Highland Border Complex, 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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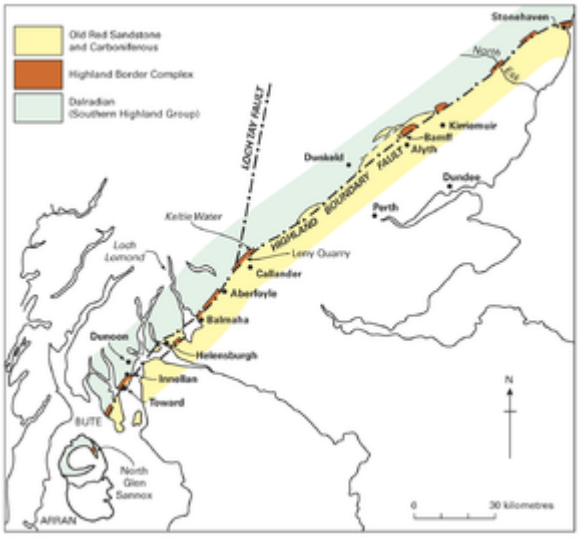
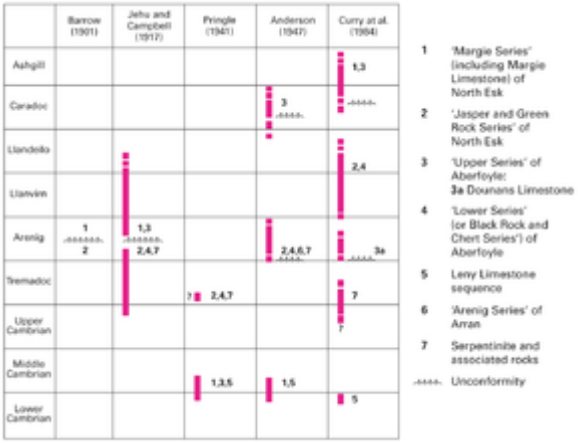
Highland Border Complex

The Highland Border Complex comprises a group of highly varied lithologies: igneous and meta-igneous rocks, terrigenous mudstones, black shales, quartz arenites and minor limestones. The rocks occur as a series of generally fault-bounded slivers, ranging from a few metres to several kilometres in size, along the Highland Boundary Fault Zone between Stonehaven and Arran (P915438). They were originally referred to as the 'Highland Border Series', following the work of Barrow (1901). The term 'series' is now considered inappropriate for lithostratigraphical units and the terms Highland Boundary Complex (Henderson and Robertson, 1982) or Highland Border Complex (Curry et al., 1984) have been proposed instead, the latter being the more commonly used. Subdivisions of this group of rocks have also in the past been called various 'series'; some of these are quoted in the following text, although most have now been renamed as 'formations' or informal 'assemblages'.



Distribution of Highland Border Complex rocks. P915438.



Evolution of the stratigraphical interpretation of the Highland Border Complex rocks. P915439.

Lithology

The following account draws heavily on descriptions provided by Henderson and Robertson (1982), and Robertson and Henderson (1984). Where not otherwise referenced data have been taken from these two sources.

Igneous rocks

Ultramafic rocks, commonly with faulted contacts against other lithologies, occur at several localities along the Highland Border. They are invariably altered to serpentinites and carbonate-quartz rocks. The ultramafic rocks were derived mainly from harzburgites. Basic plutonic rocks or their metamorphic equivalents are present at a number of localities. Albitised gabbros occur at Aberfoyle in association with serpentinites (Jehu and Campbell, 1917) and amphibolites thought to be altered equivalents of gabbros are found in Arran. Hornblende-schists, of tholeiitic affinity and locally garnetiferous, are found at Aberfoyle and at Scalpsie Bay in Bute. At both localities the hornblende-schists are in contact with serpentinite. Immediately adjacent to the serpentinite at Aberfoyle the hornblende-schist belongs to the lower amphibolite metamorphic facies, the metamorphic grade falling to green-schist facies away from the contact (Henderson and Fortey, 1982). Basic volcanic rocks, commonly with intercalated sedimentary rocks, occur locally in the Highland Border Complex, notably at Stonehaven, the River North Esk and in Arran. The lavas are commonly altered to spilites and may be pillowed or massive. Brecciated lava has been described from Arran. Two magmatic types have been distinguished, one with mid-ocean ridge basalt (MORB) characteristics, the other of 'within plate' chemistry; the hornblende-schists are chemically identical to the MORB lavas.

Sedimentary rocks

The sedimentary rocks may be described in three groupings, namely, 'Margie unit', interlava sediments and 'Loch Lomond clastics'.

The 'Margie unit' is the predominant lithological group (and is not to be confused with the obsolete lithostratigraphical term 'Margie Series' (P915439) and occurs extensively within the Highland Border Complex. It consists for the greater part of quartzose arenites with subordinate black shales and minor limestones (the most prominent being the Margie Limestone). Lithologically the group is

similar to rocks of the Dalradian Southern Highland Group and distinguishing between the two has caused considerable confusion.

The interlava sedimentary rocks consist of siltstones, mudstones and cherts, the majority of which originated as terrigenous muds deposited as distal turbidites with a subordinate amount of locally derived, largely volcanic, detritus. Certain iron-rich sedimentary rocks are regarded as hydrothermal precipitates.

The 'Loch Lomond clastics' is an informal term covering all rocks containing notable amounts of basic and ultramafic detritus. The grouping contains a number of small but stratigraphically significant units; these include the serpentinite rudites at Balmaha (Henderson and Fortey, 1982); the Loch Fad Conglomerate on Bute, which consists mainly of greywacke boulders with subordinate clasts of serpentinite; the basement breccias at Aberfoyle, which contain clasts up to 1 m in length of shale, limestone and volcanic material (Jehu and Campbell, 1917); the Dounans Conglomerate near Aberfoyle, which contains rare gabbro detritus (Henderson and Robertson, 1982); and the Green Conglomerate of Pringle (1941) in the North Esk, which contains clasts of lava, hornblende-gabbro and chert.

Stratigraphy

Elucidation of the stratigraphy of the Highland Border Complex is greatly complicated both by relatively poor exposure and by the faulted contacts within the complex and the consequent tectonic repetition of units. led to a wide variety of interpretations and correlations over the years (see P91543931 and reviews in Anderson, 1947b, Curry et al., 1984) and present understanding of the stratigraphy and relationships between the various components of the Highland Border Complex is still incomplete.

The first attempts to interpret the stratigraphy were made by Barrow (1901) and Jehu and Campbell (1917) working in the North Esk–Stonehaven area and the Aberfoyle area, respectively. They both recognised a group of lavas, black shales and cherts, apparently overlain by a group of coarse arenites and shales with subordinate but stratigraphically significant limestones. Pringle (1939), using the evidence of sedimentary structures, reversed the two groups placing the arenite-dominated sequence as the older. Pringle also determined a palaeontological age of late Lower Cambrian for the Leny Limestone at Callander (see also Cowie *et al.*, 1972) which he believed to be the correlative of the limestones at Aberfoyle and the North Esk.

This view was accepted and expanded by Anderson (1947) in an extensive examination of the Highland Border. Anderson was impressed by the similarity between the Dalradian rocks and the adjacent arenite sequences of the Highland Border Complex and proposed that the latter (including the limestones) formed the uppermost part of the Dalradian sequence, which was therefore of Cambrian age. These Dalradian rocks he regarded as unconformably overlain by the black shale and lava sequences which he believed to be of Ordovician age.

In recent years, however, intensive palaeontological investigations of the Highland Border rocks have radically revised the stratigraphy. The results of this work are summarised in Curry et al. (1984), who suggest that the Highland Border Complex rocks rest unconformably on the Dalradian succession and range in age from Lower Cambrian to uppermost Ordovician. They divide the Highland Border Complex into four lithostratigraphical groupings (P915439). The first group comprises the serpentinites and associated ophiolitic rocks which are believed to be of pre-Arenig age. The black shale and limestone sequences of the Leny area, which are accepted as late Lower Cambrian age, may also be part of this grouping. The second group, of early Arenig age, comprises the serpentinite conglomerate at Balmaha, the Dounans (or Lime Craig) Conglomerate and the

Dounans Limestone at Aberfoyle. The third group consists of the black shale and lava sequences which are ascribed a Llanvirn–Llandeilo age. This group is unconformably overlain by the youngest assemblage which comprises the arenite-dominated sequences (including the Margie Limestone). This last group is believed to be of Caradoc–Ashgill age; its base is an unconformity marked by the basal breccia of Jehu and Campbell (1917) at Aberfoyle and possibly the Green Conglomerate in the North Esk. Curry et al., (1984) point out that the upper group contains blackened and deformed fossils of Llanvirn–?Llandeilo age and unblackened fossils of Caradoc age. This is taken as evidence of a pre-Caradoc period of low-grade metamorphism and uplift.

The black shale and limestone sequences exposed around the Leny quarries are recognised to be of Cambrian age. However, their status within the Highland Border Complex stratigraphical sequences is complicated by their relationship to similar sequences in the nearby Keltie Water and the relationship between these sequences and the adjacent Dalradian rocks. Two factors are important in considering the problem. Firstly, detailed mapping by Pringle (unpublished manuscript, deposited with BGS) suggests that the Leny Limestone is the correlative of the limestones in the Keltie Water (cf. Harris, in discussion of Rogers et al., 1989); secondly, the black shales and limestones in the Keltie Water can be traced with apparent conformity into the underlying Dalradian grits (Anderson, 1947, p. 495; Harris, 1969). However, Rogers et al. (1989) have published a U-Pb zircon age of 590 Ma as the date of intrusion of the Ben Vuirich Granite; this granite cuts early structures in the Dalradian rocks, implying that the Dalradian sequence and its earliest deformation phase(s) are Precambrian. This apparent contradiction in the available evidence is still unresolved.

Structure and metamorphism

Much debate has centred around the structural and metamorphic setting of the Highland Border Complex and its relationship with the Dalradian. Barrow (1901) originally separated the arenite sequences of the North Esk from the adjacent Dalradian rocks on the presence of clastic micas in the Highland Border Complex rocks and their absence from the Southern Highland Group rocks. This view, however, was not supported by subsequent workers. Jehu and Campbell (1917) suggested that the relatively high metamorphic grade of the hornblende-schists at Aberfoyle reflected locally greater cover and more intense shearing than in the adjacent rocks. Anderson (1947), in support of Clough (1897), noted that the Dalradian phyllites at Inellan, south of Dunoon, showed evidence of contact metamorphism at their junction with a serpentinite body. In general Anderson (1947) regarded the degree of metamorphism and ‘intensity of cleavage development’ as similar in both the Highland Border Complex and Dalradian rocks. A structural analysis of the North Esk section led Johnson and Harris (1976) to the conclusion that the earliest fold phase to affect the Dalradian was the same as the earliest phase recognised in the Highland Border Complex, thus in effect supporting Anderson’s (1947) view. Harris (1969) argued that the Leny Limestone had a similar deformational history to the neighbouring Dalradian sequences.

Henderson and Robertson (1982) suggested that the carbonation of the serpentinites was an early event and had started before deposition of the serpentinite rudites at Balmaha. They also noted that the Dalradian rocks have been subjected to four major phases of regional deformation (see Harte et al., 1984) and considered the relationship of the Highland Border Complex to the Dalradian events, basing their arguments on a number of points. Firstly, they regarded the contact metamorphism of the Dalradian phyllites at Inellan as overgrowing the earliest Dalradian fabrics (D_1) with the porphyroblasts lineated and deformed by the second phase-structures (D_2), the degree of deformation increasing towards the serpentinite. They also recognised similar relationships at Toward, south of Dunoon, and at Scalpsie Bay on Bute. Secondly, they described high-strain zones, or mylonites, at a number of localities throughout the Highland Border Complex, including Arran, where folded mylonite zones and downward-facing structures were identified. These observations,

along with regional considerations, led Henderson and Robertson (1982) to suggest that the Highland Border Complex rocks had been brought into contact with the Dalradian on a series of thrusts, probably during the regional D_2 event. Frictional heat arising from the thrusting, allied to possible residual heat within the Highland Border Complex rocks, led to the development of the observed contact effects, analogous to effects on the soles of other obducted ophiolitic sequences (Henderson and Robertson, 1982; Curry et al., 1984). However, the presence of Caradocian fossils in parts of the Highland Border Complex, taken in association with the radiometric age (see above) which indicates that the early regional deformation in the Dalradian took place in the late Precambrian, makes the above structural interpretation untenable (Robertson and Henderson, 1984; Harris, 1991).

In an examination of the contradictary radiometric, structural and metamorphic evidence Harte et al. (1984) concluded that there was no good evi– dence that the Highland Border Complex rocks had a common structural history with the Dalradian rocks, at least before the regional D_4 event at about 460 to 440 Ma (see also Curry, 1986). Although the structural model of Henderson and Robertson (1982) has been largely abandoned, their interpretation that the contact metamorphic effects seen at Dunoon and elsewhere are the result of the tectonic emplacement of the Highland Border Complex rocks against the Dalradian is still regarded as generally valid (e.g. Curry et al., 1984).

Tectonic setting

The early workers, including Anderson (1947), regarded the Highland Border Complex as essentially an upward extension of the Dalradian succession, the variable lithologies reflecting basin development with minor tectonism responsible for unconformable relationships.

The emergence of modern plate tectonic theories and the new evidence on the stratigraphy and structure of the complex have greatly changed modern interpretations of the tectonic setting. The Highland Border Complex was envisaged as developing initially within a marginal basin on the north side of the Midland Valley block (Longman et al., 1979). Robertson and Henderson (1984), basing their arguments largely on the chemistry of the rocks, suggested that the rocks of the complex developed in a small marginal basin next to a continental massif (analagous to the present Gulf of California) and were subsequently emplaced onto the Dalradian nappe pile. Curry et al. (1984) suggest that the Highland Border Complex formed in a basin on the landward side of a volcanic-arc massif, possibly in a faulted or fragmented basin, with subsequent obduction, faulting and deformation movements. Harte et al., (1984) concluded that the Highland Border Complex could not easily have been brought into thrust contact with the Dalradian and that it was probably emplaced against the Southern Highland Group rocks as part of a regional strike-slip regime allied to periodic uplift, the movements taking place in the late Ordovician and subsequent to the nappe-forming events in the Dalradian succession.

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