Central Grampians Complex, Grampian Caledonides

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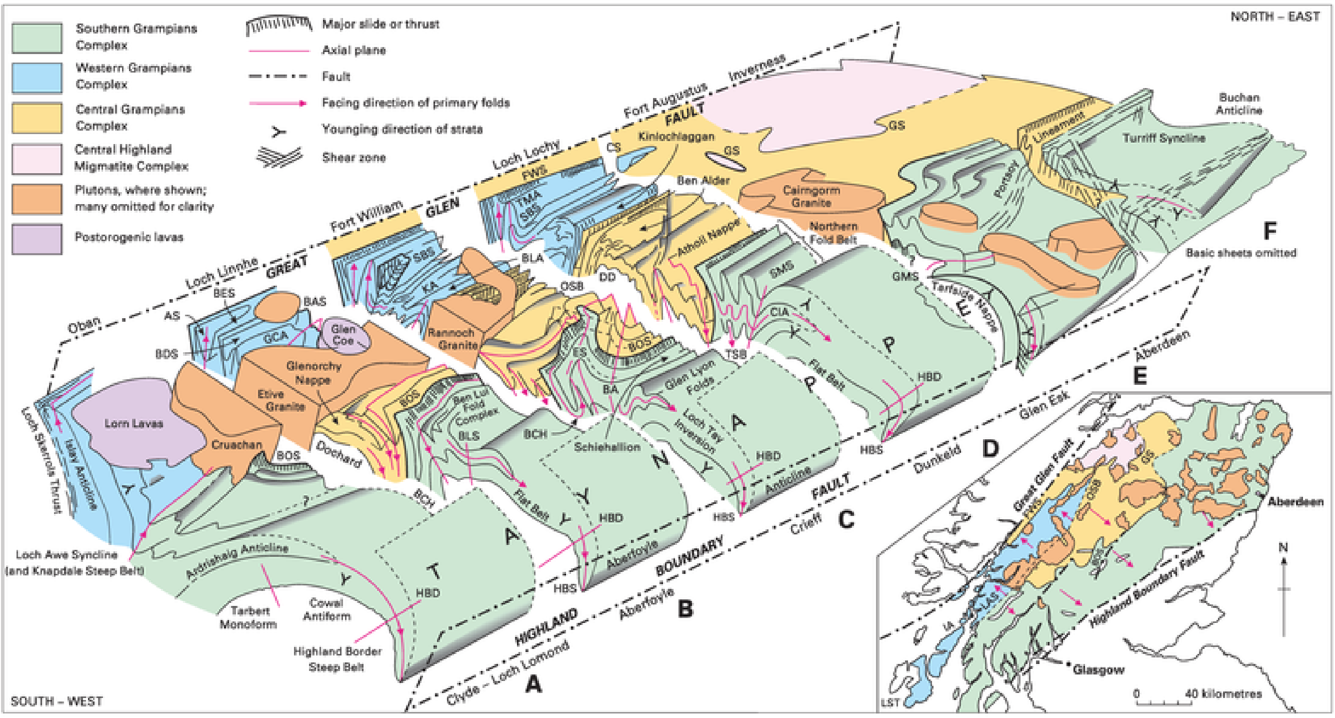
Central Grampians Complex

The Central Grampians Complex corresponds broadly to Bailey's 'Sub-Eilde Complex' which was defined as all rocks stratigraphically below the level of the Eilde Quartzite. It therefore consists almost entirely of rocks of the Grampian Group and Central Highland Migmatite Complex. However, since it is defined here as a structural rather than a stratigraphical unit, it also includes local infolds of Appin Group strata. Its south-eastern and eastern boundary is defined by the Boundary Slide and its northern continuation, where major slides and/or shear zones commonly occur close to the Grampian/Appin group boundary. In the west the Western Grampians Complex overlies the Central Grampians Complex and is separated from it by the Fort William Slide. This slide is not continuous around the Western Grampians Complex so that on its south-eastern edge the boundary is difficult to define. For descriptive purposes and on P915427 the boundary of the complex is taken as the north-western edge of the Ossian–Geal Charn Steep Belt, where slides locally separate Appin and Grampian group strata.



Block diagram of major structures in the Grampian Highlands. P915427.

Folds beneath the Boundary Slide: Glen Orchy and Atholl nappes

In the area around Glen Orchy and Dalmally, Thomas and Treagus (1968) recognised three major isoclinal, recumbent primary D_1 folds beneath the Boundary Slide (P915427, block B), the *Glen Lochy Anticline*, the *Beinn Udlaidh Syncline* and the *Beinn Chuirn Anticline*. In later papers, Roberts and Treagus (1975, 1977c) interpreted the uppermost, Beinn Chuirn Anticline, as a secondary D_2 fold, associated with strong deformation along the Boundary Slide, and correlated it with the Kinlochleven Antiform to the north-west. Thomas (1979) subsequently reiterated his belief in a D_1 age for all three folds and added a further fold, the *Dochard Syncline*, at the base of the pile. Whatever their age, it is agreed that all of the isoclinal folds, which together constitute the *Glen Orchy Nappe*, face towards the south-east (i.e. in the same direction as the major nappes above the Boundary Slide). These folds are arched across the broad dome, of the Glen Orchy Antiform, so that they face upwards on the north-west side of the dome and downwards beneath the Boundary Slide on the south-east side.

Farther to the north-east (P915427, block C), in the Glen Lyon area, Roberts and Treagus (1979) have identified three D_1 closures, analogous to the isoclinal folds of the Glen Orchy Nappe. A similar structure to the Glen Orchy Antiform has also been recognised in which the dome configuration is attributed to mutual interference of D_3 and D_4 antiforms.

Still farther to the north-east, detailed studies of the stratigraphy and structure around Strathtummel and along the A9 road section (Thomas, 1979; 1980) are interpreted to show that the Grampian Group strata are disposed in a large-scale, isoclinal D_1 fold termed the *Atholl Nappe*, beneath the Boundary Slide (P915427, block D). The nappe has the form of a broad arch, the *Drumochter Dome*. Over most of the dome, in the Drumochter area, the level of exposure lies in the flat-lying, inverted lower limb of the nappe. To the south-east the dip of both bedding and S_1 cleavage steepens and the hinge-zone of the nappe is exposed as the downward, SE-facing *Meall Reamhar Anticline*.

On the south-eastern side of the Drumochter dome, D_2 folds occur on similar axes to the D_1 folds. The D_2 folds are overturned, with SE-dipping axial planes and S_2 cleavages, well seen for example in the *Clunes Antiform* and *Clunes Synform*. In parts of the D_1 hinge-zone, the S_2 cleavage is sub-parallel to and overprints S_1. Corresponding D_1/D_2 interference on the north-west side of the dome is well seen at Crubenmore where, despite refolding by D_2 folds overturned to the south-east, the D_1 folds can be seen to have been SE-facing originally (Thomas, 1987).

The nature of the Drumochter Dome has been the subject of some controversy. Thomas (1979; 1980) originally considered that the attitude and sense of overturning of the D_2 folds change relative to their position on the dome in a manner which suggests that the dome is an early structure developed during the primary deformation. He also attributed marked variations in axial trace and plunge of major later folds such as the Bohespic Antiform and Errochty Synform to their position relative to an early dome. However, subsequent work by Lindsay et al. (1989) has shown that D_2 axial planes and cleavages are folded across the dome, which is consequently now generally accepted as a later structure, possibly D_3 (D_4 of other authors) as proposed by Roberts and Treagus (1977c; 1979) for the related domes of Glen Orchy and Glen Lyon.

The existence of large-scale, SE-facing isoclinal D_1 folds must now be considered well established. However, Treagus (1987) has suggested that it is not necessary to invoke a separate Atholl Nappe. In his view the whole of the inverted sequence to the south-east from Drumochter can be considered as the same limb of a single major D_1 fold. Such a suggestion would considerably simplify the overall structural interpretation, removing the need to identify an intervening major syncline between the Tay and Atholl nappes and consequently reducing the amount of displacement inferred on the Boundary Slide.

Ossian–Geal Charn Steep Belt

To the north-west of the Drumochter Dome is a 4 km-wide zone in which all the fold limbs and fold axes are near vertical, forming a complex of upward-facing isoclines. This is the *Ossian–Geal Charn Steep Belt* of Thomas (1979), which can be traced for some 40 km from south-west of Loch Ossian, through Aonach Beag and Geal Charn, to Kinlochlaggan. In the Geal Charn–Aonach Beag area, three major slide zones are recognised, which commonly form steep boundaries between Grampian Group and Appin Group strata. The steep belt includes, on its north-western side, the *Kinlochlaggan Syncline* which has long been regarded as a major isoclinal primary fold (Anderson, 1947; 1956; Smith, 1968; Treagus, 1969).

Throughout the belt, Thomas recognises a strong axial plane schistosity, cut in places by two fabrics dipping NW and SSE respectively. These later fabrics and associated minor folds are comparable in orientation to major D_2 and D_3 folds immediately adjacent to the steep belt. Consequently Thomas regards the steep isoclines as primary D_1 folds.

To the south-west the Ossian–Geal Charn Steep Belt may be aligned approximately with the axial trace of the D_1 Loch Awe Syncline, although the Rannoch and Etive granitic complexes intervene, making direct correlation difficult. Both structures appear to mark a fundamental structural divide between NW-facing D_1 folds on one side (i.e. the Islay Anticline and other primary structures of the Western Grampians Complex) and SE-facing D_1 folds on the other (i.e. the Atholl, Glen Orchy and Tay nappes). Consequently, Thomas proposed that the Ossian–Geal Charn Steep Belt constitutes a root zone, lying directly below the Loch Awe Syncline, from which all of the fundamental D_1 nappes of the Grampian Highlands have diverged.

To the north of Kinlochlaggan a continuation of the steep belt may be traced as a zone of steeply inclined strata, thrust slices and intense deformation extending in a NNE direction through the Monadhliath Mountains (Piasecki and van Breemen, 1983). However, many of the upright folds in this zone are interpreted as late, secondary structures (Smith, 1968) and this casts doubt upon the origin of the Ossian–Geal Charn Steep Belt as a fundamental D_1 structure and root zone for the primary D_1 nappes.

Strathspey and the Monadhliath Mountains

The general structure of the southern part of this area was determined by Anderson (1956). In the ground to the south-east of the continuation of the Ossian–Geal Charn Steep Belt, a detailed petrofabric study by Whitten (1959) identified two generations of minor folds trending south-east and north-east but failed to discern any early major structures. In upper Strathspey, Smith (1968) identified a series of asymmetrical overturned folds, with axial planes dipping steeply to the south-east, which refold earlier isoclines. These late folds may correlate with the D_3 folds of the Ben Alder area to the south-west, identified by Thomas (1979).

A detailed study of the area around Kincraig, coupled with reconnaissance mapping and traversing over much of the Monadhliath area between Lochindorb and Kingussie, led to the first detailed comparison of structures in the Central Highland Migmatite Complex and Grampian Group (Piasecki and van Breemen, 1979a; 1979b; Piasecki, 1980). Here rocks of the Grampian Group appear to young consistently upwards. The earliest recognisable folds are tight asymmetrical folds, overturned to the north-west and are associated with slides located near the base of the Grampian Group sequence. These folds deform an earlier schistosity (presumed D_1) and therefore the folds and the early sliding are regarded as D_2. A major D_3 event resulted in overprinting of D_2 structures by a new subparallel regional schistosity, the development of minor folds, similar in form and orientation to those of D_2, and renewed sliding. Major NW-trending open domes (D_4) have a considerable influence on the local outcrop pattern, around Kincraig for example. These were followed by three further successive sets of minor folds (Piasecki, 1980).

North-west of the projected continuation of the Ossian–Geal Charn Steep Belt, many of the major fold structures are downward continuations of those recognised in the Western Grampians Complex. Anderson (1956) recognised the *Corrieyairack Syncline*, and regarded it as a primary structure, as did Piasecki (1975) working farther to the north-east in the upper Findhorn area. Piasecki also recognised other regional-scale isoclinal folds to the south-east, including the *Loch Laggan Anticline* and the *Loch Laggan–Monadhliath Syncline Complex* which he termed D_1. Open, near-upright folds, such as the NW-trending *Glenmazeran Antiform,* were termed D_2. A more intense, more widespread phase of folding produced tight, near-upright D_3 folds, with an overall NNE trend, subparallel to the earlier major folds. Minor structures and fabrics of this phase dominate the area to the north-west of the steep belt, overprinting the earlier structures, but subsequent work has shown that they are only weakly developed or absent to the south-west.

South-west of the River Findhorn, in the area around Loch Killin and the Corrieyairack Pass, Haselock et al. (1982) recognised apparent stratigraphical repetitions, minor structures and a widespread foliation which suggested the presence of major isoclinal axes folded by the more upright major regional folds. Thus the Corrieyairack Syncline and other related near-upright, NE-trending folds became regarded as D_2 structures. No significant NW-trending folds occur in this area and D_3 structures consist of open folds with axes generally trending around north–south, possibly comparable with the D_3 structures of Piasecki (1975) farther east. A similar structural pattern was recorded in the area between the Corrieyairack Granite and Loch Laggan by Okonkwo (1988). Both studies recognised a major tectonic discontinuity and zone of high strain, attributed to the D_1 deformation and termed the *Gairbeinn Slide*, which separates the Corrieyairack Subgroup from the underlying Glenshirra succession. A similar pattern of deformation is recognised in the Glen Roy district where rocks of greenschist facies, lithologically similar to those of the Glenshirra succession, are separated from the amphibolite facies Corrieyairack Subgroup by the *Eilrig Shear Zone*, a tectonic discontinuity on which significant NW-directed transport has taken place (Phillips et al., 1993).

The phases of deformation described above are broadly comparable to those established to the south and south-west in fold complexes which affect higher structural and stratigraphical levels of the Dalradian. Structural continuity and a common deformational history have been used as an argument for including the Grampian Group in the Dalradian, which accords with the proposal of Harris et al. (1978), based largely on local stratigraphical continuity. Recent structural studies along the A9 road section, summarised by Lindsay et al. (1989), have strengthened the belief in a common structural history. Structures can be traced with some confidence from the Boundary Slide at Blair Atholl, across the Drumochter Dome to mid-Strathspey. Here the stratigraphical way-up evidence fails due to increased tectonic strain and the development of gneissose fabrics. Comparable tectonic fabric relationships have been traced somewhat more tentatively north and south-west from Aviemore into Strathnairn and the Corrieyairack area, and are recognised both in the Grampian Group and in the highly migmatised rocks.

The implications of this structural correlation are far-reaching and affect the interpretation of the overall history of the Scottish Caledonides. A major problem, based on currently available age dates, is the wide timespan involved. Pegmatites developed in the slides which underlie and cut the basal part of the Grampian Group have been dated at around 750 Ma, so sedimentation must have commenced at least prior to this. If the Grampian Group structures are to be correlated with those of higher structural levels, then at least one deformation phase had been completed by the time of intrusion of the Ben Vuirich Granite, at 590 Ma, but the peak of metamorphism at around D_3 did not occur until Ordovician time, at around 490 Ma. At present these problems are well identified, but no satisfactory explanation has yet been presented.

Central Highland Migmatite Complex

The controversial nature of the relationship between the Grampian Group and the Central Highland Migmatite Complex has been discussed in detail elsewhere. One view advocates that the migmatite complex constitutes an older basement beneath a cover of Grampian Group sedimentary rocks and consequently that it has undergone more phases of deformation and metamorphism (Piasecki and van Breemen, 1979a; 1979b; 1983; Piasecki 1980; Piasecki and Temperley, 1988). However, an alternative interpretation suggests that the earliest recognisable fabrics in the migmatite complex are coeval with those in the Grampian Group of the Atholl Nappe (Lindsay, et al., 1989). These workers, therefore, favour the view that the Grampian Group extends down stratigraphically to include the Central Highland Migmatite Complex, in which the rocks are at a higher metamorphic grade and are commonly migmatised. The descriptions which follow are essentially those of Piasecki and his co-workers; it is the interpretation of these structures which is currently a matter of great debate.

Throughout much of its length, the boundary between the Grampian Group and the Central Highland Migmatite Complex is taken at a complex zone of multiple sliding or ductile thrusting, up to 200 m in thickness, known as the *Grampian Slide* (P915427, blocks E and F). Minor slides occur locally both above and below this zone and the slides appear to anastomose on a regional scale. The slides generally follow lithological boundaries and movement is concentrated locally within pelitic units, although stratigraphical units are cut-out in places. A complete range of textures is observed in a transition from unsheared rocks to ultramylonites. Approaching the slide zone, foliations develop into a distinctive thin platy fabric with a striking parallel orientation of micas. Within the slides, lenticular augen or stripes of quartz and feldspar are separated by trails of mica to form tectonic schists. The intensity of this schistosity varies according to lithology. Stretching lineations related to the shearing movements trend between north and NNE, and related asymmetrical folds are overturned towards the north.

The main movement on the Grampian Slide is regarded as syn-D_2 in the structural sequence of the overlying Grampian Group, since the slide schistosity is coincident with the axial surface of near isoclinal folds which fold an earlier fabric assumed to represent D_1. A suite of podiform amphibolitised gabbros, which occurs within this slide zone and in related zones of high strain, was emplaced after the early metamorphism and migmatisation, but prior to the D_2 deformation (Highton, 1992). A suite of foliated, concordant pegmatite veins also occurs in the slide zone throughout its 60 km outcrop length. The field and petrographical relationships of the pegmatites with the foliation in the tectonic schists indicate that they segregated during the main sliding. Rb-Sr ages of around 750 Ma from whole-rock and muscovite porphyryoblasts in the pegmatites are therefore considered to date the D_2 sliding event (Piasecki and van Breemen, 1979a; 1979b; 1983). These dates are similar to those obtained from pegmatites north-west of the Great Glen Fault which define a *Morarian* tectonothermal event.

Most of the outcrop of the Central Highland Migmatite Complex is characterised by a composite gneissose fabric. The gneissose banding consists typically of alternating micaceous and quartzofeldspathic layers, from millimetres to several centimetres in thickness. Broad compositional banding occurs locally and may define original bedding, generally concordant with the gneissose banding. No major D_1 folds are recognised but the disposition of rare D_1 minor folds and local low-angle discordance between the gneissose fabric and compositional banding suggest that early larger-scale recumbent structures do exist. This deformation is considered to be broadly coeval with middle-to upper-amphibolite facies metamorphism and regional migmatisation. In areas of intense migmatisation, concordant granitic (quartz-alkali feldspar) leucosomes are developed within psammitic rocks and trondhjemitic (quartz-plagioclase) segregations are prominent in semipelitic lithologies.

The disposition of lithological units within the migmatite complex is controlled largely by major and intermediate-scale second and third folds. The D_2 structures are tight to isoclinal and recumbent to reclined, with a low to moderate plunge and a well-developed axial planar crenulation cleavage. On the limbs of these structures the earlier gneissose fabric becomes transposed into a new banding which is predominant over much of the outcrop. A large fold of regional extent, which dominates the outcrop pattern in the Kincraig area, is largely due to a later phase of folding (Piasecki, 1980; Piasecki and Temperley 1988).

According to Piasecki (1980) the early structures are cut by the Grampian Slide and are overprinted locally by the characteristic fabric of the slide zone. He therefore considered that they predate the earliest structures seen in the Grampian Group which are D_2, coeval with the sliding and dated by syntectonic pegmatites at around 750 Ma. He suggested, therefore, that the early structures in the Central Highland Migmatite Complex were formed during the *Grenvillian Event*, at around 1000 Ma. Unfortunately the only pre-750 Ma dates available, from a granitic gneiss at Ord Ban, are poorly constrained within a range of 1300 to 950 Ma (Piasecki, 1980).

Several phases of near-upright folding, which affect the gneissose structures and the shear zones, were recognised by Piasecki (1980), and correlated with the later deformations in the Grampian Group. Most of these phases are local and only one, NNE-trending, is of regional extent. Folds of this regional phase have been traced into the extension of the Ossian–Geal Charn Steep Belt where they become isoclinal (Piasecki and Temperley, 1988).

The alternative interpretation of the Central Highland Migmatite Complex outlined by Lindsay et al. (1989) proposes that all of the phases of deformation identified in the Grampian Group can be traced into Central Highland Migmatite Complex rocks, regardless of their metamorphic/migmatitic state, and that no earlier structures or fabrics can be recognised. The presence and distribution of migmatitic rock is attributed to a change in original lithology and/or an increase in tectonic strain superimposed on a general gradational increase in metamorphic grade. They considered that the slides have no major regional structural significance. In areas of the migmatite complex where tectonic strain and migmatisation are less intense, lithologies are seen to be similar to those of the adjoining Grampian Group, and in some areas a continuous local stratigraphical succession has been proposed. If this interpretation is accepted the implication is that rocks of the whole of the Grampian Highlands constitute a continuous Dalradian stratigraphical succession from migmatised rocks cut by 750 Ma pegmatites, upwards into Grampian, Appin, Argyll and Southern Highland group rocks, all of which were affected by orogenesis at 600 Ma or younger and by high-grade metamorphism at around 490 Ma.

There is no doubt that slide zones exist in both the western and eastern parts of the Central Grampian Highlands, some coinciding with major changes in metamorphism, migmatisation and stratigraphy. The significance of the slide zones and in particular whether any of them separate sequences of widely differing ages and structural histories, continues to be a subject of active research. In the absence of reliable dates older than 750 Ma, the case for a separate Grenvillian basement in the Central Highland Migmatite Complex remains not proven.

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