Greenfoot Quarry, County Durham

[NY 984 392]

S. C. Loughlin

Introduction

The abandoned Greenfoot Quarry, near Stanhope in Weardale, reveals the best available exposures of the distinctive Little Whin Sill, an important member of the Whin Sill-complex. This sill is intruded at a higher stratigraphical level than the Great Whin Sill, into the Upper Visean Three Yard Limestone, which has been slightly metasomatized at the contacts. Both the Little Whin Sill and the Great 'Whin Sill were intersected by the Rookhope Borehole, some 6 km north-west of the quarry; there the sills are about 130 m apart.

The Little Whin Sill was first described by Trevelyan as early as 1831. Clough (1880) suggested that the dolerite of the sill had assimilated the country rocks, and Egglestone (1910) described the field relationships in some detail. Principal descriptions of the petrography include those by Teall (1884a,b, 1888), Holmes and Smith (1921), Holmes and Harwood (1928), Tomkeieff (1929) and K.C. Dunham (1948). Geochemical studies by Smythe (1930a), A.C. Dunham and Kaye (1965) and Harrison (1968) have shown that the sill is similar to, but geochemically and mineralogically distinct from, other members of the Whin Sill-complex. It is the only intrusion in which fresh olivine phenocrysts have been found and may represent a more primitive parental magma to the complex (A.C. Dunham and Kaye, 1965; A.C. Dunham and Wilkinson, 1992).

Description

Greenfoot Quarry is situated 1 km west of Stanhope (Figure 6.32). The eastern end of the quarry is partially flooded obscuring the basal contact of the sill, but the upper contact is exposed all along the upper part of the south-facing quarry wall and is clearly visible from the Stanhope–Wearhead Road (A689). The sill is intruded into the Upper Visean Three Yard Limestone, which is about 2.5 m thick throughout Weardale. The west end of the quarry face reveals a complete section through the sill, with metasomatized limestone above and below. The sill is 13 m thick and takes the form of a flat-lying sheet, with columnar jointing. This is the maximum known thickness of the Little Whin Sill, which thins westwards along the banks of the River Wear until it dies out in the vicinity of Ludwell (Figure 6.32). To the north, in the Rookhope Borehole [NY 937 427], the Little Whin Sill is about 2 m thick but it dies out rapidly to the west of Rookhope Burn. The sill has also been encountered to the north of the River Wear in Stotfield Burn Mine [NY 943 424] and Stanhope Burn Mine [NY 987 413]. However, the absolute northern extent of the sill is unknown because mine workings and boreholes are too shallow to reach the northerly dipping Three Yard Limestone into which it is intruded. In the Woodland Borehole [NZ 091 277], some 15 km to the south-east of Stanhope, the Little Whin Sill is encountered 20 m above the Three Yard Limestone (Mills and Hull, 1968), but it is not present in outcrops in Upper Teesdale or in boreholes drilled to this level around Crook to the east.

The Little Whin Sill is a very fine- to fine-grained porphyritic dolerite. The grain size increases rapidly away from the chilled margins. Lath-shaped phenocrysts of plagioclase up to 2 mm long have labradorite cores (An_{70-68}) and may show normal, oscillatory and reversed zoning. The overall compositional range is from An_{70} to An_{35} and individual grains may show a great variation as a result of the zoning. This range increases away from the margins of the sill. Rare phenocrysts of calcic plagioclase (bytownite) with resorption textures have been observed. Clinopyroxene phenocrysts up to 2 mm long are granular and also show zoning. Sparse orthopyroxene phenocrysts are elongate and commonly embayed. Phenocrysts of fresh olivine, up to 1.5 mm in length, have been observed at the base of the Little Whin Sill in the Rookhope Borehole and at Turn Wheel Linn, but only pseudomorphs after olivine occur elsewhere, and even these are rare. Opaque minerals make up about 10% of the rock, with magnetite and ilmenite the dominant phases. Groundmass minerals include plagioclase, clinopyroxene, magnetite and ilmenite, and intersertal areas are filled by a mixture of quartz and alkali feldspar. Hornblende, biotite and apatite occur as accessory minerals, and pyrite and chalcopyrite have also been found at Greenfoot Quarry In the central parts of the sill irregular vugs occur, containing quartz rimmed by carbonate (ankerite and calcite). In places, granular pyrite is associated with these vugs.

The Little Whin Sill has a relatively high total iron content but, in comparison to the Great Whin Sill, contains less silica (47%) and potassium. There is a detectable increase in the FeO/Fe_2O_3 ratio towards the centre of the sill, but other major elements and trace elements show little variation (A.C. Dunham and Kaye, 1965).

Interpretation

The first paper to concentrate on the Little Whin Sill described it as a basaltic lava (Trevelyan, 1831). At that time the Great Whin Sill was also considered by many to be a lava flow, despite the compelling evidence of intrusion presented by Sedgwick (1827), but the intrusive nature of the Whin Sill-complex as a whole was eventually recognized (Topley and Lebour, 1877). Topley and Lebour considered the two sills to be branches of one large intrusive sheet and Teall (1884a,b) showed that they are petrologically almost identical. Egglestone (1910) also proposed that they are contemporaneous.

Based on the lack of disruption to, and varying thickness of, the Three Yard Limestone, Clough (1880) suggested that substantial quantities of the limestone must have been assimilated by the sill during emplacement. However, Smythe (1930a) found no evidence of assimilation in his abundant analyses of the Little Whin Sill, and A.C. Dunham and Kaye (1965) also discounted the assimilation hypothesis, pointing out the constant thickness of the Three Yard Limestone where it is intruded by the sill. They suggested that variations in the thickness of the limestone to the north-west and south of the Alston Block are structural and sedimen-tological features unrelated to the Little Whin Sill.

In contrast to the Great Whin Sill, the Little Whin Sill is lacking Ca-poor pyroxene in the groundmass. A.C. Dunham and Kaye (1965) suggested that this is partly due to the presence of olivine, which would have removed Mg and Fe from the system. In addition, a reduction of water vapour pressure on emplacement of the sill would have increased the solidus temperature of the magma and therefore inhibited orthopyroxene crystallization. A.C. Dunham and Kaye (1965) also investigated the apparent lack of crystal settling. They calculated that the Little Whin Sill in Greenfoot Quarry would have cooled in one and a half to two years (compared to 75 years for the Great Whin Sill at its thickest point) and they went on to suggest that rapid crystallization of microlytes impeded the settling of the phenocrysts. This process would also have inhibited circulation of the magma, thus explaining the zoning of the phenocrysts. The phenocrysts would have rapidly depleted their surrounding magma in Ca and Mg and hence the plagioclase crystallized with relatively Na-rich rims and the mafic minerals with Fe-rich rims. The centre of the Little Whin Sill, with its quartz-carbonate-filled vugs, was interpreted by A.C. Dunham and Kaye (1965) as the last zone to crystallize.

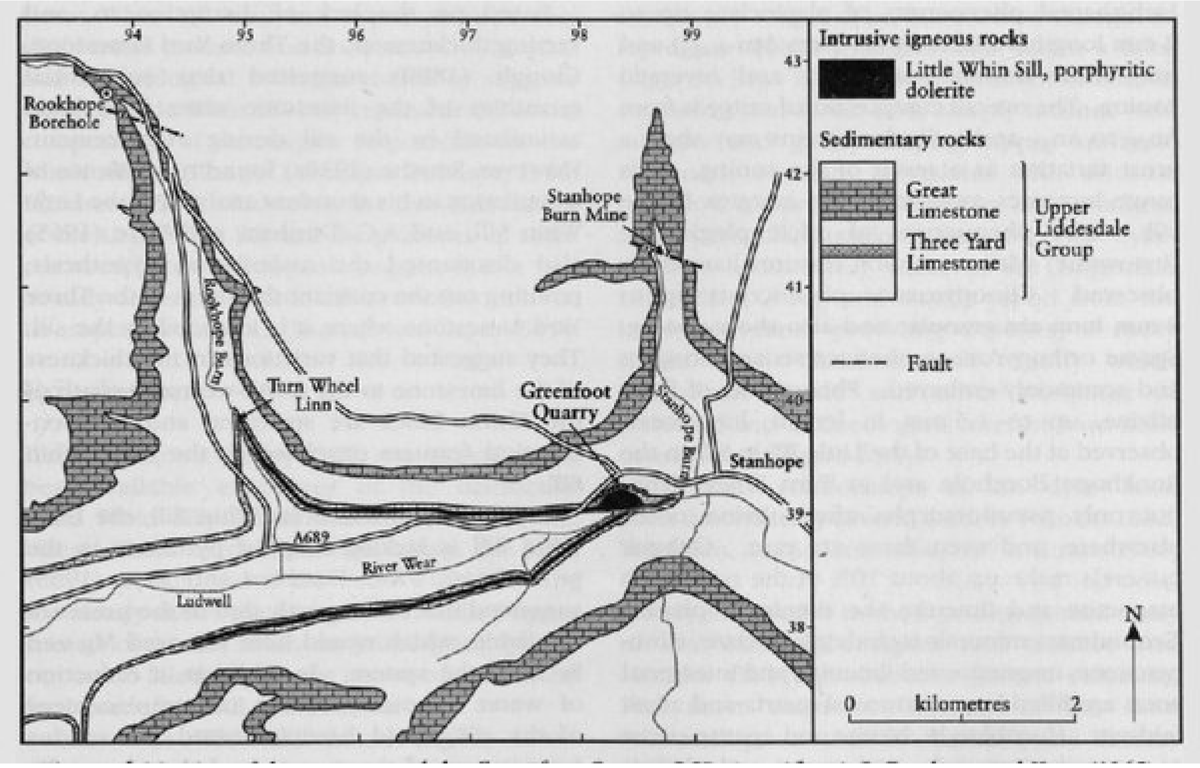
Geochemical analyses of all of the Whin Sill-complex samples plot between the alkaline and tholeiite fields on a silica–total alkali discrimination diagram and so may be described as transitional. Nevertheless the petrographical affinities are dominantly tholeiitic (A.C. Dunham and Kaye, 1965). When plotted on an AFM diagram, $(Na_2O + K_2O)$–FeO–MgO, the Little Whin Sill analyses form a tight cluster, in contrast to the Great Whin Sill analyses, which show a very slight trend towards iron enrichment. Chemical and mineralogical evidence therefore suggests that the Little Whin Sill may represent the initial composition of the magma responsible for the whole sill-complex (A.C. Dunham and Kaye, 1965; Harrison, 1968). However, the iron-rich nature of the Little Whin Sill and the presence of some resorbed bytownite crystals suggest that it had already undergone some differentiation prior to its emplacement (A.C. Dunham and Kaye, 1965).

Conclusions

The Greenfoot Quarry GCR site provides the best available exposures of the distinctive Little Whin Sill, which was intruded into the Visean Three Yard Limestone, above the local stratigraphical level of the Great Whin Sill. The site clearly shows the fine-grained, chilled upper contact of the sill, columnar jointing and quartz-carbonate-filled vugs in the centre of the sill, the final part of the sill to crystallize.

The Little Whin Sill has a slightly lower silica content than the Great Whin Sill and contains rare olivine phenocrysts. It is of great importance in understanding the origin of the Whin Sill-complex as a whole because it is thought to he close to the composition of the initial magma from which the complex evolved. However, a relatively high iron content and a rare occurrence of feldspar crystals that show signs of having reacted with the magma after they crystallized, suggest that the magma had already undergone some modification prior to emplacement.

References



(Figure 6.32) Map of the area around the Greenfoot Quarry GCR site. After A.G. Dunham and Kaye (1965).