

## STOCKDALE BECK, LONGSLEDDALE

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### Introduction

Pyroclastic rocks and an enigmatic felsite seen within the Stockdale Beck, Longsleddale GCR site were probably erupted about 10 Ma after the end of the Borrowdale Volcanic Group (BVG) activity (Figure 4.29). These rocks are important in understanding the latest stages of Early Palaeozoic volcanism in northern England. Furthermore, the felsite is a good example of an extensive lava-like body of silicic composition with characteristics that have been taken to indicate that it is either a lava or a rheomorphic ignimbrite. The GCR site contains the type section of the Yarlside Volcanic Formation (Kneller *et al.*, 1994), the new name for the suite of rocks formerly known as the 'Yarlside Rhyolite' (Marr, 1892; Ingham *et al.*, 1978), 'Stockdale Rhyolite' (Gale *et al.*, 1979) and 'Stockdale Rhyolite Member' (Millward and Lawrence, 1985; Lawrence *et al.*, 1986). The formation is the thickest of several minor volcanic successions within the Dent Group of the Lake District and neighbouring northern Pennines. The felsite was distinguished first by Sedgwick (1836), but was described comprehensively only recently (Millward and Lawrence, 1985). The Rb-Sr isochron age of  $421 \pm 3$  Ma has been used by Gale *et al.* (1979) to revise calibration of the Palaeozoic time-scale.

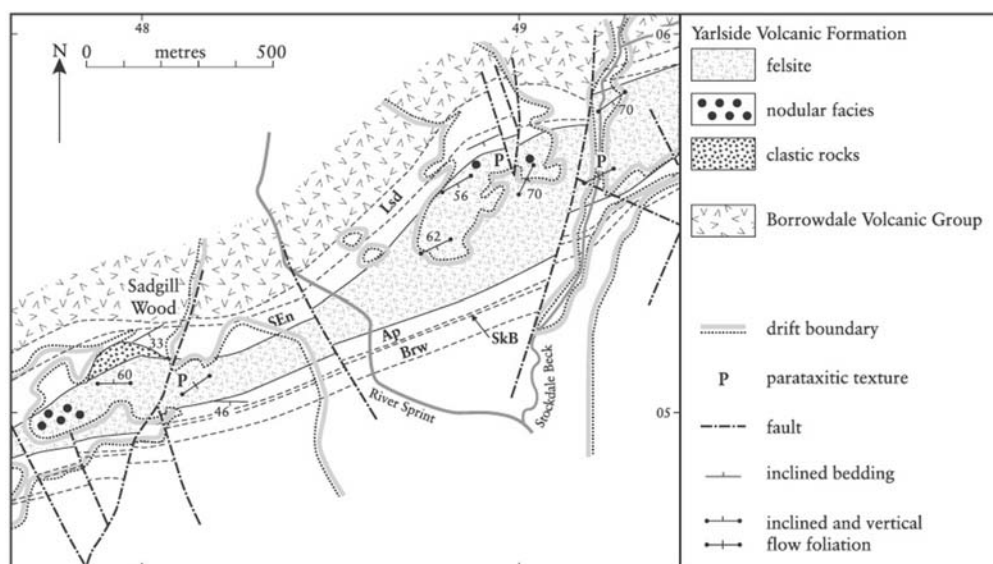


Figure 4.29: Map of the Stockdale Beck, Longsleddale GCR site (after Millward and Lawrence, 1985). Windermere Supergroup abbreviations: Ap, Kirkley Bank and Ashgill formations; Brw, Browgill Formation; Lsd, Longsleddale Member; SEn, Stile End Formation; SkB, Skelgill Formation.

### Description

The Yarlside Volcanic Formation crops out from Stile End (471 047) to near Shap Wells (577 096) in the eastern Lake District, but is in places extensively covered by Quaternary deposits. The formation overlies fine-grained sandstone and conglomerate of the Stile End Formation and locally, between the River Sprint and Stockdale Beck, volcanic rocks fill small-scale depressions in the top of the underlying formation (Figure 4.29). The uppermost beds of the Stile End Formation may have been thermally metamorphosed by the volcanic rocks (Ingham *et al.*, 1978). The volcanic rocks are overlain by a pebble-conglomerate comprising felsite fragments at the base of the Kirkley Bank Formation (formerly Applethwaite Member of Lawrence *et al.*, 1986). About 60 m of volcanic rocks are preserved near Sadgill Wood, thickening to 180 m east of Mere Crag around Stockdale Beck; the formation thins out west of the GCR site towards Stile End.

Most of the succession consists of a single bed of pink to pale-grey and greyish-green, splintery, massive to intensely fractured felsite that is platy jointed, flow-banded and flow-folded. It is high-silica rhyolite in composition. In Stockdale Beck, the type section, an almost completely exposed section through 180 m of felsitic rock comprises a single unit in which the lowest 45 m are strongly flow-folded and the uppermost 30 m are massive with a vitroclastic-like texture and a devitrified fabric overprinting perlitic cracking; the central part comprises a mixture of these two facies. Abundant small, subangular to subrounded felsite clasts are present throughout. In the lower part of the unit, flow-banding is generally concordant with bedding in the underlying sedimentary rocks; in the upper part dips are generally steeper than the regional dip suggesting that ramp-like structures may be present. Flow folds range from small-scale open undulations to isoclinal, intrafolial structures, with amplitudes of a few centimetres to several metres. No autobreccia is associated with the felsitic rock.

The abundant small spherulites and perlitic cracking testify to the original glassy state. Devitrification textures include sutured fine-grained mosaics of quartz and feldspar, snowflake texture and elongate axiolitic structures. Recrystallization of the felsic rock has produced a fine- to medium-grained mosaic of anhedral quartz and subhedral albite. Locally the rock is riddled with small veins of quartz. Concentric perlitic cracks locally provide nucleation points for recrystallization, the fractures marked by chlorite and the intervening areas by partial, spherulite-like clusters of quartz and feldspar.

A nodular facies, referred to as 'agate-ball' structure by Sedgwick (), is well developed within the site (Figure 4.30). Most of the locally abundant nodules are single or intergrown expanded spherulites, up to 20 cm diameter, in which the original radiating quartz–feldspar fibres commonly have been ghosted by an overprinted snowflake texture. The central star-like cavities were filled subsequently by quartz with subordinate sericite and carbonate. The basal part of the unit west of Stockdale Beck (489 056) contains another type of nodule, up to 40 cm, without central cavities and with a concentric recrystallization fabric overprinting the undisturbed flow-banding.

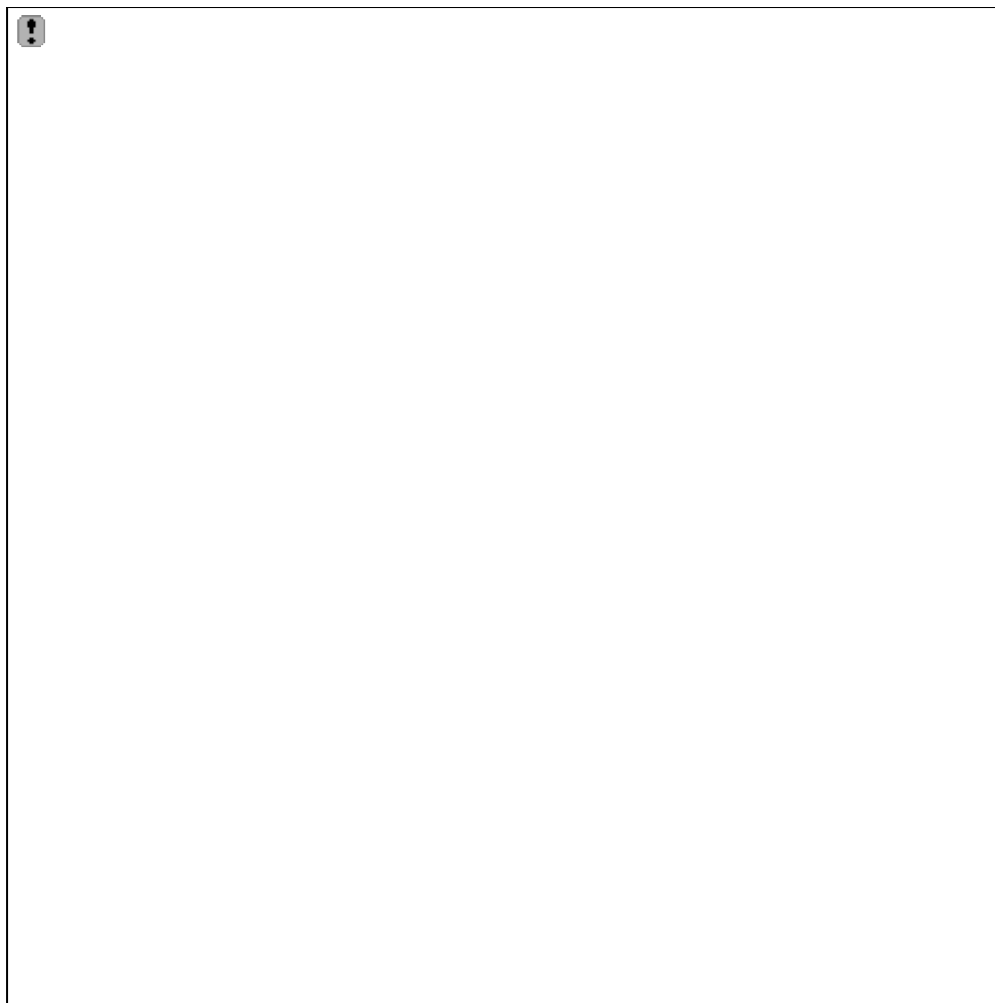


Figure 4.30: The Yarlside Volcanic Formation, approximately 450 m NW of Stockdale, showing flow-banded felsite containing large nodules formed by intense silicification. (Photo: BGS no. L3143.)

In the west of the GCR site approximately 10 m of medium-bedded eutaxitic-textured lapilli-tuff occur at the base of the formation. Small lapilli-sized chloritized fiamme and pink felsite clasts occur within a vitroclastic matrix (Millward and Lawrence, 1985, fig. 4A). In the upper part of the formation in Stockdale Beck, and immediately to the east, grey, unbedded tuff contains subangular to subrounded felsite clasts set in a microcrystalline siliceous groundmass, which in places has a recrystallization fabric overprinting perlitic cracking. Strata up to 40 cm thick, locally showing evidence of reworking, occur at the top of the formation east of Stockdale Beck (498 061) and comprise devitrified glass shards, fragments of pumice and sparse rhyolite clasts, but crystals are notably absent.

## Interpretation

The Yarlside Volcanic Formation is probably the most voluminous post-BVG Lower Palaeozoic volcanic deposit in the Lake District and adjacent areas (Ingham *et al.*, 1978). The felsite is the only post-BVG lava-like volcanic rock, because the rest are clearly volcanoclastic. After the end of the major volcanic episode represented by the BVG, the Lake District underwent erosion and thermal subsidence that allowed clastic sediments derived from the volcanic massif to accumulate in a shore-face or beach environment, and this gave way subsequently to shallow-water carbonate shelf conditions. The similar outcrop distributions of the Yarlside Volcanic Formation and the underlying Stile End Formation suggest that they filled a coastal embayment (Kneller *et al.*, 1994). Rocks of the Yarlside Volcanic Formation were erupted into this environment, probably from a source to the south of the outcrop (Ingham *et al.*, 1978). Eruption of the felsite probably caused temporary emergence and the rocks were reworked into the base of the overlying Kirkley Bank Formation (Millward and Lawrence, 1985).

Rocks of the Yarlside Volcanic Formation have been interpreted in most accounts as extrusive and probably lava (Rutley, 1885a; Green, 1915b; Marr, 1916; Mitchell, 1934, 1956; Gale *et al.*, 1979). Gale *et al.* (1979) interpreted the three separately exposed parts of the outcrop as evidence for three lavas. However, Millward and Lawrence (1985) proved by detailed mapping that a single continuous outcrop is present. They described characteristics of the felsite that, in their opinion, are not typical of felsic lava. These include the facies association with thin pyroclastic beds in a marine and otherwise non-volcanic environment, the absence of autobreccia, and the local presence of welded-tuff-like textures. They suggested that the felsite is interpreted best as a rheomorphic ignimbrite. During the last ten years there has been considerable debate about whether lava-like felsic bodies elsewhere are rheomorphic ignimbrites or true lavas (see Manley, 1996). The Bad Step Tuff in the BVG of the central Lake District described by Branney *et al.* (1992) is an excellent example of a lava-like ignimbrite (see the Ray Crag and Crinkle Crags GCR site report). However, textures seen in the felsite of the Yarlside Volcanic Formation have been described from probable lavas by Manley (1996), casting doubt on the interpretation by Millward and Lawrence (1985) and it remains possible that the felsite is an extensive lava.

The probable short time span represented by the volcanic episode and the close biostratigraphical control from fossiliferous beds above and below make the felsite a potential control point for calibration of the geological time-scale. Gale *et al.* (1979) used the Rb-Sr isochron age of  $421 \pm 3$  Ma for the felsite as the date for the Ashgill. However, the same numerical age was obtained subsequently for the Laidlaw Volcanics near Canberra, Australia, which are also well constrained biostratigraphically, as early Ludlow (Wyborn *et al.*, 1982). Compston *et al.* (1982) re-examined the data presented by Gale *et al.* (1979) and concluded that emplacement of the felsite took place at least 430 Ma ago and that there was a net loss of Sr during hydrothermal circulation at around 412 Ma. The biostratigraphical age for the Yarlside Volcanic Formation is unequivocal and the time-scale of Harland *et al.* (1990), which does not use the Yarlside Volcanic Formation date, suggests an age of about 445 Ma.

The debate on the radiometric age of the felsite in the Yarlside Volcanic Formation has wider implications in Lake District research. Rundle (1979) defined a *c.* 420 Ma magmatic event on the basis of similar Rb-Sr isochron ages obtained for the Stockdale Rhyolite, the Ennerdale and Carrock granites, and the Harestones Rhyolite. In addition to the earlier biostratigraphical age for the Yarlside Volcanic Formation, U-Pb determinations on zircons from the Ennerdale intrusion have indicated a Caradoc age ( $452 \pm 4$  Ma, Hughes *et al.*, 1996), considerably older than its Rb-Sr date. Other dating methods have not yet been applied to the Carrock microgranite nor to the Harestones Rhyolite, but it seems unlikely that the Rb-Sr dates for these represent the age of intrusion. If the *c.* 420 Ma date is not the age of emplacement then what is the significance of this early Ludlow event? Hughes *et al.* (1996) suggested that resetting may be related to water-rock interaction caused by tectonic events at the onset of basin inversion which was associated with foreland basin and mountain front development in the Lake District upon closure of the Iapetus Ocean (Kneller *et al.*, 1993a).

## Conclusions

The Stockdale Beck, Longsleddale GCR site contains the type section of the Yarlside Volcanic Formation, which comprises an extensive lava-like felsite and locally preserved pyroclastic and reworked pyroclastic rocks that were erupted about 10 Ma after the main phase of volcanism in the Lake District had ceased. These rocks were erupted into a shallow-marine environment, probably causing emergence locally. Lava and very intensely welded ignimbrite are possible interpretations of these rocks. The site is important because it contains the only Early Palaeozoic example of a lava-like felsite that post-dates the BVG. The felsite is also probably the most voluminous volcanic rock that postdates the BVG. The intercalation of the felsite within a biostratigraphically well-constrained marine sedimentary succession gives this site potential value for the calibration of the geological time-scale.

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