11 Black Water

[NJ 355 303]–[NJ 378 308]

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11.1 Introduction

The lower part of the Black Water, a major tributary of the River Deveron in the Cabrach area, south-west of Huntly, provides a continuous section through the most-extensive sequence of metavolcanic rocks in the Dalradian of the North-east Grampian Highlands.

The metavolcanic rocks occur within a varied succession of gritty psammites and pelites of turbiditic character that crop out immediately to the east of the Portsoy Lineament (see 1.1.3 in *Introduction*). Together, these metasedimentary and metavolcanic rocks form the Blackwater Formation. As with most stratigraphical units to the east of the Portsoy Lineament, direct correlation at formation level with Dalradian outcrops to the west and south is not possible (Fettes *et al.* 1991; Stephenson and Gould 1995). However, the rocks have lithological characteristics that are typical of the Argyll Group and pass upwards and south-eastwards into Southern Highland Group strata. This would seem to be consistent with a stratigraphical position near the top of the Argyll Group, probably equivalent to the Crinan and/or Tayvallich subgroups elsewhere.

The lower part of the Blackwater Formation has been divided into three members, based upon the compositions of the metavolcanic rocks. In ascending stratigraphical order these are the *Lynebain Basic Volcanic Member*, the *Kelman Hill Ultrabasic Volcanic Member* and the *Ardwell Bridge Basic Volcanic Member*. The Lynebain and Ardwell Bridge members consist mainly of metabasaltic rocks, which locally exhibit complete or fragmental pillow structures. The Kelman Hill Member contains some metabasalts but is dominated by a variety of ultrabasic rocks (metapicrites), some of which are highly fragmented with a fine-grained hyaloclastite appearance. Above, the formation consists mainly of dark-grey pelites, graphitic in parts, with conspicuous andalusite schists and a number of persistent beds of gritty psammite (the Corinacy Pelite Member).

The Blackwater Formation is poorly exposed over much of its outcrop but high-amplitude magnetic anomalies, mostly restricted to the part of the formation that is known to contain metavolcanic rocks, have greatly assisted in its mapping. Measurements of magnetic susceptibility on pelites from the Black Water section indicate that some of the anomalies result from high magnetite contents in metasedimentary rocks (Fettes *et al*., 1991). An igneous source for this magnetite seems likely and this strengthens the case for the meta-igneous rocks being penecontemporaneous with their host sediments in a volcanic setting. Magnetic evidence is unable to differentiate between the basic and ultrabasic types.

The first Geological Survey map of this area was published as one-inch Sheet 85 (Rothes, 1898), with an accompanying memoir (Hinxman and Grant Wilson, 1902). Mackie (1908) was the first to suggest that some of the basic meta-igneous rocks in the area had a volcanic origin and Dewey and Flett (1911) identified pillow lavas at this GCR site. The pillow structures were described in some detail by MacGregor and Roberts (1963), together with an account of their petrography and metamorphic history. A detailed resurvey, incorporating the results of ground magnetic traverses at 200 m spacing, was undertaken by the British Geological Survey and published as 1:50 000 Sheet 85E (Glenfiddich, 1996). This work was incorporated in a regional synthesis (Fettes *et al*., 1991) and formed the basis for a programme of geochemical sampling and drilling that targeted the igneous rocks as potential hosts of gold and platinum-group elements (Gunn *et al*., 1990). However, the mineral investigations were not encouraging, with uniformly low PGE (maxima 11 ppb Pt, 10 ppb Pd, 5 ppb Rh), only sporadic slight enrichment in gold (maximum 150 ppb Au) and no attendant enrichment in base metals or chalcophile elements. Mineralogical and geochemical aspects of the volcanic rocks have been described

and discussed by Macdonald *et al.* (2005) and by Fettes *et al*. (2011), and there is a brief field guide to the eastern end of the section by Gillen (1987).

11.2 Description

The Blackwater Formation is bounded to the north-west throughout its outcrop by the Portsoy Shear-zone. In this area, the shearing is concentrated in a 1 km-wide zone, in which lie many pods of sheared serpentinite and metagabbroic rocks between the larger Succoth–Brown Hill and Blackwater intrusions of the North-east Grampian Basic Suite (Fettes *et al*., 1991). To the south-east of the shear-zone, for a cross-strike width of at least 2 km, and certainly extending across the entire outcrop width of the metavolcanic rocks, all lithologies have a single, possibly composite, planar fabric sub-parallel to the bedding. The whole sequence strikes north-east–south-west with a generalized steep dip to the south-east. No folds of any scale are seen, and instances where the fabric in pelitic beds is slightly oblique to bedding are rare.

The stream section that is the GCR site extends from the faulted contact of the Blackwater Formation with the sheared margin of the Blackwater Intrusion at [NJ 355 303], downstream to Blackwater Bridge [NJ 378 308], which was formerly known as Ardwell Bridge (Figure 6.21). From this section, the outcrop of the metavolcanic rocks extends north-eastwards, averaging *c.* 2 km in width, for some 8 km. To the south-west lava exposures become impersistent in poorly exposed ground and their magnetic anomalies cannot be traced for more than 5 km.

The metavolcanic rocks are, for the most part, interbedded with gritty psammites and mica schists, locally with black, graphitic, schistose or phyllitic pelites. Some gritty psammites have been mapped out separately and commonly have distinctive blue-grey quartz clasts. A basal predominantly pelitic unit is present in places. Excellent graded units at the western end of the Black Water section (for example, at [NJ 3596 3040] and [NJ 3621 3040]) indicate younging to the south-east.

The metavolcanic units range from a few metres to 50 m in thickness and are concordent with the metasedimentary rocks. Contacts with the metasedimentary rocks are variable; in some cases these are relatively sharp, in others the metavolcanic rock is rather nodular with carbonate veining and in some cases the edge of the metavolcanic unit is brecciated with metasedimentary infilling. In excellent examples at [NJ 3714 3058] and [NJ 3734 3087] a metavolcanic unit has a carbonated nodular margin passing into a relatively massive centre, the opposite margin being brecciated with a metasedimentary matrix. This asymmetry is consistent with an origin as a lava, although it is not clear which margin marks the base and which the top. Vesiculation is common in all three members.

Metabasaltic pillows are well exposed near Blackwater Bridge, at [NJ 3776 3083] and [NJ 3751 3082] (MacGregor and Roberts, 1963). Fragmental pillows also occur in places and are particularly well developed in the River Deveron at Lynebain [NJ 412 351], some 7 km north-east of the Black Water section. The pillows at Blackwater Bridge are ellipsoidal, with horizontal cross-sections of some 60 x 15 cm and vertical dimensions of up to 150 cm. Small, originally spherical vesicles within the pillows show concentric banding in places and, rarely, elongate vesicles radiate around the noses of individual pillows. The pillows are bordered by fine-grained, non-vesicular selvedges and small volumes of altered basaltic material occur between the pillows. Both pillows and amygdales are flattened within the regional fabric, which is most strongly developed at the margins of and between the pillows. Interpretation of the pillow orientations is equivocal but better evidence from the metasedimentary rocks confirms that the Black Water section traverses a continuous south-east-younging sequence.

In terms of their whole-rock chemistry, the metavolcanic rocks range from ultrabasic (metapicrites) to basic (metabasalts and meta-basaltic andesites), with some intermediate compositions (meta-andesites) (Macdonald *et al*., 2005). As a result of amphibolite-facies regional metamorphism, they have mineral assemblages dominated by amphiboles.

The metabasalts and meta-andesites are mainly aphyric. They consist of aggregates of dark green clinoamphibole (actinolite to magnesiohornblende to pargasitic magnesiohastingsite in composition), with lesser amounts of plagioclase, quartz and ilmenite, the latter commonly rimmed or replaced by titanite. Aggregates of epidote and quartz could represent pseudomorphs after plagioclase phenocrysts. Distinctive pyroxene-phyric types crop out near Shenval [NJ 368

308] and have been found as float on Kelman Hill [NJ 396 334], some 3 km to the north-east. In these rocks, amphibole pseudomorphs after phenocrysts of original, igneous clinopyroxene contain rare relict cores of ferroan diopside.

The metapicrites are variable, ranging from massive to highly fragmented with sharp fine-grained shards, giving the appearance of a hyaloclastite. The more-massive forms consist almost entirely of felted intergrowths of colourless to pale green magnesian clinoamphibole (tremolite to magnesiohornblende in composition) with chlorite and sparse small rounded grains of chromian magnetite. Excellent examples of brecciated ultrabasic rocks are found as float to the east of Shenval. These consist of ultramafic clasts set in an ultramafic matrix (Figure 6.22). The fragments are of varying type, up to several centimetres in size and constitute 60–80% of the rock; they are generally flattened into alignment with the regional fabric. The matrix to the fragments is highly sheared, streaky and chlorite rich. At the microscopic scale, so few original features are preserved that it is difficult to determine whether the rocks are of extrusive or intrusive origin. Some sections contain highly elongate grains of ilmenite, which might indicate rapid cooling and therefore a volcanic origin. In others a variolitic texture is preserved, while some of the fragments were originally glassy and now have a grain size less than 10 microns.

Overall, there is little doubt of the predominantly volcanic origin of most of the meta-igneous rocks, although some of the more-massive sheets could have been shallow, subvolcanic sills. An undoubtedly intrusive metabasaltic unit occurs near Torr of Shenwell [NJ 3746 3083], where a *c.* 20 m-thick sheet shows a sharp, non-vesiculated contact against psammites and andalusite schists. The intrusion is geochemically similar to extrusive rocks of the Ardwell Bridge Member and it is assumed that they were broadly coeval. The most evolved, and finest grained, rock occurs at the eastern margin of the intrusion and there is a gradational increase in grain size towards a metagabbroic central facies, which is less evolved. The intrusion seems, therefore, to have formed from a magma column that had become differentiated at greater depth.

The ENE-trending faults that are prominent on (Figure 6.21) are part of a regional set, which has been particularly well delineated in this area by the ground magnetic survey (Fettes *et al*., 1991). The linear magnetic anomalies are clearly displaced, the inferred dislocations commonly coincide with topographical features and some are readily seen on air photographs. This is one of the youngest sets of regional faults, which elsewhere in the North-east Grampian Highlands are associated with late-Carboniferous quartz-dolerite dykes.

11.3 Interpretation

The geochemical studies of Macdonald *et al.* (2005) and Fettes *et al*. (2011) have shown that the Blackwater metavolcanic rocks as a whole are of tholeiitic affinity and are broadly similar to metavolcanic rocks elsewhere in the Dalradian succession. Their inferred parental magmas were relatively Ti- and Fe-rich high-magnesia basalts with total iron oxides *c.* 14 % and MgO *c.* 10 %. Fractionation of iron-titanium oxide minerals, olivine and clinopyroxene from the parental magmas generated a range of daughter magmas extending to tholeiitic andesite composition. Some of the more-evolved rocks show evidence of minor accumulation of iron-titanium oxides. A continuous enrichment in Al_2O_3 indicates that plagioclase fractionation must have been absent or muted, which is consistent with an absence of Eu anomalies in rare-earth patterns. Crystallization of plagioclase can be significantly delayed under conditions of high P_{H2O} and hence Macdonald *et al*. (2005)suggested that the Blackwater magmas might have been relatively hydrous. The picritic rocks formed by accumulation of olivine and minor chrome-spinel within the parental basalts, probably at deep crustal levels. Their high MgO content (over 18% and ranging up to 35%) had originally led to speculation that they might reflect primary, high-temperature (possibly komatiitic) magmas, which to some extent prompted the investigations for gold and platinum-group mineralization (Gunn *et al*., 1990; Fettes *et al*., 1991). However, this was not considered likely by Macdonald *et al.* (2005).

Concentrations of incompatible trace elements such as Zr, Nb and Y suggest that the primary magmas of the Blackwater metavolcanic rocks were generated from a mantle source that was relatively enriched compared to a Mid-Ocean Ridge Basalt (MORB) source. This is a feature that they share with other late-Argyll Group metavolcanic rocks such as the Tayvallich lavas (Fettes *et al*., 2011). Other metavolcanic rocks, from lower in the Dalradian succession, have geochemical characteristics more typical of a depleted, MORB-like, mantle source (e.g. Goodman and Winchester, 1993). Hence Macdonald *et al.* (2005) and Fettes *et* al. (2011) have speculated that Dalradian metavolcanic rocks

represent varying degrees of mixing of magmas from these two mantle sources.

It would appear that there was an overall trend in the Dalradian from basalts generated in more-depleted mantle sources, which were erupted earlier, to ‘enriched’ types, which were erupted later. The latter, including the Blackwater metavolcanic rocks, can be classed as Fe-Ti basalts, which are developed typically at propagating rifts that are progressively breaking through rigid lithosphere, and Macdonald *et al.* (2005) suggested that progressive rupturing along the margin of Laurentia, resulted in the more-enriched source rising to higher levels and tending to mix less with the depleted source.

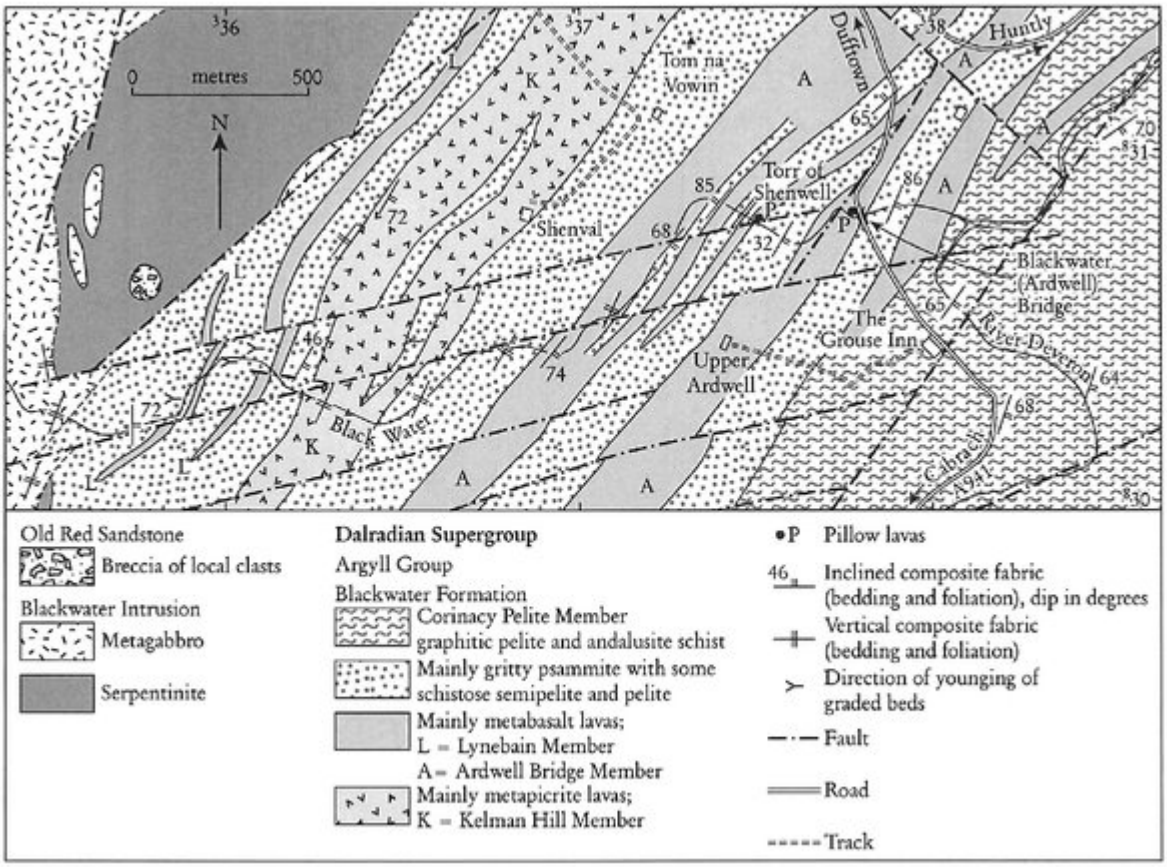
The Blackwater metavolcanic rocks are interbedded with metasedimentary lithologies, characterized by coarse turbidites that originated as deep-water basin sediments. Together they record a crucial stage in the break-up of the supercontinent of Rodinia, as lithospheric thinning, crustal instability and continental rifting led into the formation of the Iapetus Ocean during Argyll Group times (Fettes *et al*., 2011). The siting of this sub-marine volcanism, along the Portsoy Lineament, emphasises the importance of the lineament as a tectonothermal boundary and suggests that its origins might lie in the basin architecture that evolved as a result of the initial continental rupture (Ashcroft *et al*., 1984; Fettes *et al*., 1986).

11.4 Conclusions

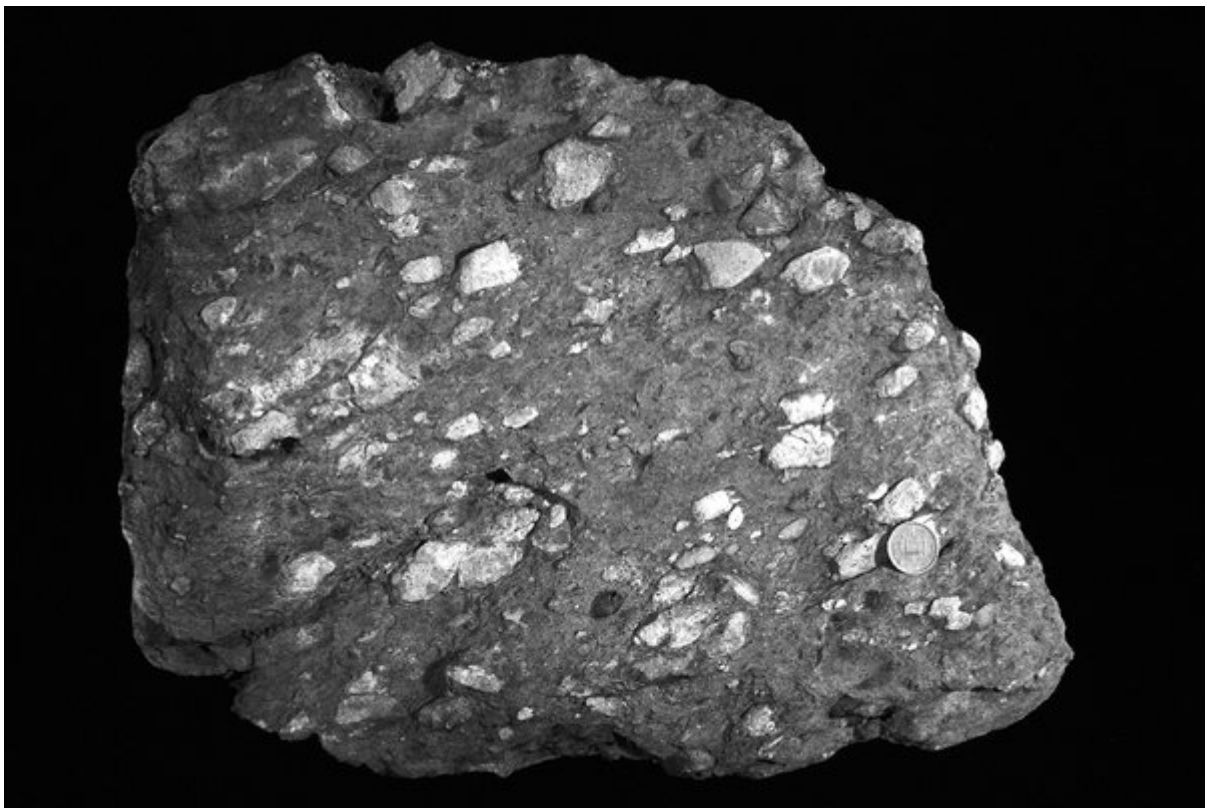
The Black Water provides a continuous river section through the thickest and most extensive sequence of metavolcanic rocks in the Dalradian of the North-east Grampian Highlands. The presence of metabasaltic pillow lavas in this section has long been known but even more remarkable are the wide range of fragmented high-magnesium ultrabasic lavas (metapicrites) that originated by the accumulation of olivine from the basaltic magmas in deep-crustal magma chambers. The formation of pillows and the fragmentation of the metapicrites are the results of sub-marine eruption in deep unstable basins, characterized by turbibitic sedimentation.

The Blackwater metavolcanic rocks, together with the near-contemporaneous Tayvallich lavas in the South-west Grampian Highlands, are typical chemically of volcanic rocks in propagating rift basins, and provide vital information about the tectonomagmatic conditions that resulted from the break-up of Rodinia and the initial formation of the Iapetus Ocean, some 600 million years ago. The basin in which the Blackwater rocks were erupted might have been related in some way to the initial formation and location of the Portsoy Lineament, which was to influence sedimentation, magmatism and tectonics for the following 140 million years or more.

References



(Figure 6.21) Map of the section through metavolcanic rocks in the lower part of the Blackwater Formation, exposed in the Black Water. Adapted from the BGS 1:10 000 Sheet NJ33SE (1993).



(Figure 6.22) A typical fragmental ultrabasic volcanic rock from the Kelman Hill Member of the Blackwater Formation. The dominant, pale, subrounded to subangular clasts are derived from picritic lavas and there are smaller, darker and more-rounded clasts that are probably from metabasalts. Loose block near Shenval, Black Water GCR site [NJ 363 308]. Coin is 20 mm diameter. (from Macdonald et al., 2005, figure 4.) (Photo: BGS No. P 582442, reproduced with the permission of the Director, British Geological Survey, © NERC.)