15 Cairnbulg to St Combs

[NK 031 654]–[NK 062 626]

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15.1 Introduction

The coastal foreshore between Cairnbulg and St Combs, at the north-eastern tip of the Grampian Highlands, provides an across-strike section through migmatitic semipelites, pelites and psammites of the Inzie Head Gneiss Formation (Crinan Subgroup) that are intruded by numerous sheets, veins and irregular lenses of diorite and granite. The metasedimentary rocks show evidence of amphibolite- to granulite-facies metamorphism and anatectic melting. They have been variously interpreted as gneissose basement forming the core of the Banff Nappe (Read and Farquhar, 1956), allochthonous Neoproterozoic basement gneisses (Ramsay and Sturt, 1979), and migmatitic Argyll Group semipelites that have been subject to partial melting (Kneller, 1987; Johnson *et al*., 2001a, 2001b). These different designations have important consequences for models of the structural and metamorphic history of the North-east Grampian Highlands.

The gneisses lie in the core of the Buchan Anticline and their outcrop extends south-west in a broad swathe to Mintlaw. Their distribution, and western and eastern transition through the more-calcareous Strichen and Kinnairds Head formations (Tayvallich Subgroup) and into the overlying Southern Highland Group turbiditic succession, suggests that they are Argyll Group rocks that belong to the Crinan Subgroup. Thus, they are considered to be laterally equivalent to the Cowhythe Psammite Formation, the Ellon Formation, the Aberdeen Formation, the Queen's Hill Formation and the Ben Lui Schist Formation (including the Duchray Hill Gneiss Member). All of these lithological units generally show amphibolite-facies metamorphic assemblages, ranging from garnet to sillimanite grade, but in parts the mineral assemblages imply that conditions reached granulite facies. In the Cairnbulg–St Combs section, peak metamorphic temperatures of over 775° C and pressures of 3–4.5 kbar have been inferred (Johnson *et al*., 2001a). Many of the rocks have experienced significant retrogression, resulting in extensive chlorite and sericite replacement of the high-grade mineralogies.

The area was first mapped as part of the primary geological survey of one-inch Sheet 97 and a brief account of the gneissose and intrusive rocks was given in the sheet memoir (Grant Wilson, 1882). Somewhat later, H.H. Read and O.C. Farquhar visited the coastal sections, as the Inzie Head gneisses were integral to their model of the Banff Nappe (see Read, 1955; Read and Farquhar, 1956). Sturt *et al.* (1977) obtained a Rb-Sr isochron from gneisses at Cairnbulg Point that gave an age of *c.* 691 Ma, which was accepted by Ramsay and Sturt (1979) as dating the migmatization. They modified Read's hypothesis of the Banff Nappe and described a complex and lengthy history for the gneisses, which they considered to be allochthonous basement. Subsequently, Kneller (1987) described the Cairnbulg–Inverallochy coast section and noted that migmatization post-dated most of the deformation. He also mentioned the presence of a gravity and magnetic anomaly beneath the area implying the presence of a basic intrusion at shallow depth. Later petrographical and geochemical work by Johnson (1999) has documented the high-grade metamorphic assemblages, migmatitic textures and detailed migmatite–granitic melt relationships together with a link to mafic rocks of the North-east Grampian Basic Suite (Johnson *et al*., 2001a, 2001b, 2003).

15.2 Description

The Cairnbulg–St Combs coastal section (Figure 6.35) is some 4.7 km long and encompasses rocky foreshore, smooth glacially scoured rock platforms, and sandy bays, all within the intertidal zone. Blown sand backs much of the coast and there is no bedrock exposure immediately inland.

The compositional banding and accompanying foliation in the Inzie Head Gneiss Formation dip at between 40° and vertical towards the north-west and west. The foliation is composite but basically reflects the D2/3 deformation that accompanied the main period of migmatization and partial melting. The section appears to lie on the north-west limb of the open Buchan Anticline but it is not possible to determine the detailed structural profile owing to the degree of migmatization, partial melting, and number of intrusive sheets present. In places early tight folds (F1) with axial planes subparallel to the bedding are cross-cut by migmatitic segregations and leucogranite veins (Johnson *et al*., 2001b).

The metasedimentary rocks consist of thin- to medium-bedded, semipelite, micaceous psammite and feldspathic psammite with pelite interbeds and subsidiary calcsilicate pods and lenses. Where migmatized, the calcsilicate pods have remained relatively refractory and obviously behaved in a more brittle manner. In places a 'ghost' bedding can be reconstructed from their incidence. In the more-feldspathic psammites a spaced cleavage resembling that seen in Southern Highland Group psammites of the Collieston–Whinnyfold and Rosehearty areas is present. The psammite has been recrystallized and the defining mineralogy is now high grade, but the relict nature is still apparent. In places, pelitic rocks show prominent cordierite and more-rarely andalusite porphyroblasts. Sillimanite is common throughout the section.

Kneller (1987) was the first to mention the different types of migmatite that can be seen in the section but Johnson (1999) has mapped and studied their distribution and origin in detail. The migmatites show variable development of segregation and partial melting giving rise to abundant quartzofeldspathic material, termed leucosome, which in most places resembles a pale-grey medium-grained leucocratic granite. The material remaining after loss of melt is termed melanosome and is richer in biotite and plagioclase feldspar. Johnson *et al.* (2003) described the leucosome in thin section as consisting of quartz, variably zoned plagioclase, cordierite, biotite and potash feldspar with apatite, zircon and opaque phases, mainly ilmenite as accessory minerals. Garnet, orthopyroxene, tourmaline, muscovite and andalusite can occur as additional phases. Potash feldspar is commonly altered to myrmekitic blebs where it is in contact with plagioclase, and larger muscovite and quartz symplectites, common in some leucosomes, are interpreted as pseudomorphs after potash feldspar. Many of the minerals are altered and pseudomorphed in these rocks, with cordierite invariably altered to shimmer aggregate of chlorite and white mica (rarely pinite) and no pristine orthopyroxene preserved. The amount of leucosome present increases from north-west to south-east with a concomitant decrease in the size and abundance of the relict metasedimentary rocks (termed schollen).

Johnson *et al.* (2001b) distinguished three main migmatite zones based on the mineralogy of the leucosomes; Leucosome-cordierite (L-crd), Leucosome-garnet (L-gt) and Leucosome-orthopyroxene (L-opx). The indicator minerals, cordierite, garnet and orthopyroxene, which formed at the time of melting of the metasedimentary host rock, were in equilibrium with the melt and are termed peritectic phases. (Figure 6.36) shows the distribution of the various migmatite types and diorite and major granite sheets across the section.

The limit of melting, marked by initial generation of leucosome, is now concealed beneath Fraserburgh Bay. However, exposures at West Haven and Cable Shore, south-west of Cairnbulg Point show sections with less than 10% leucosome in the effectively unmodified metasedimentary mesosome, the resulting migmatite being termed a metatexite. The leucosome occurs as small blebs or discontinuous streaky (stromatic) layers parallel to the bedding and foliation as well as in dilatant zones such as shear-zones or boudin-necks. In other instances the leucosome layers converge laterally or are connected vertically by small extensional shears to give a veined network, termed a diktyonitic structure (Johnson *et al*., 2001b). Thicker sheets and veins of white to pale-grey leucogranite up to a few metres across containing metasedimentary schollen and ragged and diffuse schlieren are also present, notable on Cable Shore west of Cairnbulg Harbour (Figure 6.37). Generally, the sheets trend near-parallel to the foliation but some do show local discordance. Typically, they have a consistent grain size (1–2 mm) and show diffuse margins with the adjacent mesosome, commonly dark coloured and leucosome deficient. The nearby 300 m-thick Cairnbulg 'granite' body shows a much higher degree of leucosome development and is best described as a diatexite; only the more-refractory elements of the original parent metasedimentary material remain, forming abundant dispersed 'ghost' schollen and resulting in a nebulitic texture.

Immediately south-east of the Cairnbulg 'granite' is a *c.* 125 m-wide zone of veined (diktyonitic) metatexites with an enhanced foliation, in turn bounded to the south-east by a *c.* 25 m-thick diorite sheet. Psammite with relict spaced cleavage forms enclaves in the migmatitic semipelite section beyond. The enclaves attain some tens of metres thick, e.g.

by Gowan Hole [NK 0448 6512] at the east end of Inverallochy.

The boundary of the L-crd and L-gt zones is crossed between Gowan Hole and the Point of Whitelinks at around Broad Hive. It is marked by the incoming of dark purplish red almandine garnets up to 5 cm across in the white to pale-grey leucosomes; the garnets are commonly retrograded wholly or in part to biotite, chlorite and shimmer aggregate. Good examples are seen on the clean, striated rock platform between Boat Hive and the Point of Whitelinks (Figure 6.38). Leucosome abundance reflects the original compositional banding in the semipelitic rocks and is commonly focussed around the calcsilicate-rock schollen and smaller pelitic inclusions. Mafic selvidges occur at the margins of some of the plagioclase-rich L-gt sheets and veins and they contain mafic schlieren (mainly biotite) and 'ghost' schollen that are manifested as rounded concentrations of now-relict cordierite. In places flame-like L-gt sheets are mingled with L-crd.

On the peninsula between Whitelinks Bay and Millburn Shore (by The Gwights), diatexites with schollen are cut by a thin diorite sheet. To the south-east, at the northern end of Millburn Shore, leucosome of both granitic and granodioritic composition is dominant with abundant dispersed biotite schlieren and schollen of calcsilicate rock and psammite. Rare pelitic and semipelitic 'ghost' enclaves are also present. Sinuous contacts can be recognized between the compositionally different phases of leucosome, but individual garnet porphyroblasts lie across such boundaries showing that the different leucosome melts were coeval. This zone must lie only a short distance above the north-western boundary of the St Combs diorite, which is concealed beneath the sands of Millburn Shore.

The section at St Combs is dominated by two thick diorite sheets, some 100–200 m thick (Figure 6.35). Sandwiched between them is a large metasedimentary raft consisting of coarse-grained garnet and/or orthopyroxene, cordierite, biotite, quartz and feldspars and containing irregular intergranular leucosome. Johnson *et al.* (2001b) termed this unit a granoblastic restite. Larger accumulations of leucosome form irregular pods and lenses that in places form centimetre-scale stromatic layers parallel to the regional foliation. Thicker discordant leucosome veins also occur, which Johnson *et al.* (2001b) interpreted as channelways. Underlying the diorite, to the south-east of Bailiff's Skelly, are melanosome-rich migmatites (leucosome less than 10%) with a strong foliation and abundant pseudomorphs after orthopyroxene. These dark-green porphyroblasts are up to 3 cm long and are now composed of green biotite and shimmer aggregate, but still retain their prismatic form and perpendicular cleavages. Cordierite is also present and biotite is variably abundant. Leucosome pods here are discontinuous and locally form a fine millimetre-scale stromatic layering. Only relics of the metasedimentary bedding are preserved, notably where psammite beds are present. Leucosome becomes more abundant towards Inzie Head as the migmatites grade from metatexites up to diatexites with a moderate foliation defined by aligned mafic schlieren and semipelitic schollen. Orthopyroxene occurs in the thicker leucosome veins but the thinner ones typically contain cordierite.

Microdiorite and diorite sheets, ranging from some 10 cm up to 300 m wide, are common throughout the migmatitic sequence and lie subparallel to the regional banding/foliation. They show evidence of only minor deformation and commonly cross-cut the metasedimentary banding and early structures. The diorites consist of essential hornblende, plagioclase and quartz with ilmenite and titanite present. Johnson *et al.* (2001a) noted that they are similar to uralitized gabbros near Ellon with no trace of clinopyroxene now remaining. Good examples of the relationships between diorite, granite, leucosome and mesosome are seen on Cable Shore, some 200 m south-west of Cairnbulg pier (Figure 6.35). Back-veining of the granitic leucosome material into the diorite is common and granite-diorite contacts range from sharp to gradational. Leucosome/granite veins penetrate the diorite, commonly forming wispy tongues that invade lobate pillows of diorite. Leucosome is developed preferentially marginal to the diorite sheets, particularly adjacent to their upper margins. In contrast, beneath the diorite sheets the foliation in the migmatitic rocks is intensified and the amounts of leucosome are generally low. The diorite commonly shows evidence of multiple intrusion, with the darker, more-mafic parts of the diorite sheet cross-cutting the earlier paler grey hybridized parts. Within the Cairnbulg 'granite', sheets of diorite show evidence of magma mingling with the leucogranite, which in places is finely porphyritic.

15.3 Interpretation

At various times the gneisses of the Cairnbulg–St Combs section have been ascribed to an earlier succession of basement rocks. Read (1955) interpreted them as part of an older Dalradian succession, the 'Keith division', overlain unconformably by younger Dalradian rocks of the 'Banff division' in the Banff Nappe. However, Read and Farquhar (1956) inferred that the migmatization post-dated the metamorphism and that both were superimposed on the Banff Nappe. Sturt *et al.* (1977) obtained an Rb-Sr whole-rock isochron from gneisses at Cairnbulg Point that gave an age of 691 ± 39 Ma (674 Ma with currently accepted decay constants). They interpreted this age to date the formation of the migmatitic gneisses and the linked diorite and granite bodies. Ramsay and Sturt (1979) subsequently described a complex multistage tectonic, metamorphic and intrusive history based on detailed field relationships in the gneisses. Accepting the Rb-Sr isochron age, they viewed the lower gneissose rocks as Cadomian basement rocks transported to the North-east Grampian Highlands from elsewhere and inferred that the mid-Ordovician Grampian Event was responsible only for the later deformations. However, Rb-Sr isochron ages are dependent on the Rb- and Sr-bearing minerals in the sample being in isotopic equilibrium and having not been disturbed by subsequent igneous or metamorphic processes or subjected to loss of Sr. The Inzie Head gneisses fail most of these tests and the ages are now regarded as spurious. A clear structural and stratigraphical pattern has now emerged in which all of the dominantly semipelitic gneissose rocks in the North-east Grampian Highlands can be allocated to the Crinan Subgroup in the upper part of the Argyll Group (Kneller, 1987; Stephenson and Gould, 1995; Strachan *et al*., 2002).

The Inzie Head gneisses lie on the western flank of an antiformal structure that was originally recognized by Grant Wilson (1886) and termed the Ellon Anticline. Read (1923, 1955) renamed this structure the Buchan Anticline and envisaged it as an integral part of the Banff Nappe, reflecting the presence of the migmatitic geissose core of the nappe beneath a resistant 'cap' formed by the Mormond Hill Quartzite. However, as the anticline patently folds both the foliation in the migmatitic rocks and the metamorphic isograds, it is most probably a late-stage Caledonian structure, complementary to the Turriff Syncline to the west (Stephenson and Gould, 1995). Its precise age of formation is not known, but it post-dates the early Ordovician and pre-dates the deposition of the Early Devonian Crovie Group of the Turriff Outlier.

The migmatitic nature of the Inzie Head Gneiss Formation has long been recognized and these rocks represent the acme of the classic high-temperature–low-pressure assemblage characteristic of the Buchan-type metamorphism (see Chinner, 1966; Harte and Hudson, 1979). Further work between 1980 and the present has shown that the high-temperature metamorphism in these rocks was supplemented by heat and an initial fluid input due to the intrusion of a significantly large body of basic magma at shallow depth.

Johnson *et al.* (2001a, 2001b, 2003) documented the petrography and whole-rock geochemistry of the semipelitic rocks together with the leucosomes and leucogranite sheets from the Inzie Head Gneiss Formation. They concluded that the granitic bodies were formed effectively *in situ* by melting of the semipelitic host, initially at *c.* 2.9 kbar and *c.* 650°C with abundant fluid present ($a\text{H}_2\text{0}$ =1). Fluid input was ascribed to dehydration of the metasedimentary rocks resulting from the emplacement of a basic magma accompanied by the formation of shear-zones. The mineral assemblages and nature of the peritectic phases suggest that P–T conditions increased south-eastwards to *c.* 4.5 kbar and *c.* 775°C such that melting occurred in the absence of a volatile fluid phase. When the normative compositions of the granites are plotted on a quartz–albite–orthoclase diagram they cluster around the minimum-melt compositions at pressure and temperature conditions of *c.* 3 kbar and over 750°C, with low $a\text{H}_2\text{0}$ (*c.* 0.3) as implied by the mineralogies. The melting reactions largely consume biotite (in addition to quartz and feldspar) in these circumstances.

The nature of the protolith semipelitic and pelitic rocks prior to migmatization and partial melting is not fully known but the mineralogies and geochemistry strongly suggest that they were magnesium-rich aluminous pelitic and semipelitic rocks. Following the method of Inger and Harris (1993) Rb vs Sr plots of the pelites, migmatites, leucosomes and leucogranites imply that potash feldspar differentiation (assuming *c.* 10% crystallization) has controlled melt composition during its ascent to higher crustal levels. The steeper Rb vs Sr trends for the related garnetiferous aplitic veins that are found in the Fraserburgh area suggest that plagioclase feldspar differentiation has controlled melt evolution at a late stage (Johnson *et al*., 2003).

Johnson *et al.* (2001b; 2003) suggested that the anatectic melting gave rise initially to melt generation in small patches and vein networks from which the melt then passed upwards into channel ways. The movement of melt material was accompanied by some potash differentiation to give rise to the leucogranites. The rocks seen in the Cairnbulg–St Combs section provide a 'snapshot' of this overall process. Johnson *et al.* (2003) argued that much of the leucosome is still *in situ* but their geochemistry also suggests that a variable proportion has moved out of the rocks. Melt has moved to higher levels and some granitic material has certainly moved up from structurally lower levels. The amount of melt produced in the L-crd zone is only possible in the presence of considerable quantities of fluid and Johnson *et al.* (2001a) argued that fluid supply was enhanced by the formation of numerous shear-zones. Quantities of melt seen in the L-gt and L-opx zones are considerably less and are compatible with dry melting reactions.

The proportion of leucosome is greater directly above and below the diorite intrusions, and the metasedimentary rocks beneath show higher concentrations of more-mafic material suggesting that melt has been generated there and migrated upwards. The presence of a gravity and magnetic anomaly suggests that the diorite intrusions are probably related to a mafic–ultramafic intrusion that underlies the area at a very shallow depth and is a member of the mid-Ordovician North-east Grampian Basic Suite (Johnson *et al*., 2001b). (Figure 6.36) shows the overall pattern envisaged by Johnson *et al.* (2001b), whereby they postulated that this process could ultimately have been responsible for the generation of the mid-Ordovician granite plutons such as Strichen and Aberdeen. They hypothesized that at the time of emplacement of the North-east Grampian Basic Suite an overlying subhorizontal zone of migmatitic melts would have been generated and that (D2) strain would have been partitioned into such zones giving rise to a network of ductile shear-zones. Field relationships and age dates from the Portsoy and Huntly areas do indeed imply that major shearing, emplacement of the mafic and ultramafic plutons, and formation of migmatitic rocks all occurred in a short episode at around 470 Ma (Strachan *et al*., 2002; Carty, 2001; Oliver, 2002). The older foliated muscovite-biotite granite plutons were also intruded at about this time.

15.4 Conclusions

The Cairnbulg to St Combs coastal section displays a spectacular range of migmatites that developed in Dalradian metasedimentary host rocks during mid-Ordovician (Grampian Event) low-pressure–high-temperature metamorphism. The rocks belong to the Inzie Head Gneiss Formation, which consists dominantly of gneissose semipelites, with pelites, psammites and lenticles and bands of calcsilicate rock. Some researchers have ascribed these gneisses to various basement successions, which according to one theory were pre-Dalradian and were transported to the North-east Grampian Highlands from elsewhere. However, later work has rejected the basement hypotheses and has re-affirmed the overall coherence of the Dalradian succession across the area. The Inzie Head gneisses, along with most other gneissose sequences in the North-east Grampian Highlands, are now assigned to the Crinan Subgroup of the Argyll Group.

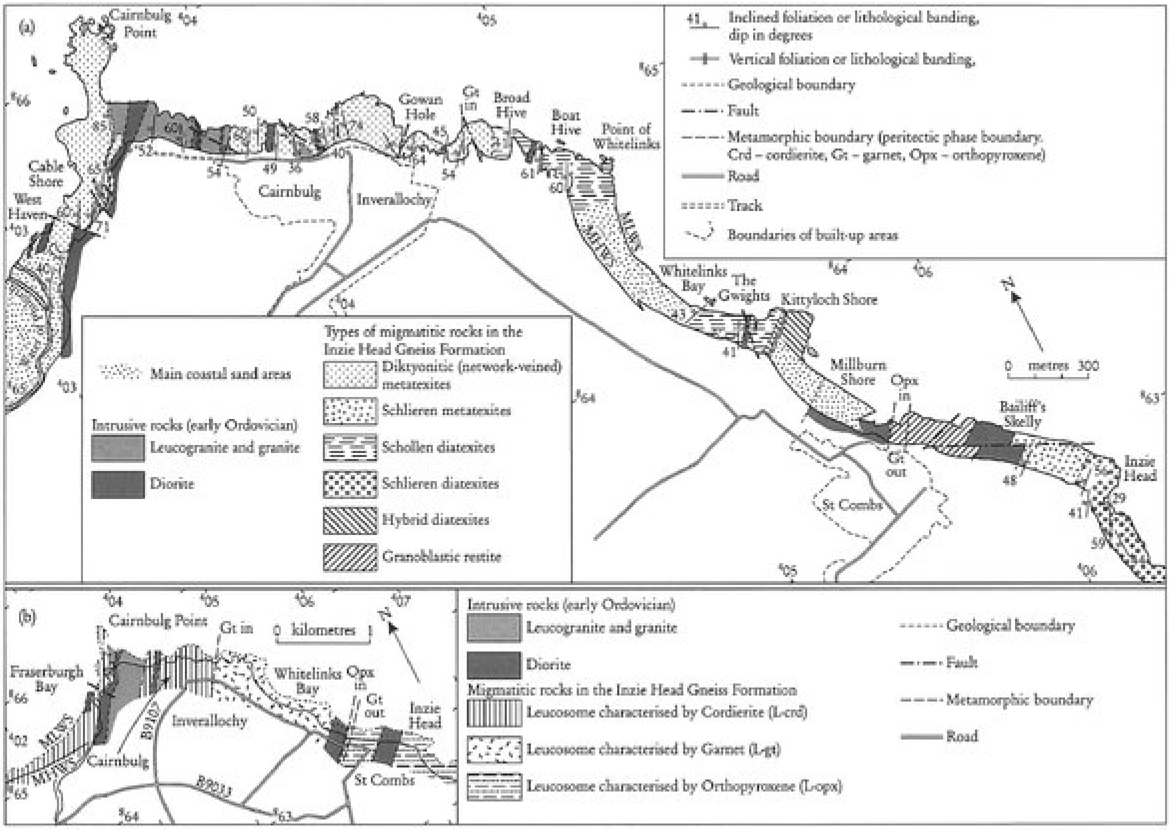
The gneissose rocks are at the sillimanite grade of metamorphism and show evidence of partial melting, at first in the presence of excess fluid but later in a fluid-absent mode. The granitic material generated (termed the leucosome) pervades the host rocks as pale-grey veins, lenses, streaks, patches and larger irregular bodies. Thicker discordant veins, commonly formed of white to pale-grey leucogranite, are interpreted as channel ways, through which granite that had been mobilized at slightly deeper levels migrated upwards to be ‘frozen’ in its present position. The leucosome material has resulted from the melting of semipelite and pelite at pressures of 3 to 4.5 kbar (equivalent to 10–14 km crustal depth) and temperatures of 650–775°C. Minerals that crystallized in the leucosome at the time of melt formation show zonation of the migmatitic rocks from cordierite- up to garnet- and ultimately orthopyroxene-bearing leucosome. The highest grades are seen around St Combs, where the original bedding of the metasedimentary rocks is preserved in places as a ‘ghost stratigraphy’. Only rarely has the accumulation of granitic material been sufficient to result in larger granitic bodies, as for example by Cairnbulg Point. This ‘migmatitic granite’ contains abundant metasedimentary relics that represent the more-refractory components of the host rock.

Diorite sheets that have been intruded throughout the section show textural and structural relationships with the granitic leucosome, implying that their intrusion coincided with melt generation. The diorite intrusions are probably related to a mafic–ultramafic intrusion that underlies the area at a very shallow depth and belongs to the mid-Ordovician North-east Grampian Basic Suite. If this is the case, it is valuable evidence that the basic suite was emplaced close to the peak of regional metamorphism in the Buchan area.

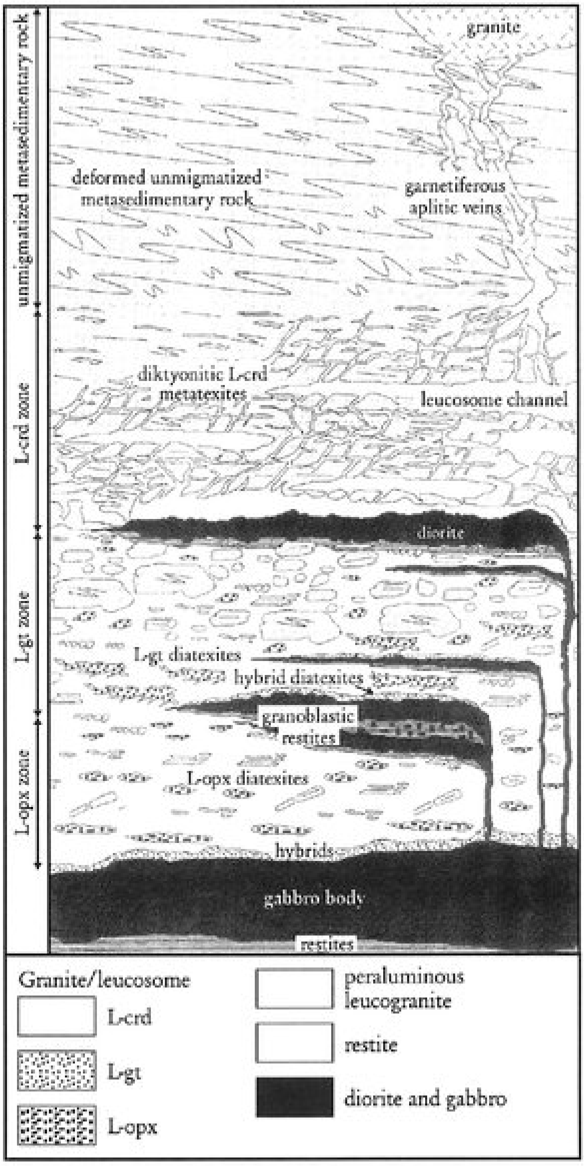
The migmatization and associated partial melting post-date an earlier penetrative deformation phase but were accompanied by a secondary deformation that generated the overall foliation seen in the migmatitic rocks. The foliation dips moderately to steeply to the north-west, as the outcrops lie on the western flank of a major late-stage antiform termed the Buchan Anticline, which controls the distribution of Dalradian units and folds the metamorphic isograds in the Ellon–Fraserburgh–Peterhead area.

This GCR site clearly has a wide significance in terms of the overall history of the Grampian Event, including the peak of metamorphism and the role of the mafic and ultramafic intrusions of the North-east Grampian Basic Suite. It is also clear that studies of the gneisses have been particularly significant to our understanding of the small- and medium-scale processes of migmatite formation and generation of granitic melts from semipelitic and pelitic protoliths. In this they have potential international importance.

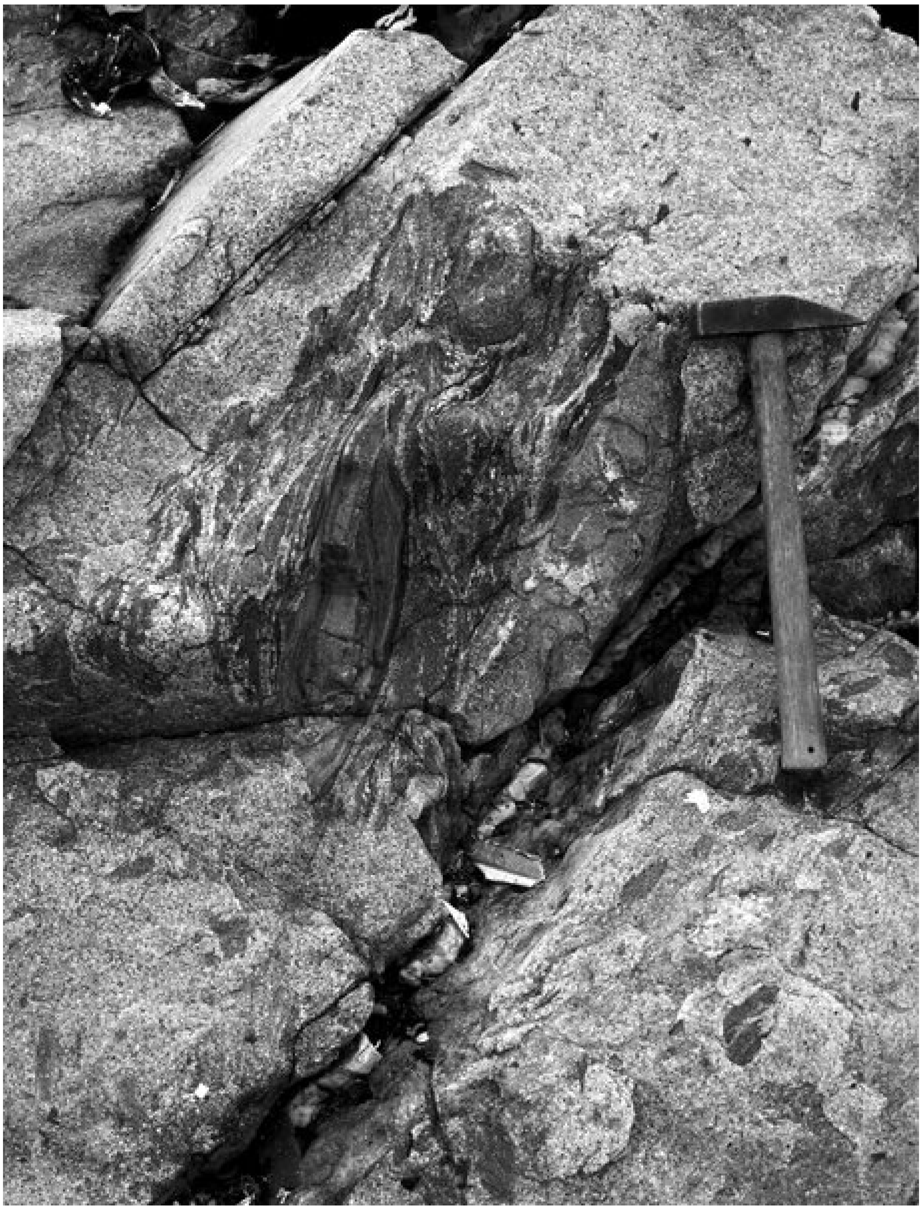
[References](#)



(Figure 6.35) (a) Map of the Cairnbulg to St Combs coast section showing the textural varieties of migmatitic rocks within the Inzie Head Gneiss Formation. Modified after Johnson et al. (2001b). See text for explanations of the terminology. (b) Map summarizing mineralogical characteristics of the leucosome element of the gneisses.



(Figure 6.36) Schematic crustal section prior to D4 folding and uplift, showing the nature of migmatitic rocks in the Inzie Head Gneiss Formation and their relationships with the mid-Ordovician mafic and felsic intrusions. From Johnson et al. (2001b).



(Figure 6.37) Cairnbulg Granite intruded into diktyonitic metatexite and nebulitic diatexite with relict metasedimentary schollen of the Inzie Head Gneiss Formation. Top of beach, south of Cairnbulg Harbour. The hammer shaft is 35 cm long. (Photo: J.R. Mendum, BGS No. P 726603.)

(Figure 6.38) Schollen diatexites (L-gt zone), with large garnets now mainly retrogressed to chlorite in the Inzie Head Gneiss Formation. The calcsilicate lenses and psammites form metasedimentary schollen. The rocks were derived by anatectic partial melting of the dominantly semipelitic rocks. Point of Whitelinks, east of Inverallochy, Cairnbulg to St Combs GCR site. The hammer shaft is 35 cm long. (Photo: J.R. Mendum, BGS No. P 726604.)