9 Glen Esk

[NO 586 733]–[NO 583 736], [NO 579 744], [NO 583 756], [NO 574 766], [NO 560 785]

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9.1 Introduction

The valley of the River North Esk in the Angus Glens is in the heart of the area where George Barrow first demonstrated the development of successive mineral assemblages during the progressive regional metamorphism of pelitic rocks (Barrow, 1893, 1912). Here, the transition from low to high metamorphic grade can be studied over a distance of a few kilometres and the GCR site comprises six localities, one for each metamorphic zone, selected largely on grounds of ease of access (Figure 4.30). These localities, together with alternatives for some of the zones, were described by Harte (1987).

While working for the Geological Survey in this area, Barrow was the first person to define a scheme of indicator minerals for different degrees of regional metamorphism in pelitic rocks. He initially defined seven zones: the lowest grades were 'clastic mica' and then 'digested clastic mica', and up grade of these were zones defined by the progressive incoming of biotite, garnet, staurolite, kyanite and sillimanite. Tilley (1925) combined the two lowest grades into a single chlorite zone, since the distinction between clastic and non-clastic white micas was doubtful. Hence we now recognize six zones ranging from chlorite to sillimanite (Figure 4.31). This scheme, known as the Barrovian scheme, was found to apply to large areas of the Dalradian outcrop, and has been recognized in many other regional metamorphic terranes worldwide. In terms of overall metamorphic facies, it corresponds to a relatively high-pressure part of the greenschist and amphibolite facies.

However, in the area north of the River Dee and east of the Portsoy Shear-zone, a different sequence of metamorphic zones is developed. This, the Buchan scheme of Read (1955), corresponds to lower pressures over the same range of temperatures (see Stephenson et al., 2013b). A transitional zonal sequence between the two regimes is exposed on the coast north of Stonehaven (Harte and Hudson, 1979) (see the *Garron Point to Muchalls* GCR site report).

Barrow's original zonal scheme has stood the test of time, although Chinner (1966) regarded the development of fibrolitic sillimanite as a later thermal 'overprint' upon both the Barrovian and the Buchan zones. However, Harte and Johnson (1969) used thin sections to date the development of the metamorphic fabric of the rocks with respect to the various fold episodes in the district. They showed that prograde metamorphism continued longer in the higher grade rocks than in the lower grade rocks, and that the post-D3 crystallization of sillimanite, although overstepping the lower grade zones in places, was the culmination of a single long period of prograde metamorphism. Retrogression was associated with D4 and later movements.

Also in this area, Atherton and Brotherton (1972) showed that the first appearance of kyanite in regionally metamorphosed pelites and semipelites is controlled by the effective Mg/Fe^{2+} ratio of the rock. Harte and Hudson (1979) used petrological and geochemical methods to attempt to quantify pressures and temperatures at various stages in the metamorphic history of the eastern Grampian Highlands.

Field excursions that visit this GCR site have been described by Harte (1987) and MacGregor (1996).

9.2 Description

The first three localities are along the banks of the River North Esk; the others are on crags away from the river (Figure 4.30).

9.2.1 Locality 1, Chlorite Zone: North Esk Gorge [NO 586 733]

The North Esk Fault at this locality separates Dalradian rocks to the north-west from Highland Border Complex rocks to the south-east. The Dalradian rocks consist of compositionally layered, grey-green schistose chlorite-muscovite pelites, semipelites and psammites. Porphyroblasts of magnetite and rare pyrite up to 2 mm across are widely visible. A spaced cleavage developed during D1 is overprinted by an S4 crenulation cleavage, which is only visible in the more-micaceous lithologies.

9.2.2 Locality 2, Biotite Zone: North Esk Gorge [NO 583 736]

This locality is only *c*. 200 m upstream of locality 1. The lithologies are similar to those at locality 1, but also include beds of gritty psammite up to 1 m thick. The rocks look very similar to the chlorite-zone rocks, but a few flakes of brown biotite are visible in some layers. In thin section, the rocks are well-foliated semipelites and pelites with a good fabric formed by the alignment of muscovite and chlorite parallel to an S1 foliation. This fabric has been crenulated during D4. Post-dating the S1 fabric but pre-dating the S4 crenulations, are scattered, randomly orientated biotite porphyroblasts up to 1 mm long by 0.5 mm wide, which are visible on freshly broken surfaces of the more-pelitic rocks.

9.2.3 Locality 3, Garnet Zone: Auchmull [NO 579 744]

One of the few accessible exposures of garnet-zone rocks is *c*. 800 m upstream of locality 2, on the west bank of the River North Esk, near the end of the largely continuous exposures through the chlorite and biotite zones. Here, the rocks are grey-green schistose semipelites and pelites, similar to those at localities 1 and 2, but slightly coarser in grain size. The S1 foliation can be seen to be disrupted locally by a widely-spaced S2 cleavage, which gradually becomes more persistent northwards. The F4 folds are less numerous than at locations 1 and 2, and the S4 crenulation cleavage is only weakly developed. The locally abundant garnet porphyroblasts, up to 5 mm in diameter, are best seen on the south-east side of low exposures that protrude into the river. Elsewhere, where the rocks are more psammitic, garnet is hard to find. The garnets are seen in thin section to be poikilitic, with inclusions generally smaller than the grain size of the matrix. The folds in the inclusion trails show that the garnets grew post D2 andpre D4. Biotite porphyroblasts up to 3 mm across also occur.

9.2.4 Locality 4, Staurolite Zone: Craig of Weston [NO 583 756]

This is the upper of the two localities described by Harte (1987), in an area where there is much loose rock but little material definitely *in situ*. Staurolite is developed in the more-pelitic layers lying within a dominantly psammitic to semipelitic succession. Here, the dominant fabric in the pelitic rocks is a penetrative schistosity, which is related to the well-developed S2 spaced cleavage in the semipelites and psammites. Relics of S1 are preserved in the microlithons between the S2 cleavages. The S2 cleavage is in places folded by tight minor folds ascribed to D3, but the broad open F4 folds, characteristic of lower Glen Esk, are absent.

The pelites are considerably coarser grained than those at localities 1 to 3. A fabric defined by 2–3 mm-long muscovite and biotite crystals dominates the rock. Randomly orientated porphyroblasts of garnet and staurolite reach 5 mm in size. Some of the rocks contain anhedral porphyroblasts of poorly twinned plagioclase. Much of the coarsening of the fabric of the rocks and the prophyroblast growth probably occurred during D3.

9.2.5 Locality 5, Kyanite Zone: Craigoshina [NO 574 766]

At this locality, the rocks have the same coarse mica fabric as at locality 4, and the dominant fabric is S2, which is folded by minor F3 folds. In the Glen Esk–Glen Lethnot area in general, kyanite is best developed in silvery muscovite-rich pelites, many of which also contain abundant haematite porphyroblasts. These pelites form units up to 100 m thick, extending for up to 2 km along strike, and represent a distinctive lithology with a higher Fe^{3+}/Fe^{2+} ratio than the surrounding rocks. Because of the oxidized nature of the rocks, kyanite is abundant at this locality despite the rocks being below the regional kyanite isograd for less-oxidized rocks (Chinner, 1960; Harte, 1966; Atherton and Brotherton, 1972). The fabric of the rocks is dominated by abundant well-aligned muscovite flakes with relatively little biotite. Porphyroblasts of garnet and staurolite reach 5 mm in size, and kyanite crystals are typically up to 3 cm in length. The kyanite porphyroblasts contain abundant inclusions of fine-grained haematite, and many of them have retrogressed to fine-grained aggregates of white mica. Better crystallized, and more typically blue kyanite is present in some of the numerous quartz veins. Garnet occurs in the haematite-kyanite schists but is fine grained and hence difficult to see (Chinner, 1960).

9.2.6 Locality 6, Sillimanite Zone: Hillock [NO 560 785]

At this locality schistose semipelites and pelites form rough craggy knolls. The rough surface of the more-pelitic rocks displays welts and knots up to several centimetres long, consisting of tiny fibres of sillimanite, usually intimately associated with quartz. Larger upstanding 'blobs' of fibrous sillimanite, 1–2 cm across, on weathered surfaces, can be found surrounding garnets. In this area, the main foliation of the rocks is still the composite S0-S1-S2, but in the cores of the tightest of the abundant flat-lying F3 folds, the axial planar S3cleavage merges with the earlier composite foliation. Minor folds showing crenulation of the mica fabric are attributed to D4. Between the kyanite-zone exposure and this exposure, the more-feldspathic semipelites and impure psammites show incipient segregations of quartzofeldspathic laminae, typically with biotitic selvedges, indicating the commencement of migmatization in susceptible lithologies.

9.3 Interpretation

The sequence of six typical exposures illustrates the effects of progressive regional metamorphism of pelitic rocks at medium to high pressures. The first five of these exposures occur within the Glen Lethnot Grit Formation, a 1500 m-thick succession of gritty, turbiditic psammites, with interbeds of semipelite and pelite, typically forming graded units 0.5–2.5 m thick (Harte, 1979; Gould, 2001*)*. The sillimanite-zone exposure lies within the older, Glen Effock Schist Formation, which contains more semipelite and less psammite than the Glen Lethnot Formation.

The Barrovian index minerals are typically confined to the pelitic lithologies, although chlorite and biotite also occur in semipelites and impure psammites. Kyanite is best developed in an atypical, highly oxidized type of pelite characterized by silvery mica felts and numerous small haematite porphyroblasts. One of these pelites has been chosen for inclusion in the GCR site.

The local peak of metamorphism occurred progressively later in the higher metamorphic grades (Harte and Johnson, 1969; Robertson, 1994); it was syn to post D2in the chlorite and biotite zones, post D2 but pre D3 in the garnet zone, and syn D3 in the staurolite, kyanite and sillimanite zones. The migmatization in the highest-grade rocks overlapped D3 in nearby Glen Clova (Robertson, 1991). Retrogressive effects, with alteration of biotite to chlorite and of staurolite and kyanite to sericitic felts, are associated with areas of intense D4 crenulation, and with the post-D4 folds associated with emplacement of the Mount Battock Pluton. Dempster (1985a) has used Rb-Sr and K-Ar dating to plot pressure-temperature paths and to work out the cooling and uplift history of the area. He concluded that the main metamorphism occurred at 520–490 Ma, with peak temperatures occurring progressively later at greater burial depths. After local uplift at 520–490 Ma, two major periods of uplift occurred at 460–440 Ma, associated with D4, and 410–390 Ma, associated with intrusion of the Mount Battock Pluton. Dempster (1985b) also estimated that peak metamorphism in the kyanite and sillimanite zones in nearby Glen Lethnot occurred at a temperature of 630–660 °C and a pressure of 5.7–6.2 kbar.

The temperature and pressure gradients estimated from the compositions of pairs of co-existing minerals is steeper than would be calculated from the exposed outcrop width of the zones in Glen Esk. This probably implies a considerable degree of tectonic thinning within the Glen Lethnot Grit Formation. A clue to the timing of the thinning occurs in areas a short distance to the east, where Phillips and Auton (1997) described blastomylonites within Glen Lethnot Formation rocks south of the Mount Battock Pluton. From their mineral textures, they deduced that most of the mylonitization and accompanying attentuation of the metamorphic zones occurred during D2.

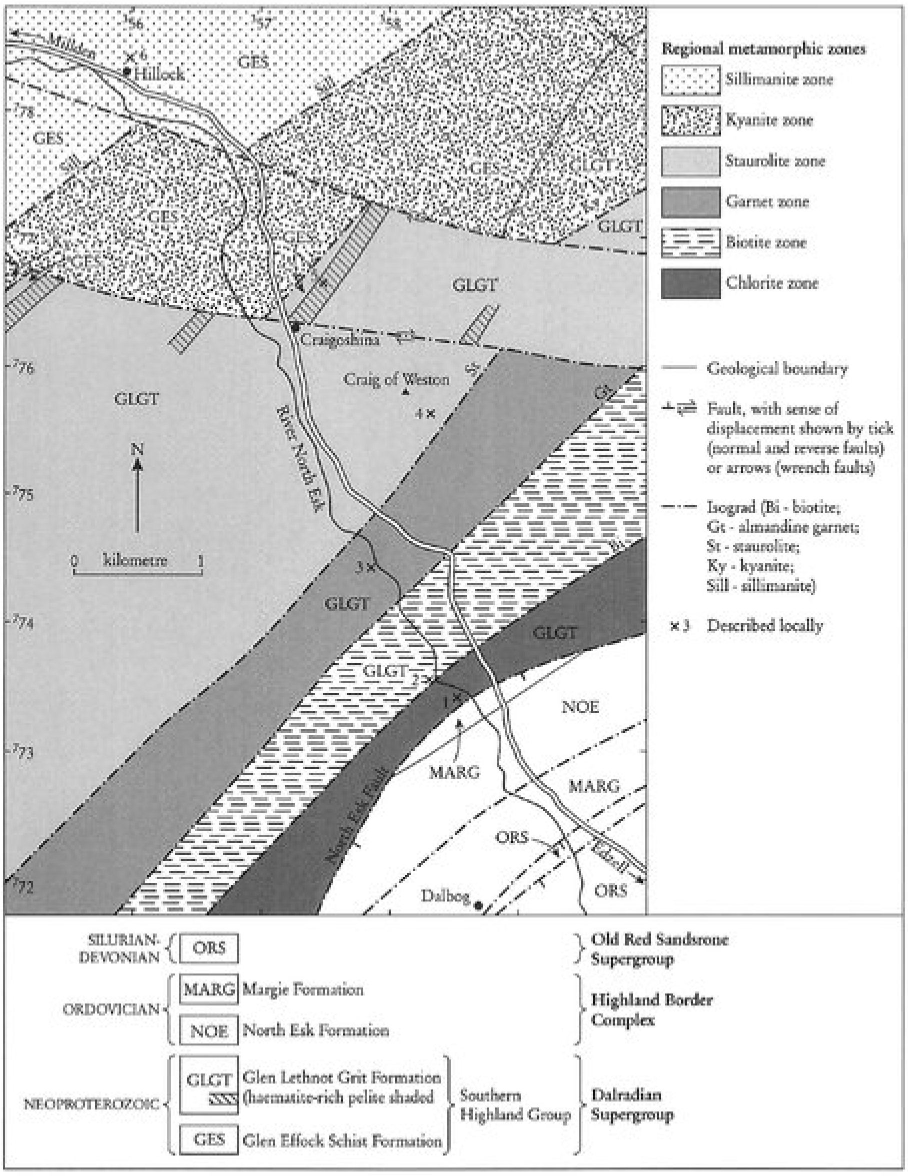
9.4 Conclusions

The Glen Esk GCR site is within the internationally recognized type area for the Barrovian type of regional metamorphism. It was here in 1893 that George Barrow first erected a scheme of metamorphic zones based upon the first appearance of various index minerals with increasing metamorphic grade in pelitic rocks. These zones are typical of regional metamorphism at moderate to high pressures within the greenschist and amphibolite facies and have subsequently been recognized throughout the world. The GCR site provides, within a short distance, examples of Dalradian pelitic rocks from all of the Barrovian metamorphic zones, which are characterized, with increasing grade, by chlorite, biotite, garnet, staurolite, kyanite and sillimanite.

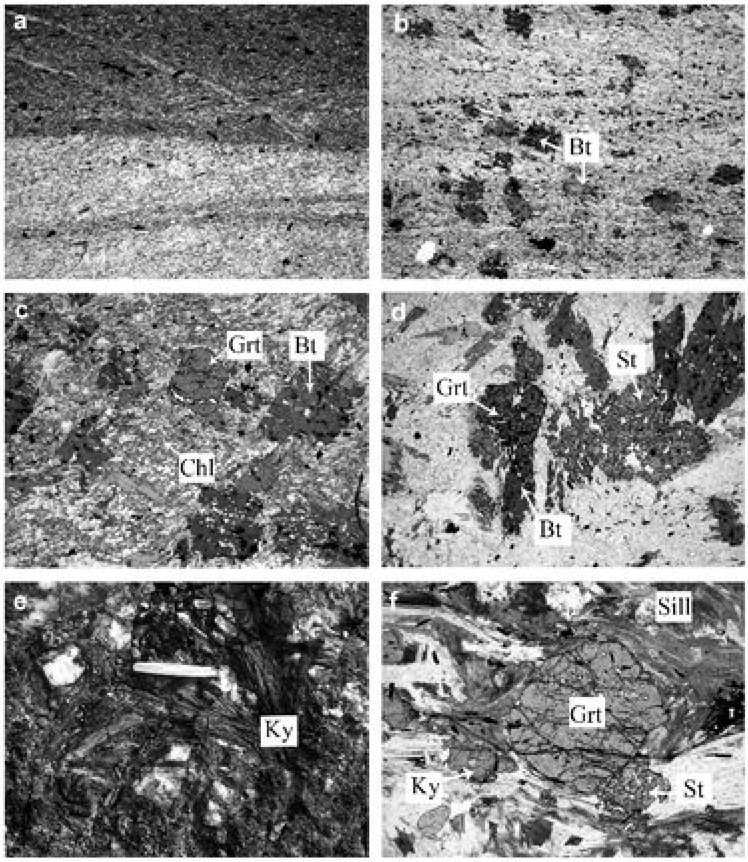
The exposures are all readily accessible and are invaluable for teaching purposes. Only the garnet-zone exposure is of less than excellent quality, and even it is acceptable. The index minerals can mostly be seen with the naked eye, and all are conspicuous under a hand lens. The exposures can also be used to demonstrate the development of folds and cleavages during successive deformation and progressive coarsening of texture within rocks of increasing metamorphic grade.

Thin sections from these rocks have enabled the timing of growth of the various minerals to be worked out with respect to the four regional deformations that affected Dalradian rocks of the eastern Grampian Highlands. Further work could involve electron-microprobe analysis of co-existing mineral phases to work out the temperature and pressure during deformation in different parts of the site. However, such studies would be partly hampered by the effects of retrogression that are particularly associated with the D4 deformation.

References



(Figure 4.30) Map of lower Glen Esk showing the full range of regional metamorphic zones first erected by Barrow (1893, 1912). Redrawn from Harte (1987), with modifications based on BGS 1:50 000 Sheet 66W (Aboyne, 1995).



(Figure 4.31) Photomicrographs (a–d, f) and one field photo (e) illustrating the sequence of Barrow's Zones, as represented in the Glen Esk GCR site. Rocks photographed come from the localities described in the text, except for the sillimanite zone (f), which is from a locality by Glen Effock (described by Harte, 1987). All photomicrographs are at the same scale with a width equivalent to approximately 4.5 mm. (Photos: B. Harte.) (a) Chlorite Zone. Principal minerals are quartz, white mica, chlorite and opaques (iron oxide and sulphide). The bedding and main cleavage are approximately parallel to the top edge of photo, and the upper (darker) half of the photo represents a chlorite-rich layer, whilst the lower part is more quartz rich. A later cleavage is visible as pale (white mica-rich) seams cutting obliquely across the chlorite-rich layer. (b) Biotite Zone. Biotite porphyroblasts (Bt) overgrow a finer grained matrix of quartz, white mica, chlorite and opaque iron minerals. The bedding and main cleavage are roughly parallel to the top edge of the photo. (c) Garnet Zone. Biotite (Bt) and garnet (Grt) porphyroblasts in a finer grained matrix of quartz, white mica, chlorite and opaque iron minerals. Areas in the matrix richer in chlorite (Chl) have a darker appearance. (d) Staurolite Zone. Porphyroblasts of garnet (Grt and highest relief), staurolite(St and high relief) and biotite (Bt and moderate relief) in a matrix of quartz and muscovite with a small amount of opaque iron minerals. (e) Kyanite Zone. Field photo of a vein dominantly of quartz and kyanite; the label is in the centre of a rosette of kyanites. Penknife is 10 cm long. (f) Sillimanite Zone. A large (2 mm) porphyroblast of garnet (Grt) in the centre, together with smaller porphyroblasts of kyanite (Ky) and staurolite (St). The 'Sill' label is on a cluster of sillimanite fibres (fibrolite). Darker areas to the left and right of the garnet are of biotite intergrown with fibrolite. Pale areas are dominated by muscovite and quartz.