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# Cairnbulg to Inzie Head — Dalradian migmatites

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## Purpose

To examine migmatised metasedimentary rocks of the Inzie Head Gneiss Formation and associated igneous bodies across the upper amphibolite to granulite facies transition. A diverse range of migmatite structures are displayed, two mineral isograds are crossed, and the relationships between deformation, partial melting and igneous intrusion can be examined.

## Access

The exposures lie along the shore between West Haven on the east side of Fraserburgh Bay and Inzie Head, south of St Combs (Figure 1). In the southeast corner of Fraserburgh take the B9033 towards St Combs, Cairnbulg and Inverallochy. After about 5 km

## Introduction

The metasedimentary rocks on this excursion form part of the Inzie Head Gneiss Formation, which is generally regarded as part of the Dalradian, probably Crinan Subgroup (Johnson 1999; Stephenson *et al.*, 2013). The gneisses, which were first described in detail by Read & Farquhar (1956), are migmatites (i.e. they were partially molten at the metamorphic peak) that are intruded by numerous syn-migmatitic sheets of diorite. Bodies of granite ranging from a few centimetres to hundreds of metres across occur throughout the section. The metasedimentary rocks are dominated by metapelite, metasediment and metapsammite with subordinate calc-silicate. A moderate to steep northwesterly dipping foliation occurs throughout the section which, although generally poorly developed, is in places more intense. The main partial melting event appears to have post-dated much of the deformation (Kneller, 1987).

Migmatised metapsammites underwent relatively low degrees of partial melting (metatexites) and occur as large rafts in which bedding and an earlier spaced cleavage is preserved. Migmatised metapelitic and metasedimentary rocks underwent extensive partial melting in which pre-anatectic (sedimentary) structures were largely destroyed. These rocks are diatexites containing numerous fragments of metasediment (schollen) and discontinuous layers rich in biotite (schlieren).

At the lowest-grade (northwestern) end of the section metapelitic migmatites contain cordierite and biotite with sillimanite, quartz and feldspar. Further upgrade (southeast) garnet appears, recording the transition from upper amphibolite facies to granulite facies conditions. At the highest grades, in the core of the Buchan anticline (Read & Farquhar, 1956), the migmatites lack sillimanite and garnet and contain pseudomorphs interpreted as former orthopyroxene (Johnson, 1999). Along with transitional upper amphibolite to granulite facies rocks south of Deeside (Baker & Droop, 1983; Goodman, 1990), the gneisses here are amongst the highest-grade regionally metamorphosed rocks in the Dalradian. However, the rocks have experienced pervasive retrogression and the original high-grade minerals have largely been replaced by chlorite and white mica.

The section is bounded by geophysically defined faults/shear zones trending NE through Fraserburgh Bay and Whitelinks Bay (Kneller, 1987). These may be the extension of the regional shear zones that surround the Buchan block (Ashcroft *et al.*, 1984) and which may have provided the H<sub>2</sub>O required for the high degrees of partial melting and retrogression (Johnson *et al.*, 2001). Gravity and magnetic anomalies suggest a mafic/ultramafic mass at shallow depth beneath this area and upper zone cumulates crop out in shallow pits only 1 km inland (Trewin & Rollin, 2002). These mafic/ultramafic masses probably provided much of the heat required for migmatisation. Many of the granulite facies metapelitic rocks in

the aureole of the Huntly mass (Droop *et al.*, 2003) have assemblages similar to those around Inzie Head. Peak metamorphic temperatures in both localities were > or >> 800 °C at crustal depths of around 15–18 km (Johnson *et al.*, 2001; Droop *et al.*, 2003).

## **Itinerary**

### **Locality 1. West Haven [NK 0305 6515]**

From the harbour carpark, walk west along the track for 600 m and onto the beach to flat lying wave-washed exposures on the westernmost part of West Haven on the east side of Fraserburgh Bay. West Haven is a natural collection point for sea-borne detritus, and the rocks at localities 1 & 2 are partially to completely covered in a heady mix of rotting seaweed and worse.

The westernmost exposures consist of medium-grained, dark green quartz-diorite (mainly hornblende–plagioclase–biotite–quartz) cut by veins of granitic pegmatite. The NW margin of this diorite body can be located near the eastern end of the sandy beach where the track ends [NK 0307 6524], where it is in contact with enclosing metasedimentary gneiss. The contact is broadly concordant with the foliation in the gneisses, which is rather more intense adjacent to the contact.

The metasedimentary gneisses are mostly metapelitic and metasemipelitic migmatites in which pre-existing structures have largely been destroyed (i.e. they are diatexites; Figure 2). Wispy discontinuous layers of biotite (schlieren) and fragments of diffuse metapelite and metasemipelite and more angular blocks of calc-silicate and metapsammite (schollen) are abundant. The pale grey quartzofeldspathic leucosome occurs in patches and as veins that exhibit complex cross-cutting relationships (Figure 2). Small (< 1mm) dark-green spots within leucosome are pseudomorphs after cordierite rich in chlorite. The generally chaotic nature of the diatexites suggests high degrees of partial melting.

### **Locality 2 [NK 0325 6541]**

The marginal relations of the diorite are well displayed where the sheet seen at locality 1 re- emerges from beneath the grassy bank. At its margins the diorite is penetrated by, and mingled with, leucosome derived from the surrounding migmatites (Figure 3). 'Pillows' of diorite are common. Where the granitic leucosome has penetrated further into the diorite it forms a net-vein (diktyonitic) complex. The further the veins penetrate into the diorite, the less distinct and darker in colour they become. Many of the rocks are intermediate in colour between leucosome and diorite. The field evidence suggests that the diorites intruded the migmatites at or close to the peak of metamorphism when the host rocks were partially molten.

### **Locality 3. Cairnbulg granite [NK 0367 6561]**

Return to the harbour and walk east to exposures at the top of the beach just to the north of the isolated house. The rocks are dominated by fine-grained weakly to unfoliated leucogranite with abundant pink veins. In places the granite contains mafic schlieren and the diffuse schollen, and there is no clear distinction between granite and leucosome-rich diatexite migmatite. This granite is an extensive body several hundred metres in width. It is intruded by, and mingled with, several diorite sheets (exposed, for example, at low tide around the harbour wall), suggesting the coexistence of felsic and mafic magmas.

### **Locality 4. Janet's Craig [NK 0408 6539]**

Return to the vehicle and drive back past the first row of houses in Cairnbulg. Take the left fork onto Shore Street and find a parking place. Walk onto the rocky headland (Janet's Craig) opposite the only buildings on the northern side of the road.

The rocks here are dominated by migmatised metapsammities. The metapsammities occur as large boudinaged rafts several metres in length in which a spaced pressure solution cleavage is clearly preserved. Overall, the amount of

leucosome in these rocks is significantly lower than at West Haven, and the original bedding is easily traced through the rafts (i.e. the migmatites are metatexites). The rafts (and bedding) are aligned subparallel to the variably developed foliation.

Some 150 metres back to the northwest [NK 0391 6544], the foreshore is crossed by anastomosing quartz veins up to about a metre thick that define a steep NW trending fault adjacent to which the Cairnbulg granite is shattered and disaggregated. A northwest dipping foliation is particularly strongly developed in schlieren and schollen metatexites between the granite and Janet's Craig.

#### **Locality 5. Point of Whitelinks [NK 0495 6476]**

Continue to follow the road southeast along the shore into Inverallochy (to the uninitiated there is no obvious boundary between these villages) and follow the pot-holed track round the northern edge of the golf course and park where it ends (a total distance of around 1.8 km). Walk southeast and onto the broad flat-lying rock pavement around Point of Whitelinks to superb exposures of diatexitic migmatites (Figure 4). The rock surface is unusual for NE Scotland in that it is a striated glacial pavement.

The metapelitic migmatites are schollen diatexites containing abundant grey cordierite-bearing leucosome and a second paler-coloured leucosome that contains abundant dark-green rounded clots rich in chlorite. These clots are up to 10 mm in diameter and represent pseudomorphs after garnet; many retain cores of fresh garnet (Figure 5). Schollen of calc-silicate, metapsammite and metapelite are abundant. Schollen of specific compositions can commonly be traced in trails for several metres or tens of metres, suggesting extreme attenuation and disruption of the original (now "ghost") stratigraphy. Metapelite schollen contain dark spots (altered cordierite porphyroblasts) and small leucosome veins indicating *in situ* partial melting of these compositions (Figure 4).

Garnet first appears some 350 m or so to the northwest of this locality marking the position of the garnet isograd in the migmatites (Johnson, 1999). The coexistence of garnet and cordierite in metapelitic rocks is generally regarded to record granulite facies conditions, and the garnet isograd thus also marks the amphibolite to granulite facies transition.

A generalized reaction appropriate to the formation of garnet in these rocks is: biotite + sillimanite + quartz = garnet + cordierite + K-feldspar + melt. This reaction probably records temperatures in excess of 750 °C and would have resulted in the production of a significant quantity of melt over a small temperature interval. Although exposure is limited, sillimanite does not occur in higher-grade rocks to the southeast.

#### **Locality 6. St Combs [NK 0555 6339]**

Drive back through and out of Inverallochy and, at the next crossroads, turn left onto the B9033 towards St Combs. Drive into the village and follow the High Street, turning left into Gordon Street and parking in the small car park at the end of this road just as it bends sharply left. Walk east onto the sandy beach and to the obvious wave washed exposures of dark coloured rock.

The exposures are of a large diorite body containing abundant veins of granitic pegmatite. The diorite here (as elsewhere in the section) is dominated by hornblende, biotite, plagioclase and quartz. No primary clinopyroxene occurs, although clots of hornblende may have replaced this mineral. The diorite generally is fractured where intruded by the pegmatites. However, finer-grained veins of granitic leucosome have diffuse contacts with the diorite suggesting they mingled as magmas.

#### **Locality 7 [NK 0568 6327]**

Walk southeast along the beach a further 200 m. The rocks here are coarse-grained granoblastic migmatites containing a chaotic mixture of leucosome, schlieren, small schollen, (altered) cordierite, biotite and garnet (Figure 6). In addition, rectangular dark-green aggregates, rich in fine-grained chlorite and greasy to the touch occur (Figure 7). These are interpreted by Johnson (1999) as pseudomorphs after orthopyroxene and mark the orthopyroxene isograd. These

residual rocks are sandwiched between, or included within, diorite and appear to have melted extensively.

Garnet and orthopyroxene (pseudomorphs) coexist in the northwestern part of the coarse granoblastic migmatites, but garnet is not found in metapelitic rocks much more than 50 m or so further southeast. A generalized reaction appropriate to the formation of orthopyroxene (and the disappearance of garnet) is: biotite + garnet + quartz = orthopyroxene + cordierite + K-feldspar + melt. This reaction probably records temperatures in excess of 800 °C at low pressures (4–5 kbar) and would have resulted in a further pulse of melt production.

### **Locality 8. Inzie Head [NK 0607 6292]**

Exposure from here down to Inzie Head to the south consist of residual migmatites containing abundant biotite and (altered) cordierite and orthopyroxene (Figure 8). Orthopyroxene pseudomorphs may occur within discontinuous leucosomes, consistent with their formation (with melt) via the reaction above. These rocks are in the core of the Buchan anticline and are some of the highest-grade regional metamorphic rocks in the Dalradian (Baker & Droop, 1983; Stephenson *et al.*, 2013).

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## **Acknowledgements**

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## **Appendix — addition photographs**

(Additional field photographs 1)

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## Figures

(Figure 1) Map of the coastal section between Cairnbulg and Inzie Head. The granite and diorite bodies are not extrapolated inland due to lack of exposure. Contains Ordnance Survey data © Crown Copyright and database right 2013.

(Figure 2) Typical diatexitic migmatite around West Haven comprising biotite-rich schlieren, schollen of migmatized semipelite (left) and pale granitic leucosome containing dark cordierite pseudomorphs.

(Figure 3) Contact between diorite and migmatite. The dark diorite commonly occurs as rounded 'pillows' with wispy diffuse margins suggesting mingling of magmas. The diatexitic migmatite in the foreground is very rich in leucosome (50 pence on diorite for scale; locality 2).

(Figure 4) Typical schollen diatexitic (locality 5). Migmatized schollen of spotted metapelite are surrounded by pale garnet-bearing leucosome that is mingled with grey cordierite-bearing leucosome.

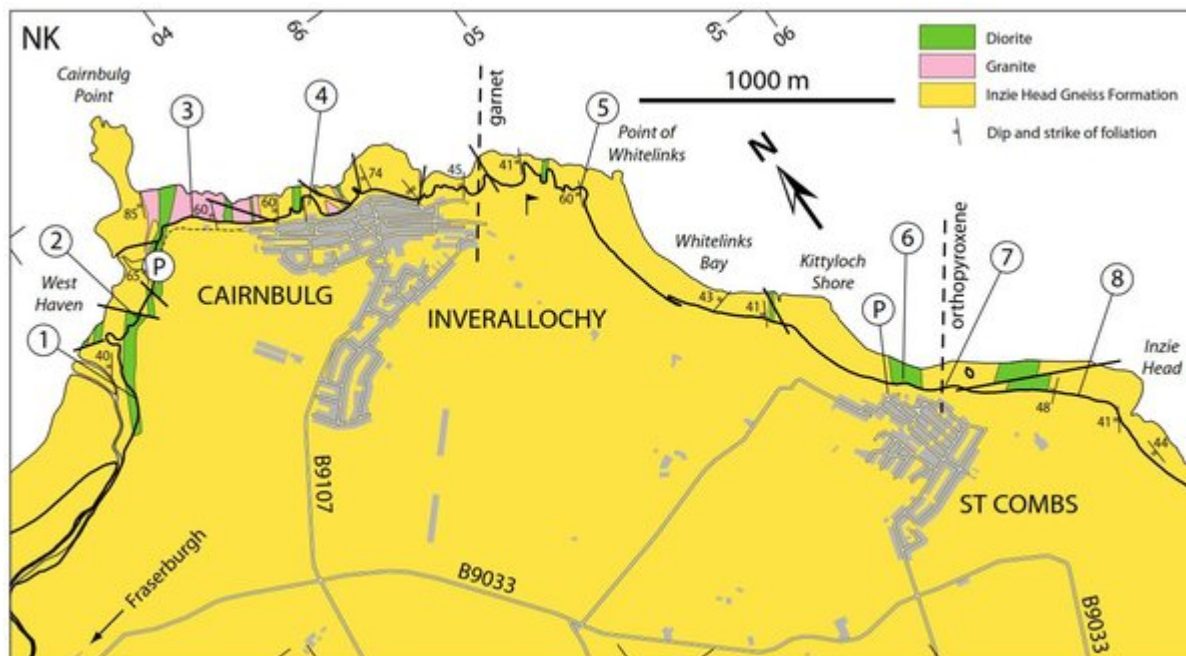
(Figure 5) The pale leucosome contains abundant schollen and schlieren and porphyroblasts of garnet that are partially to completely replaced by chlorite (locality 5).

(Figure 6) Coarse-grained granoblastic rocks containing garnet (locality 7).

(Figure 7) Coarse-grained granoblastic rocks containing greasy green chlorite-rich pseudomorphs after orthopyroxene (locality 7). These rocks are close to the inferred orthopyroxene isograd.

(Figure 8) Typical residual migmatites close to Inzie Head (locality 8). Pseudomorphs after orthopyroxene commonly occur within coarse discontinuous leucosomes.

(Additional field photographs 1) **Top left** — Diorite intruded by veins of coarse-grained granitic leucosome derived from proximal migmatites (locality 1). **Top right** — Leucosome-rich diatexitic containing biotite schlieren and migmatized semipelite schollen (locality 2). **Middle left** — Granulite facies diatexitic containing two distinct leucosome types. Most leucosome is grey in colour and contains abundant small chlorite-rich pseudomorphs after cordierite. The pale-coloured leucosome running from left to right through the centre contains abundant biotite schlieren and large garnet porphyroblasts that are partly to completely replaced (locality 4). **Middle right** — Schollen diatexitic comprising a chaotic mix of two types of leucosome, schlieren, mafic minerals and schollen of metapsammite and calc-silicate (locality 4). **Bottom left** — The St Combs diorite containing wispy diffuse veins of leucosome derived from nearby migmatites (locality 5). **Bottom right** — Flattened metasemipelitic schollen within residual coarse-grained granoblastic migmatites (locality 6).



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*(Figure 5) The pale leucosome contains abundant schollen and schlieren and porphyroblasts of garnet that are partially to completely replaced by chlorite (locality 5).*



*(Figure 6) Coarse-grained granoblastic rocks containing garnet (locality 7).*





*(Figure 7) Coarse-grained granoblastic rocks containing greasy green chlorite-rich pseudomorphs after orthopyroxene (locality 7). These rocks are close to the inferred orthopyroxene isograd.*



*(Figure 8) Typical residual migmatites close to Inzie Head (locality 8). Pseudomorphs after orthopyroxene commonly occur within coarse discontinuous leucosomes.*





(Additional field photographs 1) **Top left** — Diorite intruded by veins of coarse-grained granitic leucosome derived from proximal migmatites (locality 1). **Top right** — Leucosome-rich diatexite containing biotite schlieren and migmatized semipelite schollen (locality 2). **Middle left** — Granulite facies diatexite containing two distinct leucosome types. Most leucosome is grey in colour and contains abundant small chlorite-rich pseudomorphs after cordierite. The pale-coloured leucosome running from left to right through the centre contains abundant biotite schlieren and large garnet porphyroblasts that are partly to completely replaced (locality 4). **Middle right** — Schollen diatexite comprising a chaotic mix of two types of leucosome, schlieren, mafic minerals and schollen of metapsammite and calc-silicate (locality 4). **Bottom left** — The St Combs diorite containing wispy diffuse veins of leucosome derived from nearby migmatites (locality 5). **Bottom right** — Flattened metasemipelitic schollen within residual coarse-grained granoblastic migmatites (locality 6).