Post-tectonic granitoid intrusions, Caledonian magmatism, Grampian Highlands

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Stephenson, D, and Gould, D. 1995. British regional geology: the Grampian Highlands. Fourth edition. Reprint 2007. Keyworth, Nottingham: British Geological Survey.

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Post-tectonic granitic intrusions

The main phase of igneous activity in the Grampian Highlands is represented by the emplacement of large volumes of calc-alkaline magma during a period of post-orogenic uplift (Pitcher, 1982). These post-tectonic intrusions, the Newer Granites of Read (1961), are a diverse group in terms of mode of emplacement, petrology and geochemistry. Petrographically, they have been divided into three groups (Stevens and Halliday, 1984; Plant, 1986):

1. South Grampians Suite: diorite to granite plutons, mostly relatively small in size, in the south and south-east Grampians

1. Argyll Suite: tonalite–granodiorite–granite complexes which show ring structure or compositional zoning, located up to 50 km south-east of the Great Glen Fault

1. Cairngorm Suite: intrusions of biotite-granite, some very large in size, concentrated in the northern part of the Grampians.

The three suites have all yielded emplacement ages in the range 420 to 395 Ma, see table in Caledonian magmatism, Grampian Highlands. The three groups share essentially I-type isotopic and geochemical characteristics, with low initial $^{87}Sr/^{86}Sr$ ratios (0.704–0.708), although group (iii) is transitional to A-type. They are interpreted (Harmon and Halliday, 1980; Stevens and Halliday, 1984) as having formed from an admixture of a primary, mantle-derived component with a proportion of lower crustal material. Stevens and Halliday ascribed the geochemical differences between the suites to differences in lower crustal lithology and water content in different parts of the Grampians. Little or no Dalradian material appears to have been involved in the origin of the granites.

The tonalite–granodiorite–granite complexes of group (ii) commonly show marked enrichment in Sr and Ba, whereas the pink biotite-granites of group (iii) have low Sr and Ba and high Rb, Li, U and Th, due to their more advanced stage of magmatic differentiation (Plant et al., 1990). The larger complexes of the Argyll and Cairngorm suites are associated with closed negative Bouguer gravity anomalies, albeit superimposed on a composite regional negative anomaly; this has been interpreted as indicating that the plutons from Monadhliath to Mount Battock rise from an underlying batholith. Strong differences in magnetic susceptibility between phases have been recorded in several of the granites and this is reflected in annular magnetic anomalies, locally of significant (> 400 nT) amplitude, although the magnetic anomaly pattern in and around the granites might also be interpreted as due to ring-shaped bodies of basic igneous rocks or hornfelsed pelitic rocks at depth.

South Grampians Suite

This suite of largely granodioritic complexes is developed in the South-west and Southern Grampians; some are associated with NE-trending faults. The suite is characterised by a significant dioritic component, together with smaller amounts of more mafic rocks (peridotite, kentallenite (olivine-monzonite) and pyroxenite).

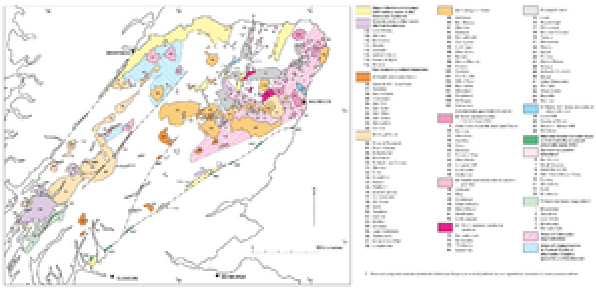
The ***Garabal Hill–Glen Fyne Complex*** (56) is divided into two parts by the Kinglas–Garabal fault. To the north-west of the fault lies the main part of the body, which comprises mostly granodiorite with K-feldspar megacrysts, with a subsidiary nonporphyritic granodiorite (Nockolds, 1940). Along its south-east margin, adjacent to the fault, the granodiorite has a contact with a small body of hypersthene-gabbro containing a minor ultramafic phase (augite-peridotite). To the south-east of the fault, contaminated pyroxene-mica-diorite with subsidiary pyroxenite and other ultramafic rocks crop out. Each successive phase carries xenoliths of one or more of the earlier phases. The more acid members define a liquid line of descent believed to be a product of differentiation from a dioritic magma. Nockolds (1940) and Nockolds and Mitchell (1948) concluded that the parental magma was of pyroxene-mica-diorite composition, and close to that of a pyroxene-andesite lava from Glencoe. The absence of an Fe-enrichment trend in the diorite complex suggests that the more basic rocks represent a substantial cumulus component.

The ***Arrochar Complex*** (57) forms an elongate, composite intrusion, predominantly pyroxene-mica-diorite, with subsidiary components ranging from peridotite/pyroxenite to tonalite and biotite-granodiorite. Internal contacts are sharp, with the successively younger phases both veining and bearing xenoliths of the older ones. The Arrochar body differs slightly from other members of the group in having enhanced V, Y, FeO, MgO and Co values. The parental magma of the intrusion is thought to be dioritic, with the various phases representing products of continuous differentiation. Again the ultramafic rocks are thought to represent cumulus phases.

The ***Doune Farm Complex*** (58) consists of seven separate diorite bodies with associated breccias, appinites and minor granodiorites. Early breccias and coarse-grained appinites are succeeded by several varieties of diorite. The ***Inversnaid*** body (59) is similar.

The ***Glen Tilt Complex*** (60) bears some similarity to the Garabal Hill–Glen Fyne Complex, comprising a main granitic intrusion, with a marginal basic to intermediate complex to the south-east (Deer, 1938; 1950; 1953). The earlier phases of the complex range in composition from augite-diorite through tonalite to granodiorite, with small enclaves of appinite. Contacts between the main phases are gradational, with evidence of hybridisation (Deer, 1938; 1950). The main intrusion, and a small satellitic body, consist of pink, coarse-grained biotite-granite. A related suite of NE-trending lamprophyre, microdiorite, felsite and quartz-porphyry dykes is well developed in country rocks to the south-west of the complex.

The ***Glen Doll Diorite*** (61) is the largest of a number of dominantly intermediate plutonic intrusions (61–64) that occur between Glen Shee and the south-eastern margin of the Cairngorm Granite (Barrow and Craig, 1912; Jarvis, 1987). It consists mainly of hornblende- and pyroxene-diorite, with small areas of gabbro, monzonite and granite. Some rocks are appinitic, and some gabbros and diorites show layering and cumulus textures. Partly assimilated metasedimentary xenoliths are common in the diorites, where enhanced zinc levels have been attributed to this assimilation. Contamination is particularly apparent in 20 to 350 m-wide at the eastern margin, where diorite grades into monzodiorite and granite adjacent to hornfelsed rafts and xenoliths. The ***Comrie Complex*** (65) consists of a peripheral xenolithic diorite, locally pyroxene-bearing, which is cross-cut by a highly leucocratic aplitic granite (Tilley, 1924). An extensive thermal aureole is developed in the low-grade country rocks, with pyroxene-, cordierite-, corundum- and spinel-bearing hornfelses.



Distribution of Caledonian igneous rocks in the Grampian Highlands. P915434.

Argyll Suite

This group of tonalite–granodiorite–granite intrusions comprises large multiphase high-level complexes in the Lochaber and Lorn areas and smaller, mostly zoned plutons forming a well-defined NE-trending belt adjacent to the Great Glen Fault (P915434). Certain phases of the Skene Complex and some other small intrusions of the north-east Grampians have been included here because of petrographical similarity, without implying a genetic relationship to the Lochaber intrusions. The large plutonic complexes of Lochaber and Lorn postdate Lower Old Red Sandstone lavas of the Lorn Plateau. A close association between volcanic and plutonic rocks is seen at Glen Coe and Ben Nevis. The ring-faulting and rim-synclines suggest that there was only a thin cover (less than 3 km) above the Lochaber and Lorn plutons when they were emplaced (Roberts, 1966).

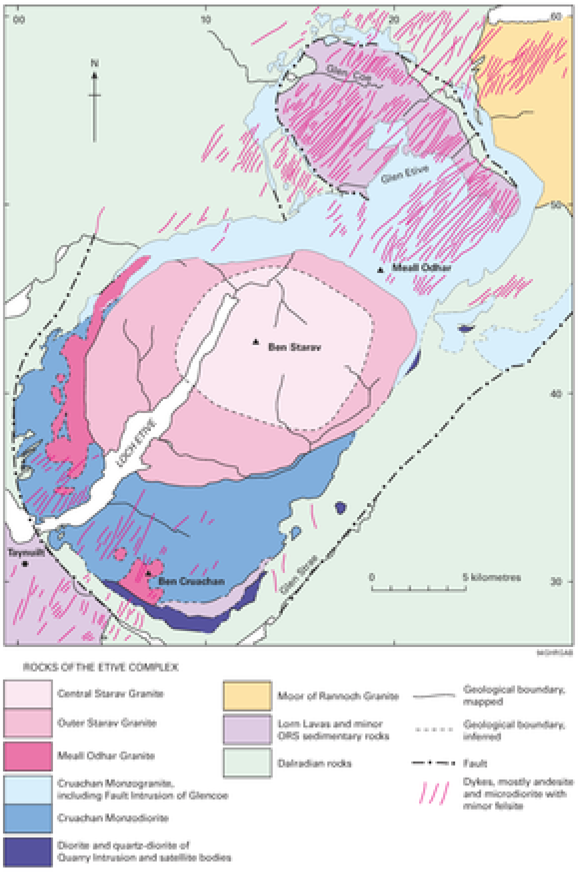
The ***Moor of Rannoch Granite*** (66) is the earliest intrusion of the Lochaber group (Hinxman et al., 1923). Its original roughly circular outline has been modified by displacement along the Ericht–Laidon Fault. An early phase of quartz-monzodiorite to monzogranite is intruded by a phase of monzodiorite and quartz-monzodiorite, and both phases are intruded by pink syenogranite. However, no chilled contacts have been detected between the monzodiorites and the syenogranite. The roughly circular shape of the pluton hides a complex sheeted geometry of individual phases, and shows evidence of forceful intrusion; a metamorphic aureole up to 700 m wide is developed.

Unlike the other members of this group, which are roughly circular or show a north-easterly elongation, the ***Strath Ossian Complex*** (67) shows a pronounced north-westerly elongation. It consists of three main lithologies. An older melanocratic granodiorite to quartz-diorite is intruded by the areally dominant medium- to coarse-grained, xenolithic hornblende-biotite-granodiorite. The third lithology is a feldspar-phyric granite, which forms a marginal facies transitional to the main granodiorite. The igneous complex was emplaced, with local disruption of country rock structures, into cold country rock (Key et al., 1993).

The ***Ballachulish pluton*** (68) is a composite intrusion comprising a zoned envelope of dioritic composition intruded by a younger core of porphyritic granite (Weiss and Troll, 1989). The inner part of the diorite consists of two-pyroxene-monzodiorite with cumulus texture, which exhibits a flow foliation marked by alignment of pyroxene and plagioclase crystals, and contains inter-cumulus opaque minerals, poikilitic biotite, and interstitial alkali feldspar. This grades outwards into grey quartz-diorite of variable grain size, which in many places is abundantly xenolithic. The main porphyritic granite forming the central part of the complex contains 5 to 15 per cent of perthite phenocrysts set in a granodiorite matrix. A marginal hybrid facies of the granite contains partially resorbed mafic enclaves. A small stock of nonporphyritic fine-grained leucogranite, showing strong hydrothermal alteration, occupies the centre of the pluton. Satellitic intrusions of basic to intermediate, volatile-rich magma formed bodies of appinite and lamprophyre; pipes of explosion breccia are associated with these intrusions. They closely predate the main phase of diorite intrusion and show restricted hybridisation with quartz-diorites near the south-east margin of the Ballachulish pluton. Fluid pressures in the thermal aureole of the complex are estimated at 3.0 ± 0.5 kb (Pattison, 1989), with contact metamorphic temperatures ranging from 450°C to 800°C. Two zones of anatectic migmatite are genetically related to the emplacement and crystallisation of the quartz-diorite and granite respectively (Pattison and Harte, 1988).

The ***Ben Nevis Complex*** (69) consists of a sequence of concentric intrusions with a central block of Dalradian metasedimentary rocks and Lower Old Red Sandstone lavas faulted down in a cauldron subsidence structure (Anderson, 1935; Bailey, 1960; Haslam, 1968). The Outer Granite phase has three components. The earliest member is confined to the north-west, and consists of fine- to medium-grained quartz-diorite, bearing augite and rare hypersthene; in places, it can be seen to become more acid and more leucocratic upwards. The second member is a coarse-grained augite-diorite to tonalite, which becomes more acid and leucocratic both inwards and upwards. It everywhere has a gradational contact with the third member, a megacrystic hornblende-biotite-granite, which is believed to have been intruded while the quartz-diorite was still partly molten. The plutonic rocks crystallised under low pressure, at which the alumina-rich hornblende, typical of the more deep-seated plutons, was unstable. As a result, pyroxene crystallised in all but the most acid rocks, to be replaced in the final stages of solidification by a pale green alumina-poor hornblende. All members of the Outer Granite are cut by the NE-trending andesite dyke swarm centred on the complex. The Inner Granite has a sharp contact against the Outer Granite and truncates almost all of the dykes. It is a fine-grained, non-porphyritic leucocratic white to pink biotite-granodiorite. The outer contact with the porphyritic Outer Granite shows no sign of chilling but at its inner contact with the downfaulted metasedimentary rocks and lavas it becomes markedly chilled, with a fine-grained matrix enclosing phenocrysts of plagioclase and biotite. The chilling at the inner contact of the granite is attributed to subsidence of the central block of volcanic rocks in the liquid granitic magma. The adjacent ***Mullach nan Coirean Granite*** (70; Bailey, 1960) is a leucocratic biotite-granite which predates the Ben Nevis dyke-swarm.

The ***Glencoe*** cauldron subsidence (71; (P915436)) has a volcanic expression at the present level of erosion, except for the Fault Intrusion (Bailey, 1960; Roberts, 1966). This is a north-eastward extension of the Cruachan Granite of the Etive Complex, and is marked by a gradation in texture from coarse-grained tonalite or granodiorite to a microgranodiorite with phenocrysts of plagioclase, hornblende and biotite set in a fine-grained quartzo-feldspathic matrix. A thin band of flinty crush-rock occurs at the inner margin of the Fault Intrusion. The Fault Intrusion was regarded by earlier workers as being disrupted by the ring-faulting, but Roberts (1966) interpreted it as having been emplaced as a fluidised mass of crystals, rock fragments, liquid droplets and interstitial gas, and as having acted as a feeder to the Upper Group 2 and Group 5 ignimbrites of the volcanic succession.



Simplified geological map of the Etive and Glencoe complexes (after Anderson, 1937 and Batchelor, 1987). P915436.

The ***Etive Complex*** (72; (P915436)) is an elliptical composite pluton in which three distinct intrusive phases are recognised (Anderson, 1937; Batchelor, 1987). It was emplaced at a high structural level, between 3 km and 6 m depth (Droop and Treloar, 1981), roughly contemporaneously with the Glen Coe cauldron subsidence. The first phase was the intrusion of several bosses and sheets of basic to intermediate material, ranging from olivine-monzonite (kentallenite) to quartz-diorite. The largest of these, the Quarry Intrusion, consists of medium-grained diorite and quartz-diorite, and forms an arcuate body along the south-east margin, separated from the main pluton by a screen of variably hornfelsed and foliated andesitic lavas with sedimentary intercalations. The second, Cruachan, phase of the complex ranges in composition from monzodiorite in the southern lobe to monzogranite in the northern lobe. The monzodiorite is heterogeneous, medium to fine grained, comprising subhedral, zoned plagioclase phenocrysts with interstital quartz, feldspar, biotite and, more rarely, hornblende. The medium- to coarse-grained monzogranite of the northern lobe is more equigranular, though it locally contains megacrysts of K-feldspar. The facies becomes more silicic and finer grained northwards, grading into the Fault Intrusion of the Glencoe cauldron subsidence. The boundary between the two variants of the Cruachan phase is gradational (Batchelor, 1987). Emplacement of the Cruachan phase appears to have been through cauldron subsidence. The outcrop of the Cruachan phase is cut by irregular sheets and ring-dykes which dip inwards towards the Starav Granite. They are typically fine- to medium-grained pink monzogranites and, more rarely, syenogranites. Collectively they are referred to as the Meall Odhar Granite (Anderson, 1937), and show both sharp and transitional contacts with the Cruachan facies.

The Starav Granite, a body of medium-grained leucocratic monzogranite, was forcefully emplaced into the centre of the Etive Complex, with local development of a tectonic fabric in the earlier

Cruachan phase and its contained microdiorite to felsite dykes. The megacrystic Outer Starav Granite was considered to show a gradational contact with the inner nonporphyritic phase by Anderson (1937) and Bailey (1960). However, the absence of sphene from the inner phase granite contrasts markedly with the outer phase, suggesting that each phase represents a separate pulse of magma. Three petrochemically distinct zones are recognised in the Outer Starav Granite, becoming progressively more acid towards the centre. The Meall Odhar Granite has an arcuate outcrop, and is interpreted as a ring-dyke. Its composition lies close to the eutectic composition in the quartz–albite–orthoclase–water system. It is consanguineous with the Central Starav Granite, and the two bodies are probably contemporaneous (Batchelor, 1987).

The ***Kilmelford Complex*** (73) varies from diorite to granodiorite, with hornblende-tonalite dominant (Peach et al., 1909, pp. 67–71; Hill, 1905, pp. 98–100). There are three closely adjacent areas of outcrop, probably joined to each other at a shallow depth. The complex has a pronounced metamorphic aureole.

The ***Foyers Granite*** (74) consists of two phases: an early fine- to medium-grained tonalite grading into locally porphyritic granodiorite, and a later pink medium-grained nonporphyritic monzogranite (Mould, 1946; Marston, 1971). The intrusion is funnel shaped overall, and the individual phases are irregular and, in places, vein-like in form. The foliation of the surrounding country rocks has been rotated into parallelism with the contacts of the complex pointing to a forceful mode of emplacement. A broad metamorphic aureole, containing sillimanite-bearing hornfelses, and with cordierite-K-feldspar migmatites in the innermost zone, is developed.

The ***Findhorn Complex*** (75) consists principally of of an elongate NE-trending mass of grey, medium- to coarse-grained, foliated biotite-granodiorite containing mafic schlieren and flattened, platy metasedimentary xenoliths. A number of small bodies of texturally heterogeneous pyroxene-bearing diorite and quartz-diorite, associated with a relatively melanocratic hornblende-granodiorite, cut the main granodiorite.

The ***Boat of Garten*** intrusion (76), lying in Strathspey, is largely obscured by drift. It consists of coarse-grained hornblende-biotite-granodiorite with abundant sphene and allanite. Locally it is megacrystic, with pink subhedral alkali feldspar phenocrysts up to 2 cm long.

The major portion of the ***Corrieyairack Complex*** (77) consists of a uniform pink-grey, medium-grained hornblende-biotite-granodiorite containing very few xenoliths (Key et al., 1997). However, the south-western portion is quite different, consisting of medium- to coarse-grained leucocratic granite choked with country-rock xenoliths. The two lithologies are separated by a narrow band of speckled black and white granodiorite. The south-western granite is roughly coeval with the Loch Laggan vein complex. The main granodiorite has not been directly dated but has been suggested to be coeval with the granodiorite phase of the adjacent Strath Ossian Complex (Anderson, 1956).

The ***Allt Crom Granite*** (78) is an elongate body lying between the Corrieyairack and Findhorn granodiorites. Recent mapping has shown that the southern part consists mainly of grey, equigranular biotite-granodiorite carrying large rafts of Grampian Group country rocks; a pink leucocratic monzogranite is present locally as a marginal facies. Further north the intrusion is mainly biotite monzogranite occurring for the most part as a vein complex but with some larger, mappable bodies.

In central Aberdeenshire a group of juxtaposed dioritic to granitic plutons was described by Bisset (1934) as the ***Skene Complex***. The group is now believed to comprise intrusions of several different ages and affinities (Harrison, 1987). The ***Kemnay*** (36), ***Tillyfourie*** (55) and ***Corrennie*** (84), intrusions are probably late-tectonic; they have been described above. The ***Hill of Fare Granite***

(102) is a typical member of the Cairngorm Suite, and is described below. The remaining elements show a range from quartz-diorite to monzogranite, but the ring-structure typical of the Lorn and Lochaber plutons is absent.

The ***Gask*** (79) and ***Torphins*** (80) diorites (Harrison, 1987) consist largely of coarse-grained quartz-diorite and tonalite, but a fine-grained mafic quartz-diorite is present in places, often showing a complex relationship with the coarser-grained facies. The coarse-grained megacrystic ***Crathes Granodiorite*** (81) contains megacrysts of K-feldspar and locally becomes a monzogranite. It contains accessory hornblende and is locally rich in sphene. It is veined by the more melanocratic and finer-grained grey ***Balblair Granodiorite*** (82). The Balblair and Crathes granodiorites cut the Torphins Diorite and the Tillyfourie Tonalite, but are themselves cut by the Hill of Fare Granite. The roughly circular ***Clinterty mass*** (83; Munro, 1986b) consists of white coarse-grained granodiorite to granite.

Several additional granitic intrusions have been recognised during the course of recent mapping in the area to the west of the Skene Complex (Gould, 1997). The ***Logie Coldstone Tonalite*** (85) and ***Tomnaverie Granodiorite*** (86; Read, 1927) are coarse-grained nonporphyritic grey granitoids. The ***Kincardine O'Neil Granodiorite*** (87) forms a group of small bodies of coarse-grained nonporphyritic granodiorite lying within a vein-complex. The ***Lumphanan Granodiorite*** (88) is finer grained and slightly more mafic, resembling the Balblair Granodiorite.

Cairngorm Suite

These plutonic bodies form a distinct suite within the northern Grampian Highlands, extending from the Monadhliath pluton in Strathspey to Peterhead (89–107); they are I-type granites with $^{87}Sr/^{86}Sr$ initial ratios of about 0.706 on the few examples measured. The intrusions comprise many textural varieties of biotite-granite; primary muscovite is rare (Stephens and Halliday, 1984; Plant et al., 1990). Most are pink coarse-grained rocks (the groundmass may reach 20 mm in some phases) and variants containing megacrystic K-feldspar are widespread. However, microgranites, mostly leucocratic and often porphyritic in places, form a sizeable component of some intrusions (e.g. Cairngorm and Mount Battock). Quartz is typically dark grey or brown and smoky and is called 'cairngorm(ite)' where it forms semi-precious crystals in drusy cavities. The main phases within each pluton are usually cross-cut by late pegmatite and aplite sheets and veins; some of these are locally silicified and/or brecciated, with faults in places developed along their contacts. Late hydrothermal alteration caused reddening of feldspars, associated with turbidity of quartz, over wide areas, and affects coarse-grained granites, microgranites and pegmatites. Epidotisation of feldspars, associated with quartz veining and brecciation, occurs in discrete areas. Some of the masses are bounded by faults, e.g. Bennachie. Contact metamorphic effects are small, but extend in places for up to 1000 m from the contact. These aureoles are often poorly developed in rocks previously affected by high-grade regional metamorphism or by the much more extensive contact metamorphism produced by the late-tectonic basic intrusions. Granites which show widespread alteration, the presence of aplitic and pegmatitic phases and abundant vuggy cavities are thought to have been emplaced at relatively high structural levels, possibly 5 to 8 km below surface (Harrison and Hutchinson, 1987). A large negative Bouguer gravity anomaly with an amplitude locally less than -60 mGal extends from the Monadhliath Granite to Mount Battock and Bennachie, indicating the presence at depth of a granite batholith. The exposed granites probably represent cupolas rising from this regional batholith. The thickness of granite underlying the Cairngorm pluton has been estimated at 12 km (Brown and Locke, 1979) but might be substantially thinner. Geochemical and geothermal data suggest that the deeper parts of the intrusions are slightly less acidic (e.g. granodiorite, tonalite) than the biotite-granites presently exposed (Webb and Brown, 1984). Significant, often annular, magnetic anomalies are associated with some of the intrusions (e.g. Monadhliath, Cairngorm, Lochnagar, Mount Battock, Hill of Fare). In some cases these can be ascribed to differences in the magnetite content of different phases of the granites, but in other cases basic rocks at depth or pelitic hornfelses around the margin of the pluton may be the source of the anomaly. The aplitic and pegmatitic phases of the granites show in many cases a marked enrichment in Rb, Li and other large-ion lithophile elements, and depletion in Sr and Ba. The granites of this group show relative enrichment in U and Th compared with the plutons of the South Grampians and Argyll suites.

Harrison and Hutchinson (1987) have made a controversial two-fold division of the post-tectonic granites of the eastern Grampians into an early approximately 415 Ma group in Caledonian magmatism, Grampian Highlands, showing forceful modes of emplacement or with strongly veined and magnetised aureoles, and a later approximately 408 Ma group which shows a more passive mode of emplacement, such as stoping or cauldron subsidence. However, this classification is decidedly speculative, as the mode of emplacement of several of the granites is still uncertain and the variation in trace element geochemistry is as great within the groups as between them. The inaccuracies in the ages quoted in Caledonian magmatism, Grampian Highlands are too large for a reliable division on age alone. Both groups were emplaced at 5 to 8 km depth and show similar ranges of major and trace element and isotope geochemistry.

The ***Cairngorm*** (94), ***Ballater*** (97), ***Mount Battock*** (98) and ***Bennachie*** (103) granites have been investigated (Lee et al., 1984; Webb and Brown, 1984) as a possible source of 'hot dry rock' geothermal energy. Heat flow measurements were made down specially drilled boreholes, and samples from the boreholes and the outcropping granite were analysed for U and Th as well as for major and other trace elements. The results show that the granites have a high heat generation capacity at the levels sampled, but this is believed to decrease considerably in the deeper, unexposed levels of the granites. Combined with the low heat generation of the metasedimentary and basic igneous country rocks this gives rise to a much lower geothermal gradient than in the concealed Caledonian granites of northern England or the Hercynian granites of south-west England.

The ***Saddle Hill Granite***, previously referred to as the Finglack alaskite, is a pink leucocratic coarse-grained granite, which occurs as three small intrusions cutting the Moy granite (47) to the north of Moy (Fletcher et al., 1995).

The ***Auldearn Granite*** (89) is a pink medium- to coarse-grained granite with orthoclase megacrysts. Its contact relations are unknown due to lack of exposure.

The composite ***Ben Rinnes*** pluton (90) crops out almost entirely to the south of the river Spey. The earliest phase, a reddened, foliated K-feldspar megacrystic granite, crops out along the southern and eastern margins, and is cut by a small ellipsoidal intrusion of foliated biotite-microgranite. The central part of the pluton comprises a grey, medium-grained porphyritic biotite-granite, which is locally xenolithic. These phases are cut by a chemically distinct medium- to coarse-grained leucocratic granite, relatively rich in opaque minerals, sphene and allanite, which forms an ellipsoidal mass in the west, and a sheet-like intrusion in the east. To the north of the River Spey, a few small exposures of granite, possibly forming a vein-complex or roof-zone, occur, together with a body of moderately coarse-grained augite-diorite, the Rothes or Netherly Diorite.

The ***Glenlivet Granite*** (91) is a coarse-grained leucocratic pink biotite-granite, with a porphyritic microgranite phase in its western part (Hinxman, 1896, pp. 26–27). A small body of pink biotite-granite has been intruded and altered by the complex appinite–diorite ***Dorback*** intrusion (92; Zaleski, 1983).

The subcircular, stock-like ***Monadhliath Granite*** (93) comprises a main phase of medium- to coarse-grained, variably porphyritic, grey monzogranite and a younger, more evolved fine- to medium-grained biotite-monzogranite. Both phases are cut by sheets and irregular masses of porphyritic microgranite, aplite and pegmatite. Miarolitic cavities, with topaz and cairngorm, are locally abundant in the biotite-granite. The granitic components are highly reddened along NE-trending discrete zones, within which quartz-epidote veins, commonly associated with veins and masses of breccia, are confined (Highton, 1999).

The ***Cairngorm Granite*** (94) is the largest of the Eastern Highlands granites, with an outcrop area of about 365 km^2. It is a steep-sided, stock-like body (Harry, 1965; Harrison, 1986), with an annular high magnetic anomaly pattern. The granite at the surface, however, is mostly nonmagnetic, probably due to alteration associated with the strong reddening of the rocks. The Main Granite is a coarse-grained, variably porphyritic, leucocratic red-pink biotite-granite. It intrudes the earlier coarse-grained, strongly porphyritic Glen Avon Granite, and is itself intruded by the finer-grained nonporphyritic Beinn Bhreac Granite. These three phases are intruded by flat-lying sheets of porphyritic microgranite and by the texturally similar Carn Ban Mor Granite. Pegmatite and aplite sheets and quartz veins cut all of the earlier phases. A layer up to 50 m thick of porphyritic microgranite, containing biotite, muscovite and garnet, is developed in places near the west contact of the Main Granite, possibly indicating local concentrations of volatiles near the contact. The Glen Avon Granite is geochemically less evolved, and poorer in radiogenic elements, than the main body of the intrusion. The contacts of the mass are sharp, subvertical, and cross cut the foliation of the country rock.

Lochnagar (1155 m), south-west Aberdeenshire, from the north. All the high ground in the distance is formed of various phases of the Lochnagar Granite pluton. P220336.

The Lochnagar and Glen Gairn granite plutons are chemically very similar and were emplaced into a zone of small precursor intrusions of diorite and granodiorite which extends from Glen Doll in the south to the eastern end of the Cairngorm Granite in the north. ***Lochnagar*** (95; (P220336)) was previously interpreted as having been emplaced by forceful intrusion and cauldron subsidence mechanisms (Oldershaw, 1974), but recent BGS work has cast doubt on this interpretation; intrusion by passive stoping seems more likely. The Lochnagar granites were emplaced as a zoned pluton of four main phases, each multicomponent. The earliest post-diorite phase was a large pluton of several coarse-grained and porphyritic granites, some containing a little hornblende. Subsequent phases comprise the central pluton of medium-grained inequigranular biotite-granite, which is cut by two bodies of microgranite, and several irregular bodies of very evolved pink and white leucogranites. On the basis of limited geochronological data, Lochnagar appears to be slightly older than the Cairngorm Granite see table in Caledonian magmatism, Grampian Highlands.

The earliest phase of the ***Glen Gairn pluton*** (96) consists of medium- to coarse-grained porphyritic hornblende-biotite-granite with an associated granite vein complex. A later phase, consisting of pink biotite-granite with an extensive aplitic, drusy and pegmatitic marginal facies, forms an arcuate body along the northern boundary of the pluton.

The ***Coilacreich Granite*** (107) consists of a medium-grained, white to pink lithium-mica-bearing granite with an aplitic-pegmatitic facies well-developed close to the margins and roof of the intrusion. Zinnwaldite occurs in a small cupola exposed close to Gairnshiel Lodge (Hall and Walsh, 1972; Webb et al., 1992). Greisen is developed in places, particularly in the zinnwaldite-bearing granite. Associated aplite and pegmatite veins contain pyrite, sphalerite and rare wolframite and beryl. A scheelite- and wolframite-bearing quartz vein complex is also marked by marginal greisenisation of the country rock.

The western part of the ***Ballater Granite*** (97) consists of a pink, medium- to coarse-grained, locally porphyritic granite, whereas the eastern part consists of a very coarse-grained (2 cm groundmass) granite with K-feldspar megacrysts up to 5 cm; Webb and Brown, 1984). The two granite variants show a gradational contact. In the Pollagach Burn, the coarse-grained phase intrudes the pelites, calc-silicate rocks and amphibolites of the Dalradian Tayvallich Subgroup. Wollastonite, diopside, idocrase and grossularite are developed in the calcareous hornfelses, while andalusite, cordierite and, more rarely, sillimanite and corundum are present in the pelitic hornfelses. The granite is cut by a lead- and silver-bearing vein in the Pass of Ballater.

The large ***Mount Battock*** or ***Kincardine Granite*** (98) comprises several irregular intrusions (Harrison and Hutchinson, 1987). The Main Granite is a pink biotite-granite, moderately coarse-grained and nonporphyritic in the western half of the outcrop, but coarser-grained and moderately porphyritic in the eastern half. Bodies of coarse-grained, abundantly megacrystic granite occur in the Birse area and in the vicinity of Clachnaben. A distinctive microgranite with scattered K-feldspar megacrysts up to 40 mm in size, the Water of Feugh Granite, is exposed to the south of the Birse megacrystic granite. A body of fine-grained lithium-mica-bearing granite occurs in the vicinity of Bridge of Dye. Harrison and Hutchinson (1987) suggested that the major phases of the granite are probably fault-bounded, but recent work indicates that faulting is much more localised, although poor exposure precludes establishment of many of the age relationships. There are numerous sheets and veins of microgranite ranging from 1 m to 200 m in thickness and including a relatively biotite-rich variant. Hydrothermal alteration and reddening are widespread, especially to the north and south-west of Mount Keen. The principal phases of the Mount Battock pluton are more mafic and less geochemically evolved than those of the other East Grampians pink granites (Webb and Brown, 1984).

The ***Cromar Granite*** (99) is a roughly arcuate body of pink, nonporphyritic, moderately coarse-grained granite; the ***Cushnie*** (100) and ***Ord Fundlie*** (101) granites are small bodies of similar, but slightly finer-grained granite.

The medium- to coarse-grained pink granite of the ***Hill of Fare*** (102) is intruded into the ***Crathes*** (81) and ***Balblair*** (82) granodiorites along an arcuate contact (Harrison, 1987). There is some evidence of a fine-grained margin along the north-eastern contact. Irregular, often diffuse, patches of variably porphyritic leucocratic microgranite are present in the central parts of the pluton and it is cut, especially in the western part, by a suite of pink aplite sheets. At its south-western contact the Dalradian semipelites are hornfelsed for up to 300 m from the granite.


Granite tors on Mither Tap, Bennachie, Aberdeenshire, with well-marked horizontal and subvertical joints (D 4523). P220488. P220488.

The ***Bennachie Granite*** (103; (P220488); Webb and Brown, 1984) is bounded to the east and west by faults. Other contacts are steep, but some veining of the country rock can be seen in the south-west. The pluton comprises a coarse- to very coarse-grained (5–10 mm), variably porphyritic granite; a separate porphyritic microgranite phase occurs in the western part. The pluton is traversed by N–S-trending veins of reddened, brecciated and silicified aplite, the largest of which is coincident with the eastern contact. Beyond the eastern boundary fault, a number of small occurrences of fine-grained, reddened granite are interpreted as parts of a downfaulted eastern continuation of the Bennachie Granite. One of these, the ***Middleton Granite*** (104; Colman et al., 1989), is cut by quartz veins bearing molybdenum and tungsten mineralisation.

The ***Peterhead Granite*** (105) comprises a pink coarse-grained outer phase and a central finer-grained more-acid phase; both have been cut by microgranite dykes (Wilson, 1886; Buchan, 1934). The Peterhead Granite exposed in the coast section contains large xenoliths of the grey ***Forest of Deer Granite*** (41). Although lithologically similar to the Cairngorm suite, the Peterhead Granite produces a relatively small Bouguer gravity anomaly (-8 Mgal).

The ***St Fergus Granite*** (106) is not exposed at surface, but has been proved in boreholes around the gas terminal site. Veins of pink and white granite crop out on the coast a few kilometres to the north (Peacock, 1983).

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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