CONISTON

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Introduction

North-west of Coniston village, Mouldry Bank and Long Crag provide a well-exposed and readily accessible example of a section through the uppermost formations of the Borrowdale Volcanic Group (BVG) in the SW Lake District (Figure 4.26). About 1800 m of steeply dipping pyroclastic and volcaniclastic sedimentary rocks are intruded by basaltic andesite sills (Figure 4.27). The section is a typical example of the upper part of the BVG succession in which fluvial and lacustrine volcaniclastic sedimentary deposits are intercalated with the products of voluminous silicic pyroclastic flow eruptions. These events post-date the Scafell Caldera ignimbrite succession. On Long Crag are spectacular examples of columnar joints in welded ignimbrite. Just to the west of this site are the Coniston Copper Mines, the location of a significant British mining industry during the last century, and represented in the 'Mineralogy of the Lake District' site network of the GCR. The sedimentary rocks are strongly cleaved and have been quarried extensively for slate.

Figure 4.26: View of Long Crag from Coniston. The crags have been sculpted out of the ignimbrite of the Lincomb Tarns Formation and the low ground exposes Windermere Supergroup rocks, unconformably overlying the volcanic rocks. (Photo: D. Millward.)

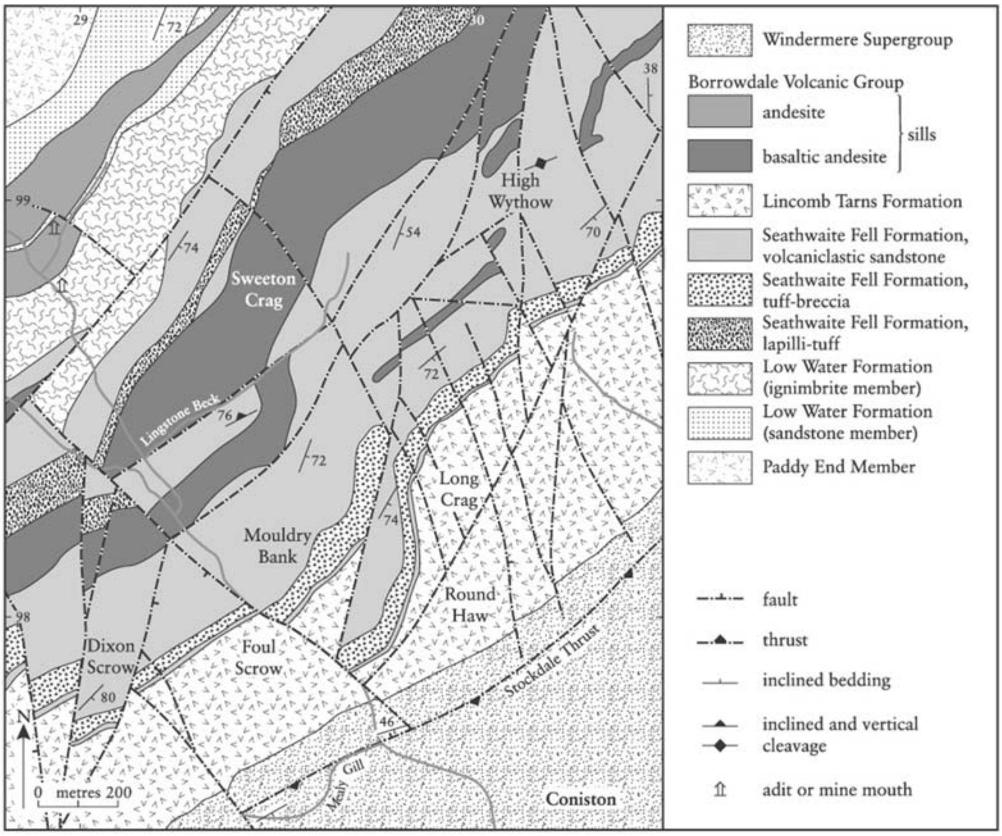

Figure 4.27: Map of the Coniston GCR site (based on BGS 1:50 000 Sheet 38, 1996).

The Coniston Fells were first mapped by the Geological Survey in 1882, but it was Mitchell (1940), who established the volcanic stratigraphy and structure of the area. The repetition of volcaniclastic sedimentary and pyroclastic rocks, both at Coniston and elsewhere in the BVG, was interpreted by Mitchell and others (e.g. Green, 1920) in the first half of the twentieth century as a set of tight folds with steeply dipping axial planes. This structural model for the BVG was subsequently abandoned by Mitchell (e.g. 1956) as studies of the sequence progressed. The GCR site description is based on work by Millward (1980), Millward *et al*. (in press) and the Geological Survey 1:50 000 Sheet 38 (1996). Re-interpretation of the stratigraphy and structure of the central Lake District has resulted in revision of the lithostratigraphical nomenclature from Mitchell (1940). His Upper Tilberthwaite Tuffs are divided between the Low Water and Seathwaite Fell formations; the Yewdale Bedded Tuffs become part of the Seathwaite Fell Formation; and the Yewdale Breccia is correlated with the Lincomb Tarns Formation of the central Lake District. The Wrengill Andesites are re-interpreted as sills (Branney and Suthren, 1988). Watson (1984) considered brecciated rocks at Colt Crag (280 980) to the west of the GCR site to lie within a possible vent for the BVG, but these rocks have been interpreted subsequently as autobrecciated andesite sills. Part of the area is covered by a field guide (Moseley, 1990).

Description

In the Coniston area the volcanic rocks dip steeply to the SE, within the steep limb of the monocline that is the principal structure of the area encompassing the uppermost BVG and Windermere Supergroup SW of Ambleside. The volcanic sequence in the Coniston area postdates the pyroclastic fill to the Scafell Caldera (Figure 4.12). The volcanic rocks are overlain unconformably by the basal beds of the Dent Group (formerly Coniston Limestone and basal unit of the Windermere Supergroup), but these rocks are poorly exposed in the site. NE-trending faults (Figure 4.27) are associated with back-thrusts within the monocline.

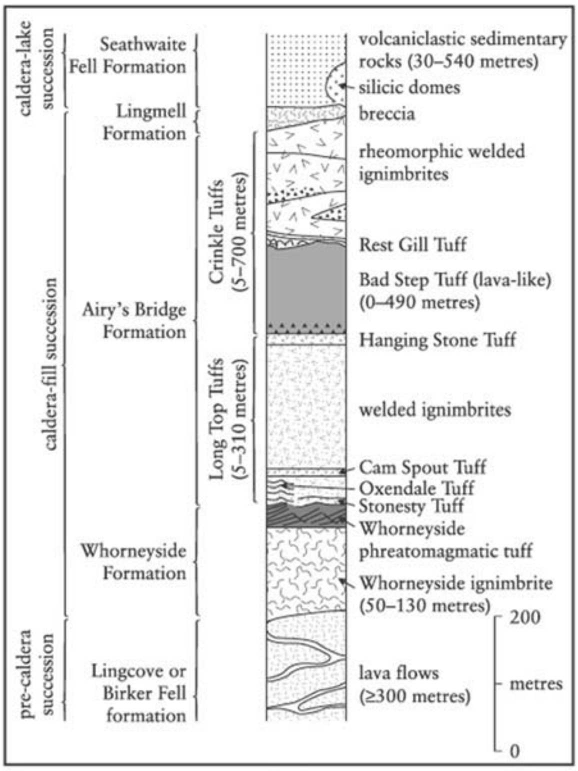

Figure 4.12: Generalized lithostratigraphy of the Scafell Caldera succession (after Branney and Kokelaar, 1994a).

The lowest unit in the succession, the Paddy End Member of the Lickle Formation crops out in the NW of the site, has the appearance of a rhyolite and is 150–170 m thick (equivalent to the Paddy End Rhyolite of Mitchell, 1940). The Paddy End Member comprises a single bed of homogeneous, white to pale-pink weathered, splintery, devitrified felsite, having a fine-scale foliation parallel to the base. Relict vitroclastic textures are present; the crystal content is low and there are few lithic clasts. The base and top of the unit are autobrecciated.

The Paddy End Member is overlain unconformably by the Low Water Formation, consisting of about 600 m of welded dacitic lapilli-tuff and intercalated volcaniclastic rocks. The basal 220 m comprise thinly to thickly parallel-bedded sandstone and pebbly sandstone, intercalated with coarse tuff and fine lapilli-tuff. Some of these deposits were probably water-laid, as is indicated by some dark-grey laminae of non-volcanic detritus and soft-sediment deformation. The succeeding two sheets of unbedded dacitic lapilli-tuff have a well-developed eutaxitic texture. Fiamme comprise up to 20% of the rock, which is also rich in angular, non-vesicular lithic lapilli. A lithic-rich basal zone up to 10 m thick contains blocks up to 70 cm across and forms a very poorly sorted, clast-supported breccia.

The Seathwaite Fell Formation mainly consists of up to 850 m of bedded volcaniclastic siltstone and sandstone locally intercalated with thin units of pyroclastic rock, particularly near the top of the formation. Though the base is conformable in the type area for the formation in the central Lake District (see the Langdale Pikes GCR site report), in the Coniston Fells an unconformity marks the base of the formation and the basal beds are probably markedly diachronous (Millward *et al.*, in press).

The basal lithofacies comprises up to 150 m of greenish-grey thinly bedded and laminated fine- and medium-grained sandstone and siltstone with sparse interbeds of pebbly coarse-grained sandstone intraclasts. Bedding and lamination are predominantly planar, but wavy bed forms, ripple cross-lamination and climbing ripples occur in places. Soft-state deformation structures occur throughout the succession. Dark-grey and brownish-grey beds occur locally near the base of the succession, and contain rare and poorly preserved acritarchs. None of the genera is demonstrably indigenous or diagnostic of age and they may have been derived from older marine strata, such as the Skiddaw Group. A 60–135 m-thick bed of massive poorly sorted dacitic lapilli-tuff, containing abundant lithic lapilli overlies these rocks.

Most of the formation in the area comprises a coarse lithofacies association of massive and thickly bedded, coarse-grained and pebbly sandstone intercalated with well-bedded and laminated, medium- to coarse-grained sandstone and minor siltstone. Bedding is generally poorly defined and predominantly planar, though trough and ripple cross-bedding are common locally. Sedimentary structures that are associated with rapid rates of deposition occur throughout the succession and include convolute laminae, flames, ball and pillow structures and dewatering pipes; soft-state syndepositional deformation and microfaults are also common. Towards the top of the succession, scours and channels, some containing pebble and cobble conglomerate, indicate fluvial deposition.

Though beds of tuff and lapilli-tuff occur throughout the formation, the most prominent that crops out throughout the GCR site is a coarse volcaniclastic rock, 25–80 m thick, occurring within the uppermost 150 m of the formation (Figure 4.27). Lithic blocks are concentrated in a basal 10 m-thick tuff-breccia, which passes gradationally upwards into overlying massive, lithic-rich eutaxitic lapilli-tuff; the uppermost 2 m are stratified. Characteristic pock marks on the rock surface show where pumice has been removed by weathering. This is overlain locally by the Glaramara Tuff, a white-weathered, splintery, bedded fine tuff, locally with accretionary lapilli and interbedded with thin beds of eutaxitic lapilli-tuff (see also the Side Pike GCR site report). Up to 30 m of parallel-laminated and cross-laminated, fine- to coarse-grained sandstone separates the tuff from the overlying Lincomb Tarns Formation.

The Lincomb Tarns Formation is a lithic-rich eutaxitic lapilli-tuff, up to 350 m thick. It is part of an extensive ignimbrite that crops out from the Coniston area, through Ambleside and Grasmere to the Scafell area. It forms the rocky fells of Long Crag and Foul Scrow that overlook Coniston. Particularly conspicuous are abundant pink, angular, welded tuff and non-vesicular rhyolite fragments, commonly up to 2 cm. The lithic population is bimodal, also including many fine-grained basaltic andesite pyroclasts, in places with cumulose margins. Crystals, dominantly plagioclase with subordinate pseudomorphs after pyroxene and an opaque, form 4–14% of the rock. Fiamme are sparse to abundant (less than 5% to more than 35%) and some are identifiable pieces of long-tube pumice, altered to chlorite and an opaque mineral. A relict vitroclastic texture is preserved locally.

A characteristic feature of the formation in this area is columnar cooling joints, spectacularly displayed on Foul Scrow and Long Crag (Millward, 1980). At Long Crag at least two columnar zones have average column dimensions of 11 cm and 5.5 cm respectively. At Long Crag there is local small-scale variation in the inclination of the columns, which Millward attributed to unevenness in the cooling surfaces, possibly of separate eruptive units. The columnar zones have sharp bases and tops, and the column diameters remain constant along their length. However, the columnar zones have very restricted lateral extents.

Andesite and basaltic andesite sills were emplaced into the sedimentary rocks. These are variably massive to autobrecciated and locally intensely amygdaloidal. The contacts cut across bedding and the marginal breccias are intimately mixed with sandstone that in places is amygdaloidal.

Interpretation

Along with most of the early workers, Mitchell (1940) considered the volcaniclastic rocks in the BVG to be dominantly pyroclastic and the others, including the Paddy End Member and columnar-jointed parts of the Lincomb Tarns Formation to be lavas. Radical re-interpretation of the volcanic rocks of the Coniston area has occurred with the resurvey by the British Geological Survey, such that the new facies model shows a sequence dominated by volcaniclastic sedimentary deposits.

Abrupt lateral facies variations and faulting have caused many problems in correlating the volcanic succession across the Lake District and in particular between the Scafell and Coniston areas (Mitchell, 1956; Millward *et al.*, 1978). These problems have been resolved during recent work by the British Geological Survey (1:50 000 Sheet 38 and Millward *et al.*, in press). Within the Scafell Caldera, the pyroclastic succession of the Airy's Bridge and Lingmell formations

(Figure 4.12) is overlain conformably by the dominantly sedimentary Seathwaite Fell Formation. By contrast, in the Coniston area the Airy's Bridge Formation (exposed to the NW of the GCR site) is succeeded by other welded ignimbrites and then overlain unconformably by the Seathwaite Fell Formation. The intervening ignimbrites of the Paddy End Member and the Low Water Formation are part of a succession that is developed more fully in a depositional centre in the SW of the Lake District. Detailed correlation of units within the Seathwaite Fell Formation in the Scafell and Coniston areas shows that only the uppermost part of the formation is present in the latter (Millward *et al.*, in press). Thus, the base of the Seathwaite Fell Formation is strongly diachronous.

Bedded volcaniclastic rocks are a significant feature of this GCR site. Their petrographical characteristics, bed forms and abundant sedimentary structures are indicative of deposition in fluvial and lacustrine regimes (Millward *et al.,* in press). Thin beds of accretionary lapilli-tuff and andesitic tuff represent small-scale subaerial ash-fall eruptions that occurred periodically during the major periods of relative quiescence represented by parts of the Low Water Formation and by most of the Seathwaite Fell Formation. However, the thin pyroclastic deposits are probably under-representative of the volcanic activity during deposition of the sedimentary formations, because of the poor preservation potential of unconsolidated tephra in the subaerial environment. Also, the presence of grey beds near the base of the Seathwaite Fell Formation, compared with the generally green colour of most of the sedimentary rocks is indicative of an influx of non-volcanic detritus from outside the volcanic basin, possibly associated with an interruption in the supply of volcanic detritus.

Interpretation of pyroclastic rocks in the Lake District underwent major change because of Oliver's (1954) recognition of many of the thick and extensive massive, eutaxitic lapilli-tuffs as ignimbrite. An extrusive origin for the Paddy End Member is confirmed from the basal field relationships and from the inclusion of felsite blocks in the overlying formations. The massive, lava-like felsite of the Coniston area passes south-westwards into welded lapilli-tuff (Millward *et al.,* in press), indicating that it is interpreted best as a rheomorphic ignimbrite. Mitchell (1940) mapped the columnar jointed parts of the Lincomb Tarns Formation (his Yewdale Breccia) as separate columnar lavas, but Millward (1980) demonstrated the pyroclastic nature of these rocks and included the columnar parts as part of a compound ignimbrite comprising multiple flow units. The bases to columnar zones may thus coincide with flow-unit boundaries, though there is little other evidence to support this.

The Wrengill Andesites were interpreted as lavas by Mitchell (1940). Branney and Suthren (1988) critically examined the contact zones of a number of andesite sheets at different levels in the BVG, including one NE of Church Beck. They included the intimate mixing of marginal andesite breccia with sandstone, sandstone amygdales in the andesite blocks and injection of sandstone into the andesite among extensive criteria diagnostic of intrusion of the andesite bodies into wet sediment. These andesite bodies also cut across the stratigraphy. Thus, there are no lavas within the succession seen in the GCR site.

Conclusions

The Coniston GCR site is an excellent and well-exposed representative example of the rocks deposited during the latest stages of mid-Ordovician volcanism in the Lake District. Fluvial and lacustrine sedimentation following major episodes of caldera collapse associated with the Scafell Caldera was interrupted by the emplacement of further voluminous dacitic ignimbrites from other centres. One such ignimbrite has spectacular developments of columnar cooling joints. Basaltic andesite and andesite magma was intruded into the water-saturated sediment pile.

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