5 Cairn Leuchan

[NO 380 908]–[NO 393 941]

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5.1 Introduction

The hill of Cairn Leuchan (679 m) is located 5 km south-east of Ballater in upper Deeside, on the broad NE-trending ridge that separates Glen Muick to the west from Glen Tanar to the east. The GCR site is representative of a variety of rocks that have contributed considerably to the understanding of conditions of high-grade regional metamorphism in the Grampian Terrane. Firstly it lies within the area where Barrow established the concept of metamorphic zones and index minerals. Secondly, it lies close to the trace of the kyanite–andalusite isograd, which in simple terms has been taken to define the boundary between the Barrovian and Buchan styles of metamorphism. Thirdly, and perhaps most importantly, geothermometric and geobarometric studies on gneisses from Cairn Leuchan have established that peak metamorphic temperatures and pressures were among the highest recorded in the Grampian Terrane, and that this was one of the few areas in the Scottish Highlands where metamorphic conditions during the Caledonian Orogeny approached granulite facies.

The primary survey of the Glen Muick–Glen Tanar area was carried out by Barrow in 1896 and the results were incorporated into the one-inch Sheet 65 (Balmoral, 1904) and the accompanying memoir (Barrow and Cunningham Craig, 1912). The area lies close to the boundary between the Dalradian of Perthshire and that of the North-east Grampian Highlands and, as such, forms an important link between these two contrasting successions, as was highlighted by Read (1928). Cairn Leuchan was the focus of detailed studies of metamorphic conditions by Baker and Droop (1983) and Baker (1985). The area was resurveyed by staff of Aberdeen University and Queen's University, Belfast under contract to the British Geological Survey, resulting in a new edition of the 1:50 000 Sheet 65E (Ballater, 1995) and an accompanying memoir (Smith *et al*., 2002).

Bedrock at the GCR site consists dominantly of the Queen's Hill Formation, which in this area constitutes the entire thickness of the Crinan Subgroup and comprises two main gneissose lithologies, one semipelitic to pelitic and one hornblendic. The hornblendic rocks are metamorphosed basic sheets, which were mostly intruded before deformation, although some fine-grained rocks exposed near the base of the formation are regarded as metavolcanic.

The Dalradian rocks were affected by four phases of folding as a result of which the strata are inverted and dip steeply to the north-west. At the same time the rocks underwent high-grade metamorphism and were extensively migmatized. They were intruded subsequently by small late-tectonic ultrabasic to intermediate bodies and, to the north and east of Cairn Leuchan and Pannanich Hill, by post-tectonic silicic rocks of the Ballater and Mount Battock granite plutons. Later faults trend north, north-west and east-north-east.

5.2 Description

The following account is based on descriptions by Baker and Droop (1983), Goodman *et al.* (1990) and Smith *et al.* (2002). Exposures in the immediate area of Cairn Leuchan are dominated by gneissose basic meta-igneous rock with subordinate interlayered metasedimentary gneiss (Figure 6.10). The meta-igneous rocks show a wide range of magnetic susceptibilities, but generally record higher values than the surrounding metasedimentary rocks, and hence ground magnetic surveys were employed extensively in the last resurvey of the area.

The intrusive meta-igneous rock is part of a sheet-like unit that can be traced along strike for nearly 12 km. To the south of Am Mullach [NO 375 904] the outcrop width of this sheet is generally less than 200 m but in the vicinity of Cairn Leuchan, largely as the result of repetition in the core of a major F2 fold, it reaches a width of around 1 km. In common with other meta-igneous sheets in the area it consists of coarse-grained hornblendic gneiss, which is locally agmatitic.

Semipelitic to pelitic metasedimentary gneisses are exposed *c.* 400 m to the north-west of Cairn Leuchan and are inferred from magnetic mapping to underlie the unexposed ground at a comparable distance to the south-east. The outcrop width of these units ranges from nearly 500 m to less than 30 m.

Three episodes of folding, corresponding to the D1–D3 regional events have been recognized in the Dalradian rocks of the Cairn Leuchan to Pannanich Hill area. In common with the surrounding ground there is no evidence of any large-scale F1 folds. However, the earliest event produced a number of small-scale (5–10 cm wavelength or less) rootless isoclines that are intrafolial to the regional fabric and are particularly evident in the hinge-zones of F2 folds. These early structures fold an evenly spaced fabric marked by quartzofeldspathic material, reminiscent of tectonic striping or spaced cleavage. This suggests that these are not truly F1 folds, but could be an early D2 phase. The main deformation occurred during D2 with the development of large asymmetrical folds, and the axial surface trace of a major synform passes directly through Cairn Leuchan. These F2 folds have long NW-dipping and short horizontal or SSE-dipping limbs and plunge to the south-west. It has been suggested that they verge to the north-west, but the outcrop pattern suggests that they verge to the south-east. The main regional fabric (S2) is aligned parallel to the long limbs and hence, in common with the sheet dip, strikes north-east–south-west and is inclined steeply to the north-west. Few examples of F3 folds are to be seen in the area, but the orientation of the S2 fabric is largely attributed to that phase of folding.

The Dalradian rocks are all coarse-grained gneisses or migmatites, whose mineral assemblages and textures largely reflect the peak metamorphic conditions that prevailed during the D2 deformation. The meta-igneous rocks vary from those with a planar gneissose foliation to heavily agmatized types. The latter are characterized by lenticular clots rich in ferromagnesian minerals, surrounded by anastomosing stringers of leucocratic material that can form up to 40% of the rock; the subparallel alignment of these clots gives rise to an indistinct foliation. Compositional banding is not present. They have the mineral assemblage garnet-clinopyroxene-hornblende-plagioclase-quartz-ilmenite-apatite-titanite, although there is considerable variation in the proportions of minerals present; e.g. hornblende content can range from 10–70%. Garnets are common, particularly in the more-mafic examples, and are of almandine composition, typically $Alm_{56}Gr_{30}Py_{7}Sp_{7}$, little zoned, and stable within the metamorphic assemblage. In the Cairn Leuchan–Drum Cholzie area, diopside occurs as large idioblastic porphyroblasts, several centimetres in diameter, with a typical composition of $Ca_{1}Mg_{0.5}Fe_{0.5}Si_{2}O_{6}$. They too are stable within the regional metamorphic assemblage.

The metasedimentry gneisses also exhibit a wide range of mineral assemblages. Simplest are those that consist of quartz, andesine, K-feldspar and dark brown biotite, with accessory opaques, apatite, zircon and titanite. The foliation in the rocks is defined by the orientation of biotite laths and by elongation of quartz grains, which commonly show considerable strain. Almandine garnets are common in pelitic rocks, often being full of biotite and quartz inclusions. They typically have the composition $Alm_{73}Py_{16}Gr_{7}Sp_{3}$, although they can show some zoning, the rims being slightly more Fe rich and Mg poor than the cores. In places the garnets have atoll shapes, the central parts having been replaced by a fine-grained biotite symplectite. Sillimanite is present in pelites as fibrolite, and is also found at the centre of atoll garnets; the sillimanite sworls seen in some specimens could be pseudomorphs after garnet.

Two main episodes of migmitization in the metasedimentary rocks are recognized in the Ballater district; an early generation, which is widely developed and is characterized by stromatic leucosomes of leucotonalitic composition, and a later episode from which the ultimate product is a massive coarse-grained rock of igneous aspect, consisting of biotite, oligoclase and quartz. The later episode has a much more localized development than the earlier. Although it has not been recognized in the immediate area of Cairn Leuchan, there is an extensive development 2–3 km to the north, where it is known as the Pannanich Hill Complex (Goodman, 1991). (See also the *Balnacraig* GCR site report.)

5.3 Interpretation

Major- and trace-element analyses of the basic meta-igneous rocks show they have tholeiitic affinities, typical of the volcanic rocks that were erupted during the extensional tectonic regime that prevailed during deposition of the Argyll and Southern Highland groups (Fettes *et al*., 2011). It has been suggested that such meta-igneous rocks, which occur throughout the Crinan and Tayvallich subgroups in various parts of the Grampian Highlands, were high-level intrusions associated with the volcanic activity. However, those in the area of Craig Leuchan and Pannanich Hill intruded rocks that post-date the nearest metavolcanic rocks (the Meall Dubh Metabasite Formation and the Balnacraig Metabasite Member, close to the Easdale–Crinan subgroup boundary). Hence they were most likely to have been associated with the tuffaceous Green Beds that occur within the Southern Highland Group and crop out extensively in the Glen Clova area, some 15–20 km to the south (Smith *et al*., 2002).

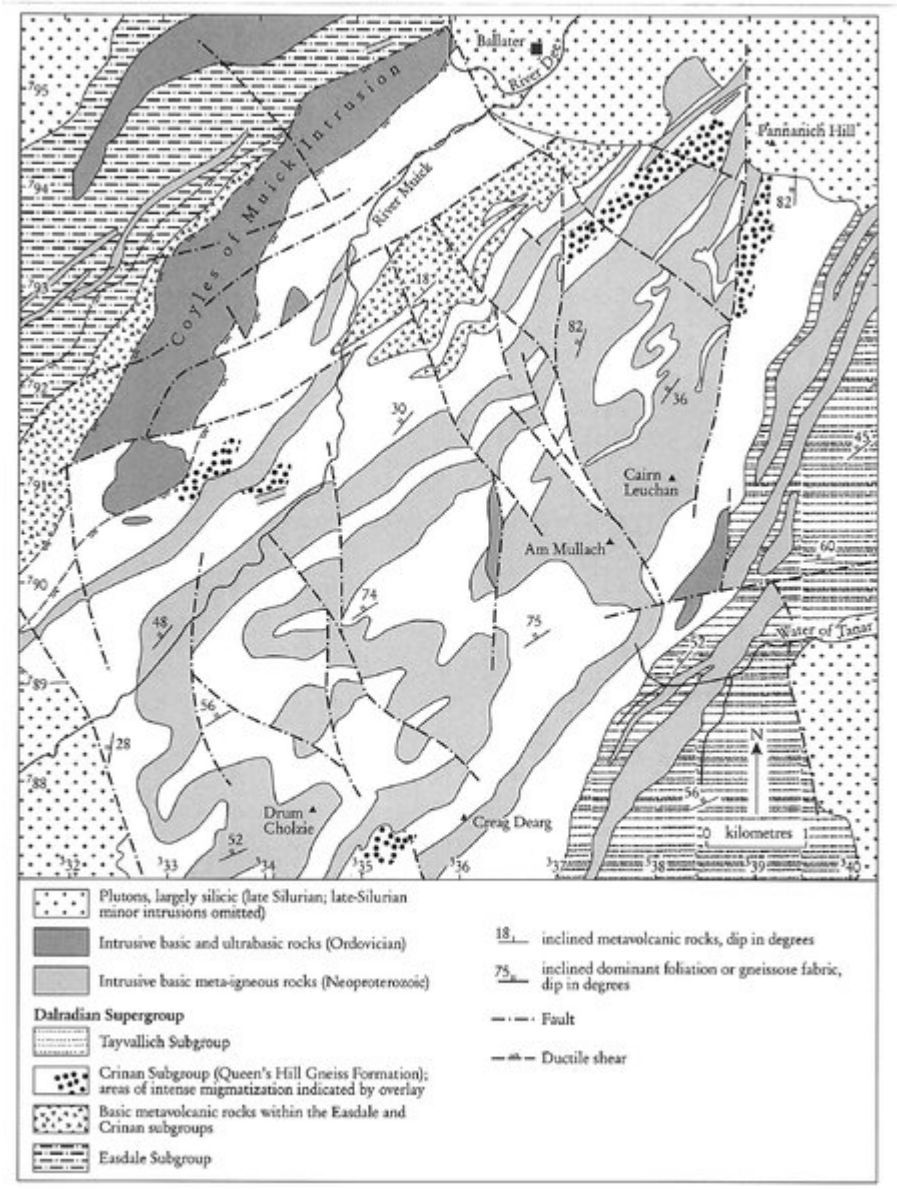
The coexisting mineral phases present in the rocks of the Cairn Leuchan to Pannanich Hill area are considered to represent equilibrium assemblages and, other than some minor patchy retrograde alteration, these are the products of peak metamorphic conditions. The assemblage garnet-clinopyroxene-hornblende in the basic meta-igneous rocks suggests conditions that approach granulite facies, although Smith *et al.* (2002) have suggested that the presence of diopside might reflect the protolith composition rather than metamorphic grade. But, using the garnet-clinopyroxene (Ganguly, 1979; Ellis and Green, 1979) and garnet-biotite (Ferry and Spear, 1978) Fe-Mg exchange thermometers, Baker and Droop (1983) calculated peak pressure in the area to have been close to 8 kbar at 820°C. Baker (1985) subsequently suggested that pressures might even have exceeded 9 kbar, and these are undoubtedly the most extreme metamorphic conditions so far recognized in the Grampian Terrane.

The mineral assemblages, including abundant sillimanite in the regional foliation, are intimately associated with F2 folds, and hence the peak of metamorphism and the early migmitization were syn-D2. Although there is some evidence in the area (e.g. near Creag Dearg, [NO 360 876]) that some of the sillimanite developed from kyanite, this is considered to be a continuous prograde regional event and there is no evidence of it being a separate later overprint as was suggested by Chinner (1961, 1966). In rocks of the nearby Pannanich Hill Complex, reaction rims between peak metamorphic assemblages preserved in inclusions of refractory material and the migmatized matrix indicate that the later migmatites developed some time after peak temperatures, almost certainly between D2 and D3 (Goodman, 1991). Formation of these later migmatites was aided by the presence of aqueous fluids, shearing and high heat flow, the latter attributed by Goodman to intrusions of the 470 Ma North-east Grampian Basic Suite that crop out nearby (e.g. the Coyles of Muick Intrusion). There are no estimates of the pressures and temperatures under which the later migmatization occurred, but the minerals present in the Pannanich Hill Complex inclusions, particularly andalusite and sillimanite, indicate that their re-equilibriation occurred at lower pressure than the regional maximum, though possibly still at high temperature, suggesting some post-D2 uplift.

5.4 Conclusions

Mineral assemblages in both metasedimentary and basic meta-igneous gneisses of Cairn Leuchan, Pannanich Hill and adjacent areas clearly demonstrate that the peak metamorphic conditions here were the most extreme so far recorded in the Scottish Dalradian, with pressures in excess of 8 kbar and temperatures approaching 820°C. The metasedimentary rocks, together with those of the nearby Pannanich Hill Complex, clearly show two generations of migmatites, the first coinciding with D2 deformation and peak metamorphism, the second occurring somewhat later, after some regional uplift and probably between the D2 and D3 events. The rocks also demonstrate that the growth of sillimanite was the climax of a single prograde metamorphic event and does not represent a later overprint as has been previously suggested. The metamorphic rocks of this GCR site therefore provide a wealth of information on the nature and timing of high-grade regional metamorphism in the Grampian Terrane.

References



(Figure 6.10) Map of the area around the Cairn Leuchan to Pannanich Hill GCR site, adapted from the BGS 1:50 000 Sheet 65E (Ballater, 1995). The Coyles of Muick Intrusion is bounded on both sides by ductile shears that define the Coyles of Muick Shear-zone. The shear-zone also marks the position of the regional andalusite–kyanite isograd; to the north-west metasedimentary rocks contain andalusite ± staurolite (a Buchan-type assemblage), whereas to the south-east they contain the assemblage sillimanite ± kyanite ± staurolite, characteristic of Barrovian metamorphism.