Traprain Law, East Lothian

[NT 582 747]

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Introduction

The prominent rocky hill of Traprain Law in East Lothian is composed of phonolite, a rare, evolved, silica-undersaturated igneous rock. The phonolite forms a high-level intrusion, emplaced within the Ballagan Formation of the Inverclyde Group, and forming a marked structural dome beneath the Garleton Hills Volcanic Formation (Strathclyde Group; see Garleton Hills GCR site report) (Figure 2.12). The phonolite is believed to be associated with the development of the Garleton Hills Volcanic Formation and therefore of Dinantian age. A K-AT whole-rock determination of 322 ± 3 Ma (*c.* 328 Ma using new constants) (De Souza, 1974) and a Rb-Sr isochron date of 342 ± 4 Ma (De Souza, 1979) appear to support this. The well-documented dome-like outcrop is considered to be a particularly fine example of a laccolith, and is one of only a handful of examples of this form of intrusion in the British Isles. Although there are several phonolitic intrusions in East Lothian, rocks of this composition are extremely rare elsewhere in the Carboniferous-Permian Igneous Province of northern Britain and hence the Traprain Law mass provides an additional insight into the magmatic processes involved.

The Traprain Law intrusion was described first by Howell *et al.* (1866) as 'clinkstone', an archaic term for phonolite. Further descriptions are by Geikie (1897) and Bailey (in Clough *et al.,* 1910). Details of the petrography and chemical composition were presented by MacGregor and Ennos (1922), but the most recent descriptions of the intrusion, including details of its structure, petrography and age, are by McAdam and Tulloch (1985). British occurrences of this igneous rock-type are few, and petrographical descriptions of the Traprain Law example are featured in textbooks of igneous petrology such as Hatch's *An Introduction to the Study of Petrology* (1891), Harker's *Petrology for Students* (1895) and Sutherland's *Igneous Rocks of the British Isles* (1982). The considerable educational value of this GCR site is demon strated by its prominence in field guides to this part of Scotland (McAdam *et al.* in Upton, 1969; Upton and Macdonald in McAdam and Clarkson, 1986). The following description is based on these accounts.

Description

Traprain Law (221 m) rises abruptly from the fertile, undulating farmlands of East Lothian to dominate the surrounding countryside, about 3 km south-west of East Linton (Figure 2.13). The hill has a pear-shaped plan that is partially the result of glacial erosion, and measures about 1 km along its long axis. Its present-day, domelike outline closely mirrors the original three-dimensional shape of the upper surface of the intrusion. The steeper slopes of the hill are craggy and are covered locally by talus cones. The crags on the south side are a popular rock-climbing venue. The surrounding terrain is formed by rocks of the Ballagan and Garleton Hills Volcanic formations, and a series of escarpments blanketed by till are present. In addition to abundant, glacially sculpted, weathered exposures scattered across the hill, the rock is well exposed in the former roadstone quarry at the north-east end of the hill [NT 5835 7495].

Most of the sedimentary rocks covering the phonolite mass have been removed by erosion but, locally, exposures of bedded mudstone, calcareous sandstone and argillaceous limestone are tilted at up to 80° away from the hill (Figure 2.12). On the south-eastern side of the hill, sedimentary rocks are exposed well up the hillside and are steeply inclined at angles of about 50°. These demonstrate that strata are domed over the intrusion.

The phonolite mass is heterogeneous and shows considerable variation in texture and colour. The outer, glaciated surfaces of the intrusion exposed on the higher parts of the hill, most especially towards the summit, are variably vesicular, and there is an apparent increase in grain size towards the centre of the mass. Colour varies from pale pink and speckled through to darker grey, a feature that is exemplified by flow banding. This is clearly seen in the former quarry where the contact between dark and light rock is generally sharp and complex patterns are displayed. Towards the edge of the intrusion, the banding is more marked and is commonly sharply convoluted. Colour mottling is also noted. Bailey (in Clough *et al.,* 1910) and Tomkeieff (1952) both regarded the variations in colour as due to alteration of the feldspars, and Upton and Macdonald (in McAdam and Clarkson, 1986) attributed this to slight hydrothermal effects.

Jointing is prominent throughout the intrusion. In the former roadstone quarry a set of curvilinear joints is orientated approximately parallel to the surface outline of the hill. These impart a coarse platy appearance to much of the exposure. The joints become more closely spaced towards the outer parts of the intrusion and are generally sub-parallel to, but locally cut, the flow banding. On the flanks of the hill, platy jointing is more-or-less conformable with bedding in the country rock and dips outwards at moderately high angles (Figure 2.12).

Baked xenoliths of sandstone and fissile mudstone are quite common, and several large masses, up to almost 3 m across, were noted in the quarry by Day (1930d, 1932b). Xenoliths of basic volcanic rock are small and less common (Bennett, 1945; Tomkeieff, 1952).

The rock of Traprain Law was described as a 'sodalite-bearing phonolitic analcime-trachyte' in *Petrology of Igneous Rocks* (Hatch *et al.,* 1961) and as a 'phonolitic trachyte' by Upton in Sabine and Sutherland (1982). However, the former work noted the presence in the rock of about 20% analcime, 4% nepheline and a few crystals of sodalite, which along with the abundant alkali feldspar, indicate that it should be classified as an analcime phonolite after the scheme of Le Maitre (2002). Some parts of the mass are aphyric but others are sparsely porphyritic, containing phenocrysts, up to 5 mm long, of oligoclase and sanidine-cryptoperthite. Also present are opaque oxide pseudomorphs, up to 4 mm long, after amphibole and scattered crystals of augitic pyroxene. The pilotaxitic-textured groundmass is composed of abundant twinned sanidine laths, magnetite, anhedral aegirine-augite, fayalite, which poikilitically encloses alkali feldspar crystals, apatite and the feldspathoids mentioned above. The feldspathoids are wholly interstitial. Alteration of the phonolite is extremely patchy on a millimetre scale, with abrupt gradation from areas in which the alkali feldspar is intensely sericitized to other areas in which it is unaltered. Analyses have been published by MacGregor and Ennos (1922) and Day (1930c).

A number of unusual minerals have been collected from veins, druses and vugs in the phonolite. The most common species found include calcite and alkali feldspar, but Upton and Macdonald (in McAdam and Clarkson, 1986) list analcime, anhydrite, apophyllite, datolite, natrolite, pectolite, prehnite, selenite and stilpnomelane. Batty and Moss (1962) recorded powellite ($CaMoO_4$).

In the same general vicinity as the laccolith, there are a few other intrusions (Figure 2.12). A sheet-like body of phonolite is seen at Hairy Craig [NT 577 751] and small plugs of olivine-dolerite are noted at Cairndinnis [NT 573 745] and Gold Knowe [NT 580 752], all within about one kilometre of Traprain Law.

Interpretation

Early mapping of the area by H.H. Howell of the Geological Survey showed that strata adjacent to the Traprain Law phonolite are steeply inclined away from the hill (Howell *et al.,* 1866), a feature that has been regarded since as being associated with emplacement of the mass (see also Geikie, 1897, fig. 132). The domed outline of the intrusion, together with its contact relationships with the sedimentary rocks, and the arrangement of the flow-banding and jointing, suggested to Bailey (in Clough *et al.,* 1910) that emplacement as a laccolith was likely. This view was reiterated by McAdam and Tulloch (1985). However, neither Bailey nor McAdam and Tulloch were entirely certain about the interpretation because lower contacts of the mass are not exposed. Nevertheless, there are several pieces of evidence to suggest the possibility of a concordant lower contact supporting the laccolith model. First, Clough *et al.* (1910) recorded vertical columnar jointing at one location on the deeply eroded western side of the mass. From this they inferred an approximately horizontal floor to the phonolite 'at no great distance below the surface'. The second clue is from a temporary excavation made at the entrance to the quarry in 1955 (examined by C.J.S. Stillman and cited by McAdam *et al.* in Upton, 1969). This exposed 12 m of bedded sedimentary rocks, with phonolite both above and below. The contacts were seen to be almost concordant and the bedding was inclined in a similar direction to that of sandstones in the adjacent fields, though at a shallower angle. Stillman concluded that the evidence present in the trench supported the long-held view that the Traprain Law mass has a laccolithic form. The complex patterns exhibited by the flow-banding at the north-eastern end of the outcrop suggest magmatic convection, and McAdam and Tulloch (1985) suggested that a feeder pipe to the laccolith may have been located in this area.

Further evidence for the three-dimensional form of the intrusion comes from ground magnetic profiles run by the Institute of Geological Sciences in 1965, which suggest very steep-sided contacts to the intrusion on the north-west and south-east sides of the hill. A pronounced, elongate aeromagnetic anomaly extends south-westwards from the phonolite outcrop at least as far as Whitelaw Farm [NT 567 720] and this too is compatible with a steep-sided igneous body with high magnetic susceptibility located at a shallow depth. The phonolite has the required susceptibility value to produce the observed anomaly, which is thus probably caused by a buried extension of the exposed intrusion (McAdam and Tulloch, 1985). Whether or not the elongated shape of the intrusion in some way reflects a buried fissure, crudely parallel to deep-seated basement structures such as the Southern Upland Fault, is debatable. However, Upton (1982) has pointed out that the rocks of the Garleton Hills Volcanic Formation lie over the sub-surface extension of the main Southern Upland Fault.

Though the emplacement age of the Traprain Law laccolith, and a large number of other intrusions in East Lothian, cannot be fixed with certainty at present, their geographical association with the Garleton Hills Volcanic Formation suggests that many of them may be sub-volcanic components of this Visean volcanic field. The vesicular nature of the upper surfaces of the laccolith suggests emplacement at a high crustal level and it is possible that this, and other intrusions, may have acted as feeders to the lavas and pyroclastic rocks.

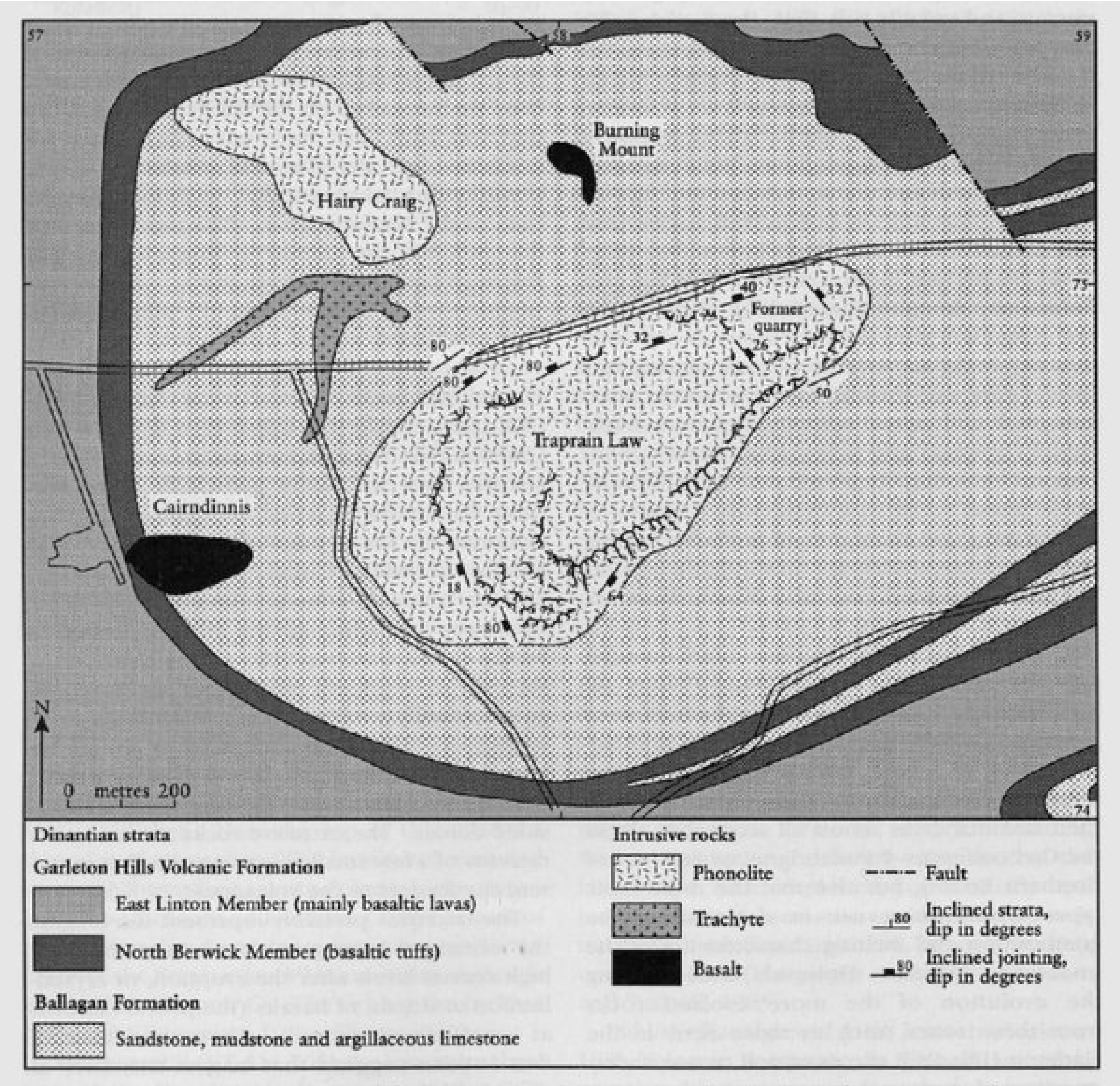
However, highly evolved silica-undersaturated rocks such as the Traprain Law and Hairy Craig phonolites and the nearby intrusive phonolitic trachytes of North Berwick Law and the Bass Rock are not represented within the Garleton Hills Volcanic Formation. Indeed, evolved silica-undersaturated rocks are virtually absent (there is one flow in the Campsie Fells) from all Dinantian volcanic successions of the Midland Valley, which evolve typically along a differentiation trend from alkaline or transitional olivine basalt to silica-oversaturated quartz-trachyte and exceptionally rhyolite. The Garleton Hills succession is unusual however, in that single flows of silica-undersaturated analcime-bearing hornblende trachybasalt (formerly 'kulaite') occur locally at the base of the earliest lava member, including one at Blaikie Heugh, only 2 km from Traprain Law. There are also xenoliths of analcime-hornblende trachybasalt in the Traprain Law phonolite, which both Bennett (1945) and Tomkeieff (1952) regarded as co-genetic with the nearby flow. Therefore, it is possible that the earliest magma chambers to form beneath the East Lothian area did evolve along silica-undersaturated lines, and that the phonolitic intrusions may represent their most extreme products. Almost all of the extrusive rocks erupted during this phase may have been removed by erosion, and the subsequent magmatism evolved entirely along a silica-oversaturated trend as seen in the preserved lava succession. The Traprain Law phonolite is thus potentially of great importance in showing that evolved silica-undersaturated rocks can be associated with a Dinantian basalt–quartz-trachyte series. It is one of only a handful of such examples within the Midland Valley of Scotland.

Conclusions

The Traprain Law intrusion is of national importance both for the form of the intrusion, a laccolith, and for its rock-type, a phonolite, which is rare in Britain. It is representative of a small group of intrusions in East Lothian of silica-undersaturated felsic igneous rocks, apparently associated with the Visean Garleton Hills Volcanic Formation. Other members of the group include the phonolitic trachyte intrusions of North Berwick Law and the Bass Rock. Rocks of these highly evolved compositions are not represented within the Visean extrusive rocks of East Lothian, which range in composition from basalt to quartz-trachyte (i.e. they are mostly silica-oversaturated). The presence of rare phonolitic rocks therefore adds considerable information to the understanding of the origin and evolution of Dinantian volcanic rocks in the Midland Valley of Scotland.

The shape of the upper surface of the intrusion is approximated by the craggy rounded outline of Traprain Law. Locally, around the lower slopes of the hill sedimentary rocks dip steeply away from the hill, indicating that these strata were arched up over the intrusion. The dome-shaped upper surface is mirrored within the intrusion by a characteristic set of curved joints, particularly in the outer part of the mass. The vesicular outer part, formed by gases and vapours escaping from the magma, indicates emplacement at shallow depth. Though the basal contact of the intrusion is not exposed, there are indications that it may be concordant with the sedimentary host rocks. Thus, the inferred form of the intrusion (a domed upper surface and a flat base) is that of a laccolith. Few laccoliths are described from Britain, and Traprain Law is featured in many geological textbooks as a typical example.

References



(Figure 2.12) Map of the area around the Traprain Law GCR site. Based on Geological Survey 1:10 560 mapping by M.F. Howells (1963–1964) and A.D. McAdam (1964–1967 and 1974–1976).

(Figure 2.13) Traprain Law from the south-east. The shape of the hill probably reflects the laccolithic form of the phonolite intrusion. (Photo: P MacDonald.)