FALCON CRAG

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OS Grid Reference: NY272206–NY274199

Introduction

Falcon Crag and Brown Knotts overlook the eastern shores of Derwent Water and provide a well-exposed, 650 m-thick succession of lavas and interbedded volcaniclastic rocks within the Birker Fell Formation, the basal part of the Borrowdale Volcanic Group (BVG). The volcanic succession dips gently to the east and forms a series of prominent terrace features, particularly on Brown Knotts, developed as trap topography (Figure 4.8). This GCR site is one of only three or four superb examples of this landform in the Lake District.

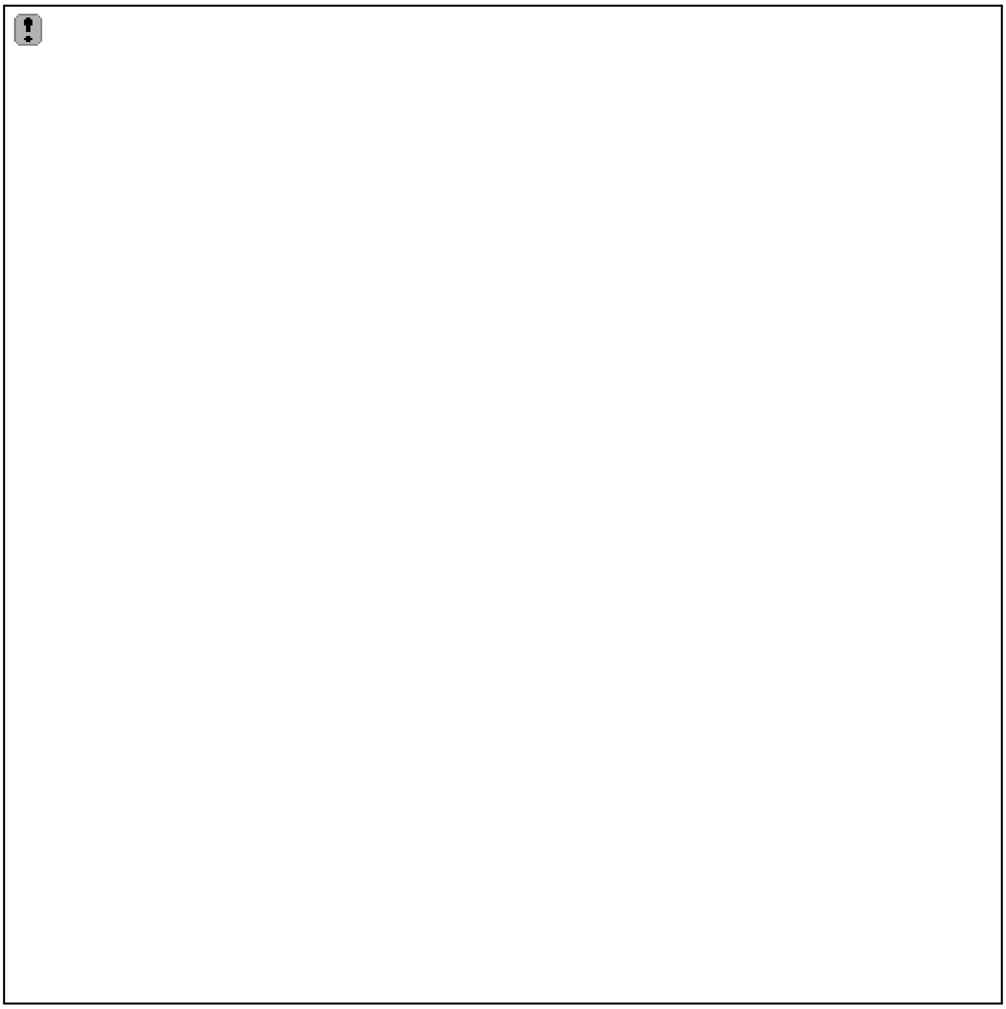

Figure 4.8: Falcon Crag (left) and Brown Knotts showing the terraced, trap-like topography of lavas and interbedded volcaniclastic rocks. (Photo: B. Beddoe-Stephens.)

The GCR site (Figure 4.9) is an excellent and characteristic example of the largely subaerial, plateau-andesite field that is exposed extensively in the south-western, western and northern parts of the BVG outcrop and which developed as a precursor to large-scale ignimbrite volcanism and caldera collapse of the upper parts of the succession (Petterson *et al.*, 1992). Features that are typical of block- and aa-lavas are displayed by flows that are generally basaltic andesite to andesite in composition. In addition, the occurrence of some high-level, co-magmatic sills emplaced into wet volcaniclastic sediment are indicated by the presence of peperitic margins (Suthren, 1977; Branney and Suthren, 1988). The inter-relationships of primary and reworked pyroclastic rocks within the largely lava-dominated succession are also illustrated and of particular interest are volcaniclastic rocks formed by hydrovolcanic processes.

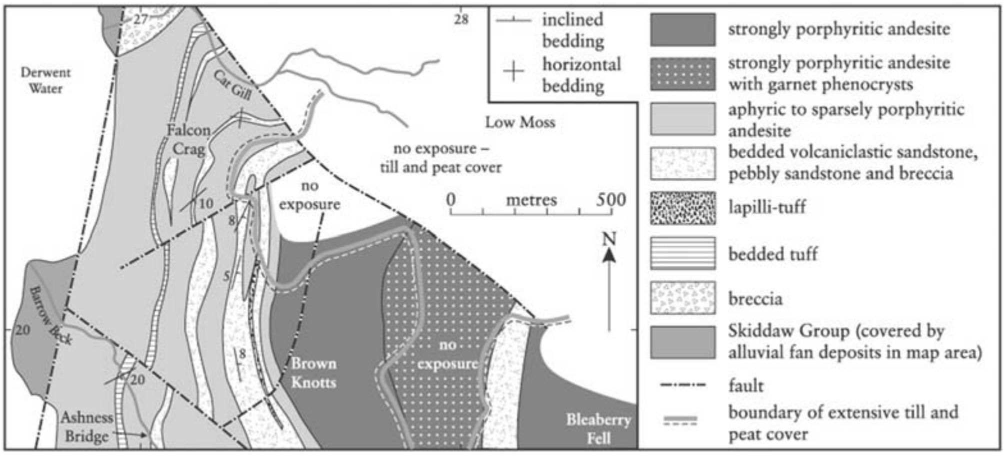

Figure 4.9: Map of the Falcon Crag GCR site.

This area was first mapped and described by the Geological Survey (Ward, 1876). Remapping and re-interpretation of the rocks in terms of volcanic environments and sedimentary facies was undertaken by Suthren (1977). Extensive fieldwork in the area, and to the south by the Geological Survey (Petterson *et al*., 1992) has shown that within the andesite-dominated lower part of the BVG the whole succession is considered best as one formation, with distinctive units defined as members.

Description

A generalized vertical section of the BVG rocks within the GCR site is shown in Figure7.10. A major fault forms the eastern shore of Derwent Water and juxtaposes Skiddaw and Borrowdale Volcanic group rocks. However, the unconformity between the BVG and underlying Skiddaw Group is exposed nearby in Cat Gill, close to Kettlewell car park (268 194), and farther south near Troutdale Cottages (261 173). In the south of the GCR site, below Brown Knotts, the lowest unit in the succession is an aphyric andesite, very fine grained and typified by a conspicuous fluidal pilotaxitic texture in thin section. It commonly contains zones of internal brecciation, suggesting that it is probably a compound flow. In places it has a prominent laminar flow fabric. This andesite, up to 200 m thick, has been mapped extensively in Borrowdale and south-westwards to Dale Head. To the north, in the lower reaches of Cat Gill (270 210), a distinctive breccia appears to underlie the aphyric andesite and probably represents the basal bed of the BVG in this area. The breccia is reddish purple, massive and very poorly sorted with a polymict assemblage of typically highly angular volcanic clasts up to block size including pale-coloured, flow-laminated felsic rocks and darker andesitic scoria. Former pumiceous clasts and fragments are also present, as are rarer clasts of (Skiddaw Group) sedimentary lithologies.

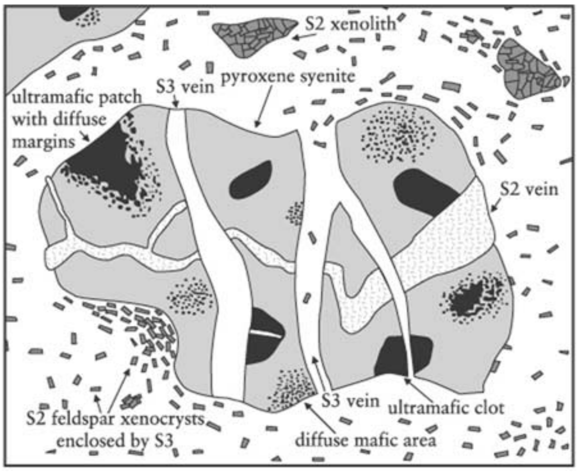

Figure 7.10: Sketch illustrating the relationships between a pyroxene syenite xenolith and feldspathic syenites in the Loch Ailsh intrusion, as seen in the River Oykel and Black Rock Burn areas. A typical xenolith would be about 1 m in length. (After Parsons, 1968, fig. 2.)

The lower half of the succession (Figure 4.10) comprises generally sparsely porphyritic to aphyric fine-grained lavas with intercalated, bedded volcaniclastic units up to several tens of metres thick. The upper part is, by contrast, dominated by moderately to strongly porphyritic andesite. The lavas vary in thickness from 10–100 m (Figure 4.10), but in many cases have a low aspect ratio (thickness/extent ratio). This is particularly evident in the lower part of the section where a conspicuous trap-like topography forms the crags of Falcon Crag and Brown Knotts (Figure 4.8). Higher in the sequence the lavas are generally thicker and probably have higher aspect ratios.

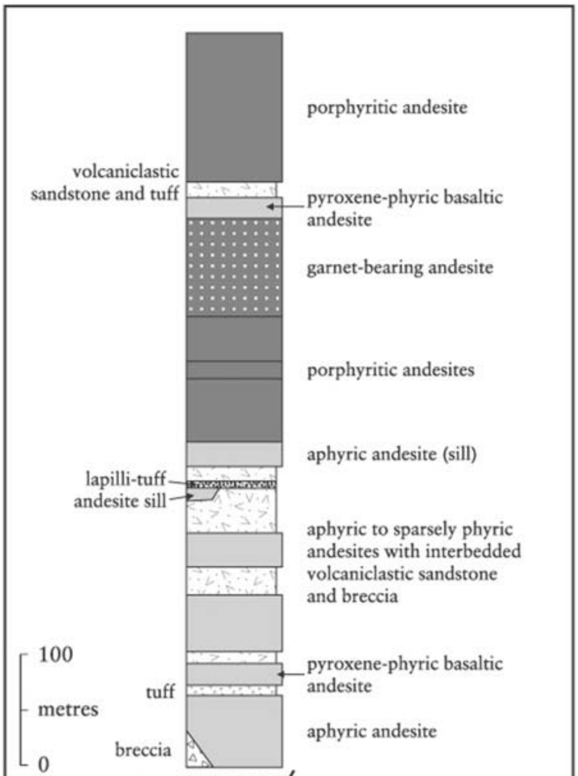

Figure 4.10: Generalized vertical section of Borrowdale Volcanic Group rocks between Brown Knotts and Bleaberry Fell; Falcon Crag GCR site.

The top, and locally the base, of the lavas are typically flow-brecciated, but the interiors are massive. Flow-breccias typically consist of angular to subangular, commonly amygdaloidal andesite blocks, and are clast supported. In the absence of volcaniclastic sandstone beds between lavas it is not always easy to establish whether a particular flow-breccia represents the top of one lava or the base of another, and in some cases a mixed breccia may form. The interstices of flow-breccias are commonly filled with finely laminated sediment washed in by percolating water. Autobreccia, in which solid blocks or crusts are re-incorporated into fluid lava, is present in the thick garnet-bearing andesite.

Within the central parts of some lavas, planar flow-laminae and jointing may be developed, usually parallel or sub-parallel to the base. In aphyric lavas at the base of the succession, flow-laminae or fine-scale banding form pervasively with superimposed platy jointing. A more discontinuous, irregular but sub-parallel flow-joint set is typically formed in the garnet-bearing andesite and the overlying andesite, which forms the summit of Bleaberry Fell.

The porphyritic andesites contain predominately plagioclase phenocrysts up to 2 or 3 mm with subordinate pyroxene (or pseudomorphs thereof). A thick lava that can be traced around the west and south sides of Bleaberry Fell, and forms the prominent knoll near the sheepfold (278 201), is distinctive for its conspicuous red garnet phenocrysts up to 5 mm across. In thin section these commonly have irregular, corroded margins. This same lava carries an accessory population of dark-coloured, irregular, rounded fine-grained diorite or dolerite xenoliths up to several centimetres across; on weathered surfaces these form recesses.

Though most of the andesites in the succession can be satisfactorily interpreted as lavas, there is evidence that some sheets were intrusive into volcaniclastic deposits. One thin, highly amygdaloidal and autobrecciated sheet terminates laterally in bedded sandstone indicating intrusion (2735 2015). Of more diagnostic value is the presence of peperitic upper margins, as described by Suthren (1977) and Branney and Suthren (1988), for the thin aphyric andesite on Brown Knotts (2744 2005).

Most of the volcaniclastic rocks are reworked, comprising sandstone, pebbly sandstone and breccia. On the bench forming the top surface to the lower main face of Falcon Crag (271 205) are massive to weakly stratified pebbly sandstone and fine breccia with andesite clasts up to 20 cm suspended in a finer matrix. Clasts vary from subrounded to subangular. Structures typical of deposition by water are common, with abundant cross-bedding, sporadic ripple sets and rip-up clasts; erosional channels are common and are filled with coarser, gravelly lags. Silt- to sand-grade, planar bedded rocks also occur and these are affected by small-scale synsedimentary deformation locally. Examples of these features can be seen either side of the footpath from Ashness Bridge and traversing Brown Knotts (273 202). Boulder conglomerates, composed dominantly of andesitic lithologies, occur in lenticular masses or within eroded channels (e.g. at 2716 1993) and commonly contain lenses of bedded sandstone.

Bedded ash-fall tuffs are preserved locally, particularly in the *c*. 15 m-thick volcaniclastic unit near the top of the section (Figure 4.10). Though the beds are locally channelled and disrupted, planar beds of lapilli-tuff and tuff dominate and drape irregular surfaces. The beds are both normally and reversely graded, and contain common angular and scoriaceous clasts. Interbedded cross-laminated sandstone beds appear to represent the flushing out of fines from the ash deposits.

Lapilli-tuff occurs at several horizons in the succession. A massive to weakly stratified fine lapilli-tuff is well exposed at the base of the lower main face of Falcon Crag (2706 2043). It comprises abundant, highly angular juvenile clasts and sporadic paler lithic fragments. In thin section the clasts are predominantly devitrified glass; blocky to vesicular forms are present. An unbedded lapilli-tuff is exposed for a distance of about 1 km on Brown Knotts. It is about 10 m thick, occurs towards the top of the thickest volcaniclastic unit and locally overlies a thin sill (2737 2015). This lapilli-tuff is rather fissile because of a prominent low-angle foliation produced by the alignment of abundant, dark fiamme-like fragments. It also contains common angular, andesitic to felsitic lithic lapilli in a fine-grained matrix, which includes siltstone fragments.

Interpretation

The GCR site illustrates most of the features that are critical to the recent interpretation by Petterson *et al*. (1992) of the Birker Fell Formation, the lowest unit of the BVG. The conspicuous trap-like topography of dominantly andesite lava interbedded with volcaniclastic rocks is well illustrated in the crags of Falcon Crag and Brown Knotts. In his analysis of the volcanic environment in which this succession was deposited,Suthren (1977) noted the lack of evidence for any significant topographic relief, such as might be expected on a steep-sided stratocone. The lavas form tabular sheets broadly concordant with the intercalated, laterally persistent, bedded volcaniclastic rocks that must have been deposited sub-horizontally. Thus, lava extrusion occurred over a subdued, flat-lying landscape. Using evidence from the western part of the BVG, Petterson *et al*. (1992) concluded that extensive areas of the Birker Fell Formation aggraded as a subaerial, flat-lying or shield-like plateau-andesite field with lavas erupted from many centres.

The development of the thick (up to 2 km or more), subaerial, flat-lying andesite pile that comprises the Birker Fell Formation suggests accumulation within an actively subsiding basin or rift zone developed within a continental arc (Petterson *et al*., 1992). Analogies in active orogenic arcs of this type of environment are to be found in Japan, New Zealand, the western USA and Central America.

The volcaniclastic rocks are also important in the interpretation of the volcanism and several features are illustrated in the succession of the GCR site.Suthren (1977) interpreted the local basal breccia as a mass flow deposit. The high degree of fragmentation, form and vesicularity of the juvenile fragments and presence of substrate material suggest an explosive hydromagmatic origin, though subsequent reworking of such a deposit to form debris flows is likely and cannot be excluded. A further example of rocks probably formed by hydroclastic processes is the massive to weakly stratified fine-grained lapilli-tuff, containing predominantly devitrified glass, that is well exposed at the base of the lower main face of Falcon Crag (2706 2043).

The distinctive, unbedded lapilli-tuff on Brown Knotts illustrates the problems inherent in the interpretation of ancient pyroclastic rocks. Suthren (1977) interpreted the lapilli-tuff as a welded ignimbrite, because of the eutaxitic-like fabric. Many of its characteristics are consistent with its origin as a lithic-rich ignimbrite. However, the fabric may not have been the result of welding. Alteration of pumice to clay minerals may occur rapidly after deposition, causing loss of strength within the clast (Branney and Sparks, 1990). Collapse of the vitroclasts may then occur through subsequent loading and resulting in a fabric that resembles the effects of welding. Alternatively, this rock may have had a phreatomagmatic origin.

In common with much of the BVG, there is no evidence (faunal or lithological) that volcanism was submarine (Branney, 1988a). However, the presence of hydroclastic tuffs towards the base of the sequence in this GCR site possibly indicates that periodically subaqueous conditions were present. Other volcaniclastic beds record the extensive reworking by runoff (transient fluvial systems or sheetwash) of ash-fall deposits and re-deposition as planar- and cross-bedded sandstone, or turbidite-like mass flows into ephemeral lakes. Locally, coarse debris-flow deposits and conglomerates record occasional high-energy conditions, with much of the coarse debris representing material stripped from the blocky carapaces of lavas.

Conclusions

The Falcon Crags GCR site illustrates the typical characteristics of the Birker Fell Formation, the thick, lowest part of the Borrowdale Volcanic Group. This rare calc-alkaline plateau-andesite lava field of Ordovician age is of international interest. The well exposed and readily accessible succession of lavas and bedded volcaniclastic rocks seen in the trap-like topography of Brown Knotts is an excellent example of the plateau-andesite lava field that dominated the early stage of volcanism. However, the dominantly reworked material in the volcaniclastic rocks was probably derived from the reworking of unconsolidated pyroclastic deposits, and illustrates the low-preservation potential of the latter within the geological record; pyroclastic and hydroclastic eruptions were far more common during the volcanic episode represented by the Birker Fell Formation than is recorded specifically in the succession.

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