SHAP FELL CRAGS

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Introduction

The Shap Fell Crags GCR site comprises the Shap Pink Quarry and is the principal exposure of the Shap granite, renowned as a distinctive, decorative building stone. The igneous processes that can be demonstrated within the quarry make this an internationally significant site. The site (Figure 4.44) has been a popular field locality for undergraduate students and amateur geologists for many years. The granite and its associated metasomatism and mineralization have been described by many authors (e.g. Harker and Marr, 1891, 1893; Rastall and Wilcockson, 1915; Grantham, 1928; Firman, 1957, 1978a, 1978b) and it is featured in numerous classic geological textbooks (e.g. Teall, 1888; Hatch *et al.*, 1971; Holmes, 1993).

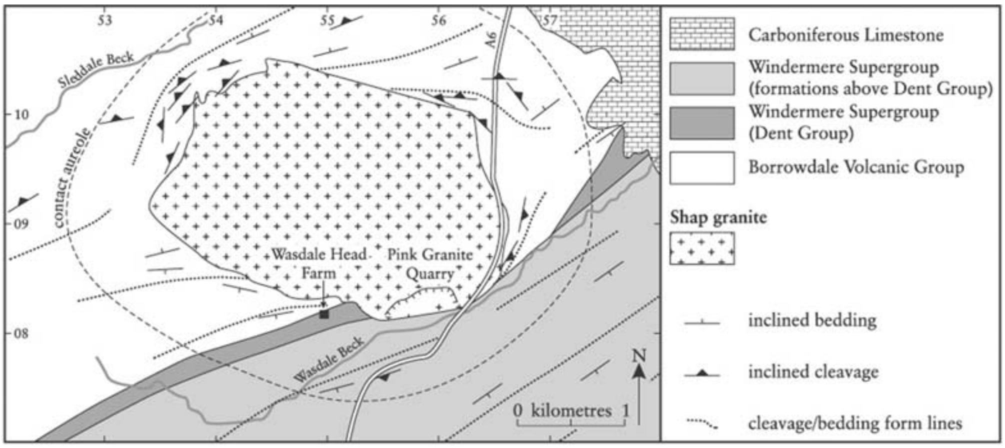

Figure 4.44: Map of the Shap Fell Crags GCR site (after Soper and Kneller, 1990).

The origin of the abundant pink Carlsbad-twinned K-feldspar megacrysts, which are the trademark of the Shap granite, has been a source of much controversy. The megacrysts occur not only in the granite but also within microgranular mafic enclaves within the granite, leading to the suggestion that the megacrysts are porphyroblasts resulting from late-stage crystallization from potassium-rich metasomatic fluids (Vistelius, 1969; Firman, 1978b; Le Bas, 1982a). However, recent work favours a phenocrystic origin for the megacrysts (e.g. Vernon, 1986; Lee *et al.*, 1995; Cox *et al.*, 1996; Lee and Parsons, 1997).

The intrusion is steep sided, and was emplaced close to the boundary between the Borrowdale Volcanic Group and the Windermere Supergroup (Locke and Brown, 1978). Radiometric dates obtained by a number of methods indicate an Early Devonian age (Pidgeon and Aftalion, 1978; Wadge *et al.*, 1978; Rundle, 1992). The granite was originally thought to post-date Caledonian deformation (Boulter and Soper, 1973), but recent field evidence proves that it was emplaced during, not after, the late Caledonian Acadian Event (Soper and Kneller, 1990). Thus, the granite is crucial in dating Caledonian deformation events within the Lake District.

A geochemical study of the Shap granite was made by O'Brien *et al.* (1985). Elevated levels of the radioactive elements U, Th, Rb and K explain the high present-day heat production of the granite which has been investigated as a potential source of geothermal energy (Wheildon *et al.*, 1984).

Description

Grantham (1928) recognized that the Shap granite was formed in three stages. To the west of the quarry, near Wasdale Head Farm (549 081), is a grey granite (‘stage' I) which grades up into, and is transgressed by, the familiar pink, coarse-grained granite (‘stage' II) which occupies up to 90% of the intrusion. The ‘stage' III granite is less common and cuts the earlier mass in dyke-like bodies between 1 cm and 1 m wide.

The ‘stage' I granite contains about 15% pink, Carlsbad-twinned orthoclase-perthite megacrysts up to 5 cm in length. The groundmass is composed of orthoclase, plagioclase zoned from andesine to albite, quartz, and biotite. By contrast, the ‘stage' II granite contains less biotite and up to 30% pink K-feldspar megacrysts which commonly show a preferred alignment. The ‘stage' III granite is very similar in appearance to the ‘stage' II granite, but contains up to 60% pink K-feldspar megacrysts and has even less biotite. Accessory minerals include titanite, apatite, magnetite, zircon, fluorite, monazite, allanite, amphibole and pyrite (Firman, 1978b). Complex microtextures in the megacrysts have been described byLee *et al*. (1995), Cox *et al*. (1996) and Lee and Parsons (1997). The megacrysts also contain numerous inclusions of plagioclase, biotite and quartz that increase in size and abundance towards the rim.

The ‘stage' I and ‘stage' II granites contain abundant enclaves (Figure4.45). Most common are rounded, microdioritic enclaves comprising fine- to medium-grained aggregates of plagioclase, quartz, biotite and K-feldspar. Slightly rounded, pink K-feldspar megacrysts with oligoclase rims may constitute 5–8% of the enclaves; some of these megacrysts occur partly within the enclave and partly within the granite host. Clots of granite matrix up to 1.5 cm across have been reported from within some enclaves (Cox *et al*., 1996). In addition, the ‘stage' II granite contains enclaves of ‘stage' I granite that range from only a few centimetres across to rafts with dimensions of 36 × 30 × 6 m (Grantham, 1928). Identifiable xenoliths of hornfelsed andesitic rocks from the Borrowdale Volcanic Group occur near the margins of the intrusion. Xenoliths of Dent Group lithologies (formerly the Coniston Limestone) were abundant near the southern contact of the intrusion, but are now rare because quarrying has advanced away from this contact. Harker and Marr (1891) noted that K-feldspar megacrysts do not occur in ‘xenoliths formed from solid rock fragments'.

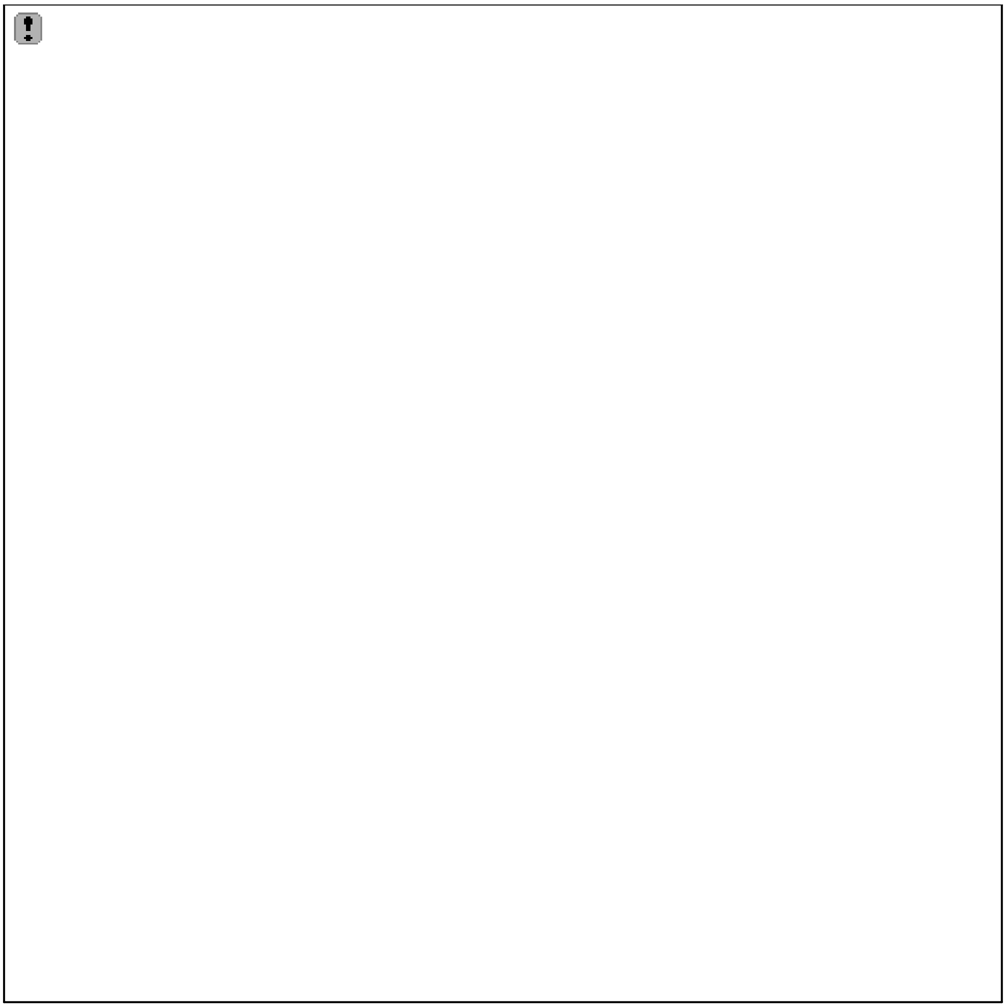

Figure 4.45: Pink granite with xenoliths containing K-feldspar megacrysts. (Photo: D. Millward.)

Aplitic veins are common within the granite and country rocks, and pegmatitic rocks are common locally; both contain quartz, K-feldspar and a little plagioclase. Molybdenite and hydrothermal vein minerals coat many surfaces within a pervasive, blocky joint system. Two distinct vein assemblages are seen: the first contains quartz, calcite, bismuthinite and chalcopyrite, and the later veins contain quartz, calcite, haematite, fluorite and baryte. These veins commonly penetrate the centre of ‘stage' III granite bodies giving the orthoclase on either side of the vein a deeper pink colour. Where such veins cut the ‘stage' II granite, darkening of the feldspars may occur up to 5 m from the vein giving rise to the ‘Dark Shap', a highly prized variety of the Shap granite that is difficult to extract. ‘Light Shap' refers to the normal unaltered pink variety of granite.

Though the Shap granite outcrop is small (*c.* 5 km^2), gravity data (Lee, 1986) and contact metamorphism suggest that it extends at shallow depths at least 10 km farther to the NW. Andesite and tuff within the metamorphic aureole have been converted to biotite hornfels with some amphibole in places. The more aluminous sedimentary rocks of the Windermere Supergroup may contain sillimanite, andalusite and cordierite. The country rocks are folded and faulted and a near-vertical cleavage is deflected around the Shap granite (Figure4.44; Boulter and Soper, 1973; Soper and Kneller, 1990). At several localities in the volcanic rocks of the metamorphic aureole, biotite has clearly overgrown the cleavage (Boulter and Soper, 1973). The granite has an associated dyke swarm which is crudely orientated NE–SW, sub-parallel to the Acadian folding and faulting.

Interpretation

Early researchers proposed that the K-feldspar megacrysts in the Shap granite are phenocrysts

(Harker and Marr, 1891; Grantham, 1928), though others preferred a porphyroblastic origin (Vistelius, 1969; Le Bas, 1982a). However, modern microtextural, geochemical and isotopic analysis favours a phenocrystic origin (Vernon, 1986; Lee *et al*., 1995; Cox *et al*., 1996; Lee and Parsons, 1997). Features cited as evidence for this theory include the following:

1. The apparent alignment of some megacrysts.

2. The higher Ba content in K-feldspar megacrysts than in K-feldspar in the groundmass suggesting earlier crystallization.

3. Chemical and isotopic zoning of the megacrysts consistent with growth in a magma body.

4. Inclusions in the megacrysts which increase in size and frequency towards the rim suggesting that the megacryst and inclusions were growing simultaneously in a magmatic environment.

5. The typically euhedral inclusions exhibit zonal alignment implying growth in a magmatic environment.

Evidence for a porphyroblastic origin is the occurrence of megacrysts within the microdioritic enclaves and, more importantly, in some examples transgressing the margins of enclaves. The scarcity of K-feldspar in the groundmass and clear evidence of metasomatism prompted several authors to suggest that late-stage potassic metasomatic fluids circulated through the granite causing porphyroblastic growth of orthoclase (Vistelius, 1969; Firman, 1978b; Le Bas, 1982a).

The microdioritic enclaves were termed the ‘Early Basic Granite' by Grantham (1928), who proposed that they represent an early peripheral hybrid granite. Grantham considered xenoliths of hornfelsed Borrowdale Volcanic Group rocks to be very rare except at the margins of the intrusion, whereas Firman (1978b) suggested that most enclaves represent material from the Borrowdale Volcanic Group at varying stages of recrystallization and assimilation. Recent work suggests that the enclaves formed during mixing between a dioritic magma and the host granite, and that some megacrysts may have been incorporated into the dioritic magma during that process (Vernon, 1986; Cox *et al*., 1996). This mechanism may account for the slightly rounded appearance of the megacrysts and the oligoclase rims, which are absent from megacrysts in the granite. Some K-feldspar megacrysts at the boundary between granite and microdiorite enclaves contain shells of inclusions that are difficult to explain if the megacrysts are porphyroblasts (Vernon, 1986). In discussion of this problem Vernon (1986) also cited the rare occurrence in granites elsewhere of xenoliths as well as megacrysts transgressing the boundary of an enclave. He considered this as evidence of their incorporation before solidification.

Based on geochemistry, O'Brien *et al*. (1985) showed that the Shap granite is unlikely to have been generated from a sedimentary source such as the Skiddaw Group, despite having moderately high initial $^{87}Sr/^{86}Sr$ values of 0.707 (Wadge *et al*., 1978) and high $*^{18}O$ of +11.0 ‰ (Harmon and Halliday, 1980). The Skiddaw Group sedimentary rocks contain particularly high concentrations of boron and on mantle-normalized plots show a pronounced negative phosphorous anomaly; neither of these features is a characteristic of the Shap granite. It is calc-alkaline with a restricted composition. High levels of large-ion lithophile (LIL) elements in the Shap granite suggest that it is magmatically evolved, but compatible elements such as Mg, Cr, Ni, Ti, V, Sr and Ba show no evidence for an extended history of crystal fractionation. Changes in fluid content or pressure, and partial hybridization appear to have dominated the geochemical evolution of these rocks. It is unclear to what extent metasomatism might have fundamentally increased LIL concentrations, though the mobility of K and Rb during metasomatism has been recognized for a long time (e.g. Vistelius, 1969). O'Brien *et al*. (1985) proposed that the Shap granite was the site of discharge of high-temperature fluids from depth thus explaining high concentrations of Li (Farrand, 1960) and other incompatible elements such as Rb.

O'Brien *et al*. () also showed that the Lake District granites as a whole have increasingly fractionated rare earth element patterns with time. The Shap granite has the most fractionated

REE pattern and also the highest La/Yb suggesting that it was derived from a mafic source containing residual garnet. Ordovician (Caradoc) Lake District granites with lower La/Yb were derived from a source without residual garnet, perhaps reflecting changing thermal conditions during magma generation (O'Brien *et al*., 1985). The younger, Early Devonian granites of Shap and Skiddaw contain higher abundances of radioactive elements than the other Lake District granites. Spears (1961) recognized that 95% of the alpha radioactivity in the Shap granite comes from accessory minerals (e.g. titanite, monazite and zircon). It has long been assumed that emplacement of the Shap granite post-dated the main Acadian deformation event, because contact metamorphic minerals have overgrown cleavage within the metamorphic aureole of the granite (Boulter and Soper,). However, some felsitic microgranite dykes within the Shap dyke-swarm, which cut folded and cleaved Silurian sedimentary rocks, are themselves weakly cleaved, implying that the dykes were emplaced during cleavage formation (Soper and Kneller, 1990). Some of these cleaved dykes cut the Shap granite and therefore the granite itself may also have been emplaced during the cleavage-forming event.Boulter and Soper (1973) interpreted the deflection of the cleavage around the Shap granite as having resulted from the forcible injection of the intrusion. However, it is also possible that the cleavage ‘wraps' around the granite because shortening continued after the granite was emplaced (Figure 4.44; , 1990). Soper and Kneller inferred from this evidence that the cleavage formed incrementally, with periods of stress relaxation allowing the injection of dykes and possibly the emplacement of the granite itself.

The age of the Shap granite is therefore crucial in determining the timing of cleavage formation. Using K-Ar and Rb-Sr methods on biotite, several early authors dated the Shap granite as late Silurian or Early Devonian (Kulp *et al*., 1960; Lambert and Mills, 1961; Dodson *et al*., 1961). In a study of these and other available isotopic dates,Brown *et al*. (1964) recognized that the Shap granite is coeval with the Skiddaw granite. More recently, three separate radiometric dating methods have produced similar dates: U-Pb on zircons gave an age of 390 ± 6 Ma (Pidgeon and Aftalion, 1978); 394 ± 3 Ma was obtained using the mineral–whole-rock Rb-Sr isochron (Wadge *et al.,* 1978), but it is the K-Ar age of 397 ± 7 Ma on fresh biotite that is taken to indicate the age of emplacement of the Shap granite (Rundle, 1992). These conclusions are consistent with the age of cleavage formation of between 418 ± 3 Ma and 397 ± 7 Ma recently obtained on mica concentrates from the Foredale metabentonite in the Ribblesdale inlier (Merriman *et al*., 1995). Thus, Acadian deformation in northern England occurred in the Early Devonian, some 23 Ma after Silurian deformation in the Southern Belt of the Southern Uplands (*c*. 420 Ma, Barnes *et al*., 1989).

Conclusions

The Shap granite is a widely used decorative building stone whose principal outcrop is within the Shap Fell Crags GCR site. This internationally significant site illustrates several important features that are crucial to the continuing debate concerning the magmatic evolution of granites and their large K-feldspar crystals. The 397 Ma Shap granite, its metamorphic aureole and dyke-swarm provide crucial evidence in the determination of the sequence and timing of the late Caledonian, Acadian Event in the Lake District. Field evidence suggests that the deformation was episodic and that the granite and the associated dyke swarm were emplaced during periods of stress relaxation.

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