Rosthwaite Fell

[NY 258 122]

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Introduction

Almost continuous exposure on the slopes of the Rosthwaite Fell GCR site, Borrowdale, provides a further section through the caldera-fill succession in the northern part of the Scafell Caldera (see the Ray Crag and Crinkle Crags GCR site report; (Figure 4.12), (Figure 4.18)). However, the site has been selected principally for two important aspects. Firstly, the pre-caldera lavas and an overlying ignimbrite are overlain by a pile of andesite sheets, which represents shallow-level ponding of andesite magma into accumulating ash in a proximal, subsiding volcanotectonic basin during the phreatomagmatic phase of the Whorneyside eruption. Secondly, post-caldera collapse magmatism is represented by the Rosthwaite Rhyolite, a coulee whose fault-controlled intrusive feeder is exposed in cross section. Silicic tuffs and ignimbrites of the Airy's Bridge and Lingmell formations, and caldera lake sedimentary rocks of the Seathwaite Fell Formation are also well displayed (Figure 4.19). The area has been described by Oliver (1954, 1961) and Millward (1976). The most recent accounts are by Davis (1989), Branney *et al.* (1993), Kneller *et al.* (1993b), Kneller and McConnell (1993) and Branney and Kokelaar (1994a); the resurvey associated with this work is included in the Geological Survey 1:50 000 Sheet 29 (1999). During the resurvey parts of the 'Birker Fell Andesite Group' of Oliver (1961) were re-assigned to the Lingcove Formation of Branney *et al.* (1990) and sills within the Whorneyside Formation.

Description

The lowest units exposed at Rosthwaite Fell are autobrecciated andesite sheets that pre-date the Scafell Caldera eruptions. They belong to the Lingcove Formation of Branney *et al.* (1990) and to the Birker Fell Formation of Petterson *et al.* (1992). These rocks are overlain by the Whorneyside ignimbrite, which was the first phase of the Whorneyside eruption and marks the start of the major explosive episode of the Scafell Caldera (Branney, 1991). The ignimbrite is coarser grained than elsewhere in the caldera (it contains abundant blocks) and this may indicate relative proximity to source. The ignimbrite varies abruptly in thickness, from 60–120 m, and this is thought to represent ponding in the underlying lava topography. The ignimbrite is overlain by more than 690 m of andesite sheets intercalated with thin beds of parallel-bedded andesitic tuff. This subaerial fallout tuff is phreatomagmatic and is interstratified with some debris-flow breccias and reworked layers. The andesite sheets are individually up to 380 m thick and have flow-banded and flow-folded central parts, and marginal autobreccias. Some are sills, and locally the upper contacts are peperitic. The origin of others is equivocal and lavas may be present. The Whorneyside Formation on Rosthwaite Fell is about 700 m thick, much thicker than on the south side of the Scafell Caldera (130 m).

The lower part of the Airy's Bridge Formation (Long Top Tuffs) comprises thin, bedded, welded silicic ignimbrites and subordinate pyroclastic surge and fall deposits. This part of the succession is thinner (75–120 m) than in the southern part of the caldera (over 200 m thick), and it thins further towards the NE (Kokelaar, in Branney *et al.,* 1993). By contrast, the upper member of the Airy's Bridge Formation (Crinkle Tuffs) is relatively thick on Rosthwaite Fell (*c.* 660 m). Ignimbrites of the Crinkle Tuffs are massive, intensely welded and commonly rheo-morphic. Parataxitic fabrics, lineations and large-scale folds, all caused by rheomorphism, are best developed in the middle part of the Crinkle Tuffs. In a 10 m-wide zone adjacent to the Rosthwaite Rhyolite and a smaller rhyolite intrusion near Langstrath Beck, welding fabrics in the Crinkle Tuffs are deflected into concordance with the intrusive contacts. Columnar jointing is also present locally. The lava-like Bad Step Tuff (Branney *et al.,* 1992) is absent from the Rosthwaite Fell succession, but a massive eutaxitic lapilli-tuff, 3–15 m thick with a fine-grained top on Bessyboot between [NY 2543 1254] and [NY 2679 1282] may represent a distal co-ignimbrite correlative (Branney *et al.,* 1993).

Subaerial, thinly stratified, clast-supported and locally eutaxitic, lapilli-tuffs and tuffs of the Lingmell Formation unconformably overlie the Crinkle Tuffs, and thicken westwards from the Langstrath towards Stickle Brow [NY 261 118].

A lens of clast-supported breccia containing blocks of welded Crinkle Tuffs thickens to 75 m towards Stickle Brow over a distance of about 300 m, possibly due to ponding in a half-graben, or formation of an apron of blocks along a volcanotectonic fault scarp (Kneller *et al,* 1993b). The breccias are avalanche deposits, possibly with some pyroclastic breccias related to the extrusion of an overlying post-caldera-collapse rhyolite coulee (called the Rosthwaite Rhyolite; Millward, 1976; Davis, 1989). The rhyolite is crystal poor, flow-folded and perlitic, and has upper and lower autobreccias. It is of particular interest because it has both intrusive and extrusive parts connected by a short rhyolite-filled conduit and vent [NY 257 118], now exposed in diagonal section. Its intrusive part is well exposed for a distance of 1.5 km [NY 264 122], and the extrusive part is 130 m thick and continuously exposed from vent to lateral terminations, 1.9 km apart (Figure 4.19). It may have risen along the fault whose scarp generated the avalanche breccias.

The Rosthwaite Rhyolite is onlapped by coarsening-upwards laminated pumiceous sedimentary rocks that represent turbidites, and/or water-laid pyroclastic deposits (Three Tarns Member, Seathwaite Fell Formation), and by overlying beds of deltaic pebbly volcaniclastic sandstone and pebble conglomerate derived from the north (Cam Crags Member) (Kneller and McConnell, 1993). The latter unit thickens markedly westwards across Rosthwaite Fell from the Langstrath [NY 262 113], and the overlying sedimentary unit, the Dungeon Gill Member, correspondingly thins in this direction, because of ponding against the delta topography. The Dungeon Gill Member comprises fine-grained sandstone and siltstone with disrupted, nebulous or chaotic bedding, patches of coarse-grained sandstone, and large pods of breccia derived from the overlying Pavey Ark Member and injected with flames of sandstone. These are sediment gravity-flow deposits with intense soft-sediment disruption involving liquefaction, probably caused by sedimentary loading, slumping, and seismic shock. The overlying Pavey Ark Member, exposed on both sides of the WNW-trending fault along Woof Gill [NY 258 112], is a breccia, *c.* 25 m thick, that grades up into 40 m of massive fine-grained sandstone (Raine, 1998). The breccia has layers containing abundant andesite blocks [NY 2598 1090] whose shapes indicate that they were once hot and fluidal, as with basaltic volcanic bombs.

Interpretation

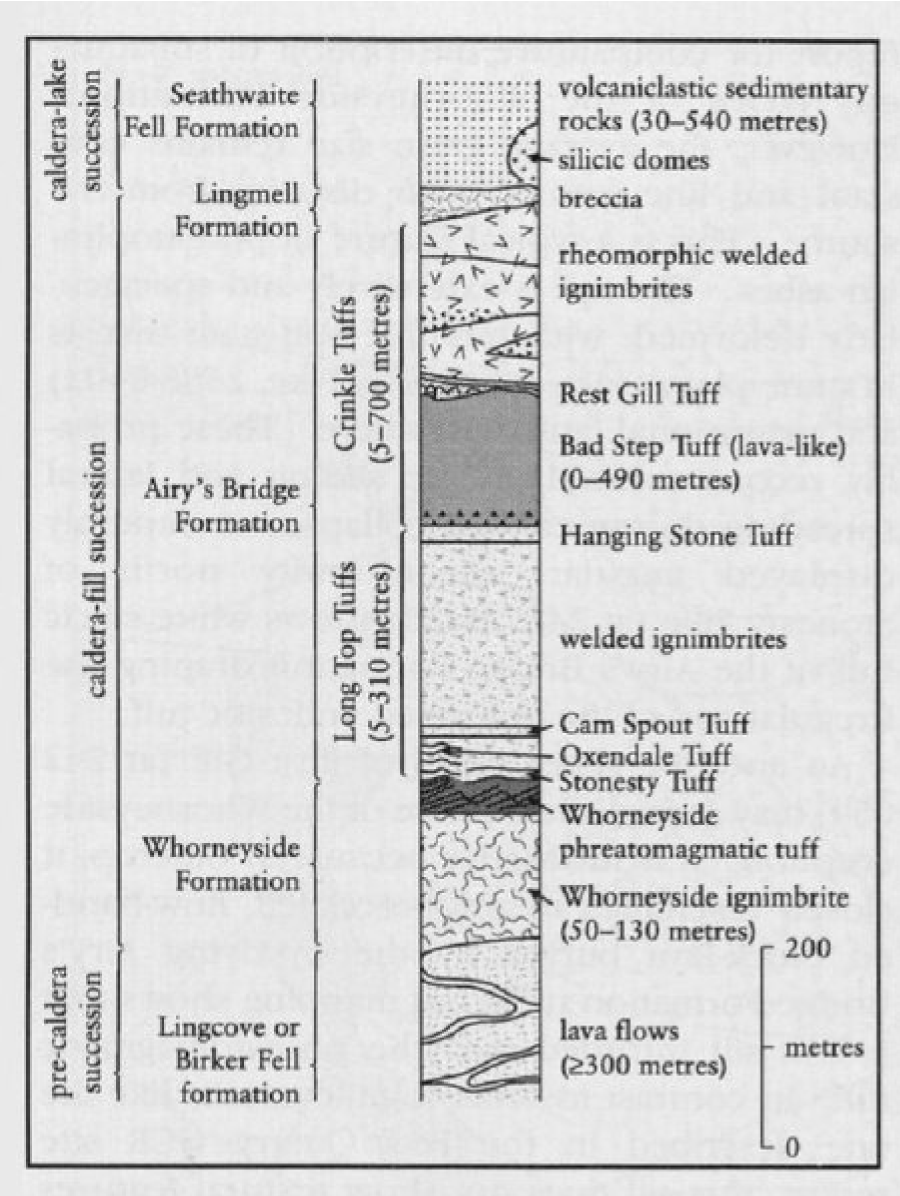
The volcanic succession of Rosthwaite Fell records the evolution of the northern part of the Scafell Caldera. It fits the generalized sequence of events inferred by Branney and Kokelaar (1994a; (Figure 4.15)). Marked differences in the succession between Rosthwaite Fell and other parts of the Scafell Caldera reflect proximities to former vents and very localized subsidence. For example, during the later stages of the Whorneyside eruption, the northern part of the Scafell Caldera (including the Rosthwaite Fell and Sour Milk Gill GCR sites) lay within an actively subsiding northern depocentre, and the deposits are thicker with more aqueously reworked components and sills than farther south in the caldera, where the Whorneyside phreatomagmatic tuff was deposited by fallout on to a flat subaerial ignimbrite plain (Branney, 1988b; 1991). However, subsidence at Rosth-waite Fell then declined during the Long Top Tuff eruptions: the ignimbrites are thin, and lowest units of the succeeding Crinkle Tuffs, the lava-like Bad Step Tuff (Branney et al., 1992) and the overlying, phreatomagmatic, Rest Gill Tuff (Branney and Kokelaar, 1994a), are not recognised in the Rosthwaite Fell succession. By contrast, other parts of the caldera (e.g. in Langdale; see the Langdale Pikes GCR site report) were undergoing dramatic subsidence at this time. Subsidence at Rosthwaite Fell then increased during the late climactic phase of the eruption, resulting in the thickly ponded uppermost Crinkle Tuffs. Thus, at Rosthwaite Fell most of the subsidence during the Airy's Bridge eruptions post-dated the Rest Gill Tuff; this is later than that farther south.

Active volcanotectonic faults produced ephemeral scarps which shed rock avalanches, and provided pathways for the ascent of the Rosthwaite Rhyolite. The entire area was then inundated and buried with caldera-lake sediments. A delta advanced from the north, and its toe was obstructed by the extant Rosthwaite Rhyolite coulee (Kneller and McConnell, 1993). The Pavey Ark Member is found extensively within the Scafell Caldera, and represents a catastrophic eruption-generated subaqueous gravity flow. It may be an intracaldera equivalent of spatter-rich co-ignimbrite lag breccias deposited from voluminous proximal pyroclastic flows, such as those that occur on rims of modern flooded explosive calderas, such as Santorini (Mellors and Sparks, 1991). If so, it is the only intracaldera example recorded worldwide.

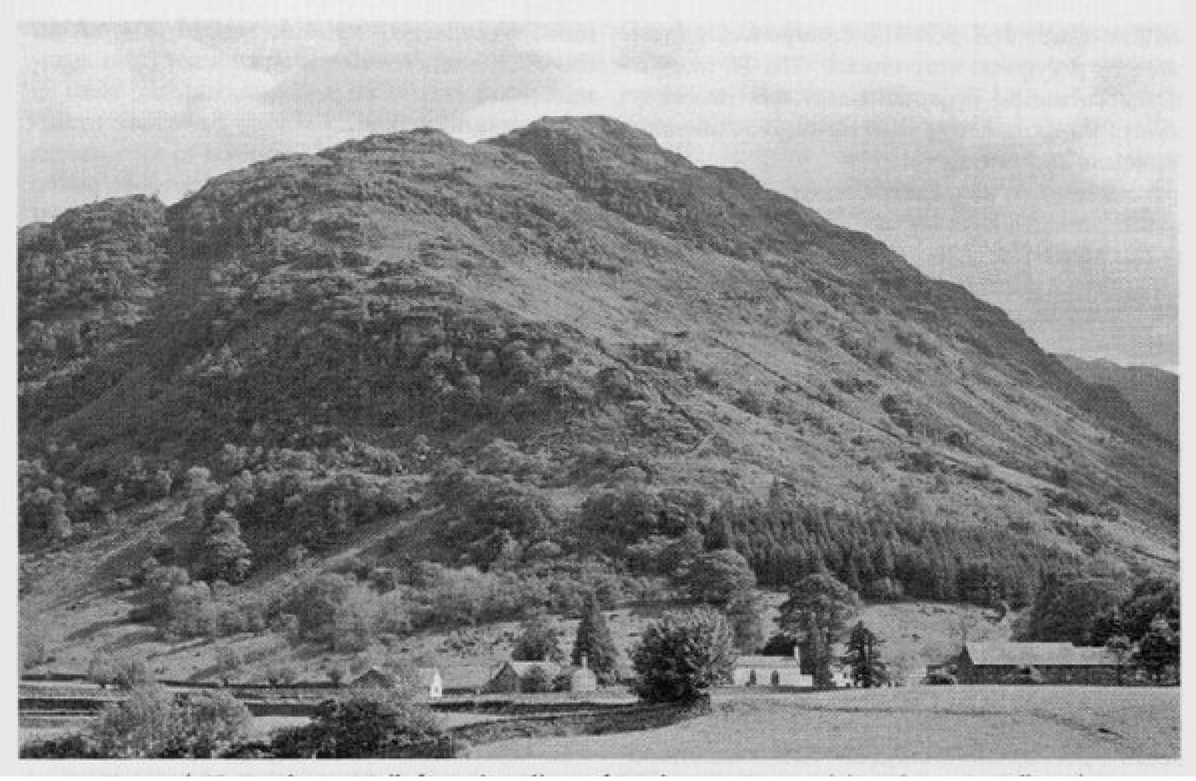
Conclusions

This GCR site is important because is provides remarkably continuous exposure through the caldera-collapse cycle within the internationally significant Scafell Caldera. The site illustrates variations in the nature of alternations between explosive eruption produced by the release of gas from magma, and those driven by explosive vaporization of water on contact with magma. It also shows how different parts of the caldera subsided at different times and at different rates. It is thus complementary to the other GCR sites within the Scafell Caldera. Post-collapse magmatism is a principal feature of this site, which provides a rare and beautifully exposed cross section through the Rosthwaite Rhyolite along with its vent and feeder, centred on a fault that was active during the volcanism.

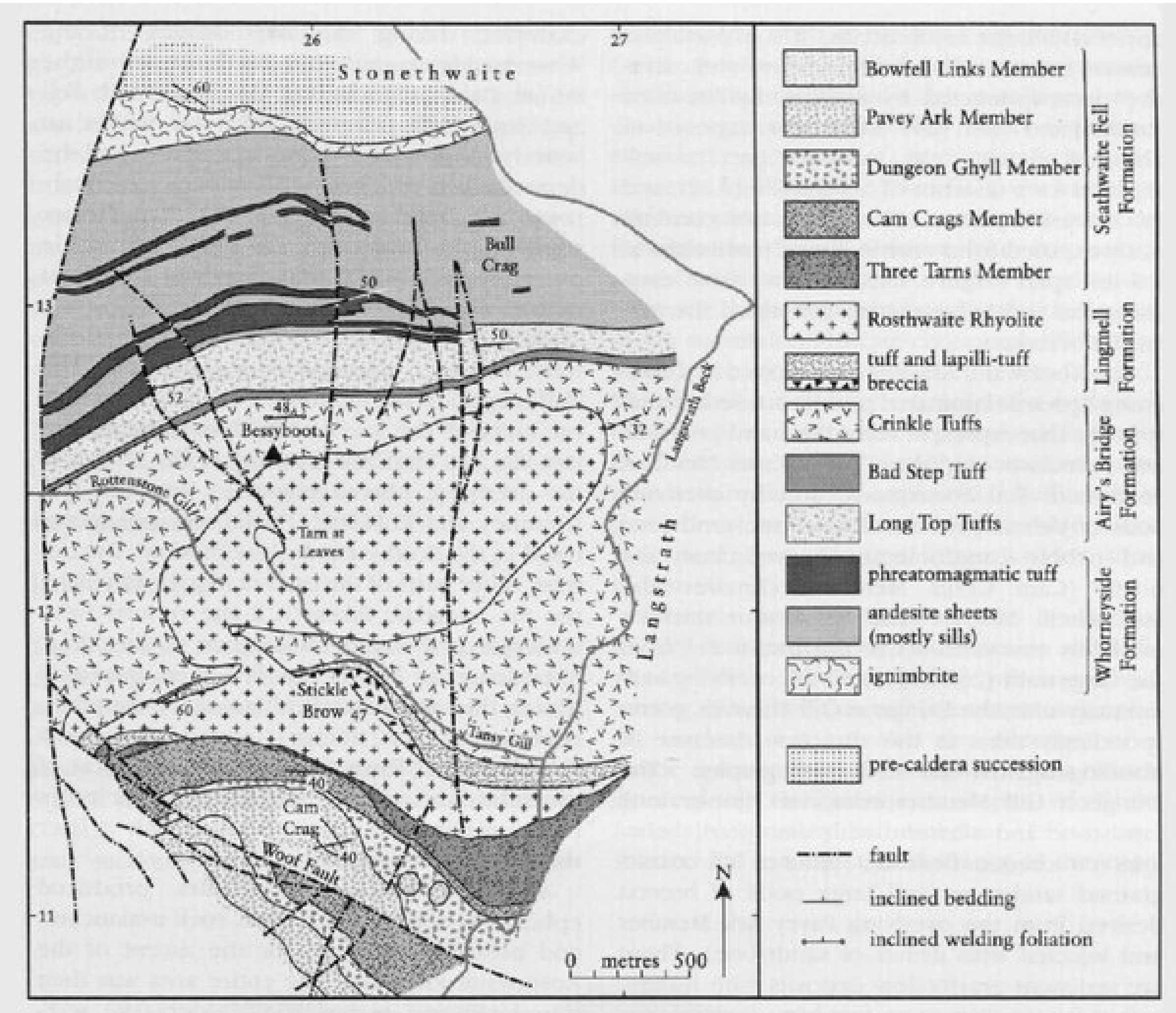
References



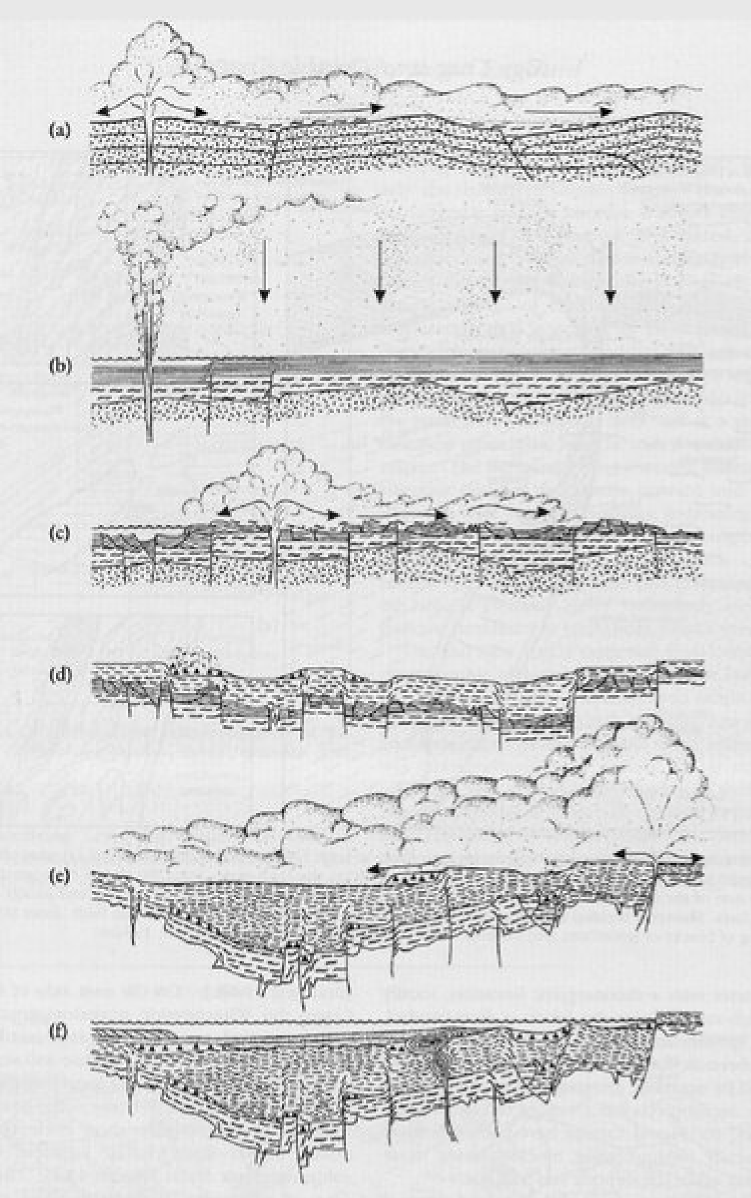
(Figure 4.12) Generalized lithostratigraphy of the Scafell Caldera succession (after Branney and Kokelaar, 1994a).



(Figure 4.18) Rosthwaite Fell, from the village of Rosthwaite, Borrowdale. (Photo: D. Millward.)



(Figure 4.19) Map of Rosthwaite Fell, Borrowdale (based on mapping by B. P Kokelaar, B. C. Kneller, N. Davies and M. J. Branney, for British Geological Survey).



(Figure 4.15) Schematic summary of the evolution of the Scafell Caldera by piecemeal collapse. The cartoons are simplified and not to scale. (a) Emplacement of the Whorneyside ignimbrite across low-profile andesite volcanoes. (b) Proximal subsidence facilitates aqueous inundation of the vent, changing the eruption style to phreatoplinian (see the Sour Milk Gill GCR site report). (c) Onset of widespread piecemeal subsidence, deformation of Whorneyside phreatomagmatic tuff deposits and burial under hot silicic ignimbrites of the Long Top Tuffs erupted from new vents. (d) Continued subsidence with ductile deformation of hot ignimbrites and collapse of growing fault scarps. (e) Final stages of the paroxysmal eruption of the Crinkle Tuffs. (f) Caldera lake formation with deposition of subaqueous volcaniclastic sediments, along with post-collapse silicic dome emplacement (see the Rosthwaite Fell GCR site report) (from Branney and Kokelaar, 1994a).