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BALMEDIE QUARRY

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OS Grid Reference: NJ944182

Introduction

In addition to the wide range of igneous components found in the 'Younger Basic' intrusions, other variations have been imposed by later tectonic events. Late Caledonian (D3) folding was responsible for the variable, and often steep, dips in the layered cumulates, and may have caused some disruption of the original igneous complex into smaller bodies. Another aspect of the post-intrusion structural disturbance was the development of major shear zones, which may have played an important part in the final emplacement and configuration of the 'Younger Basic' masses (Ashcroft *et al.*, 1984). These shear zones are associated particularly with the present margins of the intrusions, notably the Insch–Boganclogh mass (Figure3.2), but they also produced significant modifications internally. These modifications may be dominantly mineralogical, involving the progressive amphibolitization of the gabbros, or textural, involving the formation of gabbro mylonites, or a combination of both effects.

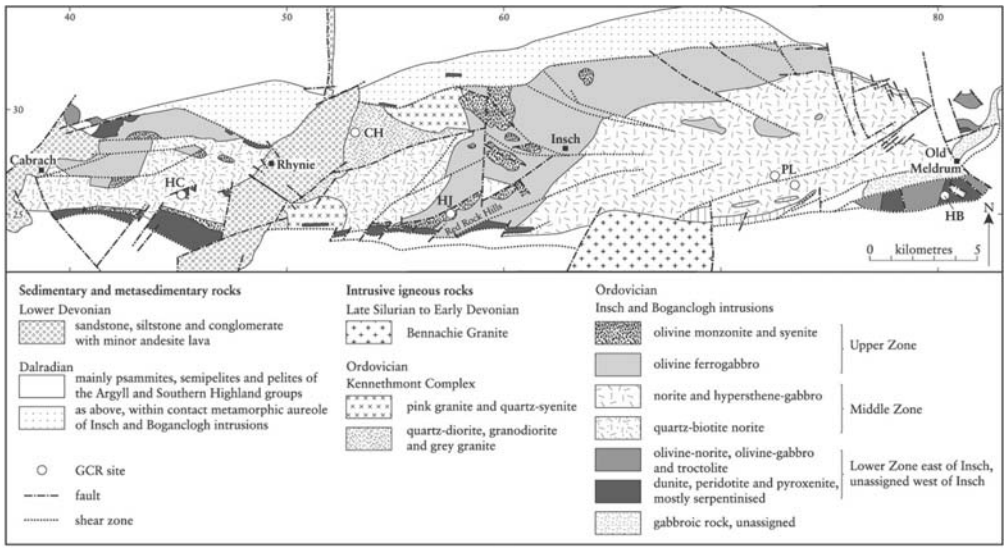

Figure 3.2: Map of the Insch, Boganclogh and Kennethmont intrusions, adapted from Gould (1997). GCR sites: CH Craig Hall; HB Hill of Barra; HC Hill of Craigdearg; HJ Hill of Johnston; PL Pitscurry and Legatesden quarries.

One of the most prominent shear zones runs approximately N–S from near Fraserburgh southwards towards Aberdeen and, near its southern end, it intersects the Belhelvie intrusion (Figure 3.15). Although enough of the intrusion is unaffected for it to be possible to establish a detailed cumulate stratigraphy (Munro, 1986; Wadsworth, 1991), substantial areas have been thoroughly amphibolitized (Stewart, 1946) and, locally at least, show evidence of pronounced textural changes with the production of schistose (or flaser) gabbros and mylonites. Excellent examples of both types of modification associated with the shear zones are seen in Balmedie Quarry, just north of Belhelvie village, and have been fully documented. (Boyd and Munro, 1978; Munro, 1986).

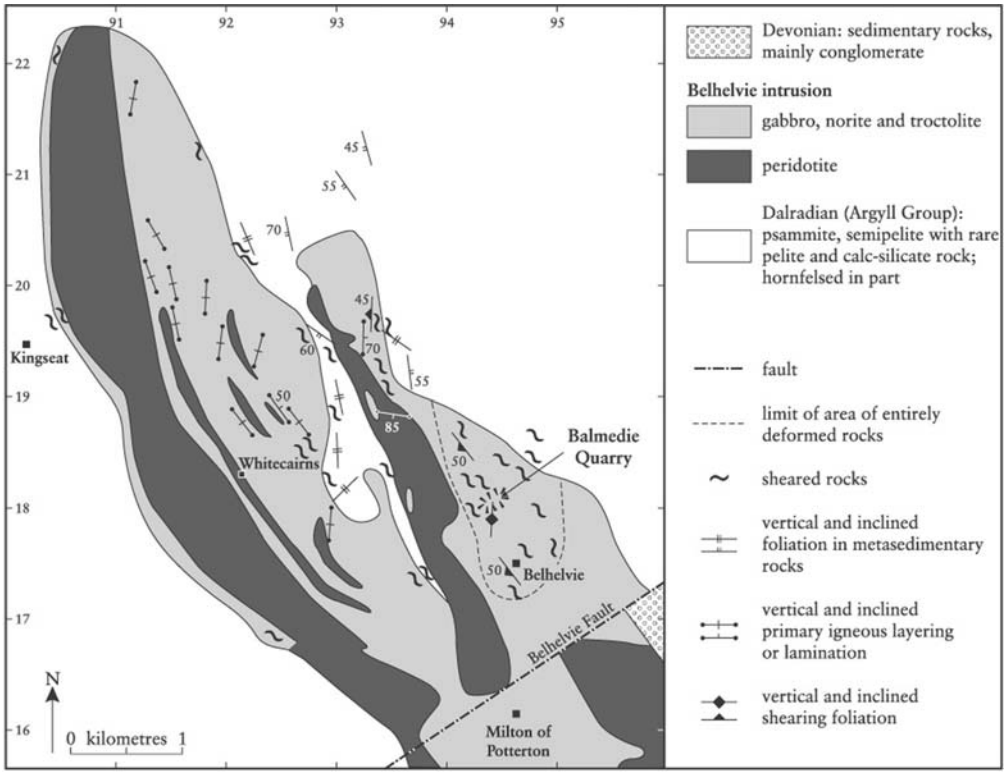

Figure 3.15: Map of the northern part of the Belhelvie intrusion, showing the position of the Balmedie Quarry GCR site in relation to a major shear zone, after Boyd and Munro (1978).

Description

Balmedie Quarry is situated in the centre of an approximately 1 km-wide shear-zone stretching northwards from Belhelvie village to the eastern margin of the Belhelvie intrusion (Figure 3.15). The original cumulates are believed to represent the upper part (LZc) of the Belhelvie succession (Wadsworth, 1991) and consist of cumulus olivine (Fo_{77}), orthopyroxene (En_{79}), augite ($Ca_{45}Mg_{45}Fe_{10}$) and plagioclase (An_{75}). Primary layering in the least-deformed examples shows a wide variety of modal variations, with all graduations between mafic (peridotite) and felsic (anorthosite) layers, although most of the these cumulates are gabbroic or noritic.

Deformation affects the whole area of the quarry, but the intensity varies considerably, even over a scale of a few centimetres. No systematic pattern of variation is recognizable within the area studied. In the initial stages of modification the original mineralogy is retained, but the texture is modified to the extent of producing localized strain effects in individual crystals, as well as some degree of marginal granulation and minor recrystallization. Where the deformation was more intense, the textural changes are accompanied by the development of aggregates of secondary amphibole crystals in place of the original pyroxene. With increasing degree of deformation the original igneous textures are obliterated, and the resultant rock consists of lensoid clusters of amphibole, biotite and opaque minerals (representing the original ferromagnesian minerals) and irregular plagioclase porphyroclasts, in a fine-grained aggregate of mafic material.

The most intense deformation is restricted to narrow zones (generally less than 1 cm wide), which cut the more typically foliated gabbros in sinuous fashion (Figure3.16). The rocks in these zones are essentially mylonites, and consist of porphyroclasts of frayed plagioclase (and more rarely amphibole or pyroxene) in a groundmass of amphibole, biotite, opaque minerals and plagioclase. The larger feldspar fragments typically retain their original composition (An_{80-75}) in their cores, but have strongly zoned margins (An_{45-40}). Large crystals of quartz occur locally, and there is considerable evidence that there has been an episode of late-stage silicification. Although the detailed attitude of both the general foliation, and the intensely mylonitized zones, is extremely variable, there is an overall tendency for these structures to strike approximately N–S, and to display steep dips. Some of the more sinuous mylonite zones

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form minor folds with steeply plunging axes.

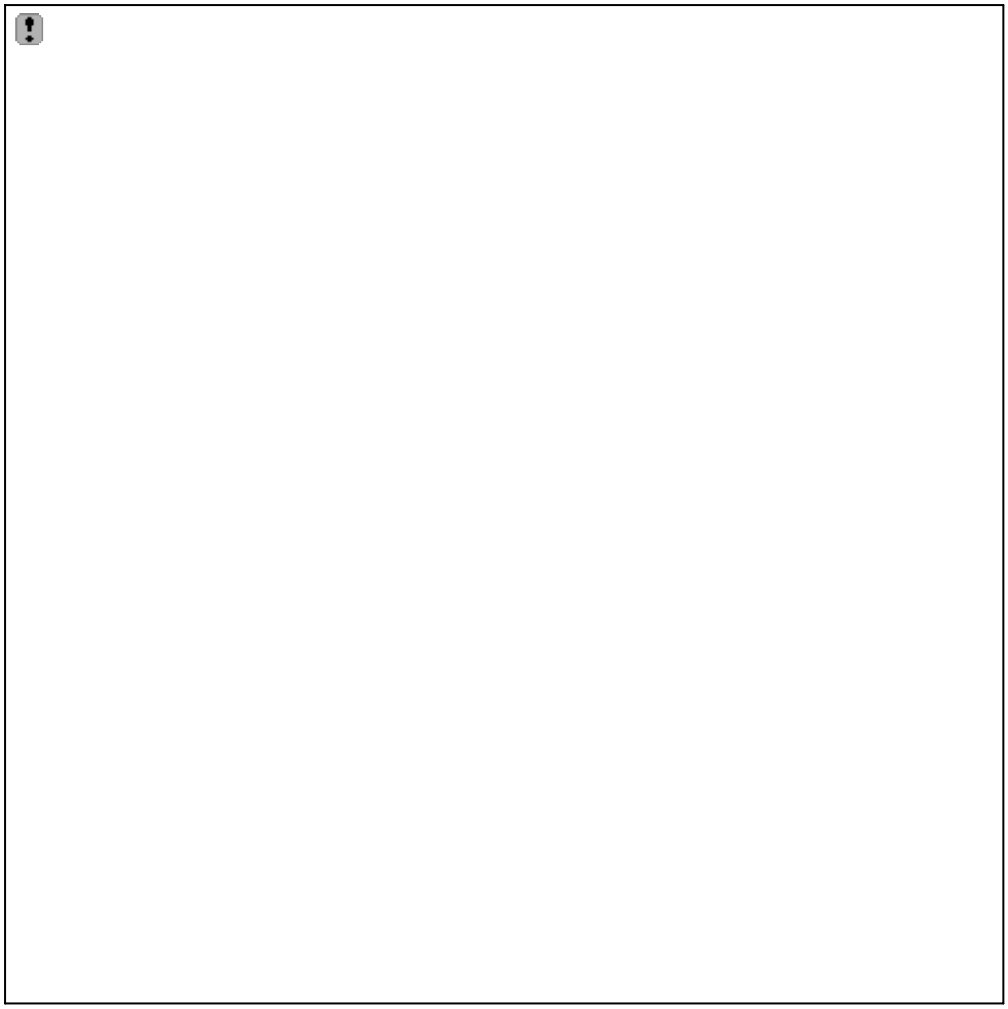

Figure 3.16: Balmeddie Quarry; block of deformed mafic rock, cut by narrow zones of mylonite that in part conform with and in part transgress an earlier foliation. Scale in centimetres. (Photo: from Boyd and Munro, 1978, plate 1a.)

In addition to the deformed gabbroic rocks, there is a small strip of hornfelsed and mylonitized metasedimentary rocks (10–15 m wide) in the eastern part of the quarry, and there are also some granitic minor intrusions, which are generally medium grained, but include tourmaline-bearing pegmatitic types. Most of these granites are undeformed, and appear to post-date the foliation in the mafic rocks but some of them have been affected by shearing, at least locally.

Interpretation

In general, the shear zones appear to represent localized regions of strong mechanical distortion and dislocation, accompanied by low pressure (2–3 kbar), amphibolite facies (600°C) metamorphism, which occurred soon after the intrusion and crystallization of the 'Younger Basic' igneous bodies approximately 470 Ma ago (Ashcroft *et al.*, 1984). In Balmedie Quarry, the shear zone is itself cut by granitic minor intrusions, one of which has been radiometrically dated at 462 ± 5 Ma (Pankhurst, 1982). Most of these granitic intrusions are undeformed, but some of them show evidence of marginal crushing and shearing (Munro, 1986). This suggests that there may have been more than one episode of granite veining, or that deformation continued, at least on a reduced scale, after the 'Younger Basic' igneous activity had ceased.

The textural features of the modified gabbros in Balmedie Quarry suggest that a pervasive foliation was developed at an early stage in the deformation history, resulting in relatively limited shearing, granulation and recrystallization. This then seems to have been followed by an episode of more intense deformation, restricted to the narrow mylonite zones. The broadly

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similar structural trends of the foliation and the mylonite zones suggests that the two types of deformation were related, and represent a continuum of structural disturbance rather than discrete events. From the mineralogical evidence, the initial stages of deformation appear to have been simply cataclastic, but the later stages were characterized by recrystallization in the presence of volatile components, resulting in the formation of amphibole, biotite and relatively sodic plagioclase at the expense of the original pyroxenes and calcic plagioclase (Kneller and Leslie, 1984). It is also evident that additional silica was added during this stage (Boyd and Munro, 1978).

Conclusions

Balmedie Quarry is important for the remarkably clear evidence that it exhibits of the effects of post-magmatic tectonic events on the original layered gabbros and norites of the ‘Younger Basic' intrusions. These effects are partly mechanical, resulting in locally intense shearing and crushing, to give rise to flaser gabbros and mylonites. Mineralogical changes are also represented; these involve metamorphism of the original high-temperature igneous assemblage (olivine, pyroxenes, calcic plagioclase) to a lower grade (amphibolite facies) assemblage of amphibole, biotite and sodic plagioclase, together with additional silica. The main period of deformation was followed by intrusion of minor granite sheets, some of which are pegmatitic.

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