Knockormal

[NX 134 885], [NX 137 890], [NX 138 890] and [NX 143 891]

P. Stone

Introduction

That part of the Ballantrae Complex ophiolite exposed between Knockormal and Carleton Mains farms spans an anastomosing fault zone trending NE–SW through the central of the three volcanic belts (Figure 2.5) and (Figure 2.32). The area has long been famous for the reported occurrence within the fault zone of 'eclogite' (garnet clinopyroxenite with, in this case, accessory hornblende and spinel) and glaucophane-crossite schist. At its SW extremity this zone cuts out the metamorphic sole developed at the base of the Northern Serpentinite Belt and farther NE it introduces slivers of serpentinite into the upper Ordovician sedimentary sequence, which elsewhere overlies the lower Ordovician (Arenig) ophiolitic lithologies unconformably. A polyphase history of post-obduction movement is evident with cataclastic and brittle fabrics imposed locally.

The first extensive study of the Knockormal rocks was by Balsillie (1937) who identified the essential paradox; these are very high-grade metamorphic rocks requiring extremely high pressure for their formation, yet they are in close proximity to the extensive Ballantrae lava successions, which have experienced only very low-grade regional metamorphism. Balsillie's solution was to regard the high-grade rocks as relics of an ancient crystalline basement onto which the lavas were erupted, a controversial proposal at the time. However, a detailed study of mineralogy and mineral chemistry by Bloxam and Allen (1960) showed that the various glaucophane and other blue-amphibole rocks had been derived from spilitic lavas identical to those widely seen elsewhere in the Ballantrae Complex. Transitional lithologies were also discovered and an origin through in-situ faulting and shearing was favoured. The eclogite was also studied by Bloxam and Allen and described as a likely segregation within a host peridotite (now serpentinized), possibly forming as a primary component of a layered ultramafic body.

With the identification of the Ballantrae Complex as an obducted ophiolite, speculation was renewed and comparisons made with better exposed analogues elsewhere in the world. Church and Gayer (1973) introduced the possibility that all of the exotic lithologies at Knockormal could be contained within a large-scale, tectonized slump deposit formed during the obduction process. Bloxam (1980) suggested that the glaucophane schist could form tectonic inclusions contained within the serpentinite and derived from an older source, an echo of Balsillie's original proposal although differently effected. Nevertheless, it was the supposed association of eclogite with glaucophane schist and their joint implication of exceptionally high-pressure metamorphism that continued to attract most attention. Hence the inclusion of Ballantrae in that category on such regional compilations as the UNESCO-sponsored *Metamorphic Map of Europe* (Fettes, 1978). With this background the Knockormal GCR site is of great importance both for interpretations of the Ballantrae Complex itself and for assessments of its large-scale regional relationships.

Description

The general distribution of lithologies in the Knockormal area is shown in (Figure 2.32). The first descriptions of the blueschist and eclogitic lithologies were given by Balsillie (1937) who referred to 'a large knoll of foliated hornblendite and smaragdite-eclogite' with adjacent garnetiferous glaucophane schists 'derived from hornblendites'. Subsequently, in their extensive and detailed study, Bloxam and Allen (1960) located several zones of glaucophane schist in the vicinity of a low ridge capped by 'a prominent crag of eclogite'. Bloxam and Allen admitted the possibility that the eclogite 'crag' 'may not be precisely *in situ'* but concluded from their observation of other small exposures nearby that the material is indeed in place. The present appearance of the 'crag' clearly confirms it as a glacial erratic and there are currently no other exposures of the same lithology nearby. In 1975, a series of shallow boreholes was drilled in the vicinity of blueschist and eclogite 'exposures' and proved till with large boulders to a depth of at least 4 m, thus raising further doubt over the provenance of the schist and eclogite Q.E. Dixon, reported in Smellie and Stone, 1984). However, Smellie and Stone also reported in-situ material revealed in trenching operations: a drainage trench to the west of the Lendalfoot–Colmonell road (Trench 1, (Figure 2.32)) exposed a sequence of glaucophane-bearing schists while a garnet clinopyroxenite similar to the eclogite was recovered from a temporary excavation a short distance east of the crag/erratic (Trench 2, (Figure 2.32)).

The field relationships between the various ultramafic lithologies are uncertain but the contacts between the ultramafic rocks and the blueschists all appear to be faulted. The blueschists are disposed along the sheared and faulted margins of a complex tectonic lens, which contains dolerite and gabbro together with serpentinized ultramafic rock, wherlite and various pyroxenites including the 'eclogite'. The schistose foliation trends approximately parallel to the margins of the gabbro-ultramafic lens and appears to be consistent between outcrops. The schists have developed by progressive deformation of spilitic lavas which form the bulk of the outcrop in the Knockormal–Carleton Mains area. Locally, for example 400–500 m WSW from Knockormal farmhouse, the spilitic lavas are interbedded with black siliceous mudstone and recrystallized limestone. For the most part the schists are of the greenschist fades but in some examples wisps of pale-blue glaucophane and/or crossite appear, apparently as replacements of actinolite or chlorite; rarely these may develop into macroscopic blue bands of fibrous crossite. These lithologies have been referred to as 'transitional glaucophane schists' by Bloxam and Allen (1960) and are the most common blueschist lithology. True glaucophane schist is rare and is restricted to narrow zones within the drainage trench and exposures 'on the crags near the Lendalfoot road' as reported by Bloxam and Allen (1960). In these examples the glaucophane forms a continuous foliation, apparently replacing chlorite and enclosing grains of epidote, titanite and albite with rare garnet present in places. In hand specimen the glaucophane schist is a hard, blue-grey rock with a silky lustre. Crossite amphibolites are interbanded with the glaucophane schists and are generally coarser grained with the crossite forming ragged fringes around crystals of green hornblende. A comprehensive account of the mineralogy and mineral chemistry of the Knockormal blueschists is provided by Bloxam and Allen (1960). All of the schistose lithologies show evidence of refolding, cataclasis and brittle deformation subsequent to the formation of the blue amphiboles.

Ultramafic lithologies exposed in the Knockormal area include serpentinized harzbur-gite, wherlite and clinopyroxenite. However, it is the reported presence of eclogite which gives this locality its unique importance. The eclogite was first reported by Balsillie (1937), together with the blueschists, as 'some of the most interesting rocks that have yet been discovered in the Ballantrae region'. Bloxam and Allen (1960) made a detailed study of material taken from the probable erratic boulder and described it as essentially amphibole (pargasite), clinopyroxene (fassaite) and garnet with accessory green spinel (ceylonite) and possibly zoisite. Smellie and Stone (1984) examined material from the same source and confirmed the earlier description although without the accessory spinel. The nearby excavation of a comparable lithology (Trench 2, (Figure 2.32)) was also reported by Smellie and Stone and is of importance in view of the uncertain origin of the originally described eclogite crag/boulder. A garnet clinopyroxenite from the NW end of Trench 2 consists of dark-green clinopyroxene (partially replaced by chlorite) and pale-pink garnet (generally fresh). Microprobe analyses presented by Smellie and Stone show that the mineral chemistry of the specimens from the erratic boulder and the trench is indistinguishable and suggests that the rocks had a common origin. The amphibole is tschermakitic hornblende, the pyroxene is fassaitic diopside and the garnet is almandine-rich pyrope. Small exposures close to the erratic boulder are of either serpentinized harzburgite or clinopyroxenite. A severely brecciated clinopyroxenite recovered from the SE end of Trench 2 consists of fresh, pale-green pyroxene occurring as large, ragged plates with strained and bent cleavage. This rock has apparently been affected by intense brittle fracture probably related to movement on the nearby fault (Figure 2.32).

Interpretation

The association of glaucophane schist and supposed eclogite has led to speculation that the Ballantrae Complex contains the remains of a high-pressure metamorphic belt (e.g. Fettes, 1978), with major implications for any interpretation of its origin. However, the ambiguous field relationships between the various lithologies and some unusual petrographical and chemical features have allowed the development of a number of alternative models.

The blueschist occurrences are all contained within an anastomosing fault zone and are marginal to a composite block of gabbro and ultramafic rock (Figure 2.32). If they formed *in situ* then an episode of intense shearing in a relatively low-temperature environment must be invoked, presumably during the obduction process. It seems doubtful that appropriate conditions could be achieved in this way since glaucophane is more characteristic of metamorphism during subduction when deep tectonic burial occurs in a zone of abnormally low heat flow. This paradox has led to alternative proposals whereby the blueschists were regarded as exotic lithologies brought into their current position by sedimentary or tectonic processes. Church and Gayer (1973) suggested that the blueschists (and the neighbouring 'eclogite) could be exotic clasts incorporated into a mélange which 'developed as a result of deformation beneath a forward moving thrust sheet of material previously produced by erosion from the leading edge of the self same nappe in an olistostrome environment.' These authors were particularly impressed by similarities between the Knockormal situation and more extensive analogues in the Newfoundland ophiolites. A different exotic origin was preferred by Bloxam (1980) who described the blueschists as tectonic inclusions contained within serpentinite; 'samples of Precambrian crust dismembered and caught-up in the serpentinite during its cold diapiric rise and tectonic emplacement.' The similarities of these proposals with the original deductions of Balsillie (1937) are striking and perhaps gain further support from the occurrence of blueschist clasts in undisputed mélange deposits elsewhere in the Ballantrae Complex (e.g. the Pinbain section within the Slockenray Coast GCR site).

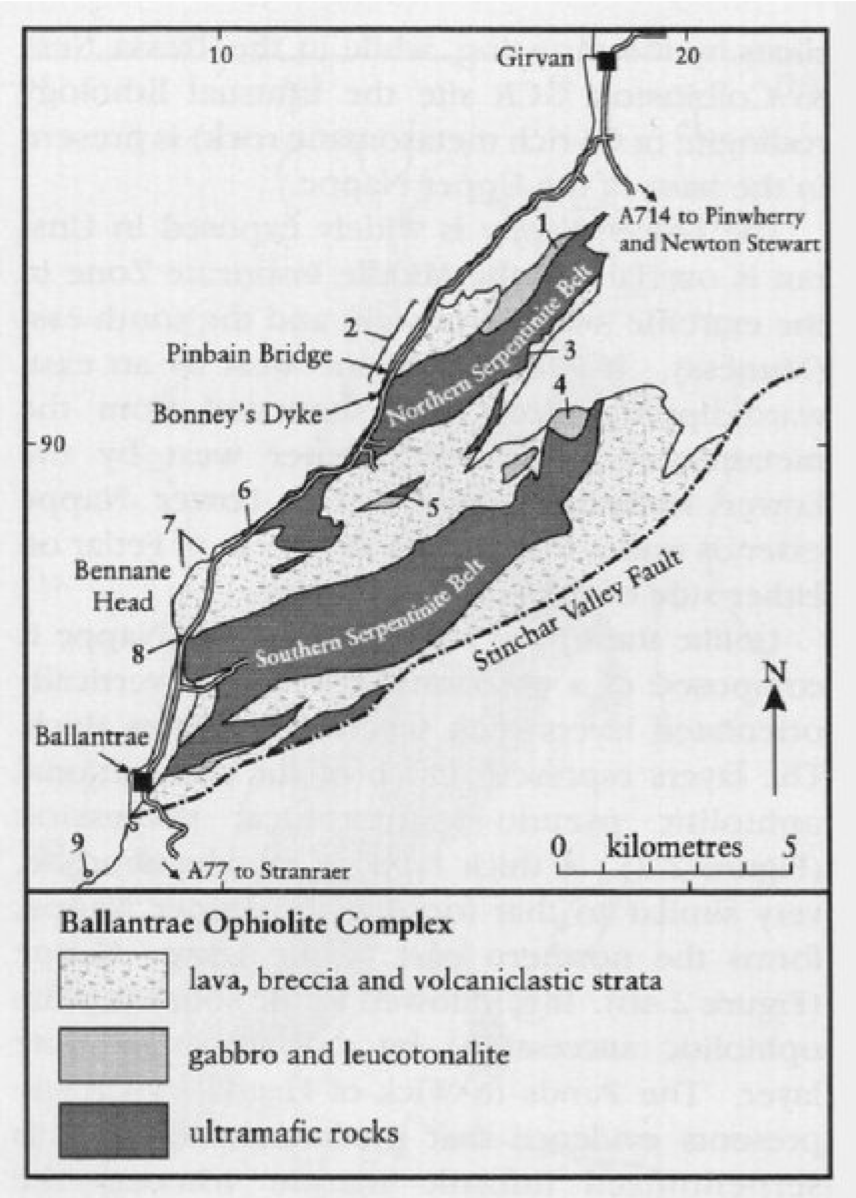
The 'eclogite' has received even more attention than the blueschists and has generated a range of interpretations. These include: an ultramafic lens within serpentinized harzburgite (Bloxam and Allen, 1960), subsequently refined as a high-pressure phase of a layered peridotite sequence (Bloxam, 1980); part of a high-grade metamorphic belt (e.g. Fettes, 1978); a tectonically isolated sliver of a dismembered metamorphic sole to the ophiolite comparable to the in-situ examples seen at the Knocklaugh GCR site (Spray and Williams, 1980; Trcloar *et* al., 1980); an exotic clast derived from a mélange deposit (Church and Gayer, 1973) comparable, as with the blueschists, to fragments of garnet-clinopyroxene rock seen in other Ballantrae Complex mélanges. The detailed study by Smellie and Stone (1984) showed that the mineral paragenesis is consistent with an origin within the lowermost crust or upper mantle; the mineral chemistry is dissimilar to that of eclogites (*sensu stricto*) found in blueschist belts but is consistent with an ultramafic association. This led the latter authors to propose an origin as garnet pyroxenite formed by partial melting of a rising lherzolite diapir beneath an Arenig oceanic spreading centre. However, age dating by Hamilton *et al.* (1984) suggested that the Knockormal 'eclo-gite' is considerably older than Arenig (early Ordovician). Using material from the originally described crag/boulder (which they considered to be a clast within a mélange) these authors obtained a Sm-Nd garnet-pyroxene-whole rock isochron of 576 ± 32 Ma, about Early Cambrian. This is the oldest age yet determined for any component of the Ballantrae Complex and strengthens those interpretations that see the 'eclogite' as an exotic clast derived from preexisting oceanic crust.

Despite a plethora of research the origin and relationships of the Knockormal blueschist-'eclogite' assemblage remain uncertain. The current consensus favours an exotic origin as clasts within a mélange deposit but the relative importance of sedimentary versus tectonic processes has not been established and the ultimate origin(s) of the clasts (if that is what they are) remains unknown. However, it does seem clear that there is no genetic link between the blueschists and the 'eclogite' and their present juxtaposition must therefore be regarded as fortuitous.

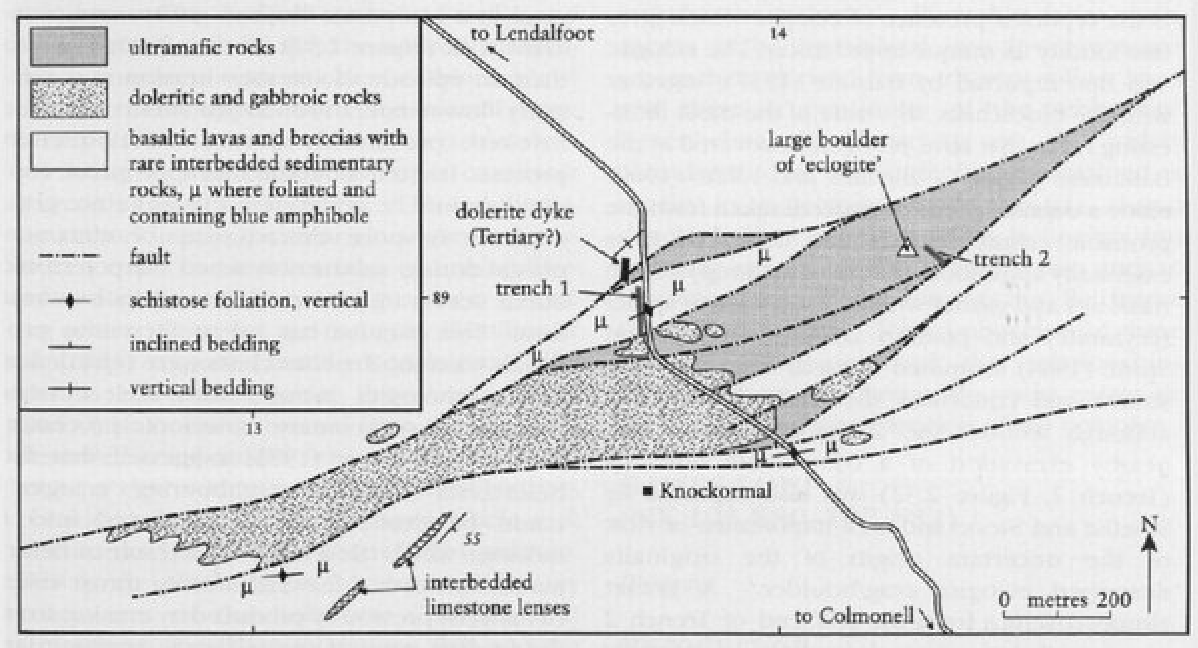
Conclusions

The 'eclogite' and glaucophane schist (blue-schist) lithologies at Knockormal are internationally known as unusual components of the Ballantrae Complex. The 'eclogite' is most likely to have originated as a garnet(-hornblende) clinopyroxenite segregation within upper mantle harzburgite. It may now occur as a tectonic inclusion within serpentinite. It is the oldest rock so far identified within the complex (*c.* 576 Ma) and may represent a fragment of the oceanic crust which formed the basement to the younger (*c.* 500–490 Ma) components. The high-pressure blueschists occur at the sheared and faulted margins of a lensoid, composite block of gabbro and ultramafic lithologies that includes the 'eclogite'. Blueschist facies rocks appear to be transitional into lower-pressure greenschists derived from adjacent pillow lavas and there is continuity of the schistosity. Nevertheless, the blueschists are also widely considered to be exotic lithologies contained as blocks in a tectonized sedimentary slump deposit. Their ultimate origin is unclear but they may indicate a phase of subduction prior to the late-Arenig obduction of the Ballantrae Complex ophiolite. The combination of these unusual lithologies and the relationships between them, are among the most enigmatic problems in the interpretation of the ophiolite.

References



(Figure 2.5) Outline geology of the Ballantrae Complex (after Stone and Smellie, 1988) showing the location of the GCR sites. 1, Byne Hill; 2, Slockenray coast; 3, Knocklaugh; 4, Millenderdale; 5, Knockormal; 6, Games Loup; 7, Balcreuchan Port to Port Vad; 8, Bennane Lea; 9, Sgavoch Rock.



(Figure 2.32) Map of the fault zone between Knockormal and Carleton Mains after BGS (1988).