# Syn- to late-tectonic basic and ultramafic intrusions, Caledonian magmatism, Grampian Highlands

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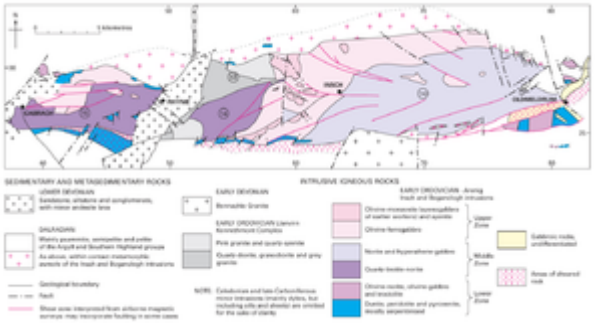

Geological sketch map of the Insch (14), Boganclogh (15) and Kennethmont (53) intrusions. P915435.

Layering in norites of the Morven–Cabrach mass, Hill of Allamuc, Aberdeenshire. The layers are alternately plagioclase-rich and orthopyroxene-rich. P220376.

## Syn- to late-tectonic basic and ultramafic intrusions

A suite of basic and ultramafic rocks was intruded into the Dalradian rocks of the North-east Grampians during the $D_3$ tectonic episode, shortly after the peak of the regional metamorphism. The largest of these intrusions, the Insch mass, has been dated at 489 ± 17 Ma (Pankhurst, 1970), while others have yielded ages between 497 and 464 Ma (See Table in Caledonian magmatism, Grampian Highlands). The bodies occur in areas of intense $D_3$ deformation, particularly along the Portsoy–Duchray Hill Lineament, and are associated with areas of high-temperature low-pressure 'Buchan' metamorphism (Fettes et al., 1986). The contacts, where seen, are mostly tectonic, and are for the most part coincident with large-scale shear structures (Ashcroft et al., 1984), which have in

places detached the aureole hornfelses from individual basic masses, and displaced them by up to several kilometres. Other shear planes are developed within several of the basic masses. The shearing commenced shortly after emplacement while the rocks were still hot, but continued for a considerable period. Basic mylonites derived from the Huntly mass are cut by granites and pegmatites belonging to a 460 Ma suite but similar pegmatites near Oldmeldrum show cataclastic textures with lensoid feldspar porphyroclasts set in a fine-grained granular quartz matrix (Munro, 1986a), confirming the syntectonic intrusion age of the basic bodies. Most of the larger bodies show local evidence of cumulate layering. The non-cumulate rocks comprise fine-grained granular gabbros and contaminated and xenolithic rocks, which include hybrid rocks derived by partial melting of the country rocks.

The Huntly, Insch–Boganclogh, Morven–Cabrach, Haddo House–Arnage, Belhelvie and other smaller masses were thought by Stewart and Johnson (1960) to be remnants of a single disrupted layered intrusion, but Munro (1970) and Weedon (1970) have suggested that they are, in fact, several sill-like bodies differing slightly in composition and conditions of crystallisation. Disruption and translocation occurred shortly after consolidation, before the rocks had acquired a permanent magnetisation.

The south-eastern portion of the ***Insch*** mass near Oldmeldrum (14, (P915435)), is much faulted but comprises layered dunites passing up into troctolites and then olivine-gabbros; all of them are assigned to a Lower Zone. They are separated by a 1 to 2 km-wide zone of sheared gabbroic rocks from the Middle and Upper zone rocks which form the remainder of the Insch mass (Clarke and Wadsworth, 1970). The Middle Zone comprises mainly coarse-grained clinopyroxene-norites showing cumulus textures, intimately associated with fine-grained clinopyroxene-norites with granular, non-cumulate textures (Wadsworth, 1988). These pass north-westwards into the Upper Zone of layered olivine-ferrogabbros, olivine-monzonites and finally syenites (Wadsworth, 1986), a sequence characteristic of the upper part of a layered tholeiitic intrusion. In the area to the west and south-west of Insch, the layering is gently folded into a broad, north-plunging syncline, cut by normal faults. On the western limb of the syncline, the equivalents of the clinopyroxene-norites are biotite-norites with interstitial quartz, similar to those of the Boganclogh intrusion. Along the south-west margin of the Insch mass a discontinuous line of serpentinite pods crops out (Read, 1956). These represent part of the lowest zones of the cumulate pile, moved to higher structural levels by the shearing event. The ultramafic rocks are extensively serpentinised and the cumulate and granular clinopyroxene-norites are widely but patchily uralitised, while the other rocks of the Insch mass are not significantly altered.

The ***Boganclogh*** mass (15, (P915435)) is the western continuation of the Insch mass beyond the late-tectonic Kennethmont Complex and the Rhynie Old Red Sandstone outlier (Busrewil et al., 1973). It consists mainly of Middle Zone quartz-biotite-norites, passing upwards into Upper Zone olivine-ferrogabbros, olivine-monzonites and syenites, as in the central and western parts of the Insch mass. An almost continuous belt of serpentinite occurs along the southern margin of the mass (Blyth, 1969). It is flanked to the north by sheared and mylonitised syenite, and contains shear zones and enclaves of sheared syenite and quartz-biotite-norite (Gould, 1997). Narrow pods of sheared serpentinite occur along the northern contact of the Boganclogh mass, and faulted inliers of massive, unsheared, lightly serpentinised dunite occur within the mass.

Small detached bodies consisting mostly of dunite, harzburgite, troctolite and olivine-gabbro occur in the area to the south of the Insch mass. The ***Lawel Hill*** mass (16; Whittle, 1936), forms a gently dipping sheet bounded by north-dipping thrust planes, and shows lithological similarity to the Lower Zone cumulates at the south-eastern corner of the Insch mass. Three small fault-bounded bodies of basic rocks occur near ***Kildrummy*** (17; Gould, 1997). Two of them consist of clinopyroxene-norite similar to the Tarland mass, but the third includes troctolites with bytownite plagioclase, more

similar to Insch Lower Zone material.

The northern tip of the ***Morven–Cabrach*** mass (18, Allan, 1970) lies close to the western end of the Boganclogh mass, and the two bodies are probably connected at depth. This northern part of the 30 km-long body consists of quartz-biotite-norite (P220376) similar to that of Boganclogh with minor quartz-diorite and monzonite. These are succeeded southwards by layered norite and hypersthene-gabbro with minor ferrogabbro and monzogabbro. In the extreme south, minor intercalations of ultramafic material are present. The rocks of the southern part of the mass have suffered extensive uralitisation of the pyroxenes and saussuritisation of the plagioclase, but the primary gabbroic texture is preserved, except in the southern extremity and close to the highly sheared western margin of the body, where sheared gabbroic rocks have been recrystallised to foliated amphibolites. There are several large serpentinite bodies along the western margin. The cumulate layering in the northern part of the body dips steeply to the east but in the southern part swings round to dip north, and the angle of dip reduces to 30° to 40°. Extensive hornfelsing and partial melting has occurred in the metasedimentary rocks along the eastern (upper) contact of the body, and xenolithic hybrid rocks are developed (Fettes, 1970). Allan (1970) suggested that Morven–Cabrach represents a feeder to the other basic masses, but the attitude of the layering, together with the shape of the related gravity anomaly, suggests that it is more likely to be a sheet-like body which has been extensively stoped by the Ballater granite at its southern end.

The adjoining ***Tarland*** mass (19, Gould, 1997) is almost entirely composed of norite, with uralitised pyroxenes and saussuritised plagioclase, showing a strong resemblance to that of the southern part of the Morven–Cabrach mass.

The serpentinised ultramafic rocks of the ***Coyles of Muick*** (20) are similar to those along the western margin of the Morven–Cabrach mass, and represent a southern continuation of the zone of tectonically emplaced ultramafic bodies.

The small ***Blackwater*** mass (21; Fettes and Munro, 1989) consists of cumulate gabbroic rocks with a number of scattered ultramafic bodies, mostly serpentinised. The rocks have been strongly deformed, and the basic rocks amphibolitised, along narrow shear zones.

The ***Succoth–Brown Hill*** mass (22; Gunn et al., 1990) consists of serpentinised dunites, pyroxenites and minor amphibolitised gabbroic rocks characterised by unusually primitive mineral compositions. The ultramafic rocks are comparable to those along the southern margin of Boganclogh, but the feldspar-bearing rocks are unique to the mass.

The ***Huntly*** (23) and ***Knock*** (24) masses (Munro, 1970; 1984; Munro and Gallagher, 1984) are joined together by a narrow neck of basic rocks. The cumulate layering within each body strikes north–south, parallel to the contacts of the bodies, and is subvertical, younging eastwards. Olivine ± plagio clase ± clinopyroxene cumulates occur as layered rocks of peridotite, troctolite and olivine-gabbro composition; cumulus textures are particularly well developed in the western parts of all three masses. Isolated patches of rather more differentiated olivine-gabbro cumulates crop out in the central and eastern parts of the Huntly mass, enclosed within granular gabbros similar to those of the Insch mass. Xenolithic and contaminated gabbroic rocks are also a prominent feature of the eastern parts of the masses (Read, 1923, pp. 128–135); in places they appear to have intruded both the cumulates and the granular gabbros. The masses are traversed by several N–S-trending shear zones (Munro and Gallagher, 1984).

The ***Portsoy*** mass (25;Munro, 1970; 1984; Munro and Gallagher, 1984) lies to the north of the Knock mass; it is very poorly exposed. Olivine-gabbros similar to those of Huntly are associated with serpentinised ultramafic rocks of uncertain affinity, some of which may be pretectonic.

The ***Belhelvie*** mass (26) is a layered complex of ultramafic and mafic cumulates (Wadsworth, 1991). The body is elongated in a NW–SE direction and the cumulate layering dips very steeply to the north-east, parallel to the contacts (Ashcroft and Boyd, 1976). A succession from dunite through troctolite to olivine-gabbro occurs along the south-western margin. It is overlain by a narrow, impersistent raft of metasedimentary hornfelses, which is overlain in turn by a repetition of the dunite–troctolite–olivine-gabbro succession. The rocks of the eastern part of the intrusion have been intensely sheared, and narrow belts of sheared and recrystallised rock occur along the contacts. The sheared basic rocks are cut by bodies of pegmatitic granite, dated at 472 ± 5 Ma, which have suffered only limited crushing (Boyd and Munro, 1978).

The ***Haddo House*** (27) and ***Arnage*** (28) masses present classic examples of contamination of basic igneous rocks (Gribble, 1967; 1968). Both intrusions are chiefly quartz-biotite-norites with minor olivine-norite, showing granular textures. These rocks are intimately associated with cordierite-norites which are considered to represent a partial melt derived from pelitic and impure psammitic Dalradian metasedimentary rocks, with only the most refractory components (quartzite and highly aluminous rocks) preserved as xenoliths. The ***Arthrath–Dudwick*** body (29), which is adjacent to the eastern margin of the Arnage mass, is bounded to the north and south by faults and cross-cut by N–S-trending dislocations. The rocks are mostly orthopyroxene-rich cumulates interlayered with olivine-rich cumulates. Minor olivine-gabbros and norites are present locally.

The poorly exposed ***Maud*** mass (30) comprises medium-grained quartz-biotite-clinopyroxene-norites with local coarser- and finer-grained variants. Xenoliths of locally derived metasedimentary rocks are abundant, particularly in the eastern part of the body, and show a strong north–south alignment. The foliation in the xenoliths typically dips steeply to the east. The basic rocks are bounded to the east by a linear ductile shear zone and a similar zone truncates the metamorphic aureole a short distance beyond the western contact.

Other, smaller, bodies ranging from ultrabasic rocks through gabbros and norites to diorites (*31–33*) occur in a belt running northwards from the Belhelvie mass, past the eastern margins of the Arnage and Maud masses, as far as the coast at Inzie Head. Another belt runs parallel to the eastern margin of the Huntly–Knock and Portsoy masses. The rocks are commonly amphibolitised (e.g. *Boyndie Metagabbro, 34*) and there is some uncertainty as to whether they are pre- or syntectonic.

Substantial metamorphic aureoles occur along the margins of most of the basic masses, but they are often incomplete; for example, intense $D_3$ shearing has removed the aureole from most of the southern margin of the Insch mass (P915435). Elsewhere, hornfels-like rocks occur in shear-bounded slices up to several kilometres away from the nearest outcrops of basic rock; they are interpreted as representing aureole rocks displaced by movement along shear zones propagated along the margins of the basic masses (Ashcroft et al., 1984). In places, however, the hornfelses are difficult to recognise because they bear mineral assemblages similar to those produced by high-grade regional metamorphism of the low-pressure Buchan facies.

The basic masses give rise to magnetic and gravity anomalies of varying intensity. Where fresh, the ultramafic rocks have low magnetic susceptibilities, but abundant magnetite is released during the serpentinisation process, giving rise to a high susceptibility within most of the ultramafic components. Most of the gabbroic rocks are moderately magnetic when fresh, but sheared and uralitised gabbroic rocks commonly have lower susceptibilities, due to destruction of the primary magnetite and ilmenite. The contaminated rocks generally have low susceptibilities, as do the more quartzitic hornfelses. However, pelitic hornfelses frequently have high susceptibilities, due partly to layers rich in recrystallised detrital magnetite, but mostly due to release of magnetite during the formation of fibrolitic sillimanite after biotite.

Most components of the basic masses (except for syenites and serpentinised ultramafic rocks) are considerably denser than the Dalradian country rocks and consequently give rise to large positive Bouguer gravity anomalies.

Gravity and magnetic survey data were used by McGregor and Wilson (1967) and Gallagher (1983) to interpret the overall shape of the basic intrusions of the north-east Grampians. The Portsoy, Knock and Huntly masses extend to a depth of no more than about 1 km. A thickness of about 5 km of basic rocks underlies the south-western part of the Boganclogh intrusion, the northern tip of the Morven–Cabrach mass and the intervening area (Gould, 1997). The thickness of the basic rocks decreases steadily southwards within the Morven–Cabrach mass, whose southern portion is underlain at shallow depth by a continuation of the Ballater granite. The Insch mass has an interpreted thickness of 2 km to the north of Bennachie (McGregor and Wilson, 1967). Its sheared southern margin dips to the north, probably at a fairly steep angle. The Belhelvie intrusion is thought to continue south-eastwards along strike for up to 10 km under a cover of younger sedimentary rocks. The main gravity anomaly lies to the north-east of the outcrop of the mafic and ultramafic rocks, indicating a probable shallowing of the dip of the contacts in that direction. Prominent gravity anomalies with a slight NNE trend in the area between Haddo House and Fraserburgh indicate that there are probably considerable quantities of basic igneous rocks at depth throughout this area.

**Seven-fold division of the Caledonian Igneous Suite**

Pre-tectonic basic magmatism

Syntectonic granitic intrusions

Syn- to late-tectonic basic and ultramafic intrusions

Late-tectonic granitoid intrusions

Post-tectonic granitoid intrusions

Late- to post-tectonic minor intrusions

Lower Old Red Sandstone volcanism

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