Grainsgill, Caldew Valley

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Introduction

The Grainsgill GCR site, located within the Caldew valley in the northern Lake District (Figure 4.43), is an area of diverse geology that has been of interest to geologists for more than a century. The northernmost of only three small outcrops of the Skiddaw granite is exposed here and the contact between the granite and the highly deformed Skiddaw Group into which it is intruded is clearly demonstrated. Locally, the northern part of the granite outcrop is extensively altered to greisen. Only 100 m north of the granite margin, the Carrock Fell Complex is intruded at the boundary between the Skiddaw Group and Eycott Volcanic Group (see also the Carrock Fell GCR site report). The greisen, the hornfelsed Skiddaw Group and the Carrock Fell Complex are cut by arsenic- and tungsten-bearing veins, the largest of which have been worked from the now abandoned Carrock Mine.

The area was first mapped by the Geological Survey (Ward, 1876) and this was followed by several accounts of specific aspects of the geology (e.g. Harker, 1895b; Finlayson, 1910). Hitchen (1934) concluded that the granite, greisen and mineralization are related to one igneous episode. Field evidence also led to the deduction that the greisen formed by metasomatism of the granite and this was confirmed by subsequent studies (Thimmaiah, 1956; Ewart, 1962; Eastwood *et al.,* 1968). Shepherd *et al.* (1976) used fluid inclusion and isotope techniques to suggest a genetic link between mineralization and alteration of the granite.

This GCR site provides a very important insight into the relationship between igneous intrusion, metasomatism and mineralization. In addition it contains important evidence of the timing of emplacement of the Skiddaw granite, one of only two late Caledonian intrusions in the Lake District. The mineral veins at Grainsgill will also be described in the *Mineralization of Great Britain* GCR volume.

Description

The oldest rocks in the Grainsgill GCR site are very strongly folded metapelites of the Skiddaw Group. Fold interference patterns suggest that several generations of deformation are present. On the sides of Carrock Fell, north of the River Caldew, the axial planes of folds are almost vertical and trend N–S, perpendicular to the contact between the Skiddaw Group and the Carrock Fell Complex. Contact metamorphism has altered rocks of the Skiddaw Group to biotite-cordierite hornfels within a classically concentric aureole 10 km in diameter. As the greisen is approached cordierite is altered to chlorite and biotite is replaced by muscovite.

The Carrock Fell Complex is a multiple dyke-like intrusion, emplaced between the Skiddaw Group and the Eycott Volcanic Group and is exposed in Brandy Gill, 100 m to the north of Grainsgill (see the Carrock Fell GCR site report for detailed description). In Brandy Gill, the southern part of the Carrock Fell Complex comprises gabbro and xenolithic gabbro of the Mosedale division, cut upstream by apatite-bearing ferromicrodiorite, ferromicrogabbro and micrographic ferromicrogranite sheets belonging to the Carrock division.

The Skiddaw granite is exposed in Grainsgill Beck and in the River Caldew (Figure 4.43); the intrusion appears to be a steep-sided dome with its long axis approximately N–S (Hitchen, 1934). It is laterally extensive at shallow depths (Lee, 1986). The contact between the intrusion and the hornfelsed sedimentary rocks is well exposed in both Grainsgill Beck and the River Caldew just upstream from their confluence. On Coombe Height, between the two rivers, Skiddaw Group rocks overlie the flat roof of the granite.

The Skiddaw intrusion is a medium-grained biotite granite comprising orthoclase, oligoclase, quartz and biotite. Accessory minerals include zircon, apatite, ilmenite, pyrrhotite, pyrite, epidote, titanite, anatase, brookite, and rutile (Rasta and Wilcockson, 1915). In the River Caldew, feldspars are partially replaced by muscovite as a result of incipient greisen formation, and the biotite is partially replaced by chlorite. The degree of greisen formation increases northwards to Grainsgill where the original biotite granite is pervasively converted to a muscovite-quartz greisen. Apatite, rutile, pyrite and arsenopyrite also occur in the greisen.

The principal rocks within the GCR site are veins ranging in width from less than 1 cm to1.5 m and dipping steeply to the west. Within about 60 cm of large veins and less for smaller veins, the granite is pervasively altered to greisen comprising quartz, muscovite, pyrite, arsenopyrite and apatite. The veins have also altered the cordierite-andalusite-biotite hornfels of the Skiddaw Group. Biotite is altered to chlorite and andalusite to sericite as a vein is approached and within 20–30 cm of the contact, the chlorite and sericite are altered to muscovite; pyrite and tourmaline occur in small amounts in this new assemblage. Alteration is also noticeable in the gabbros of the Carrock Fell Complex within 50 cm of the veins. Within 15 cm of a vein the gabbro is completely altered to quartz, biotite, sericite and some muscovite, and immediately adjacent to the vein the original mineralogy is replaced by arsenopyrite, pyrite, quartz, calcite and muscovite.

The largest veins worked at Carrock Mine are, from west to east, the Smith, Harding and Emerson (Figure 4.43). The dominantly quartz veins contain local pockets of wolframite, scheelite, arsenopyrite, pyrite, pyrrhotite, sphalerite and ankerite along with accessory molybdenite, chalcopyrite, bismuthinite, apatite, dolomite, calcite, fluorite, and muscovite with rare joseite, cosalite, cassiterite and gold (Finlayson, 1910; Hitchen, 1934; Ewart, 1962; Shepherd *et al.,* 1976; Young, 1987). Despite variable relative mineral proportions, all the veins have a similar paragenetic sequence (Hitchen, 1934; Shepherd *et al.,* 1976).

The two near-vertical, quartz- and ankerite-filled NNW-trending fault zones in the upper and lower parts of Brandy Gill do not appear to have hydrothermally altered the country rocks (Ewart, 1962). Narrow E–W veins carrying quartz, galena and sphalerite slightly displace the tungsten-bearing veins and are considered to be related to the extensive E–W lead and zinc veins found in the Caldbeck Fells to the north of the GCR site (Shepherd *et al.,* 1976). Two veins of 'greisen' were reported by Hitchen (1934): one of these is about 1 m wide and cuts the Carrock Fell Complex in Brandy Gill and the other cuts the hornfelsed Skiddaw Group in the upper reaches of Grainsgill. Ewart (1962) found several more of these veins underground, and suggested that they may be metasomatized aplitic veins.

Interpretation

Ward (1876) described a 'very quartzo-micaceous granite' at Grainsgill and suggested that this is part of the Skiddaw granite, because the contact between it and the biotite granite exposed in the River Caldew is gradational. Harker (1895b) recognized that the granite had undergone some metasomatism, but suggested that it formed primarily as a late-stage acid melt squeezed from the crystallizing Skiddaw granite by northerly directed pressure. Finlayson (1910) related the ore minerals genetically to the greisen. Rastall and Wilcockson (1915) noted that accessory minerals of the granite are relatively scarce in the greisen, and that minerals such as arsenopyrite are more common.

Hitchen (1934) proposed that the granite, greisen and mineralization are related to one igneous episode. He described the gradual change from biotite granite to greisen, involving the replacement of feldspars by muscovite. Where the greisen is entirely quartz and muscovite, the original outlines of feldspar crystals can still be discerned, even in hand specimen. He suggested further that the large number of mineral veins in the greisen, and the increase in abundance of arsenopyrite, indicate that intense localized hydrothermal activity had occurred. The scarcity of accessory minerals was attributed to their removal by hydrothermal fluids. Hitchen concluded that, following the consolidation of the granite, greisen was formed as a result of hydrothermal activity and aqueous solutions deposited minerals in fissures and cracks.

Subsequent work confirmed the metasomatic origin of the greisen (Thimmaiah, 1956; Ewart, 1962; Eastwood *et al.,* 1968). Thimmaiah (1956) and Ewart (1962) considered that the only true greisen in the area is the thoroughly altered granite near the quartz-tungsten veins, whereas Eastwood *et al.* (1968) also described the altered hornfels adjacent to the veins as greisen. However, geochemieal studies by Roberts (1983) showed that, despite their similar appearance in the field, the metasomatized hornfels has a very different chemistry to the greisen.

A genetic link between alteration of the granite and mineralization was proposed by Shepherd *et al.* (1976) using fluid inclusion and oxygen isotope data. They found that mineral deposition and greisen formation indicate equilibration with fluids of similar isotopic compositions under similar P-T conditions. K-Ar dating could not distinguish between cooling of the Skiddaw granite, greisen formation and tungsten mineralization (minimum age of granite intrusion, 392 ± 4 Ma; mean age of mineralization alteration, 385 ± 4 Ma) suggesting that they occurred within a relatively short space of time. Fluid inclusions in vein quartz contain NaCl brines and high tungsten concentrations occur in the altered granite of the mineralized area. Based on their data they suggested that mineralizing fluids were moderately saline with high Na/K, enriched in tungsten and periodically charged with CO_2; compared with magmatic fluids the mineralizing fluids were depleted in $\delta^{18}O$. Shepherd *et al.* (1976) produced a model of ore genesis whereby meteoric water was drawn convectively into the northern part of the Skiddaw granite through the adjacent relatively permeable igneous rocks of the Carrock Fell Complex. Chemical exchange increased the salinity of these fluids before they reached the granite where they became mixed with hot magmatic fluid enriched in tungsten. The granite was metasomatized to form greisen and the circulating fluids became enriched in silica due to the breakdown of primary igneous silicates. These fluids convected and mixed with more non-magmatic fluids along the N–S faults which cut the complex, producing the mineral veins.

Roberts (1983) proposed that leaching of the greisen and metasomatized hornfels by the circulating fluids provided the Na for the NaC1 brines found in the fluid inclusions. Therefore, the initial fluid did not necessarily have high Na/K ratios. He favoured a model in which brines enriched in K due to feldspar alteration were drawn down to the intrusion and then resulted in the formation of greisen and K-metasomatism.

A recent model proposed by E. S. Burden (Derby University, pers. comm. 1996) combined fluid inclusion studies with mineralogical data and mass-balance calculations to show that greisen can form from granite simply by the addition of H_2O. The process involves a series of linked ionic sub-reactions and the alteration of K-feldspar to muscovite releases K-ions which are necessary to convert plagioclase to muscovite.

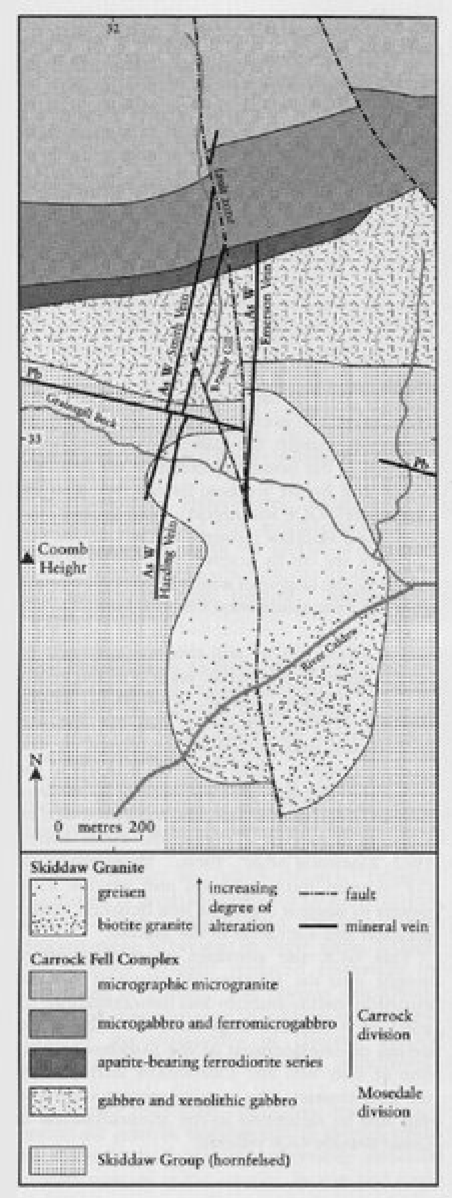
Geochemical data for the Skiddaw granite show clear magmatic trends consistent with either in-situ fractionation or derivation from a deeper fractionating magma chamber (O'Brien *et al.,* 1985). The Skiddaw granite has highly fractionated rare earth element (REE) patterns and, like the Shap granite, is thought to be derived from a mafic source containing residual garnet. It also contains elevated levels of the heat-producing radioactive elements and the geothermal potential of the granite has been assessed (Webb and Brown, 1984a; Wheildon *et al.,* 1984).

The age of emplacement of the Skiddaw granite has been discussed by several authors (Miller, 1961; Brown *et al.,* 1964; Shepherd and Darbyshire, 1981) and K-Ar dating of fresh biotite gives an age of 399 ± 8 Ma (recalculated from Shepherd *et al.,* 1976), very similar to the Shap granite (Rundle, 1982). Eastwood *et al.* (1968) showed that the hydrothermal alteration associated with the granite post-dates the Carrock Fell Complex. In the outer parts of the Skiddaw granite aureole, andalusite clearly overgrows the main cleavage indicating that contact metamorphism post-dates the Acadian deformation. However, in the inner hornfels zone of the aureole, the cleavage weakly wraps around andalusite porphyroblasts. The implication is that the granite was emplaced during the late stages of the Acadian Event, perhaps during a period of stress relaxation between successive cleavage-forming events (Soper and Roberts, 1971; Soper and Kneller, 1990; see also the Shap Fell Crags GCR site report).

Conclusions

The late Caledonian Skiddaw granite shows a clear northwards gradation from biotite granite to greisen and it can be shown that hydrother-mal alteration associated with emplacement of the granite was also responsible for the greisen formation and the deposition of some economically important mineral veins. The nearby intrusive Carrock Fell Complex provided a permeable pathway for fluids to circulate down towards the granite and explains why metasomatism and mineral deposition are concentrated only in the northern part of the Skiddaw granite. The Grainsgill GCR site is significant because it provides an important insight into the relationship of a late Caledonian intrusion to greisen formation and mineralization. The site also provides important evidence regarding the timing of emplacement of late Caledonian intrusions in the Lake District.

References



(Figure 4.43) Map of the Grainsgill GCR site (from transected by NNE-trending tungsten-bearing Geological Survey maps).