Knocklaugh

[NX 168 920]

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Introduction

The Knocklaugh GCR site provides a section through a sequence of dynamothermal metamorphic rocks developed from shale and spilitic lava marginal to the Northern Serpentinite Belt of the Ballantrae Complex ophiolite. Lithologies range from chlorite and epidote schists, pro-grading into amphibolites towards the ultramafic belt, to the highest-grade metamorphic rock seen, which is a garnet metapyroxenite. However, since this lies just within the serpentinite it may be unrelated to the schist–amphibolite assemblage. The aureole of metamorphic rocks is generally about 40 to 50 m wide and can be traced discontinuously along the serpentinite margin for over 5 km.

The unusual metamorphic assemblage was first noted by Peach and Horne (1899, pp. 456–9) and subsequently described in some detail by Anderson (1936) who proposed an origin by tectonism during the intrusion of hot ultrabasic magma. Later, the development of plate tectonic concepts and the recognition of ophiolites as obducted oceanic lithosphere allowed the re-interpretation of the Ballantrae Complex in those terms. Church and Gayer (1973) considered the Knocklaugh rocks to be part of a metamorphic aureole formed at the base of an obducting slab of still-hot mantle material. They drew attention to the similarities with dynamothermal aureoles present beneath the large, well-preserved ophiolite complexes of Newfoundland and noted the inversion of the metamorphic succession, with the highest grade rocks at the top (closest to the over-riding hot slab) of an originally sub-horizontal metamorphic layer. More recent and detailed studies of the aureole rocks (Spray and Williams, 1980; Treloar *et al.,* 1980) have confirmed the broad interpretation while stressing the range of temperature and pressure conditions required for formation of the different components.

Description

Detailed descriptions of the metamorphic aureole rocks at Knocklaugh, in both petrographic and structural terms, are provided by Spray and Williams (1980) and Treloar *et al.* (1980). A Sm-Nd isotopic age of 505 ± 11 Ma has been reported by Hamilton *et al.* (1984) for the high-grade metapyroxenite whereas Bluck *et al.* (1980) gave a K-Ar age of 478 ± 8 Ma for the lower-grade amphibolites. The geological setting is illustrated in (Figure 2.30).

The Knocklaugh GCR site provides a section wherein the Arenig lavas and interbedded cherts and shales (oceanic upper crust) of the Balcreuchan Group become increasingly sheared and schistose towards the SE margin of the Northern Serpentinite Belt. Epidote schists are seen as slaty rocks with streaked epidote augen and granular boudins, up to a few millimetres across, dispersed within finer-grained, dark-green laminae of actinolitic hornblende, chlorite and albite. Lighter-coloured, yellow-green layers of fine-grained epidote and titanite are also present in places together with sporadic metasedimentary quartz-albite-epidote-muscovite-chlorite schists and small pods of recrystallized carbonate. Closer to the serpentinite the epidote schists pass abruptly into coarser-grained, dark-grey amphibolites composed largely of plagioclase and green or brown hornblende. The more highly foliated of the amphibolites may contain garnet, and pyroxene occurs as an accessory in amphibolites adjacent to the serpentinite margin. Hornblende-bearing garnet metapyroxenite also occurs within the contact zone but in some cases is separated from the amphibolites by thin slivers of serpentinite. This may be due to structural imbrication of the schistose aureole and adjacent serpentinite during the final stages of thrust movement. Alternatively, the garnet pyroxenite may have originated as segregations near the base of the ultrabasic precursor to the serpentinite and so would not be part of the dynamothermal aureole *sensu stricto.* The width of the aureole assemblage is generally 40 to 50 m. Locally this may reduce to 20 m and in places the entire aureole has been removed tectonically; conversely the epidote schist component may broaden locally to nearly 200 m.

Structurally, the epidote schists and amphibolites of the aureole are dominated by a slaty schistosity or fine gneissose foliation with a locally developed mineral aggregation lineation. These fabric elements dip or plunge steeply to the NNW. Within the schistose fabric tight and asymmetrical, reclined interfolial folds close both SW and NE. They are refolded by small, tight and angular, straight-limbed folds with an associated axial-planar crenulation cleavage. Such a history of polyphase deformation restricted to a narrow band of rocks is characteristic of a mylonite zone. The dominant fabric in the metapyroxenite is rather different, more compatible with deformation by prolonged laminar flow under granulite facies or perhaps upper mantle conditions. The relatively abrupt transitions between the different lithologies suggests that they have been juxtaposed by the tectonic slicing of an originally more extensive metamorphic aureole. All of these structural features are believed to have developed during obduction of the Ballantrae Complex since the aureole is cut across by unsheared doleritic dykes, which are themselves of probable Arenig age (Holub *et al.,* 1984).

Interpretation

The Knocldaugh GCR site provides a section through a narrow dynamothermal metamorphic aureole adjacent to one of the major serpentinite bodies of the Ballantrae Complex. Early interpretations of these relationships were contentious, with an intrusive origin for the serpentinite as a hot, ultrabasic magma generally preferred. This was either controlled by or caused the tectonic movements necessary to produce the localized shear fabrics (e.g. Anderson, 1936). Modern interpretations regard the aureole as a metamorphic 'sole' developed beneath a hot mantle slab as it was thrust over oceanic crust and ultimately obducted at a continental margin (Spray and Williams, 1980; Treloar *et al.,* 1980). Characteristically such 'soles' are inverted in that the highest-grade rocks are at the top, adjacent to the overriding slab, with the metamorphic grade decreasing downwards. The interpretation of the metamorphic aureole in these terms thus identifies one of the key components in the recognition of the Ballantrae Complex as an obducted ophiolite.

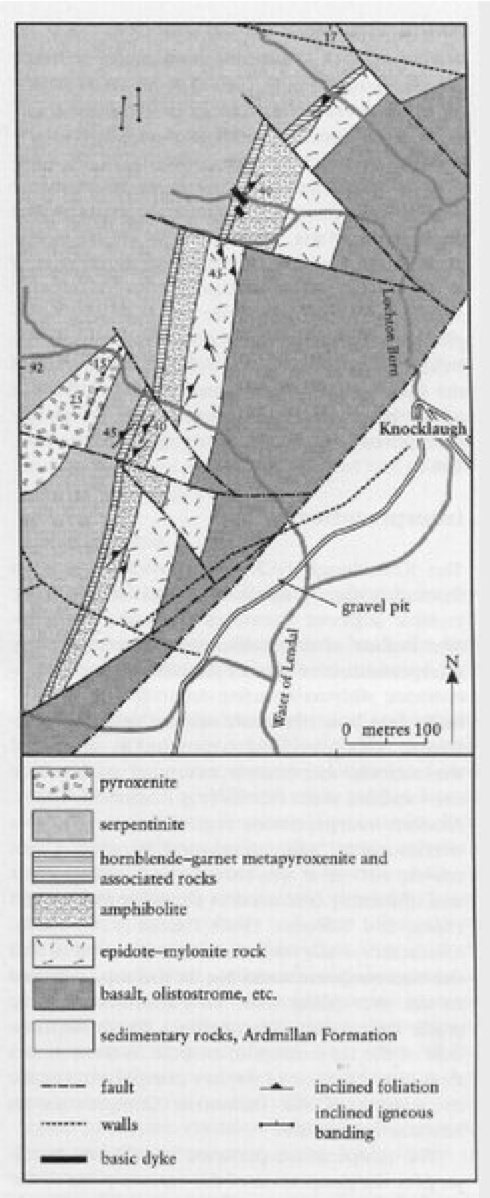
The temperature–pressure conditions necessary for the generation of the various parts of the aureole are clearly varied. The highest-grade rocks have attracted the most interest with 'texture, mineralogy and mineral chemistry used to estimate the conditions of metamorphism. Treloar *et al.* (1980) considered the garnet metapyroxenite to have recrystallized under upper granulite facies or mantle conditions with T = 900 ± 70°C and P = 10–15 kbar. This lithology may not be part of the aureole *sensu stricto* but it rather formed as original mantle segregations where the same P–T conditions would apply. However, broadly comparable conditions were determined by Spray and Williams (1980) who considered that formation of the foliated garnet amphibolite required a minimum of T = 850°C and P = 7 kbar. At these temperatures the adjacent ultramafic rock would have been unserpentinized suggesting that the onset of metamorphism was an early event in the assembly of the Ballantrae Complex, a deduction compatible with the available radiometric dates.

Various lines of evidence consistently indicate that the upper part of the metamorphic 'sole', i.e. that part closest to the serpentinite, formed under upper mantle conditions. Conversely, the lower-grade components of the aureole formed under very much less extreme conditions, perhaps as low as the greenschist facies, providing the characteristic inverted metamorphic profile. The full range of metamorphic lithologies are developed across only about 40 to 50 m, which represents an impossibly steep temperature gradient; further, the upper parts of the 'sole' were generated at much higher pressures than the lower parts. The limited radiometric age data suggests that the highest-grade rocks may have formed significantly earlier than the lower-grade components. Clearly the aureole assemblage as seen was not produced as a single entity and must have accreted piecemeal under decreasing pressure and temperature conditions. This would be in keeping with its interpretation as an obduction 'sole' wherein the metamorphic components would be both composite and tectonically transported. Treloar *et al.* (1980) envisaged 'a thin, transported and telescoped aureole made up of tectonic pieces of successively-formed metamorphic rocks that welded onto the base of an upward-moving and progressively-cooling peridotite slab'. Overall, it seems most likely that metamorphism was initiated in a deep thrust zone within oceanic lithosphere and continued as the thrust sheet moved upwards to shallower depths. The present array of aureole lithologies is thus the result of progressive incorporation at the base of the thrust sheet during its tectonic rise and emplacement.

Conclusions

Within the Ballantrae Complex ophiolite, at the SE margin of the Northern Serpentinite Belt, a range of high- to low-grade metamorphic lithologies was produced during obduction. Epidote schist, amphibolite, garnet amphibolite and possibly garnet metapyroxenite form an intermittent aureole to the serpentinite body ranging in width from 20 m to almost 200 m. The garnet metapyroxenite occurs just within the serpentinite and is succeeded, in a south-easterly direction, first by foliated and garnet-bearing amphibolite and then by slaty, banded epidote schist. The regular arrangement of lithologies within the metamorphic aureole arose by the progressive addition of metamorphic slivers onto the base of a hot mantle peridotite body during its thrusting from oceanic lithosphere onto continental crust. This crucial evidence for the obduction of the Ballantrae Complex is well preserved in the Knocklaugh section.

References



(Figure 2.30) Map of the metamorphic aureole developed adjacent to serpentinite at Knocklaugh, after Treloar et al (1980).