanic origin has been favoured by all researchers to date. Tyrrell (1920) considered that the two main parts of the Heads of Ayr outcrop formed independently as two necks beneath vents that later coalesced. However, Whyte (1963b, 1968) demonstrated that the two units represent different facies of the same volcanic structure and emphasized the role of subsidence and collapse along ring-fractures in the later stages of the vent's formation. The steep dips in the country rock near the neck, the inward dip of the bedded pyroclastic facies and the orientation of the faults indicated to Whyte (1963b) that subsidence occurred along ring-fractures when magma was withdrawn from beneath the vent. He suggested that the layering in the tuffs could be interpreted as being due to either normal sedimentary processes or fluidization, especially at the neck margins and close to minor intrusions. He also indicated that a fluidization model could explain the emplacement of the intrusive lithic tuff east of the neck.

According to Whyte (1963b), the Heads of Ayr volcano may have reached a height of 600–900 m with a diameter at its base of about 3 km. He proposed the following five-stage model for its development:

1. Neck emplacement and deformation of adjacent sediments (brecciation and upturning) beneath a volcanic vent. A tephra cone was constructed, but was rapidly degraded and re-deposited in a subsiding marginal basin.
2. A larger volcanic cone grew, but subsidence in the basin continued.
3. Subsidence continued with the lateral spread of the volcanic cone and subaerial deposits. There was some deformation of bedded tuffs due to subsidence.
4. Vent collapse and further deformation of the bedded tuffs.
5. Further faulting and intrusion of basaltic magma, with marginal brecciation to produce intrusive breccias and tuffs; followed by regional tilting.

Sowerbutts (1999) concurred that volcanic processes were dominant at the Heads of Ayr. The massive and weak bedforms present with low-angle cross-bedding and abrupt bed-by-bed changes in grain size are typical of phreato-magmatic eruptions involving the interplay between pyroclastic surge and ash-fall mechanisms; the large blocks with bedding sags beneath are typical of ballistic fallout. Eruptive processes of this type would have been readily able to gather sedimentary and ultramafic rock clasts and quartz grains from various depths beneath the volcano. The coherent form of the fragments of Ballagan Formation rocks indicates that at the time of eruption they were sufficiently well lithified to resist disaggregation, but were still plastic enough to deform. It is not unusual to find carbonized wood fragments preserved in modern deposits of this type and they are probably the remains of vegetation growing on the slopes of the volcano.

However, it is unlikely that the volcanic rocks at the Heads of Ayr are the relics of a tephra cone. Such structures have very low potential for preservation within the geological record. The steep, cross-cutting contacts seen at the Heads of Ayr suggest that these rocks represent levels beneath the substrate, probably within the volcanic neck of a tuff-ring. In such a dynamic volcanic environment, collapse of the vent rim along faults and slumping of blocks of strata into the crater are typical features, and localized erosion, mixing with newly fragmented magma and re-deposition of the pyroclastic sediment is commonplace (cf. Kokelaar, 1983). The diameter of modern maar craters, which are regarded as having similar dimensions to tuff-rings, varies up to 3 km with the mode around 800 m (Cas and Wright, 1987). At about 850 m the diameter of the Heads of Ayr structure is consistent with this. Thus, based on both lithofacies and size, the Heads of Ayr Neck may be considered as the concealed part of a substantial tuff-ring. Similar structures have also been deduced from necks in the eastern Midland Valley (see East Fife Coast and North Berwick Coast GCR site reports).

Though a Dinantian age has long been assumed for the volcanic rocks, the strong affinities between the 'monchiquitic basalt' intrusions that cut them and Permian volcanism nearby have confused discussions on the age of the neck from the earliest investigations in this area.

Recent palynological studies on the sedimentary rocks of the Ballagan and Lawmuir formations exposed a short distance east of the Heads of Ayr have thrown new light on this debate (M.H. Stephenson, 2000). Separating these two formations are volcaniclastic rocks, named the 'Greenan Castle Member', which are considered to be associated with the Heads of Ayr Neck. Evidence for the correlation of these two volcanic outcrops includes the lithofacies similarity between the Greenan Castle Member and the lowest tuffs in the western part of the Heads of Ayr, cited by Whyte (1963b). Moreover, the most common clast in the member is a greenish basalt that is distinctly different to basalts in the underlying Devonian strata, and therefore unlikely to have been derived from those earlier volcanic beds. Beds below and above the Greenan Castle Member contain a palynological assemblage indicative of a latest Tournasian and early Asbian age respectively. If the Greenan Castle Member is coeval with the volcanism at the Heads of Ayr, this gives a constrained age for the volcanism within the mid-Dinantian, and for the first time confirms correlation with the Clyde Plateau Volcanic Formation.

Thus, a scenario can be envisaged where, early in the development of the Dinantian lava fields in the Midland Valley of Scotland, magmas rising through the near-surface crust would probably have encountered groundwater, wet, unconsolidated sediments and standing bodies of water. Interaction between these and magma would have resulted in intense phreato-magmatic activity, building cones along the line of the controlling fissures. Apart from the Greenan Castle Member there are no other tuffs, lavas nor volcaniclastic sedimentary rocks in the area known to have been derived from the Heads of Ayr vent, supporting the view that such volcanoes in Dinantian times were generally short-lived structures.

Megacryst and ultramafic xenolith assemblages within fragmental deposits, lavas and intrusions are a common feature of alkali basalts across the Midland Valley of Scotland (see East Fife Coast, North Berwick Coast and Dubh Loch GCR site reports). Such assemblages provide valuable clues to magmatic processes and the nature of the crust and mantle beneath the Carboniferous–Permian Igneous Province of northern Britain. The discovery of some ultramafic xenoliths in the Heads of Ayr Neck, and megacrysts in the associated basaltic intrusions, lends added importance to the site (see Chapter 1).

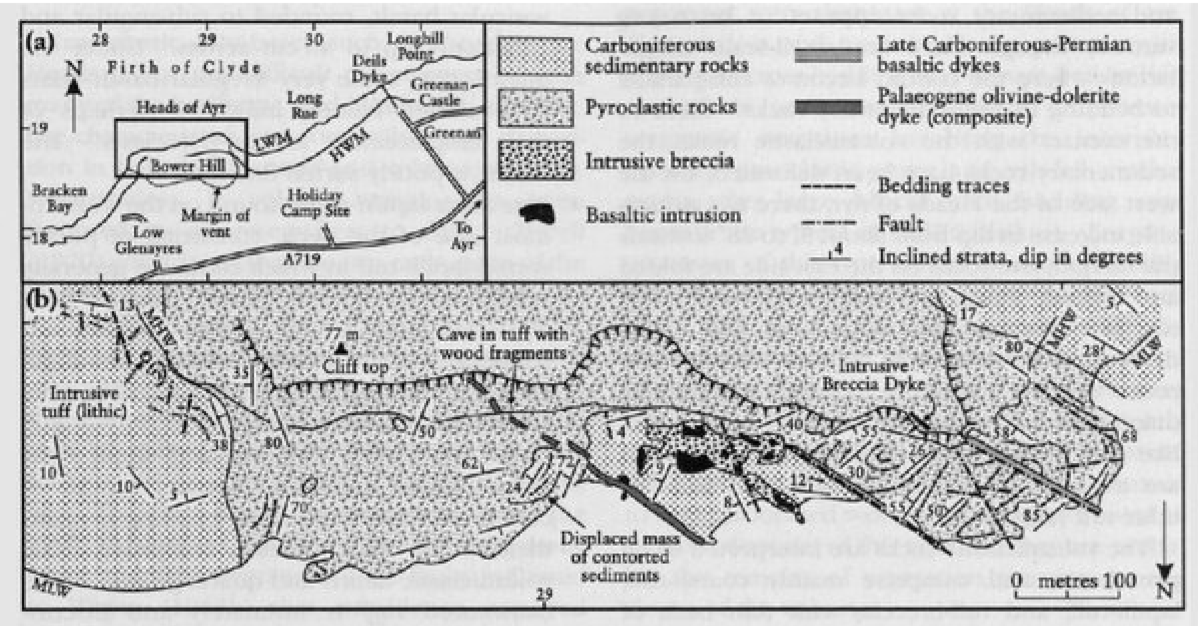
Conclusions

The superb coastal exposures in the Heads of Ayr GCR site beautifully demonstrate the rock-types and internal three-dimensional structure of a major volcanic neck of latest Tournaisian to Visean age and its relationships with the surrounding strata. This neck was emplaced through sedimentary rocks of the Ballagan Formation (Inverclyde Group) and is believed to correlate with volcaniclastic rocks that occur between the Ballagan and Lawmuir formations a little to the east of the GCR site. It is therefore thought to be contemporaneous with the western part of the extensive Clyde Plateau lava field.

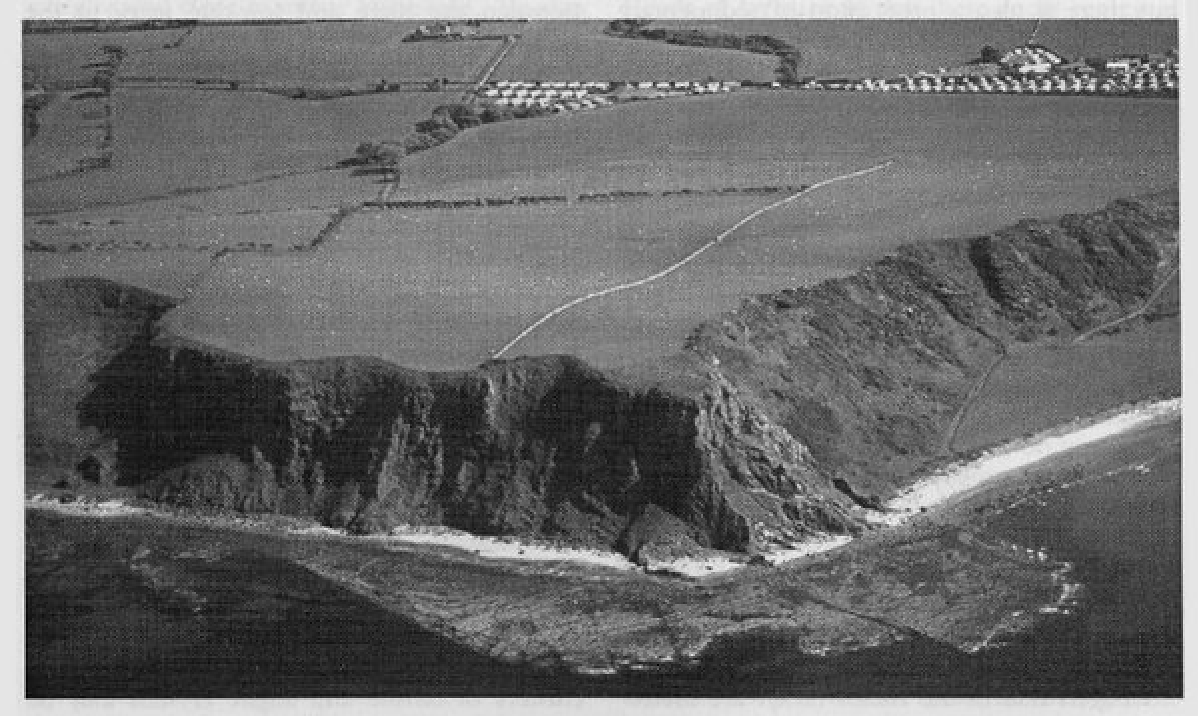
The poor size-sorting of fragments, the presence of volcanic bombs (ejected in a molten or plastic state) and the general characteristics of bedding within the neck are indicators of the type of eruption. Together they suggest an explosive (phreatomagmatic) eruption due to the interaction of basaltic magma with water-saturated sediment and/or bodies of water, giving rise to a mixture of pyroclastic surge deposits from the lateral blast and ash-fall deposits that settled out of the ash-cloud. At the time of the eruptions the Ballagan Formation substrate was sufficiently lithified to be fragmented and incorporated in the ejected material and yet still plastic enough to deform around the margin of the neck. Large slumped blocks within the neck testify to the collapse of an overlying vent structure. The Heads of Ayr Neck is thought to have underlain a tuff-ring of substantial size, but there is no evidence to suggest that large volumes of lava were erupted.

Some of the rocks in the neck contain sparse inclusions of rocks and individual crystals that are thought to have been transported from deep within the Earth's crust or from the source region of the magma in the underlying mantle.

[References](#)



(Figure 2.37) Geological map of the area around the Heads of Ayr GCR site. After Whyte (1964); and Lawson and Weedon (1992). Note the unconventional orientation of 2.37b (north at bottom) for easy comparison with (Figure 2.38).



(Figure 2.38) The West Cliff, at Heads of Ayr. Note the folded bedded tuffs within the Heads of Ayr Neck and the straight dykes on the wave-cut platform (compare with (Figure 2.37)b). (Photo: P Macdonald.)