Faulting and seismicity, 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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Contents

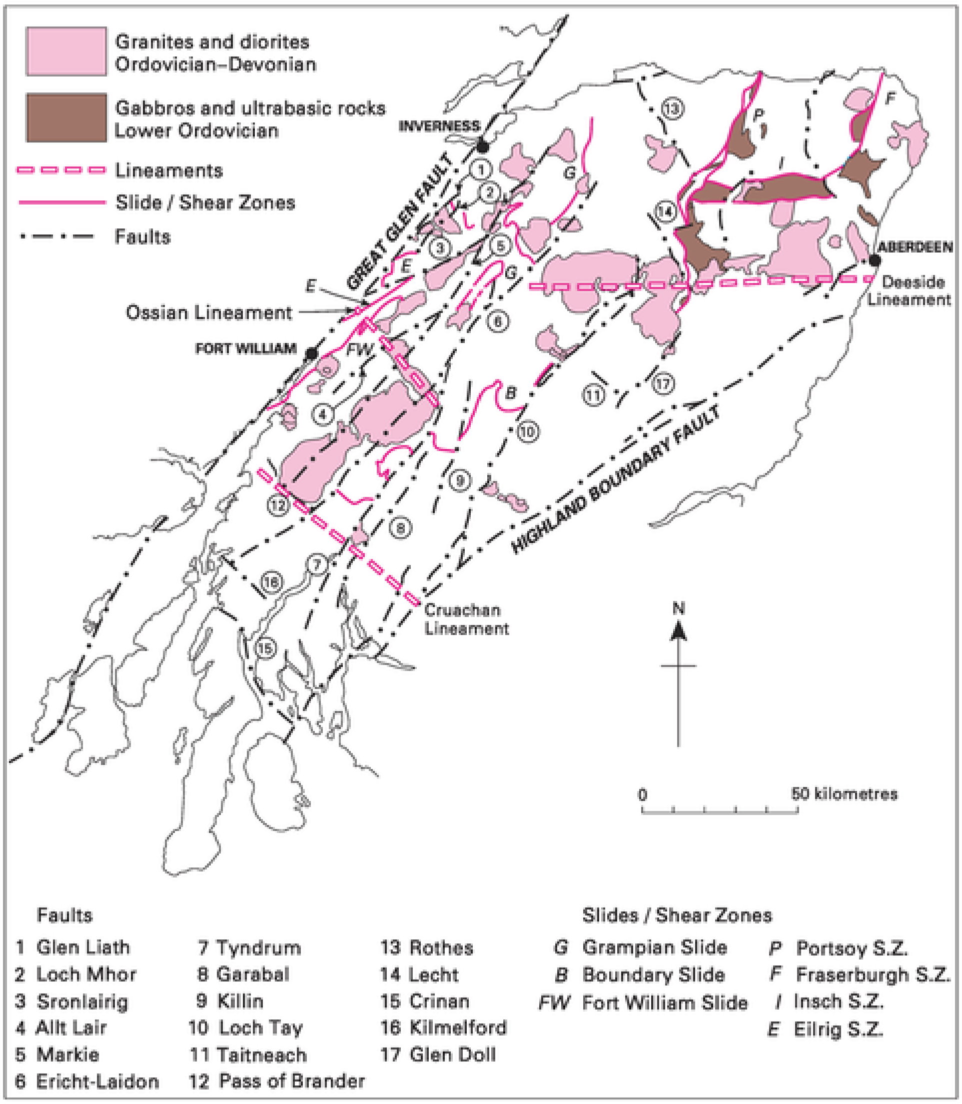
Faulting

The fault pattern of the Grampian Highlands consists of, in order of decreasing age:

Early deduced faults now represented by lineaments of various kinds, which exerted some controls on Dalradian sedimentation.

Ductile shear zones developed at elevated temperatures during the Caledonian Orogeny; represented by zones of mylonites and/or platy shear zones, and including the major slides of the Dalradian (ductile thrusts or lags).

Brittle faults developed towards the end and after the Caledonian Orogeny; the most important are a series of strike-slip faults.



Distribution of lineaments, shear zones and major brittle faults in the Grampian Highlands. P915450.

Early deduced faults

The best-documented member of this group, the *Cruachan Lineament* (P915450) was first described by Graham (1986). The trans-Caledonoid trend of the lineament is strikingly picked out by a steep NW–SE gradient on the Bouguer gravity anomaly map and was interpreted by Graham as marking a change in the nature of the sub-Dalradian basement. The marked decrease in the thickness of synsedimentary basaltic rocks where they cross the lineament emphasises its influence on the sedimentation and igneous activity of the Dalradian.

Fettes et al. (1986), using stratigraphical, structural, geophysical and igneous criteria, subdivided the Dalradian into a number of fault-controlled basins, and showed that some of the faults continued to operate during the deformation and uplift phases of the Caledonian Orogeny. The largest structure, the *Deeside Lineament*, which crosses the Grampian Highlands for a distance of about 100 km, has no surface expression as a fault but is believed to have controlled the intrusion of the East Grampian Batholith.

On a smaller scale, the *Ossian Lineament,* which extends north-westwards from the Ericht–Laidon Fault to the Great Glen, is believed to have acted as a channel for the NW-elongate Strath Ossian Complex and for a suite of appinite plugs and intrusion breccias (Key et al., 1997). It also appears to coincide with lithological facies changes in the Leven Schist suggesting, perhaps, that it existed during Lower Dalradian sedimentation.

Evidence for the renewed movement on some of the early deduced lineaments is provided by the Rothes Fault, (13 on (P915450)) along which there are marked changes in the thickness of the local Upper Old Red Sandstone succession, as well as of the Dalradian across it, indicating synsedimentary activity. The termination of the fault against the Permo-Triassic rocks provides an upper age limit to fault movements.

Ductile shear zones

As has been described in earlier chapters, the Dalradian of much of the Grampian Highlands is dominated by polyphase nappe folding and thrusting, with the development of a number of important and extensive slide zones, among which the *Boundary Slide*, *Grampian Slide* and *Fort William Slide* have been regarded as the most important. The recently recognised *Eilrig Shear Zone* of the Monadhliath Mountains (Phillips et al., 1993) is another. It has, however, long been recognised that the North-east Highlands is somewhat different. The area is characterised by the occurrence of large sheet-like syn-to late-tectonic basic and ultramafic masses (formerly known as the 'Younger Basics') which were partly deformed by the later stages of the Caledonian Orogeny. A detailed study of the area, augmented by magnetic surveys, has revealed the presence of a regional system of steeply inclined shear zones, the major ones, Portsoy, Fraserburgh and Insch (P915450), being located at the margins of these Younger Basics (Ashcroft et al., 1984). In places the shear zones have disrupted the gabbros and rotated originally flat-lying igneous layering into a vertical altitude. Basic mylonites have been formed locally and display steep down-dip extension lineations. Ashcroft et al. (1984) suggest that the main shear zones were in existence prior to the intrusion of the Younger Basics and acted as pathways along which the basic magma was emplaced. They recognised an even older history for the *Portsoy Shear Zone*, with the structure acting as a syndepositional fault during the sedimentation of Argyll Group and Southern Highland Group Dalradian rocks. Recent field work and detailed ground magnetic surveys over the region where the Portsoy and Insch lineaments converge has confirmed the main findings of Ashcroft et al. (1984) and produced firm evidence for the longevity of the shear zones (Fettes et al., 1991). The lack of continuity in Dalradian stratigraphy across the Portsoy Shear Zone, and the restriction of contemporaneous metavolcanic rocks to its immediate vicinity, is taken to indicate the influence of the shear during basin formation, thus influencing the depositional pattern and the subsequent metamorphic and tectonic histories. Some 10 to 15 km to the north-west of the Portsoy Shear Zone, the *Keith Shear Zone* has acted as a focus for the emplacement of granite sheets.

Brittle faults

The Grampian Highlands form a block sharply delineated to the north-west and south-east by the two largest and most important fractures in Scotland– the Great Glen Fault and the Highland Boundary Fault respectively, and contain a number of other major faults with a subparallel trend (P915450).

Research into the timing, sense of movement and amount of displacement of the *Great Glen Fault* has been almost continuous since Kennedy's conclusion that it is a major transcurrent fault with a sinistral displacement of about 100 km (Kennedy, 1946). A full account of the history of research is given in Johnstone and Mykura (1989). Numerous solutions, some speculative, have been advanced but the current consensus is that a main phase of sinistral transcurrent movement occurred at the end of the Caledonian Orogeny (Silurian) with reactivation, mainly as a normal fault, during and after deposition of the Old Red Sandstone (Smith and Watson, 1983; Rogers et al., 1989). Minor normal adjustments in the Permo-Triassic were followed by a period of limited dextral shift during late Triassic–early Cretaceous times (McQuillin et al., 1982; Andrews et al., 1990). That the Palaeogene Mull dyke swarm crosses the fault without deviation (Speight et al., 1982) suggests that, in the area of Mull at least, significant movement had ceased prior to dyke intrusion at 52 Ma. A much longer history for the Great Glen Fault was suggested by Bentley (1988) who proposed that it had earlier acted as a strike-slip terrane boundary along which the 1800 Ma Rhinns terrane of Islay became juxtaposed against the Lewisian terrane before the deposition of the Dalradian.

The *Highland Boundary Fault,* which defines the contact of the Grampian Highlands with the Midland Valley graben to the south-east, also appears to have had a long and complex history. It is marked by the presence of discontinuous, fault-bounded slivers of Cambro-Ordovician ophiolitic rocks known as the Highland Border Complex (see Chapter 9). The absence from these rocks of clasts from the adjacent Dalradian rocks to the north-west, which were being uplifted and eroded during the Ordovician, suggests that the emplacement of the Highland Border Complex and the juxtaposing of the Grampian Highlands and Midland Valley took place in Silurian times (Bluck, 1985). There is little convincing structural evidence as to the mechanism of emplacement, but most recent authors favour large-scale strike-slip movements (e.g. Harte et al., 1984).

Subsequent movements on the Highland Boundary Fault during the Devonian and Lower Carboniferous were mainly normal, with downthrow to the south-east into the Midland Valley graben (Cameron and Stephenson, 1985; Paterson et al., 1990). East–west late Carboniferous quartz-dolerite dykes cross the fault zone without displacement, indicating that movement had effectively as ceased by that time, about 300 Ma (Anderson, 1947b; George, 1960).

Within the Grampian region the most prominent group of faults are those with a north-easterly trend, subparallel to the Great Glen and extending eastwards as far as the Glen Doll Fault (17 on P915450). On the basis of their trend, and the fact that several of them show a sinistral sense of movement, they have been genetically linked to the Great Glen Fault and accorded a similar age and history of movement. Watson (1984) emphasised the longevity of this fault set and stressed how reactivation might obscure evidence for early movements. The Glen Liath (1), Loch Mhor (2), Ericht–Laidon (6) and Tyndrum (7) faults all display a phase of movement older than the granites which they cut and Watson proposed that many of the main-phase Caledonian granites in the western Grampians used these fault fissures as pathways for intrusion.

Recently Treagus (1991), in a detailed study of the Ericht–Laidon (6), Tyndrum (7), Garabal (8), Killin (9) and Loch Tay (10) faults, has proposed that some of them were generated on the limbs of late ductile folds during the final stages of the Caledonian Orogeny. Thereafter, the main movements on the faults were dip-slip with a cumulative downthrow to the east of about 7 km, followed by a sinistral strike-slip phase with a cumulative displacement of 23 km.

The last significant movements on the Great Glen set of faults within the Grampian block are generally thought to have taken place at the end of the Caledonian Orogeny when the compressional ductile phase gave way to a period of vigorous brittle uplift and erosion. Regeneration of the Glen Liath Fault during the deposition of Middle Old Red Sandstone sediments (Mykura, 1982), and the presence of a mini-graben at the north-west end of the Markie Fault *(5)*, attest to active faulting during Old Red Sandstone times.

By the end of the Devonian the eroded remnants of the Grampian block formed a topographic high on which little subsequent sedimentation took place. In Kintyre, the Devonian and Carboniferous rocks have been affected by faulting along various trends. There is evidence from the Carboniferous strata that some movement occurred during the Dinantian and Namurian. Only on the northern coast, where the southern margin of the Mesozoic Moray Firth Basin encroaches on to the land, is there evidence for substantial displacement of Permo-Triassic and Jurassic sedimentary rocks, by east–west normal faults. The most recent faults to affect the Grampian block are in the south-west, of which the Crinan *(15)* and Kilmelford *(16)* faults are the most prominent. They are contemporaneous with the intrusion of the Palaeogene dyke swarm which crosses the region without deviation and testify to the absence of any significant post-Palaeogene fault movements.

Seismicity

While from an examination of the structural geology one might expect the seismicity of the region to be reasonably uniform, such is far from the case. The west coast, particularly the area from Oban to Dunoon, is one of the most seismically active parts of Scotland (or Great Britain for that matter), while the east coast and Central Grampian Highlands are virtually free from earthquakes, only experiencing the vibration from earthquakes occurring elsewhere in Scotland or in the North Sea. The earthquake of 28 November 1880, with epicentre between Oban and Inveraray, is the largest known Scottish earthquake, with magnitude 5.2 on the Richter Scale. The largest recent earthquake in the Grampian Highlands area was the Oban earthquake of 29 September 1986, magnitude 4.1, which was widely felt along the west coast. An earthquake on 16 September 1985, magnitude 3.3 had an epicentre near Ardentinny and may have been associated with a NE-trending fault zone in the Loch Long area.

The reason for the localisation of earthquake activity is unclear, but there is a strong probability that it relates to old faults having been reactivated at the conclusion of the Loch Lomond Readvance phase of the last glaciation, and having remained active in the present regional stress regime.

The two major faults bounding the Grampian region, the Great Glen Fault and the Highland Boundary Fault, have long been assumed to be seismically active. This assumption has not withstood scrutiny. Many earthquakes formerly attributed to the Great Glen Fault have now conclusively been shown to have had their epicentres well away from it. This leaves the Inverness earthquakes of 1816, 1890 and 1901 which may have been caused by movement on a fault splaying northwards from the Great Glen Fault in the Aird area south-west of Inverness.

The other notable site of seismic activity is at Comrie, Perthshire, which is remarkable for its earthquake swarms, at the height of which scores of small earthquakes might occur in a single day. Two such swarms are well documented, the first lasting from 1788 to 1801, the second from 1839 to 1846. There may have been a previous swarm in the early 17th century and possibly another in the early 13th century. Since 1846 activity has been limited to a few small events at sporadic intervals. The largest of the well-documented Comrie earthquakes was that of 23 October 1839 (magnitude 4.8).

Traditionally, the Comrie earthquakes have been attributed to the Highland Boundary Fault, but this does not explain why this fault should produce earthquakes only at Comrie and nowhere else along the rest of its length. It is equally possible, and perhaps more likely, that some other fault, just north of Comrie, is responsible.

The 1839–1846 earthquake swarm is particularly remarkable for the scientific interest it aroused, and a number of early seismological advances were made in Scotland as a result. These included the first inverted pendulum seismometer, the first use of the word ‘seismometer’, the first seismometer network, and the first purpose-built seismological observatory (now restored and a tourist attraction at Comrie).

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