Faults, Northern Highlands of Scotland

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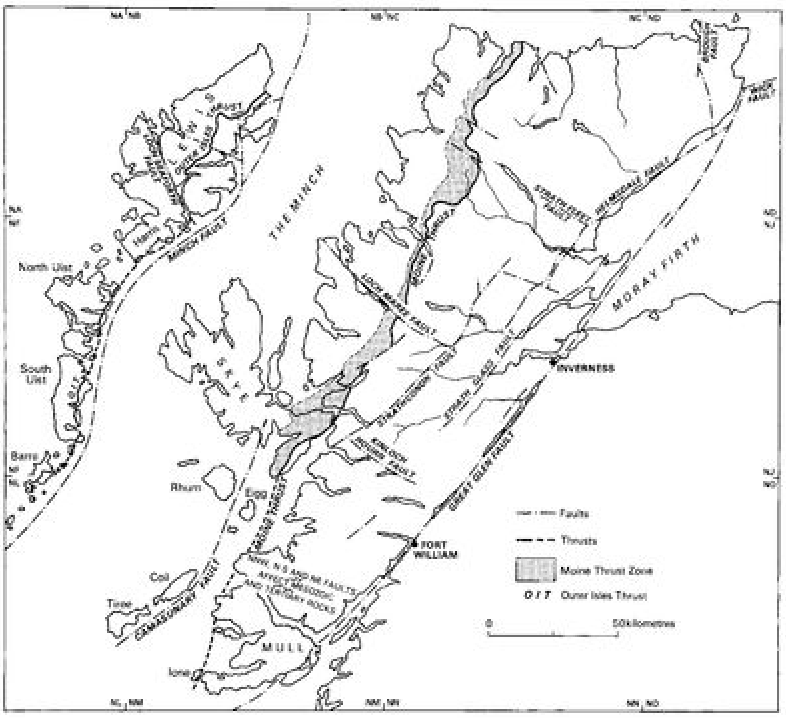
Faults, introduction



Major faults in the Northern Highlands and Hebrides.
P915505.

Numerous faults, major and minor, traverse the rocks of the Northern Highlands. Many affect only the older rocks, being unconformably overlain by younger formations or cut by unbroken intrusions and so can be related to specific episodes of crustal fracture, but it is also clear that many of ancient origin have been reactivated during later periods of movement.

Lines of Pre-Torridonian shear

The earliest fault-like features identified are planes of pre-Torridonian shear within the Lewisian gneiss of the Foreland (Peach and others, 1907). Properly speaking, these are not faults along which fracture has taken place at the level of crust now exposed. They are planes of ductile shear, trending NW–SE, in which rocks in narrow zones show grain-size reduction, mylonitisation and, in places, the development of flinty crush (pseudotachylite); they do not affect the overlying Torridonian strata. Certain of the shear planes may have acted as zones of weakness which guided the lines of the Caledonian faults (see below). Only two major structures are sufficiently defined to be shown separately on P915505. These are the Loch Seaforth Fault in Lewis and the Loch Maree Fault on the mainland.

Park (1961) and Peach and his colleagues noted less distinct areas of pseudotachylite development which are possibly of the same age as the more defined shear lines. Watson (1984) suggested that post-Caledonian faulting along the line of Loch Shin has been guided by a pre-Caledonian basement structure which, with others in the Scottish Highlands, she considered to be related to fundamental fractures in the lower crust.

Late-Caledonian faults

The main phases of Caledonian folding and igneous emplacement were followed by a period of crustal uplift and cooling during which ductile deformation gave place to block fracturing, with displacement either in a vertical or lateral sense (or both). Of the faults of this age the best-marked in the Scottish Highlands comprise two major groups whose trend are respectively NE–SW and NW–SE. In the Northern Highlands the NE-SW suite predominates. The NW–SE faults are less prominent, though in addition to those recognised by belts of crush and shift of strata, topographic lineaments suggest that there may be others (Auden, 1954; Watson, 1984).

Where relative sense of movement can be made out, it can be seen that there is an apparently straightforward arrangement of lateral sinistral slip on faults trending NE–SW and dextral slip on those trending NW–SE. The faults were formerly considered to represent a conjugate set resulting from the resolution of northsouth directed 'Proto-Armorican' stress (Anderson, 1942). Watson (1984), however, came to a different conclusion. She pointed out that the NE–SW set is dominant both in number of faults and amount of displacement and, in the Scottish Highlands as a whole, the faults of the suite seem to be the locus of emplacement of a group of Caledonian granites, which indicates a fundamental association with the Caledonian orogeny. Moreover, some of the NE–SW faults appear to have existed before, or determined, the development of basins of Old Red Sandstone deposition (Mykura, 1983a; 1983b). Watson accordingly suggested that the NE–SW sinistral-slip faults were initiated as deep-seated crustal fractures at the time of continental collision following the closure of the Iapetus Ocean in late-Silurian times. These deep-seated structures gave rise to variations in local strain which, in certain cases, facilitated the rise of late orogenic granites. The NW–SE faults are not essentially conjugate to the NE–SW suite but represent small-scale adjustments determined by pre-existing lines of pre-Caledonian (or 'pre-Torridonian') shear in the Lewisian basement. She speculated that the set of E–W joints which are a prominent feature in the Northern Highlands could be fractures conjugate to the NE–SW faults.

The main phase of movement on these transcurrent faults is thought to be pre- Devonian or early Devonian (D. I. Smith and Watson, 1983; Watson, 1984), but transcurrent movement continued to a lesser extent after the formation of the Old Red Sandstone basins. The NW–SE-trending faults show differential displacement of variously inclined strata of the Foreland and the Moine Thrust Belt, which indicates that vertical as well as horizontal movement has taken place (Coward, 1983) and this is probably also true of the faults of the NE–SW set (Mykura, 1983a;b).

By far the most important fault of the NE–SW group is the Great Glen Fault, which, once initiated as a fundamental fracture in Caledonian times, has been reactivated, with varied displacement, during subsequent periods of earth movement; and it is still active. Its net sinistral shift was considered by Watson (1984) to be about 100 km (see below). The other transcurrent faults, of both the NW–SE and NE–SW sets, show displacement of only a few kilometres at the most.

The larger faults have marked zones of cataclasis which have been eroded to form linear topographic features. As mentioned above, other linear features with no clear effect on the distribution of strata may mark the lines of concealed crushes or belts of broken rock. Several such zones (not clearly related to mappable faults) were encountered in hydroelectric tunnels in the Northern Highlands.

Post-Caledonian faults

A. G. MacGregor (1967) has analysed the fault systems of the south-west part of the Northern Highlands and finds evidence for an E–W suite of faults which he considers were initiated in Permo-Carboniferous times. However, they may represent activation as faults of the E–W joints referred to above.

The basins of Mesozoic rocks (including the Permo-Trias) of the Minch, Sea of the Hebrides and Malin Sea (see Chapter 13) are controlled by NNE– SSW-trending faults throwing down to the east, defining half-grabens in which deposits thicken to the west. The faults were probably initiated during the initial stage of the breakup of the large 'supercontinent' formed after the closure of the Iapetus Ocean (the breakup eventually resulting in the opening of the Atlantic). Of these faults, the Minch Fault (inferred from offshore studies) and the Camasunary Fault of south Skye are important members. Brewer and Smythe (1984) suggest that the location of the NNE–SSW faults of the Minch may be determined by pre-existing thrusts in the basement, while the age of the last movements on the Camasunary Fault seems to be established by the fact that its line, if continued northwards, does not cut the Tertiary Red Hills Complex of Skye.

The Mesozoic basin of the Moray Firth has been related to the widening of the North Sea Viking and Central grabens by rotation of the Northern Highlands block along the line of the Great Glen Fault with resultant dextral movement of 8 km (McQuillin and Donato, 1982). The Helmsdale Fault, limiting the Mesozoic rocks of the North Sea on their landward side, has a similar orientation to its counterparts on the western seaboard.

A. G. MacGregor (1967) recognised two sets of faults oriented N–S and NW– SE, to which he assigned a Tertiary date of movement.

The Great Glen Fault

The Great Glen Fault is such an important feature both geologically and topographically that it has attracted special attention and has an extensive literature. It consists of a zone of crushed rock (now represented mainly by indurated cataclasite) up to 0.5 km wide, flanked by zones of minor faulting and shattering. On the Northern Highlands side of the fault the zones of shattering extend up to about 1 km beyond the crush-zone. This broken rock has guided erosion to form the deep linear depression of the Great Glen, the floor of which rises to only c.40 m above OD but whose sides rise steeply up to 900 m; and the ground-level is even higher only a few kilometres away. Along this trench lie freshwater lochs, one of which (Loch Ness) is more than 200 m deep. The depression traverses the country from the Moray Firth to the Firth of Lorn, and a linear gravity anomaly indicates the south-westward continuation of the Great Glen Fault under the Mesozoic rocks of south-east Mull and thence offshore past the north end of Colonsay, possibly continuing across the

Malin Sea to pass north of Ireland (Evans and others, 1979). North of Inverness the Great Glen Fault runs along the eastern shore of the Black Isle and the Tarbat Ness peninsula, and further north again the gravity anomaly indicates that it hugs the coast of Caithness. Just north of Wick, however, the course of the anomaly cannot be traced beyond the ENE-trending Wick Fault; the suggested continuation of the Great Glen Fault towards the Walls Boundary Fault of Shetland (Flinn, 1961; Mykura, 1975) has not been confirmed by offshore geophysical studies.

It was W. Q. Kennedy (1946) who first suggested that the Great Glen Fault is a major sinistral wrench fault. Using various criteria, including the shift of the metamorphic zones of the Scottish Highlands north and south of the Great Glen, and the possible former connection of the Strontian and Foyers Granites (apparently cut into two halves and displaced by the fault), he estimated a sinistral displacement of 104 km. However, though the two granite plutons contain similar rock types, the lack of a precise fit of their component members (Marston, 1971; Munro, 1973) and differences in their trace-element content (Pankhurst, 1979) and zircon distribution patterns (Pidgeon and Aftalion, 1978) suggest that they were never joined. The presence of two similar complexes adjoining a major fracture could be accounted for by the preferential location of plutons along the NE faults, as suggested by Watson (1984) and referred to earlier. Winchester (1972) suggests a large sinistral displacement of the metamorphic zones which he has refined and amplified from the initial studies of Kennedy. Piasecki and Wright (1981) likewise postulate a large pre-Mesozoic sinistral (c.160 km), based on analogous structural and stratigraphic features within the Northern Highlands. While much of the evidence for the amount of displacement along such a large fault must be open to more than one interpretation, the fact that a certain amount of sinistral slip has taken place can be shown by small-scale deflections of granite veins in the shattered rocks within the faulted zone. However, these never amount to more than a few decimetres.

Johnstone and Wright (1951) noted that the Permo-Carboniferous dykes cut the major crust rocks of the central fault zone but were themselves only broken, thus setting an upper age limit to the formation of the crush zone. Holgate (1969) postulated a considerable dextral shift of the Permo-Carboniferous dyke swarms across the fault, and Speight and Mitchell later (1979) suggested that this shift was of the order of 6–8 km. Presumably this displacement took place along defined lines within the earlier zone of crush and shattering. Some of the dextral displacement along the fault appears to have taken place during the Mesozoic, and McQuillin and Donato (1982) have linked this with a 5–6 km distension of the Moray Firth Basin and the formation of the Viking and Central grabens of the North Sea. They estimate an 8 km dextral shift along the line of Great Glen.

Other opinions concerning the movement along the Great Glen Fault have been advanced by various authors. Garson and Plant (1972) proposed a major dextral shift. Their interpretation suggested that, before movement along the Fault, the E–W-trending north coasts of the Northern Highlands and the Grampians were in line with one another. They supported this hypothesis by what they considered was displacement of a subduction-related zonal distribution of granite plutons, metamorphic zones and old suture lines. Van der Voo and Scotese (1981) used dissimilarities in pole directions of the magnetism of Old Red Sandstone strata on either side of the Great Glen to suggest a sinistral shift of 2000 km. This view, however, is at considerable odds with the most likely interpretations of the crustal structures of Northern Britain (see among others Watson and Smith, 1983, and the review by Watson, 1984, referred to above). Storevedt (1987), using re-interpreted and new palaeomagnetic data, deduced that there was a 600 km late Caledonian sinistral displacement on the Great Glen Fault and a 300 km Hercynian dextral displacement.

If the magnitude of displacement suggested by Piasecki and his colleagues is accepted, then the Moine Thrust zone south of the Great Glen Fault would coincide with the line of the Great Glen from Fort Augustus southwards. The presence of a wide zone of early SE-dipping thrusts and mylonites in the area between Fort Augustus and Spean Bridge lends support to this concept.

Selected bibliography

Tools