BRAMCRAG QUARRY

S.C. Loughlin

OS Grid Reference: NY320220

Introduction

The Threlkeld microgranite is exposed in three main outcrops about 4 km east of Keswick (Figure 4.31). The outcrops on Low Rigg, Threlkeld Knotts and in Bramcrag Quarry are interpreted to represent a single irregular laccolith (Firman, 1978b). Prior to the excavation of Bramcrag Quarry in the early 1970s, the age and relationship of the Threlkeld microgranite to the Ordovician country rocks was difficult to ascertain (Hadfield and Whiteside, 1936; Rastall, 1940). Wadge (1972) suggested that the microgranite was emplaced prior to deposition of the Borrowdale Volcanic Group (BVG). However, the section exposed in Bramcrag Quarry clearly shows that the Threlkeld microgranite cuts both the Skiddaw Group and the lowest parts of the BVG. The petrography and geochemistry of the Threlkeld microgranite were described by Caunt (1984) who proposed that assimilation of Skiddaw Group material facilitated the low-pressure crystallization of garnet. The Threlkeld microgranite is now thought to be a high-level intrusion, contemporaneous with the thick succession of ignimbrites in the upper part of the BVG, though this theory is not entirely supported by isotopic dating (Wadge *et al.*, 1974; Rundle, 1981, 1992).

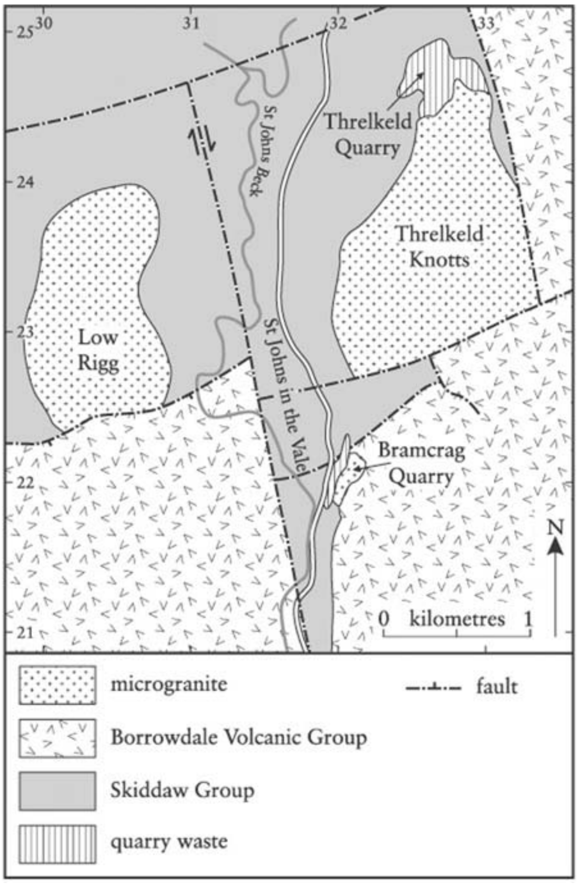

Figure 4.31: Map of the Threlkeld microgranite showing the location of Bramcrag Quarry.

The Bramcrag Quarry GCR site is one of the best exposures of the Threlkeld microgranite and thus provides critical evidence for the timing of mid-Ordovician intrusive activity in the Lake District. In addition, Bramcrag Quarry illustrates the unconformable relationship between the Skiddaw Group and the overlying BVG (Figure 4.32).

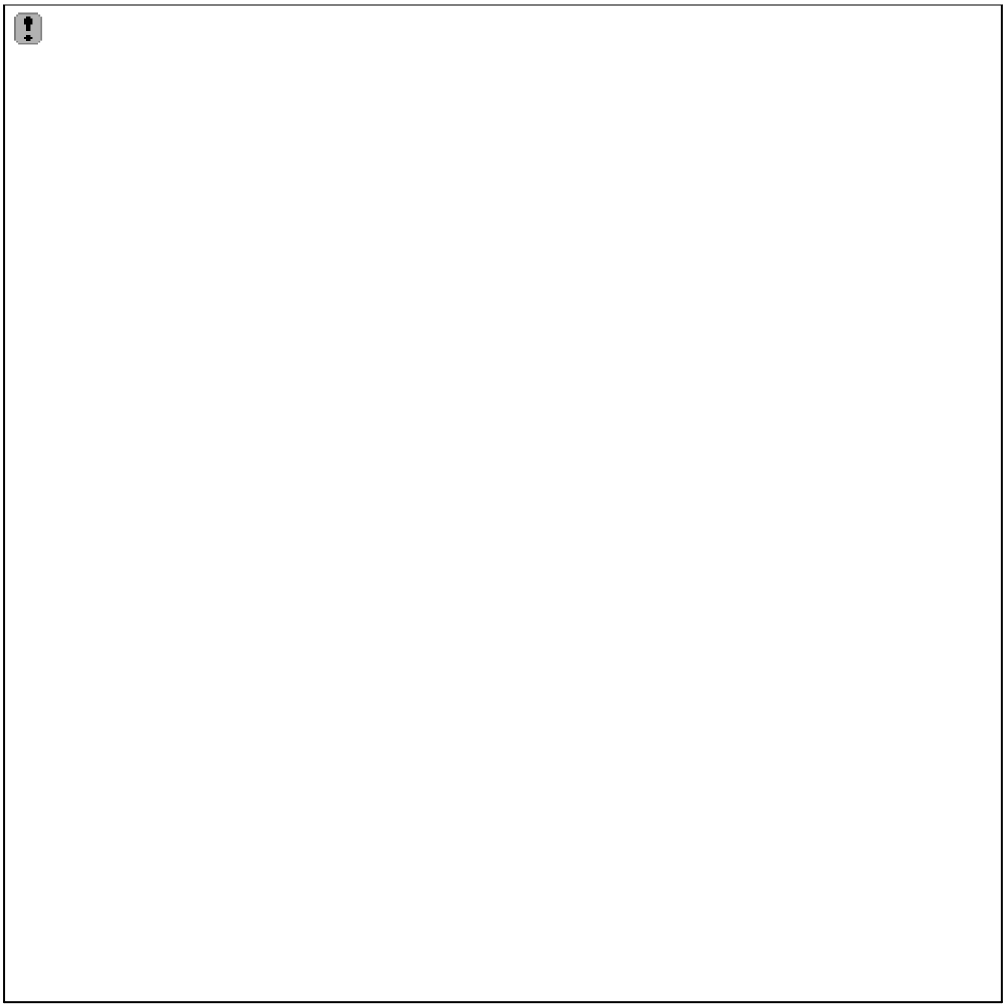

Figure 4.32: Bramcrag Quarry: the Threlkeld microgranite is overlain by lavas and volcaniclastic sedimentary rocks of the basal part of the Borrowdale Volcanic Group. The contact slopes from top right to lower left. (Photo: BGS no. L2041.)

Description

The Threlkeld microgranite, previously referred to as ‘adamellite', is medium grained, light-grey and contains abundant feldspar phenocrysts (up to 5 mm in size) together with striking rounded quartz crystals. The feldspar phenocrysts are predominantly euhedral to subhedral albite with some pink orthoclase; they show no preferred orientation and may form glomeroporphyritic clusters. The feldspar phenocrysts show varying degrees of alteration to sericite, calcite, chlorite and quartz. Subhedral, elongate chlorite pseudomorphs intergrown with iron oxides may be after amphibole (Campbell, 1995) or biotite (Caunt, 1984). Sporadic anhedral garnet with ragged margins is also present. The groundmass is mainly composed of fine-grained granular quartz and sericitized plagioclase with some iron oxide and elongate chlorite pseudomorphs, perhaps after amphibole; accessory minerals include zircon and apatite.

The upper, sub-horizontal contact of the microgranite is exposed high along an inaccessible, worked face in the eastern part of the quarry, where it is overlain by mudstone, siltstone and tuffaceous sandstone belonging to the lowest part of the BVG (Figure4.32). The sedimentary rocks are weakly hornfelsed and show thermal spotting, but this contact metamorphism typically extends for only a few centimetres from the contact and rarely to more than one metre. The microgranite has narrow chilled margins (less than 1 cm) from which phenocrysts are absent. The contact is generally sharp and planar; in the northern part of the quarry, a tongue of microgranite has penetrated the overlying sedimentary rocks with clear discordance. Debris on the quarry floor illustrates this type of intrusive relationship; there are also blocks of distinctive pyroxene-phyric basic lavas from higher levels in the BVG.

In the southern part of the quarry, the microgranite contact with the BVG dips at 5–10° to the SE. Some slickensided quartz veining can be seen along the contact suggesting that shearing has occurred. There is also some evidence that minor shearing occurred within the microgranite. Stepped slickensides and quartz slickencrysts found on selected joints within the microgranite indicate an oblique dextral-reverse movement (Campbell, 1995).

At the southern end of Bramcrag Quarry, a near-vertical intrusive contact of the microgranite cuts through the dark-grey mudstone and siltstone of the Skiddaw Group. Several metres above the Skiddaw Group rocks, which dip steeply to the SW, are sub-horizontal volcaniclastic sedimentary rocks and lavas of the BVG. Unfortunately, the plane of the unconformity is obscured by scree.

Xenoliths of Skiddaw Group lithologies are common, particularly near the margins of the Threlkeld microgranite, and range in size from a few millimetres to over one metre in diameter. These xenoliths are commonly spotted by contact metamorphism and some show intense folding within them (Rastall, 1940). Rare xenoliths of BVG rocks are also present. A near-vertical ENE-trending cleavage occurs throughout the quarry and post-dates the microgranite.

Interpretation

Hadfield and Whiteside (1936) reported whole-rock geochemical analyses on the Threlkeld microgranite which showed that, despite the abundance of xenoliths in certain places, the overall composition of the granite seemed to be largely unaffected by their assimilation. The compositional uniformity of the Threlkeld microgranite was also recognized by O'Brien *et al*. (1985) who showed that, along with other Lake District granites, it follows a calc-alkaline trend on an AFM diagram. The Threlkeld microgranite has a small negative Eu anomaly indicating that plagioclase fractionation may have occurred before intrusion (O'Brien *et al*., 1985). There are some significant similarities in trace element geochemistry between published BVG compositions (e.g. Fitton *et al*., 1982) and the Threlkeld microgranite, but there are also some differences, particularly with respect to P, Nb, Zr and Y, suggesting that they either had different fractionating phases, or different sources (O'Brien *et al*., 1985). Low initial $^{87}Sr/^{86}Sr$ ratios of 0.7055 (Wadge *et al*., 1974) attest to the I-type nature of the Threlkeld microgranite.

Garnets in the Threlkeld microgranite show a wide range of compositions, in contrast to the restricted compositions of those in the host rock (Caunt, 1984). There is a compositional overlap between garnets from the Threlkeld microgranite and garnets from the BVG. The Threlkeld microgranite garnets may be magmatic in origin (Oliver, 1956a, 1956b) or they may be xenocrystic (Rastall, 1940; Fitton, 1972). Caunt (1984) suggested that incorporation of Skiddaw Group material enriched the microgranite magma in Al_2O_3 and Fe_2O_3 allowing moderately low-pressure crystallization of garnet (cf. Fitton *et al*., 1982 for garnet crystallization in BVG rocks).

The age of the Lake District intrusions, including the Threlkeld microgranite, has been a major debate since the beginning of the 20th century (e.g. Marr, 1900; Harker, 1902; Rastall and Wilcockson, 1915). The relationship of the Threlkeld microgranite to the contact between the Skiddaw and Borrowdale Volcanic groups is of crucial importance in determining the timing of its intrusion. Green (1917) suggested that the Threlkeld microgranite is a sill intruded into a conformable contact between the Skiddaw and Borrowdale Volcanic groups. Taking into account cleavage in the microgranite he suggested an age that was post-lower BVG but pre-Devonian. Hadfield and Whiteside (1936) considered the microgranite to be a laccolith intruded below the BVG. They found xenoliths of BVG material in the microgranite and also proposed that the intrusion post-dates the lower BVG.

A different view was expressed by Rastall (1940). Based on his discovery of a xenolith of sharply folded Skiddaw Group material within the microgranite, Rastall (1940) argued that because folding of the Skiddaw Group was Caledonian, the microgranite must be Caledonian or younger. Wadge (1972) interpreted the contact between the Skiddaw Group and the BVG as an angular unconformity, suggested that the stock-like Threlkeld microgranite was intruded into the Skiddaw Group and that it was then partially eroded before deposition of the overlying BVG. Subsequently, the excavation at Bramcrag Quarry exposed field relationships that prove clearly that the Threlkeld microgranite is younger than the lowest strata of the BVG (Wadge *et* *al*., 1974).

Gravity data presented by Bott (1974) show an anomaly overlying both the Skiddaw granite and the Threlkeld microgranite, but a more recent interpretation of the gravity data by Lee (1986) revealed that each intrusion has a separate Bouguer anomaly. An anomaly beneath the NE margin of the Threlkeld microgranite (Lee, 1986) was interpreted as a separate granite cupola corroborating Firman's (1978b) interpretation of the outcrops of the Threlkeld microgranite as a single irregular laccolith.

The Threlkeld microgranite is considered to be a subvolcanic intrusion related to the extrusive rocks of the BVG (Rundle, 1992), and it must therefore be Ordovician in age (older than *c*. 440 Ma). The Rb-Sr isochron age of 445 ± 15 Ma for the Threlkeld microgranite reported by Wadge *et al*. (1974) was recalculated by Rundle (1981) as 438 ± 6 Ma. Rundle (1992) acknowledged that this date could represent either the emplacement age of the microgranite or a subsequent ‘resetting' event. He suggested that the emplacement of the Eskdale granite, which he had dated at about 430 Ma using Rb-Sr and K-Ar methods, may have been responsible for the resetting event. However, recent U-Pb analyses of zircons gave an age of 450 ± 3 Ma for the emplacement of the Eskdale granite and 452 ± 4 Ma for the Ennerdale granite (previously 420 ± 4 Ma using a Rb-Sr isochron; Rundle, 1992) suggesting that the Rb-Sr whole rock and K-Ar mineral methods do not correspond to the emplacement of the intrusions, but to a resetting event (Hughes *et al*., 1996). This in turn casts doubt on the accuracy of the Rb-Sr isochron age as the date of emplacement for the Threlkeld microgranite. Hughes *et al*. (1996) suggested that there were only two phases of acid magmatism relating to the exposed parts of the Lake District batholith: the Eskdale, Ennerdale and Threlkeld intrusions belong to a subduction-related Caradoc phase whereas the Shap and Skiddaw intrusions belong to a later, Devonian phase.

The significance of the sheared contact between the Threlkeld microgranite and the lower BVG is uncertain. The presence of apophyses of microgranite within the overlying sedimentary rocks suggests that absolute movement along this contact was minimal (Campbell, 1995).

Conclusions

The age of the Threlkeld microgranite and its relationship with the Ordovician country rock and other Lake District intrusions has been the subject of debate for many years. The relationships exposed at Bramcrag Quarry are crucial in constraining the further interpretation of the isotopic dates. The Bramcrag Quarry site is the only locality that demonstrates that the Threlkeld microgranite intrudes both the Skiddaw Group and the lowest part of the Borrowdale Volcanic Group. The intrusion is considered, on petrographical and geochemical evidence, to be contemporaneous with the thick ignimbrites of the upper part of the Borrowdale Volcanic Group. The available Rb-Sr age of 438 ± 6 Ma post-dates the cessation of volcanism and may represent either the age of emplacement of the Threlkeld microgranite or a resetting event. Accurate U-Pb dates on zircons may offer a resolution to this problem.

Reference list

Bott, M. H. P. (1974) The geological interpretation of a gravity survey of the English Lake District and the Vale of Eden. *Journal of the Geological Society of London*, **130**, 309–31.
Campbell, S. D. G. (1995) The Borrowdale Volcanic Group and related geology on 1:10 000 Sheets NY 32 SW and SE. *British Geological Survey Technical Report*, No. **WA/95/02**.
Caunt, S. (1984) Geological aspects of the Threlkeld Microgranite, Cumbria. *Trans-actions of the Leeds Geological Association*, **10**, 89–100.
Firman, R. J. (1978b) Intrusions. In *The Geology of the Lake District* (ed. F. Moseley), The Yorkshire Geological Society, Leeds, pp. 146–63.
Fitton, J. G. (1972) The genetic significance of almandine-pyrope phenocrysts in the calc-alkaline Borrowdale Volcanic Group, Northern England. *Contributions to Mineralogy and Petrology*, **36**, 231–48.
Fitton, J. G., Thirlwall, M. F. and Hughes, D. J. (1982) Volcanism in the Caledonian orogenic belt of Britain. In *Andesites* (ed. R. S. Thorpe), Wiley, Chichester, pp. 611–36.
Green, J. F. N. (1917) The age of the chief intrusions of the Lake District. *Proceedings of the*

Geologists' Association, **28**, 1–30.
Hadfield, G. S. and Whiteside, H. C. (1936) The Borrowdale Series of High Rigg and the adjoining Low Rigg Microgranite. *Proceedings of the Geologists' Association*, **47**, 42–64.
Harker, A. (1902) Notes on the igneous rocks of the English Lake District. *Proceedings of the Yorkshire Geological Society*, **14**, 487–93.
Hughes, R. A., Evans, J. A., Noble, S. R. and Rundle, C. C. (1996) U-Pb geochronology of the Ennerdale and Eskdale intrusions supports sub-volcanic relationships with the Borrowdale Volcanic Group (Ordovician, English Lake District). *Journal of the Geological Society of London*, **153**, 33–8.
Lee, M. K. (1986) A new gravity survey of the Lake District and three-dimensional model of the granite batholith. *Journal of the Geological Society of London*, **143**, 425–35.
Marr, J. E. (1900) Notes on the geology of the English Lake District. *Proceedings of the Geologists' Association*, **16**, 449–83.
O'Brien, C., Plant, J. A., Simpson, P. R. and Tarney, J. (1985) The geochemistry, metasomatism and petrogenesis of the granites of the English Lake District. *Journal of the Geological Society of London*, **142**, 1139–57.
Oliver, R. L. (1956a) The origin of garnets in the Borrowdale Volcanic Series and associated rocks, English Lake District. *Geological Magazine*, **93**, 121–39.
Oliver, R. L. (1956b) The origin of garnets in the Borrowdale Volcanic Series. *Geological Magazine*, **93**, 516–17.
Rastall, R. H. (1940) Xenoliths at Threlkeld, Cumberland. *Proceedings of the Yorkshire Geological Society*, **24**, 223–32.
Rastall, R. H. and Wilcockson, W. H. (1915) Accessory minerals of the granitic rocks of the Lake District. *Quarterly Journal of the Geological Society of London*, **71**, 592–622.
Rundle, C. C. (1981) The significance of isotopic dates from the English Lake District for the Ordovician–Silurian time-scale. *Journal of the Geological Society of London*, **138**, 569–72.
Rundle, C. C. (1992) Review and assessment of isotopic ages from the English Lake District. *British Geological Survey Technical Report*, No. **WA/92/38**.
Wadge, A. J. (1972) Sections through the Skiddaw–Borrowdale unconformity in eastern Lakeland. *Proceedings of the Yorkshire Geological Society*, **39**, 179–98.
Wadge, A. J., Harding, R. R. and Darbyshire, D. P. (1974) The rubidium–strontium age and field relationships of the Threlkeld Microgranite. *Proceedings of the Yorkshire Geological Society*, **40**, 211–22.