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The Dalradian rocks of the northern Grampian Highlands of Scotland

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ABSTRACT

The Northern Grampian Highlands are dominated by the outcrop of the Grampian Group, together with infolds and structural outliers of Appin Group strata and inliers of pre-Dalradian 'basement', consisting of Badenoch Group metasedimentary rocks. The south-eastern limit of this mountainous region corresponds with the regionally continuous Grampian Group-Appin Group boundary, which in the south is marked by a high-strain zone corresponding to the Boundary Slide of some authors. The more arbitrary southern boundary runs north-west from Blair Atholl along the A9 road and then westwards to Fort William.

The Neoproterozoic-age Grampian Group siliciclastic succession accumulated during several transgressive and regressive cycles in multiphase ensialic rift basins. The Badenoch Group constitutes the crystalline floor to those basins and had experienced amphibolite-facies metamorphism, migmatization, gneissification and deformation between *c.* 840–800 Ma, prior to deposition of the Dalradian strata. In contrast, evidence for only 470–450 Ma

Caledonian orogenic events is found at higher structural levels in the Grampian and Appin group successions. Locating and understanding the nature of the contact between the basement gneisses and the Dalradian cover sequence has long been a major challenge of Highland geology. Recent research has argued that not only is a rift-basin architecture evident from the patterns of Neoproterozoic stratigraphy, but also that it played a significant role in influencing the geometry of the superimposed Caledonian deformation, with the basin infill buttressed against its margins or intrabasinal 'highs'.

The GCR sites in this region preserve important evidence of cover-basement relationships, patterns of punctuated deposition, and onlapping sequences. The effects of both pre-Caledonian and Caledonian deformation and metamorphic events are also well represented. Despite the deformation and metamorphism, spectacular sedimentary structures are visible at several of the GCR sites and there is evidence of the earliest recorded glacigenic sediments in the Neoproterozoic rocks of the British Isles.

1 INTRODUCTION

A.G. Leslie

The Northern Grampian Highlands are dominated by a widespread and thick succession of Neoproterozoic siliciclastic deposits referred to as the Grampian Group (Figure 1). Most interpretations of the regional geological relationships have suggested that the strata were deposited upon an orogenic unconformity, now largely obscured by a zone of ductile shearing at or near the base of the group (Piasecki and van Breemen, 1979b, 1983; Piasecki, 1980; Piasecki and Temperley, 1988a and references therein). These interpretations were based upon structural and metamorphic contrasts recognized between rocks referred to an older 'Moine-like' crystalline basement of probable Grenvillian age and termed the 'Central Highland Division', and a cover sequence referred to as the 'Grampian Division' or Grampian Group. The basement rocks apparently underwent amphibolite-facies migmatization, gneissification and deformation prior to deposition of the cover sequence. While lithologically similar to the Moine Supergroup of the Northern Highlands, and formerly termed the 'Younger Moine', the Grampian Group was included within the Dalradian Supergroup by Harris *et al.* (1978) on the basis of the apparent stratigraphical, structural and metamorphic continuity south-east of the Great Glen Fault in the Grampian Terrane (Harris *et al.*, 1994; Stephenson and Gould, 1995; Strachan *et al.*, 2002). Locating and understanding the nature of the contact between the rocks of the Northern Highlands and Grampian terranes has long been a major challenge of Highland geology.

An alternative model viewed the rocks of the Northern Grampian Highlands as part of a single stratigraphical succession in which a regional metamorphic front separates the supposed basement and cover sequences (Lindsay *et al.*, 1989). Such a model was not however supported by more-recent radiometric studies that confirmed the existence of Neoproterozoic tectonothermal events (*c.* 840–800 Ma) in parts of the Northern Grampian Highlands (Noble *et al.*, 1996; Highton *et al.*, 1999), even though only Caledonian orogenic events (470–450 Ma) are known at higher levels in the Dalradian succession. Such a paradox, whereby comparable studies recognized discrete tectonothermal events in different parts of an apparently continuous stratigraphical succession, but were unable to separate or define the limits of these events, continues to be one of the key problems in Highland geology.

A lithostratigraphical framework has been erected for the Grampian Group in the western and south-western parts of the Northern Grampian Highlands, despite the problems of correlation across major structures, polymetamorphism and the absence of biostratigraphical control (Glover and Winchester, 1989; Glover *et al.*, 1995; Key *et al.*, 1997). Those authors described an evolving depositional basin in which marine and locally terrestrial deposition occurred within multiphase ensialic rift basins, during several transgressive and regressive cycles (Glover *et al.*, 1995; Glover and McKie, 1996). Smith *et al.* (1999) extended the lithostratigraphical approach and integrated detailed mapping with geophysical modelling to define a series of basin-bounding structures in the Northern Grampian Highlands (Figure 2). Current research continues to refine and improve the understanding of this depositional framework (Banks and Winchester, 2004; Banks, 2005; Banks *et al*., 2007).

The Grampian Group sediments were deposited in NE- to SW-trending marine basins formed during a major phase of Neoproterozoic rifting. These basins extended rapidly and accumulated up to 5 km of turbiditic deposits, possibly within 20–30 Ma (Ryan and Soper, 2001). Later thermal subsidence is suggested by the regional development of shallow marine-shelf environments and could have occupied a similar length of time. The margins to these basins are characterized by lateral facies and thickness changes, stratigraphical omission and onlap relationships of both Grampian and Appin group strata onto a basement of predominantly gneissose rocks that records the older, pre-Caledonian tectonothermal history. Stratigraphical relationships are summarized in Figure 3, which is based largely upon Smith *et al.* (1999).

Smith *et al.* (1999) and Robertson and Smith (1999) argued that the basin architecture thus determined is not only reflected in the patterns of Neoproterozoic sedimentation, as would be expected, but also played a significant role in predetermining the geometry of the superimposed orogenic deformation in the Northern Grampian Highlands. For example, the Geal-charn–Ossian Steep Belt has been re-interpreted by those authors to reflect buttressing of basin infill against the architecture of the basin margins or any intrabasinal 'highs'. Such analysis of preserved 'cover-basement' relationships led Smith *et al.* (1999) to propose that a significant stratigraphical and sedimentological break does indeed exist at the base of Grampian Group, much in the manner originally suggested by Piasecki (1980). Although there is presently insufficient structural or metamorphic evidence to prove an orogenic unconformity beyond all reasonable doubt, geochronological data do confirm the presence of Precambrian events in the basement rocks that have not been recognized in the cover. The basement rocks were referred to informally as the Dava and Glen Banchor successions in publications and on Geological Survey maps of the period 1999 to 2010, but have now been united formally as the Badenoch Group, with Dava and Glen Banchor subgroups.

The GCR sites described within this paper (Figure 1) preserve important evidence from locations where 'cover-basement' relationships, and the pattern of punctuated deposition and onlapping relationships within the Appin Group, are preserved. There are examples of the lithostratigraphical sequence in the Grampian Group and evidence of the earliest recorded glacigenic sediments in the Dalradian succession. Caledonian and pre-Caledonian deformation and metamorphic events are similarly well represented. A broad outline of current thinking and the geological sequence of events is provided below.

1.1 Badenoch Group

Sedimentary structures and way-up criteria are lacking in these metasedimentary gneisses and only the most-recent research has attempted to erect any level of internal stratigraphy (Robertson and Smith, 1999; Smith *et al.*, 1999). The Glen Banchor Subgroup is identified in the cores of large-scale antiformal structures in the Glen Banchor and Kincraig districts (Figure 1) (see the *An Suidhe* and *Blargie Craig* GCR site reports); comparable strata between Tomatin and Lochindorb are assigned to the Dava Subgroup (see *The Slochd* GCR site report). In broad terms, both the Dava and Glen Banchor subgroups comprise a structurally undivided lower unit of banded psammite, micaceous psammite and subordinate semipelite, and an upper unit of more-varied lithologies including quartzite, siliceous feldspathic psammite, micaceous psammite and schistose banded semipelite. The lithological associations are consistent with deposition in shallow marine environments.

1.1.1 Knoydartian orogenic events

Piasecki (1980) and Piasecki and van Breemen (1979a, 1983) identified a suite of deformed pegmatites emplaced within rocks now assigned to the Badenoch Group and from which they obtained *c*. 750 Ma Rb-Sr muscovite ages (see the *An Suidhe* GCR site report). These pegmatites are located within ductile shear-zones associated with progressive modification and grain-size reduction of gneissose fabrics within the host migmatites. The pegmatites were thought to have formed during, and hence to date, an episode of ductile shearing. They were correlated with *c*. 750 Ma 'older' pegmatites from the Northern Highlands Terrane and were thought to have formed during the Knoydartian Orogeny. However, the Rb-Sr isotope ratios have been variably reset by Caledonian tectonothermal activity (Hyslop and Piasecki, 1999), so that a spectrum of ages from *c*. 700 to 500 Ma has been obtained from the same pegmatites, resulting in ambiguous relationships that frustrate any single unifying interpretative model.

Hyslop (1992) and Hyslop and Piasecki (1999) have confirmed the temporal link between syntectonic metamorphic growth and pegmatite segregation within the ductile shear-zones, while U-Pb analyses of monazites from two large pegmatites at A' Bhuideanaich and Lochindorb have yielded high-precision ages of 808 +11/-9 Ma and 806 ± 3 Ma respectively (Noble *et al.*, 1996). Monazites from the matrix of the mylonitic host to the Lochindorb pegmatite yielded an age of 804 +13/-12 Ma. These results confirmed a phase of monazite growth, and by implication pegmatite formation, contemporaneous with metamorphic recrystallization and growth in the host mylonites at *c.* 806 Ma, lending support to the earlier Rb-Sr studies. U-Pb dating of single zircon grains within kyanite-grade migmatites within *The Slochd* GCR site yielded an age of 840 ± 11 Ma and this has been interpreted as dating high-grade metamorphism and migmatization during an orogenic event that can be correlated with the Knoydartian Orogeny (Highton *et al.*, 1999).

1.1.2 Basement–cover relationships

A major orogenic break at or near the base of the Grampian Group was first proposed by Piasecki and van Breemen (1979b, 1983), Piasecki (1980), and Piasecki and Temperley (1988a). The original lines of evidence presented by Piasecki and his coworkers centred upon apparent structural and metamorphic contrasts between what is now essentially the Badenoch Group and the Grampian Group. Alternative hypotheses to explain those contrasts have invoked metamorphic fronts (Lindsay *et al.*, 1989) or as yet unrecognized orogenic unconformities in the Appin or Argyll groups (Highton *et al.*, 1999). Previous attempts to test for an orogenic unconformity were hampered by confusion over the significance and regional extent of migmatitic and gneissose rocks in large areas of unmapped ground. With much of the area now resurveyed by the British Geological Survey (BGS), and a coherent stratigraphical framework established, many of the earlier problems are diminished. The distribution and development of gneissose and migmatitic textures is largely compositionally controlled and cannot therefore be used as a discriminant between cover and basement. Semipelite and compositionally suitable psammite of both the Badenoch Group and the Grampian and Appin groups,could have developed such textures during peak metamorphic, upper amphibolite-facies conditions (see the *Lochan Uaine* GCR site report). Any model attempting to explain relationships in the Northern Grampian Highlands should therefore take account of the nature of the stratigraphical framework, the structural and metamorphic evidence for any break, and any evidence for an isotopic break.

1.1.3 Stratigraphical framework

Critical localities in Glen Banchor, Speyside and Lochindorb are largely unaffected by intense Caledonian deformation and preserve unconformable and overstep relationships of Grampian and Appin group rocks onto the Badenoch Group (Smith *et al.*, 1999; Robertson and Smith, 1999), thus providing evidence for a significant stratigraphical break near the base of the Grampian Group. Examples of the nature of these relationships are described under the *An Suidhe*, *Blargie Craig* and *Aonach Beag and Geal-charn* GCR site reports. Since the true base of the Grampian Group has not been identified within the Northern Grampian Highlands, the magnitude of this stratigraphical break is uncertain.

1.1.4 A structural and metamorphic break?

Rocks of the Badenoch Group are intensely recrystallized, preserve no sedimentary structures and commonly contain intrafolial isoclinal folds that deform the first foliation (usually a gneissosity). The overlying Grampian Group rocks are variably recrystallized, structurally less complex and commonly preserve sedimentary structures; the first foliation, usually a schistosity, deforms bedding. Observations such as these imply a structural break, and thus support the original thesis of Piasecki (see the *An Suidhe* GCR site report), but this difference is difficult to detect where both successions are migmatitic or highly deformed. Regional metamorphic studies do not detect a break (Phillips *et al.*, 1999) but this could reflect either the intensity of the Caledonian overprint and/or the likelihood that the Badenoch Group rocks, if already dehydrated during an earlier metamorphic event, would have been essentially unreactive (e.g. Yardley and Valley, 1997).

1.1.5 An isotopic break?

Evidence for a Neoproterozoic (Knoydartian) tectonothermal event has so far only been reported from within the Badenoch Group; rocks assigned to the Grampian Group do not record this event. In addition, as yet unpublished BGS data draw a further distinction between the Grampian Group and the Badenoch Group in as much as the latter contain complex monazite populations whose ages span c. 1200-450 Ma, while Grampian Group rocks contain relatively simple monazites that record only Caledonian (470–450 Ma) events.

Taken all together, the above lines of evidence indicate a significant break in sedimentation near the base of the Grampian Group in the Northern Grampian Highlands. The rocks of the Badenoch Group are therefore thought to form a 'Moine like' metasedimentary basement, which was affected by a 'Knoydartian' event prior to the deposition of the overlying Grampian Group. The possibility that it is the Badenoch Group, rather than the Grampian Group that might more easily share affinities with the Moine Supergroup and thus establish linkages across the Great Glen Fault, requires further geochemical, provenance and structural studies.

1.2 Grampian Group lithostratigraphy and basin evolution

Flaggy psammitic metasedimentary rocks older than the Appin Group were originally regarded as 'Younger Moine' (Johnstone, 1975) and were known by such local names as the Struan Flags in Perthshire, the Eilde Flags in Argyllshire and the Central Highland 'Granulites' over much of the Northern Grampian Highlands. Based upon apparent stratigraphical, structural and metamorphic continuity in the Grampian Terrane, Harris *et al.* (1978) extended the then tripartite Dalradian Supergroup downwards to include such lithologies, which were all assigned to a new Grampian Group. A number of constituent subgroups and formations were proposed by Winchester and Glover (1988) and the lithostratigraphical relationships were synthesized by Harris *et al.* (1994) and Stephenson and Gould (1995).

Since then, application of the techniques of basin analysis to the lithostratigraphy of the Northern Grampian Highlands has made important contributions to an evolutionary model for the Grampian and Appin group depocentre in that region (Glover *et al.*, 1995; Smith *et al.*, 1999; Robertson and Smith, 1999). Three main lithofacies associations have been recognized and interpreted as representing distinct phases of early- and syn-rift extension followed by a protracted period of post-rift thermal subsidence. Modelling of basin subsidence curves, using the method developed by Ryan and Soper (2001), has indicated that both the syn-rift and post-rift phases might each have lasted *c.* 30 Ma. Thus defined, the Grampian Group is believed to record the initiation of late-Neoproterozoic extension and basin development. However Prave (1999), in contrast, has re-interpreted the Grampian Group as detritus that was shed, post-806 Ma, from a Knoydartian orogenic terrane as molasse or flysch deposits.

The timing of deposition of the Grampian and Appin groups is not well constrained and is the subject of some current debate; the general consensus is that the base of the Grampian Group is unlikely to be older than *c.* 750 Ma. That consensus is supported by chemostratigraphical data derived from Grampian and Appin group metalimestones, all of which have $^{87}Sr/^{86}Sr$ isotope ratios greater than 0.7064 (Thomas *et al.*, 2004). Comparing that data with the calibration of chemostratigraphy for global Neoproterozoic carbonates (Melezhik *et al.*, 2001) implies that precipitation of the original carbonate must have occurred less than *c.* 750 Ma ago and possibly even from as little as 670 Ma ago.

The lithostratigraphy of the Grampian Group that forms the basis for the following outline is known in detail only for the area now referred to as the Corrieyairack Basin (Figure 2; Smith *et al.*, 1999). The true base of the Grampian Group is not exposed; the oldest unit is the Glenshirra Subgroup (Figure 3), which has never been found in undisturbed primary contact with rocks of the underlying Badenoch Group.

1.2.1 Glenshirra Subgroup

The Glenshirra Subgroup comprises stacked thinning-upward sequences of immature feldspathic psammite and beds of metaconglomerate, the latter increasing in abundance up section and up dip towards the Great Glen Fault. The type locality is in the inlier formed by the Glenshirra Dome, around the upper reaches of the River Spey (Haselock *et al.*, 1982; Okonkwo, 1988; Banks and Winchester, 2004). There it is represented by the Garva Bridge Psammite Formation, locally with a distinctive Gairbeinn Pebbly Psammite Member in its upper part (see the *Garva Bridge* GCR site report). Closer to the Great Glen Fault, the subgroup is represented by the Glen Buck Pebbly Psammite Formation in several smaller inliers, such as the one traversed by the *River E* GCR site. The faulted inlier between Loch Lochy and Fort Augustus exposes a succession of psammites and metaconglomerates over 2000 m thick, which includes minor dolomitic metalimestone and graphitic pelite (Parson, 1982; May and Highton, 1997). This inlier is separated from the overlying Corrieyairack Subgroup by the Eilrig Shear-zone, a zone of mylonites up to 1.0 km thick (Phillips *et al.*, 1993), and high-strain zones are also seen elsewhere at that junction, as in the *Lochan Uaine* GCR site.

In this subgroup, abundant sedimentary structures, including convolute lamination, trough cross-bedding and ripple lamination, together with rare hummocky cross-stratification indicate deposition by traction currents in shallow marine environments subject to storms. Parts of the subgroup might represent fluviatile deposits, and Banks and Winchester (2004) interpreted the whole association as alluvial fan and shallow water sediments deposited within a SE-thinning fan-delta clastic wedge. They considered the sedimentary environment to be so different from the overlying sub-marine slope setting of the overlying Corrieyairack Subgroup to warrant elevation of the Glenshirra Subgroup to group status. However, this suggestion has not become generally accepted and has not been adopted in this special issue.

Seams of magnetic heavy minerals are common. Progressive thickening and coarsening of the strata westwards, combined with the pebble compositions (mainly granite and vein-quartz with rare amphibolite, psammite and quartzite), imply the presence of a basin margin to the west or north-west, with an exposed hinterland of mature crust beyond, perhaps composed of older Proterozoic rocks similar to parts of the Rhinns Complex of Islay.

1.2.2 Corrieyairack Subgroup

The base of the overlying Corrieyairack Subgroup is marked by a distinctive and regionally widespread succession of semipelite and striped semipelite and psammite, which corresponds to basin-wide flooding and the start of widespread subsidence and rift-related extension. Locally, as at Kincraig, a heterogeneous succession of muscovite-rich semipelites interbedded with calcsilicate rocks, thin quartzites and metacarbonate rocks marks the base of the subgroup (see the *An Suidhe* GCR site report). Such rocks probably represent a condensed basin-margin facies reflecting deposition on, or adjacent to, an uplifting high.

A near-complete sequence through the main rift cycle is preserved within the western part of the basin, around Loch Laggan and in Glen Roy (Figure 3; Smith *et al.*, 1999; Banks, 2005). The basal semipelitic facies (the Coire nan Laogh Semipelite Formation) is overlain by *c.* 4 km of siliciclastic strata (the Loch Laggan Psammite Formation), deposited by prograding turbidite complexes (see the *Rubha Magach* GCR site report). Variations in sediment supply and source area and the depositional processes are best documented for the Loch Laggan-Glen Roy area (Glover and Winchester, 1989; Key *et al.*, 1997). Bouma sequences are well represented within the main depocentre around Loch Laggan and Glen Doe, while graded bedding is reflected as 'saw-tooth' bed profiles over most of the outcrop. Inferred bottom structures are extremely rare but there is no lack of way-up criteria.

The overlying Ardair Semipelite Formation records a reduction in sand-grade sediment supply and development of shelf conditions along the basin margins. Turbidite deposition apparently continued unabated in the putative basin centre, while lateral facies changes into striped semipelite and psammite indicate more marginal settings. A return to sand-dominated turbidites (the Creag Meagaidh Psammite Formation) marks deposition in extensive turbidite fan-lobe systems, derived from the north-west and extending southwards and eastwards into shelf environments in the Glen Roy and Drumochter areas (Glover *et al.*, 1995). Rapid local facies variations and thickness variations indicate active tectonism at this time and, together with progressive overstep onto an interbasin high in the Glen Banchor area (see the *Blargie Craig* and *Aonach Beag and Geal-charn* GCR site reports), permit the tracing of outlines of former basin margins (Glover *et al.*, 1995; Robertson and Smith, 1999).

1.2.3 Glen Spean Subgroup

The turbiditic rocks in the upper part of the Corrieyairack Subgroup are overlain conformably by lithological associations with well-preserved sedimentary structures that indicate deposition in shallow marine environments. Such shelf areas were subjected to tidal influences and sea-level fluctuations that resulted in intensive sediment recycling and winnowing of the underlying turbiditic rocks. The successions reflect reduced subsidence and relative tectonic stability, which have been interpreted as indicative of a post-rift thermal subsidence phase at this time (Glover *et al.*, 1995).

On the south-western and south-eastern margins of the Corrieyairack Basin, sediments prograded into the basin from the north-west and south-east and complex diachronous and lateral facies relationships are common (Key *et al.*, 1997). The *Allt Mhainisteir* and *Aonach Beag and Geal-charn* GCR sites both lie on the south-eastern margin, within the Geal-charn–Ossian Steep Belt, and contain Glen Spean Subgroup strata. The northern part of the Strath Tummel Basin is dominated by the Gaick Psammite Formation, which was 1–2 km thick before deformation and has been repeated by a stack of recumbent F2 folds (Leslie *et al.*, 2006). It must contribute significantly to the great thickness of Grampian Group strata in this basin revealed by geophysical modelling (Smith *et al.*, 1999). The southern part of the Strath Tummel Basin is covered by GCR sites described by Treagus et al. (2013). Farther north, in the Cromdale Basin, psammites and quartzites of the Glen Spean Subgroup are well represented. There, the top part of the subgroup is dominated by thick quartzite formations, originally channel-dominated quartz-rich sands, which extend from the Hills of Cromdale to the Banff coast near Cullen, where they form the western end of the *Cullen to Troup Head* GCR site (see Stephenson et al., 2013b).

1.3 Appin Group lithostratigraphy and overstep

The Appin Group is characterized generally by consistency of sediment supply into low-energy (open to lagoonal) marine environments; many of its constituent formations can be correlated along some 280 km of strike length, despite significant lateral facies and thickness variations and local unconformable relationships. Sedimentation occurred in a régime of progressive lithospheric stretching in which listric synsedimentary growth faults apparently constrain the architecture of NE-trending basins (Hickman, 1975; Litherland, 1980; Anderton, 1985; see Stephenson et al., 2013a). In the Northern Grampian Highlands, Appin Group rocks record progressive overstep and onlap onto a substrate of rifted Grampian Group rocks as stretching and subsidence proceeded.

1.3.1 Lochaber Subgroup

The basal Lochaber Subgroup conformably succeeds the Grampian Group in the Central and Northern Grampian Highlands as alternating successions of siliceous psammite and quartzite with minor semipelite, pelite and rare metacarbonate units (Glover *et al.*, 1995; Key *et al.*, 1997). Such strata record the persistence of relatively shallow marine environments from Grampian Group times; the geometry of the basin architecture established earlier continued to exert a strong influence (Robertson and Smith, 1999; Smith *et al.*, 1999). A general pattern for the Lochaber district in the Central Grampian Highlands has offshore sediments interbedded with tidally dominated quartzites that thicken to the south-west. The nearshore sediments are interpreted as extending away from a coastline to the north and are a reflection of periodic basin shoaling events (Glover and McKie, 1996). To the north-east, around Loch Laggan, comparable sediments in the Geal-charn–Ossian Steep Belt underlie the glacigenic Kinlochlaggan Boulder Bed (Treagus, 1969, 1981; Evans and Tanner, 1996).

Upper parts of the Lochaber Subgroup record a period of renewed rifting with gradual deepening and widespread marine transgression, as is represented by the Leven Schist Formation. Laminated pale-grey schistose pelites account for up to 1200 m of strata in the Central Grampian Highlands (Harris *et al.*, 1994) but elsewhere this formation is absent or is represented by thin local correlatives (see the *Aonach Beag and Geal-charn* and *Allt Mhanisteir* GCR site reports). Such dramatic variations have been attributed to significant intrabasinal footwall uplift, reflecting continuing basin development (Glover *et al.*, 1995; Robertson and Smith, 1999).

1.3.2 Ballachulish Subgroup

Metasedimentary rocks of the overlying Ballachulish Subgroup record the further effects of major marine transgression and widespread thermally driven subsidence. There is a progressive development of shallow shelf, tidally influenced sedimentation and anoxic lagoonal environments in the Northern Grampian Highlands as elsewhere across the Dalradian outcrop (Anderton, 1985). The regional pattern of widespread stability and relatively uniform subsidence for the lower formations of the subgroup is interrupted locally by stratigraphical excision and the more sporadic distribution of the upward-coarsening, deltaically influenced Appin Quartzite (Litherland, 1980). A return to interbedded semipelite, calcsilicate rock and metalimestone (the Appin Phyllite and Limestone Formation) indicates renewed transgression and deepening. In the Geal-charn-Ossian Steep Belt, the distinctive Appin Quartzite Formation is absent; correlatives of the Appin Phyllite and Limestone Formation overstep onto underlying Lochaber Subgroup lithologies, and across the entire Grampian Group, to rest directly on the Glen Banchor Subgroup (see the *Blargie Craig* and *Aonach Beag and Geal-charn* GCR site reports). This overstep has been attributed to a combination of non-deposition and erosion on a long-standing intrabasinal 'high' (Robertson and Smith, 1999).

1.4 Caledonian deformation

The mushroom-like structure resulting from the divergent facing of the major folds in the South-western and Central Grampian Highlands encouraged the idea of a fundamental 'root-zone' beneath the Loch

Awe Syncline in early structural models (Sturt, 1961; Rast, 1963). Various geometries and locations for the extension of this root-zone into the Northern Grampian Highlands have been debated (Harris, 1963; Roberts and Treagus, 1979; Bradbury *et al*., 1979), with attention focussed latterly on the the Geal-charn-Ossian Steep Belt. Thomas (1979, 1980) interpreted this fold-complex as a 'root-zone' for the emergence of the SE-facing structures of the Atholl Nappe that lies beneath the Boundary Slide. The NW-facing nappes identified in Lochaber formed a similar architecture emerging to the north-west during the earlier phases of Caledonian compression. Other workers, whilst recognizing the existence of the steep belts, regarded them as late developments in the deformation sequence and rejected any connection with a primary or fundamental root-zone (Hall in Fettes *et al*., 1986; Krabbendam *et al*., 1997). Smith *et al.* (1999) and Robertson and Smith (1999) made a genetic link between the location of the major Caledonian structural features in the Northern Grampian Highlands and the pre-existing architecture of the Dalradian depositional basins.

Despite the differences in overall models to explain the distribution of the major fold-complexes in the Northern Grampian Highlands and the debate surrounding pre-Caledonian orogenesis in the Badenoch Group, there is a general consensus with regard to the pattern of Caledonian fabric development and metamorphism (Thomas, 1979; Smith *et al*., 1999). The Caledonian metamorphic peak is broadly coincident with the second fabric or foliation, that typically being a crenulation of a pre-existing schistosity or cleavage that has affected the bedding. There is however more debate with regard to the development of the later third or fourth fabrics, which are commonly more localized in the intensity of their development.

1.4.1 Folds beneath the Boundary Slide: the Atholl Nappe

Along the A9 road section, which forms the southern boundary of the Northern Grampian Highlands as described in this special issue, Thomas (1979, 1980) argued that the Grampian Group strata are disposed in a large-scale, isoclinal F1 fold termed the Atholl Nappe. This structure lies beneath the Boundary Slide and the Tay Nappe, is disposed in the form of a broad arch called the Drumochter Dome (see the *A9 and River Garry* GCR site report in Treagus et al., 2013). However, Treagus (1987) has suggested that there is no need to invoke a separate Atholl Nappe below the Tay Nappe and hence that there is no need to invoke considerable movement on the Boundary Slide in order to excise an intervening right way-up limb.

The nature of the Drumochter Dome has also been the subject of some controversy. Thomas (1979, 1980) argued that it is an early structure but the work of Lindsay *et al.* (1989) has shown that D2 axial planes and cleavages are folded across the dome, which is consequently now generally accepted as a later structure, possibly D4. Over most of the dome the strata were originally represented as flat-lying and inverted; however, a recent BGS survey across the Gaick region in the north-eastern part of the dome has shown that bedding is generally right-way-up in a SSE-facing system of F2 recumbent folds, geometrically similar to the original concept of the Atholl Nappe (Leslie *et al.*, 2006).

1.4.2 The Geal-Charn–Ossian Steep Belt

To the north-west of the Drumochter Dome, a 4 km-wide zone in which all the fold limbs and axial planes are near vertical, forms a complex of upward-facing isoclines (Figure 4) (see the *Aonach Beag and Geal-charn* GCR site report). This is the Geal-charn–Ossian 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 Kinloch Laggan. In the Aonach Beag–Geal-charn area, three major slide-zones are recognized, which commonly form steep boundaries between Grampian Group and Appin Group strata. The steep belt includes, on its north-west side, the Kinlochlaggan Syncline which has long been regarded as a major isoclinal primary fold (Anderson, 1947b, 1956; Smith, 1968; Treagus, 1969).

To the south-west, the Geal-charn-Ossian Steep Belt may be aligned approximately with the axial plane trace of the F1 Loch Awe Syncline, although the Rannoch Moor and Etive granitic plutons intervene, making direct correlation difficult. Both structures appear to mark a fundamental structural divide between NW-facing F1 folds on one side (i.e. the Islay Anticline and other primary structures such as the Appin Syncline) and SE-facing F1 folds on the other (i.e. the Atholl, Glen Orchy and Tay nappes). Consequently, Thomas (1979) proposed that the Geal-charn-Ossian Steep Belt constitutes a root-zone, lying directly below the Loch Awe Syncline, from which all of the fundamental F1 nappes of the Grampian Highlands have diverged (see the *Ben Alder* GCR site report).

1.4.3 Strathspey and the Monadhliath mountains

The phases of Caledonian deformation in this region are broadly comparable to those established to the south and south-west in fold-complexes that affect the higher structural and stratigraphical levels of the Grampian Terrane. 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 and the development of ideas, promoting a 'basement-cover' relationship and the presence of an orogenic unconformity (Piasecki and van Breemen, 1979b; Piasecki, 1980).

However, Lindsay *et al.* (1989) summarized structural studies that strengthened belief in common elements of a Caledonian structural history traced with some confidence from the Boundary Slide at Blair Atholl, along the A9 road section and across the Drumochter Dome to Strathspey. In the latter area, stratigraphical way-up evidence becomes less reliable as tectonic strain and the degree of migmatization intensify. However, tectonic fabric relationships have been traced north and south-west from Aviemore into Strathnairn and the Corrieyairack area, and comparable fabrics are recognized both in the Grampian Group and in the structurally underlying, highly migmatized rocks that are now assigned to the Badenoch Group. As previously discussed, current structural, metamorphic and isotope data are still insufficient to prove the existence of any orogenic unconformity beyond doubt, but recent detailed mapping in the region by the British Geological Survey has confirmed the existence of a significant stratigraphical and sedimentological break between the two sequences (Smith *et al.*, 1999).

2 AN SUIDHE, KINCRAIG (NH 810 050–NH 827 063)

M. Smith

2.1 Introduction

The lithological, metamorphic and structural correlation of the lowest Dalradian rocks of the Northern Grampian Highlands with the Moine Supergroup of the Northern Highlands has long been the subject of considerable debate (see reviews by Harris *et al.*, 1994; Stephenson and Gould, 1995). Of particular importance is the evidence for a major orogenic break at or near the base of the Grampian Group (Piasecki and van Breeman, 1979b, 1983). Recent radiometric studies have confirmed the existence of Neoproterozoic (800–750 Ma) tectonothermal events within both the Moine and the oldest rocks of the Northern Grampian Highlands (Noble *et al.*, 1996; Highton *et al.*, 1999), yet in the higher Grampian, Appin and Argyll group rocks of the Dalradian succession, only Palaeozoic (470–450 Ma) Caledonian events are known (e.g. Rogers and Pankhurst, 1993, Smith *et al.*, 1999). Comparable dating studies now recognize discrete tectonothermal events and it remains one of the key issues of Highland geology to define the limits of these events.

The GCR site at An Suidhe, north-west of Kincraig on Speyside (Figure 5), forms part of the original evidence cited by Piasecki (1980) for the existence of an orogenic unconformity, largely obscured by a zone of ductile shearing termed the Grampian Shear-zone or Slide. He recognized an apparent structural and metamorphic contrast between an older crystalline basement (his 'Central Highland Division') and a cover sequence (his 'Grampian Division'). The Central Highland Division was believed to be of possible Grenvillian age (*c.* 1000 Ma) and to have experienced amphibolite-facies migmatization, gneissification and deformation prior to the deposition of the 'Grampian Division'. Rb-Sr whole-rock and mineral (muscovite) ages from pegmatitic granites within the intervening shear-zone also provided key evidence for deformation and metamorphism of both the basement rocks and the lower parts of the cover sequence, initially by Knoydartian events (*c.* 800–750 Ma) and then by Grampian events (*c.* 470–450 Ma).

Importantly, the site is also the type area for a distinctive heterogeneous succession of metasedimentary and meta-igneous rocks including semipelite, psammite, quartzite, metalimestone and amphibolite. This succession, termed the Kincraig Formation, forms the local base to the Grampian Group and separates grey micaceous psammite from variably gneissose and sheared psammite, semipelite and quartzite typical of the sub-Grampian Group basement. The Grampian Shear-zone and dated pegmatites lie beneath this sucession, wholly within the sub-Grampian Group basement. These strata and their contacts, which are well exposed on the SE-facing glaciated crags, small quarries and stream sections south of An Suidhe summit, lie in the core and north-eastern limb of a major refolded fold termed the Leault Antiform (Figure 5). They preserve a variety of tectonic fabrics and metamorphic textures. Despite this complex deformation, sedimentary structures are recognizable within the basal Grampian Group rocks.

The area was mapped and described briefly during the primary geological survey of the Highlands (Hinxman and Anderson, 1915), but the first detailed description of the area was provided by Piasecki (1980). A useful map and brief descriptions of the outcrops are also included in an excursion guide (Piasecki and Temperley, 1988b). Recent mapping at the 1:10 000 scale by the present author is included in the BGS 1:50 000 Sheet 74W (Tomatin, 2004).

2.2 Description

2.2.1 Lithostratigraphy

The three main lithostratigraphical units distinguished in the An Suidhe area are, in upward succession, the Glen Banchor Subgroup of the Badenoch Group, the Kincraig Formation and the Loch Laggan Psammite Formation (Smith *et al.*, 1999) (Figure 6). The Kincraig Formation was previously assigned to the Ord Ban Subgroup by Winchester and Glover (1988), but this and the Loch Laggan Formation now represent the oldest strata assigned to the Corrieyairack Subgroup of the Grampian Group in the Speyside district.

The Glen Banchor Subgroup, equivalent to the basement rocks of Piasecki (1980), forms a series of low exposures south-west of Kincraig House and in the birch woods around the Leault Burn (Figure 5). It comprises variably gneissose to locally migmatitic and schistose semipelite, psammite with subordinate siliceous psammite, quartzite (the Blargie Quartzite Member of the Craig Liath Psammite Formation) and pelite with lenses of pale-brown to cream coloured calcsilicate rock.

The structurally lowest unit, lying within the core of the Leault Antiform (Figure 5), is a segregated dark schistose semipelite to pelite with thin ribs of quartzite and calcsilicate rock grading outwards into striped garnet-muscovite-kyanite-fibrolite-bearing semipelite and psammite. Where these rocks are strongly sheared, lenticular ribbons of silvery muscovite, quartz-feldspar augen and plates and veins of quartz are common, particularly towards the contact with the overlying siliceous psammite and quartzite. This overlying Blargie Quartzite Member, is a distinctive white to pale-brown well-jointed feldspathic and migmatitic quartzite with abundant microcline; it is interlayered with banded gneissose psammite and rare thin lenses of semipelite. Generally 15–25 m thick, it can be traced throughout the area as a series of ice-scoured ‘crag-and-tail’ exposures and it forms a low cliff along the northern bank of the Leault Burn at NH 8194 0602. Abundant minor folds, some intrafolial, in the quartzite are picked out by concordant bands of leucosome and provide evidence for the earliest phase of deformation in these rocks. Strongly flattened and segregated micaceous psammites within the Blargie Quartzite Member have been worked locally as walling stone (e.g. at NH 8200 0604). The overlying and structurally uppermost strata of the basement rocks comprise a striped sequence of medium-grained biotite- and K-feldspar-bearing psammite and semipelite interlayered in varying proportions.

Immediately north of Badden Cottage (NH 8251 0616), a thin unit of phyllonitic semipelite is developed along the contact between semipelite and psammite; it hosts a thin sheet (0.5 m) of foliated pegmatitic granite with rotated and recrystallized augen of quartz, feldspar and prophyroblasts of garnet and muscovite. These pegmatitic granites, hosted by sheared striped psammite and semipelite, are interpreted to have formed by strain-induced syn-tectonic recrystallization within the Grampian Shear-zone (Hyslop and Piasecki, 1999).

The overlying Kincraig Formation forms the lowest strata assigned to the Grampian Group in the area and comprises in upward succession, calcsilicate rock, quartzite, metalimestone and schistose calcareous semipelite (Figure 6). A 30–50 m-thick sill of massive to banded garnetiferous amphibolite obscures the base of the formation everywhere and intrudes the underlying rocks locally. However, evidence for the deposition of the Kincraig Formation onto gneissose psammite can be seen elsewhere in Speyside; in a fault-bounded block at Ord Ban (NH 895 085), on A’ Bhunanaich (NH 787 090) and at NH 759 291, 2.5 km south of Glenkyllachy Lodge. Banding, 5–15 mm thick, in the amphibolite is defined by variations in the amount of amphibole, plagioclase and clinozoisite. The remainder of the formation, up to 50 m in thickness, is well exposed in the lower crags north-west of Kincraig House (e.g. between NH 8221 0624 and NH 8210 0641) and a near-complete section through the upper contact is exposed above the metalimestone quarries around NH 8209 0641. At least two beds of coarsely crystalline brown-weathering metalimestone are present. They appear as a series of laterally discontinuous pods and megaboudins, 2–3 m thick and up to 40 m in length, wrapped by the main foliation; they have been quarried as a source of lime (Figure 7).

The Loch Laggan Psammite Formation is well exposed on the south-facing flanks and along the north-trending summit ridge of An Suidhe. The basal facies, approximately 20–30 m thick, comprises medium- to locally coarse-grained, schistose to weakly gneissose semipelite with thin ribs (2–7 cm thick) of micaceous and quartzose psammite in a regular alternating sequence. These striped beds (‘rhythmites’ of Piasecki, 1980) are intruded by a swarm of late- to post-tectonic veins of granite and related quartzofeldspathic pegmatite. Upslope, they pass gradationally into thicker bedded biotite-, quartz- and plagioclase-bearing psammite with thin beds and partings of semipelite bearing pods of calcsilicate rock. A repetitive bed-scale variation in grain size and mica content defines original grading cycles. Combined with evidence for lateral bed amalgamation and channelling, these data indicate that the section is right way up and consistently youngs away from the underlying Glen Banchor Subgroup.

2.2.2 Structure and Metamorphism

The An Suidhe GCR site lies within the southern part of a large structural window. The oldest rocks (the Glen Banchor Subgroup) are exposed in the core of this window and contain evidence of an early phase of deformation (D1) associated with amphibolite-facies metamorphic conditions (M1). An early gneissosity (S1), formed by solid-state recrystallization and probably mimetic on the original compositional layering, is defined in semipelite and psammite by coarse-grained mica foliae (melanosomes), which enclose lenticular quartzofeldspathic segregations (leucosomes). The original compositional banding (S0) might be represented within rare intrafolial minor folds but in general, recrystallization and deformation has destroyed the primary fabric.

The overlying Grampian Group strata display evidence for three episodes of deformation (D2, D3 and D4), which also occurred under amphibolite-facies conditions (M2). Bedding (S0), defined by variations in quartz and mica content, is overprinted by the main penetrative schistosity (S2), which in turn forms the second fabric in the Glen Banchor Subgroup rocks. S2, identified by shape-aligned biotite, quartz and plagioclase, varies from parallel to S0 to oblique (locally up to 15°) and is axial planar to a series of gently inclined SW-verging tight minor folds in the Loch Laggan Psammite Formation. On the northern limb of the Leault Anticline, S2 is parallel to or steeper than S0, whereas on the southern limb S2 is consistently shallower than S0 indicating local overturning. S3 is a steeply inclined to asymmetrical SW-verging crenulation cleavage that affects all the strata and is related to the formation of a broad NW-trending antiformal dome structure and sideways-facing minor folds, verging consistently to the south-west. The youngest deformation visible in the area (D4) is expressed as a series of weak open upright antiforms and synforms and associated crenulation fabric that trends north–south and refolds all the earlier structures.

The presence of the Grampian Shear-zone is indicated by a series of narrow zones (a few tens of metres wide) of distributed ductile shear that anastomose throughout the upper parts of the Glen Banchor Subgroup. These zones have gradational boundaries with the enclosing lithologies and are identified by a marked grain-size reduction. The S1 gneissosity is reworked into a fine-grained mylonitic and phyllonitic foliation that wraps around subelliptical augen and porphyroblasts of plagioclase and muscovite. A suite of distinctive foliated pegmatitic granite veins (up to 0.5 m thick) are developed impersistently within the zones of most-intense strain.

2.3 Interpretation

Piasecki (1980) originally proposed that the Glen Banchor Subgroup rocks had experienced amphibolite-facies metamorphism and three separate episodes of deformation prior to the deposition of the Grampian Group. He argued that the unconformity subsequently became the focus for ductile shear strain whose effects appear to have decreased with increasing distance from the contact. Both the cover and basement rocks were then deformed by a further three episodes of deformation associated with medium- to low-grade amphibolite- to greenschist-facies metamorphism. This complex history has not been substantiated by subsequent dating studies and the recent survey by the British Geological Survey.

The evidence for an orogenic unconformity can be described in terms of two lines of evidence, stratigraphical omission and tectonometamorphic history. At An Suidhe, the absence of any recognizable strata of the basal Grampian Group (Glenshirra Subgroup), combined with the shallow marine environments represented by the Kincraig Formation, imply a major stratigraphical hiatus, with the development of a shallow marine shelf upon basement. The evidence for an extra phase of deformation (the S1 gneissosity) in the Glen Banchor Subgroup, which is absent from the overlying Grampian Group strata, indicates a structural/metamorphic break and is further supported by two independent radiometric studies.

Firstly, statistical analysis of major- and trace-element data effectively discriminates the An Suidhe metalimestone pods from Appin Group equivalents and establishes their distinctive nature within the Dalradian Supergroup (Thomas and Aitchison, 1998). However, $^{87}Sr/^{86}Sr$ isotopic ratios of the carbonate in these metalimestones, which are thought to largely reflect those of the coeval seawater, are consistent with those of younger Appin Group and Islay Subgroup metacarbonate rocks. $^{87}Sr/^{86}Sr$ in seawater is known to have changed with time and a comparison with published data for limestones of Neoproterozoic age from elsewhere in the world constrains the depositional age of the An Suidhe metalimestones to be less than *c.* 800 Ma. Hence, on this evidence, the base of the Grampian Group in this area is younger than 800 Ma and possible significantly less (Thomas *et al.*, 2004). Thus the Kincraig Formation was deposited after the Glen Banchor Subgroup rocks were affected by Knoydartian tectonothermal events.

Secondly, elsewhere in the Kincraig area, foliated pegmatitic granite veins and their phyllitic host rock within the Grampian Shear-zone have yielded Rb-Sr muscovite ages in the range 718 ±19 Ma to 573 ± 13 Ma (Piasecki, 1980) and U-Pb ages on monazite of 808 ± 11 Ma (Noble *et al.,* 1996). Reworking of both the earlier mylonitic and gneissose fabrics and the granitic veins by F2 folds (e.g. at NH 8175 0567) indicates that the Glen Banchor Subgroup was affected by a ductile tectonothermal event prior to D2, which is the first phase of deformation recorded by the overlying Grampian Group. The relative age of the mylonitic fabric in the Grampian Shear-zone and hence the ages of monazite from the sheared pegmatite, and whether these formed syntectonically in the host rock to the S2 fabric of the Grampian Group, remains to be clarified. Unpublished studies (BGS, 2000) indicate that monazites in basement strata are complex, yielding both Precambrian and Palaeozoic ages, whereas those in the cover only record Palaeozoic events.

Cumulatively, these lines of evidence support the hypothesis of an orogenic unconformity with Precambrian tectonothermal events restricted to the basement.

2.4 Conclusions

The An Suidhe, Kincraig GCR site is a key section in the Northern Grampian Highlands, where the relationships between pre-Dalradian basement rocks (now termed the Glen Banchor Subgroup of the Badenoch Group) and their cover (now assigned to the Corrieyairack Subgroup of the Grampian Group) were first documented. The contact between the two successions is obscured by a basic intrusion and the relationships were controversial for many years. However, recent detailed work on the lithostratigraphy, structure, metamorphism, isotope geochemistry and age dating suggests that the original cover-basement interpretation was correct and that the contact represents not just a stratigraphical and/or structural hiatus, but a major orogenic unconformity of national, if not international importance.

Amphibolite-grade metasedimentary rocks of the 'basement' Glen Banchor Subgroup are variably gneissose and locally migmatitic. They preserve at least one phase of deformation that is not seen in the cover rocks and are cut by a major shear-zone that contains syntectonic pegmatitic granites, forming part of a suite whose U-Pb radiometric ages record an 800–750 Ma Precambrian (Knoydartian) tectonothermal event.

The basal part of the Grampian Group records the encroachment over the basement of a distinctive shallow marine sequence with metalimestones, and sedimentary way-up evidence confirms that the succession youngs away from the basement. $^{87}Sr/^{86}Sr$ isotopic ratios in the metalimestones are consistent with post *c.* 800 Ma seawater and hence support the field evidence that deposition of the Grampian Group entirely post-dated the Knoydartian Event.

3 THE SLOCHD
(NH 836 257–NH 833 240–NH 842 240)

M. Smith

3.1 Introduction

The Slochd is one of the key localities described by Piasecki and Temperley (1988b) as representative of the gneissose and migmatitic basement rocks that stratigraphically and structurally underly the Dalradian Supergroup. These authors postulated the existence of an orogenic unconformity, but in most places where it is exposed, the apparent junction was interpreted as being obscured by a zone of ductile shearing, which they termed the Grampian Shear-zone or Slide (see the *An Suidhe* GCR site report). Crucially, at The Slochd, Piasecki and Temperley (1988b) presented evidence of an undeformed contact between older crystalline basement (their 'Central Highland Division') and its cover sequence (their 'Grampian Division'). The basement was considered to be of possible Grenvillian age (*c.* 1000 Ma) and to have experienced amphibolite-facies migmatization, gneissification and deformation prior to the deposition of the 'Grampian Division'. This was in agreement with evidence from the Grampian Shear-zone to the south, where Rb-Sr whole-rock and mineral (muscovite) ages from pegmatitic granite veins indicated that the basement rocks, and possibly the lower parts of the cover sequence, preserve the record of two tectonothermal events, namely the Knoydartian (*c.* 840–750 Ma) and the Grampian (*c.* 470–450 Ma). The evidence for an undeformed unconformity at The Slochd is no longer accepted, but the overall premise of an orogenic unconformity has been substantiated by subsequent work.

The Slochd GCR site includes the A9 road section described by Piasecki and Temperley (1988b) and extends for 1.5 km southwards, via scattered exposures and stream sections to the west of the railway line (Figure 8). The site is dominated by moderate to strongly gneissose, migmatitic psammite (Figure 9), semipelite and quartzite, which were assigned to what is now termed the Dava Subgroup of the Badenoch Group by Smith *et al.* (1999). These strata are locally in sheared contact with grey micaceous striped psammites and semipelites of uncertain stratigraphical affinity. These were considered by Piasecki and Temperley (1988b) and Highton *et al.* (1999) to be correlatable with the Grampian Group on lithological and textural grounds. One possibility is that they are equivalent to the Kincraig Formation at the *An Suidhe* GCR site.

The contacts between the two main lithostratigraphical units are poorly exposed and are marked by a series of narrow N–S-trending zones of blastomylonite and phyllitic semipelite and psammite that locally host distinctive sheets of quartzofeldspathic pegmatite. Podiform lenses of metagabbro and amphibolite are distinctive and widespread throughout the site. The rocks have moderately to steeply dipping foliations and occur in a broad zone of map-scale reclined folds (F2) that have been refolded about N–S-trending axes of later upright folds (F3). They preserve a variety of tectonic fabrics and amphibolite-grade metamorphic textures. Highton (1992) and Highton *et al.* (1999) have proposed a model of tectonic interleaving or imbrication to account for the disposition of the various lithologies.

The area was first mapped during the primary geological survey of the Highlands (Hinxman and Anderson, 1915) and was resurveyed at the 1:10 000 scale as part of the BGS 1:50 000 Sheet 74W (Tomatin, 2004). The resurvey included a ground-based magnetometer survey, which was carried out to detect the extent of the shear-zones and host lithologies (Leslie *et al.,* 1999). A brief description of the geology and a useful sketch of the A9 roadcut (*cf*. Figure 10b) are included in an excursion guide (Piasecki and Temperley, 1988b).

3.2 Description

The Dava Subgroup, equivalent to the 'Central Highland Division' of Piasecki and Temperley (1988a) and the 'Central Highland Migmatite Complex' of Stephenson and Gould (1995) and Highton (1999), comprises variably gneissose to locally strongly migmatitic semipelite, psammite with subordinate siliceous psammite, quartzite and pelite with lenses of pale-brown to cream-coloured calcsilicate rock. It is divided into the Slochd Psammite, Creag Bhuidhe Semipelite and Beinn Breac Psammite formations (Figure 8). The complete absence of sedimentary structures in these rocks precludes the determination of the stratigraphical relationships and inhibits detailed interpretation of the regional structure. Parts of the Dava Subgroup, mainly the Beinn Breac Psammite appear to be similar lithologically to the Glen Banchor Subgroup farther to the south at Kincraig and in Glen Banchor but detailed correlations have yet to be established.

The Slochd Psammite Formation dominates the eastern part of the GCR site and forms the core to a major reclined fold. This unit is exposed at the south-eastern end of the A9 roadcut (Figure 10a). Its upper contacts are poorly exposed or faulted (as in the roadcut) but are marked by narrow zones of ductile shear and are assumed to be highly tectonized. The formation is dominated by coarse-grained, cream to pinkish-yellow gneisosse feldspathic psammite (Figure 9). It is commonly strongly migmatitic and contains monzogranite leucosomes, which coalesce locally into discordant veins and sheets of gneissose granite up to 10 cm in thickness. Zircons extracted from various parts of this rock (at NH 8380 2520) have yielded U-Pb ages that indicate new zircon growth at 840 ± 11 Ma (Highton *et al.,* 1999). Thin bands of semipelite occur sporadically and thicken locally into mappable units, as in the railway cutting at NH 8418 2405.

The Creag Bhuidhe Semipelite Formation crops out north of the A9 around Carn nam Bain-tighearna and in stream sections south of Torr Mor (Figure 8). It is a medium- to coarse-grained gneissose biotite and muscovite semipelite that is spectacularly migmatititic, with a well-developed stromatic texture defined by layers of tonalitic leucosome and bound by screens of biotitic melanosome. All of the original texture in these rocks has been destroyed by metamorphic processes.

The Beinn Breac Psammite Formation is exposed in crags south of Torr Mor (e.g. at NH 8319 2454 and NH 8311 2365). It is composed of grey medium- to coarse-grained banded micaceous psammite and psammite, variably gneisosse with bands of siliceous psammite and quartzite. Interbedded units of semipelite and impure quartzite and pods of calcsilicate rock are common, particularly towards the contacts with the Creag Bhuidhe Semipelite Formation. The contact with the Creag Bhuidhe Semipelite Formation is marked by a prominent band of feldspathic and migmatitic quartzite, locally interbanded with semipelite and micaceous psammite. This unit, which can be traced around the western limb of the fold structure, is lithologically similar to the Blargie Quartzite of the Kincraig and Glen Banchor districts.

The structurally, and probably the stratigraphically, highest strata are mainly bound tectonically by zones of ductile shear. These strata comprise interlayered and striped, non- to weakly gneissose, grey micaceous psammite and semipelite with lenses of calcsilicate rock. The central section of the A9 roadcut provides a section through the northern part of a thin shear-bounded unit (Figure 10b). The main exposures within the GCR site are west of the railway line at NH 8403 2418 and south-west of Torr Mor in the Allt Ruighe an-t sabhail (NH 837 242). Together these strata form the easternmost outcrops of a series of shear-bounded lenses of non-gneissose striped psammitic and semipelitic units that elsewhere contain beds of quartzite. The semipelitic component is segregated, dark and interlayered with thin ribs of quartzite and calcsilicate rock grading outwards into striped garnet-muscovite-kyanite-fibrolite-bearing banded semipelite and psammite. Muscovite porphyroblasts up to 6 cm in diameter are common and weather proud locally to impart a knobbly appearance to the rock. These strata host pegmatitic granite veins and, where strongly sheared, contain common lenticular ribbons of quartz-feldspar augen and veins of quartz, particularly towards the contact with the adjacent quartzite.

At the north-west end of the A9 roadcut, a thin bed of quartzite intervenes between the above strata and the Creag Bhuidhe Semipelite. This unit can be traced for 1.3 km southwards before pinching out tectonically. It comprises pinkish orange to grey, well-jointed feldspathic quartzite, interlayered with banded gneissose psammite and rare thin lenses of semipelite, up to 5 cm thick. All contacts between these lithologies and the Slochd Psammite and Creag Bhuidhe Semipelite formations are sheared and are marked by fine-grained bands of mylonite and phyllonite. The evidence of grading in these rocks described by Piasecki and Temperley (1988b) has not been confirmed by the recent BGS survey.

Scattered outcrops of podiform dark-green metagabbro are a common distinctive feature of the Slochd area (Highton, 1992; Wain, 1999). These bodies, up to 50–70 m in length and 20 m in width, are hosted by all the main lithologies and are elongated within the main foliation. They are medium to coarse grained and commonly preserve relict ophitic textures and schistose amphibolitic margins. The largest mass (250 × 60 m) occurs 800 m south-east of Torr Mor at NH 8394 2456 and is cut by late quartzofeldspathic pegmatite. The metagabbros are envisaged to have been emplaced after the peak of regional metamorphism and migmatization but before the main D2 shearing event.

Late-stage post-tectonic pegmatitic granite veins, thin sheets of microdiorite and felsitic minor intrusions cross-cut all the rocks of the GCR site. Bands of biotite amphibolite and hornblende schist in the A9 roadcut, reported by Piasecki and Temperley (1988b), are re-interpreted here as foliated sheets of microdiorite intruded along contacts and deformed by late-Caledonian events.

The Slochd GCR site lies within a NW-trending deformation zone dominated by SW-verging reclined folds and fabrics and termed the Foyers–Cairngorm Lineament by Smith *et al.* (1999). The local structure is dominated by a map-scale F2 fold, cored by the Slochd Psammite, that has been refolded by an upright N-S-trending F3 fold into a classic hook interference structure. In the absence of facing and fabric evidence it is not known if the early fold is antiformal or synformal. All of the rocks contain evidence of an early phase of deformation (D1) associated with amphibolite-facies metamorphic conditions. An early gneissosity (S1), formed by solid-state recrystallization and probably mimetic on the original compositional layering, is preserved within rare intrafolial minor folds. The main deformation (D2) formed large-scale, shallowly plunging, tight to isoclinal reclined folds and reworked the earlier gneissose foliation. Minor folds have S2 axial stretching and mineral lineations, which plunge consistently at low angles to the north-north-west. Shearing and reworking along fold limbs and lithological boundaries were widespread locally, producing an intense S2 shear fabric. All earlier structures were then reworked and overprinted by an upright crenulation associated with the later open F3 folds. All three structural events took place under middle to upper amphibolite-facies metamorphic conditions. Unlike at the *An Suidhe* GCR site, no difference in tectonic histories of the postulated cover and basement rocks has been identified.

The Grampian Shear-zone is indicated by a series of narrow zones (a few metres wide) of distributed ductile shear that anastomose along or close to the main lithological contacts of the Dava Subgroup with the non-gneissose banded 'cover' lithologies. These zones, which have gradational boundaries with the enclosing lithologies, are identified by a marked grain-size reduction and the reworking of the S1 gneissosity into fine-grained mylonitic, blastomylonitic and phyllonitic foliations that wrap subelliptical augen and porphyroblasts of plagioclase and muscovite. South-west of Bracklettermore, at NH 8374 2285, a distinctive flaggy unit of semipelite hosts a thin (0.2 m) foliated vein of beryl-bearing pegmatitic granite with rotated and recrystallized augen of quartz and feldspar and porphyroblasts of garnet and muscovite. This vein is comparable to others observed at the *An Suidhe* and *Blargie Craig* GCR sites and is interpreted to have formed by strain-induced syn-tectonic recrystallization and to record an early phase of deformation that took place between 800 Ma and 750 Ma (Hyslop and Piasecki, 1999).

3.3 Interpretation

The Slochd GCR site exhibits a series of outcrops of high-grade metasedimentary strata and meta-igneous rocks whose early history has been destroyed by at least two high-grade tectonothermal events. Little grain-size, bed-form or other sedimentary evidence is preserved by which one could determine the environment of deposition of these rocks. The stratigraphical correlations of the 'basement' and 'cover' strata are unconfirmed but, by comparison with sections elsewhere in the Northern Grampian Highlands, correlations with the Glen Banchor Subgroup or Grampian Group are possible. If the non-gneissose strata are the lateral equivalent of the Kincraig Formation (Corrieyairack Subgroup), then a break in sedimentation is implied by the absence of any recognizable strata of the Glenshirra Subgroup at the base of the Grampian Group. Alternatively, the non-gneissose strata could represent a distinctive facies of the basement Dava Subgroup that has not been recorded elsewhere.

Piasecki (1980) was the first to propose that an orogenic unconformity separates what are now known as the Dava Subgroup and Grampian Group strata. In the absence of clear evidence he proposed, not unreasonably, that the unconformity became the focus of ductile shear with the strain effects appearing to decrease with increasing distance from the contact. Crucial to this argument was the reported evidence in the Slochd A9 roadcut for an unconformable contact between migmatitic rocks (of the Slochd Psammite Formation) and overlying non-gneissose strata, and for the preservation of inverse grading in the latter. However, neither of these features has been confirmed by recent BGS surveys. The intensity of recrystallization and deformation during amphibolite-grade metamorphism has obliterated all early sedimentary structures and ductile deformation fabrics and has blurred original contact relations between the lithological units. The apparent striking textural contrasts between individual psammite units at The Slochd is a reflection of their bulk composition rather than of different tectonometamorphic histories. Thus microcline-rich feldspathic psammites of the Slochd Psammite Formation preferentially develop gneissose and migmatitic textures, in contrast to more-plagioclase-rich units of the 'cover' strata, which are comparatively unreactive and remain non-gneissose.

The timing of the various deformation and metamorphic events is also unclear. Peak amphibolite-facies metamorphism and development of gneissose and migmatitic fabrics is interpreted to have occurred at *c.* 840 Ma (Highton *et al.,* 1999). These fabrics were then strongly reworked in the Grampian Shear-zone and deformed during D2, whose age may be constrained, by analogy with dated monazites at Lochindorb (Noble *et al.*, 1996), to have occurred at *c.* 800 Ma. However, the relationship of the dated monazites at Lochindorb and elsewhere to the regional D2 foliation, which is recorded in Grampian Group strata, and to the mylonitic fabrics in the Grampian Shear-zone, has not been confirmed and continues to be the subject of debate. Thus, unlike at the *An Suidhe* GCR site, there is no structural or metamorphic evidence at The Slochd to support an orogenic unconformity between any of the lithological units. There is however mounting evidence from elsewhere in the region that Piasecki (1980) and Piasecki and Temperley (1988b) were correct in their overall interpretation, even though some of their detailed evidence has not been substantiated.

3.4 Conclusions

The Slochd GCR site has played an important historical role in the development of ideas regarding the structural and stratigraphical relationships of the basal Dalradian strata of the Northern Grampian Highlands. It includes one of the first documented examples of a possible cover–basement relationship for the Dalradian, but much of the original evidence has not been confirmed by recent surveys. Although the roadcut is easily accessible, the strata are highly disturbed by later faulting and evidence for an 'unconformity' is problematical. However, sheared contacts with syntectonic granitic veins between gneissose and non-gneissose strata are present and, as is the case elsewhere in the region (e.g. the *An Suidhe* GCR site), these could represent shearing along an original unconformity in what has been referred to regionally as the Grampian Shear-zone.

Migmatitic metasedimentary rocks of the Dava Subgroup of the Badenoch Group have provided the first radiometric evidence from south-east of the Great Glen Fault of new zircon growth during the Precambrian Knoydartian Event (*c.* 840 Ma). They clearly form an older basement to non-gneissose strata, which are tentatively assigned to the Grampian Group, although their exact stratigraphical relationships remain to be established.

4 LOCHAN UAINE
(NH 611 224–NH 613 228)

M. Smith

4.1 Introduction

Locating and understanding the nature of the contact between the rocks of the Northern Highlands and Grampian terranes has long been a major challenge of Highland geology (Harris *et al.,* 1994; Strachan *et al.,* 2002). In particular the junction and relationship between the Moine and Dalradian supergroups and the correlation of their tectonothermal histories, has provided a focus of study for many eminent geologists for over a century. Despite this attention, the junction remains elusive and interpretations are based on educated guesswork or model-driven hypotheses.

The Lochan Uaine GCR site is situated south of Dunmaglass Mains farm in the headwaters of the River Farigaig in Strath Errick (Figure 11). Its importance stems from the original belief that it represents a candidate for the missing junction between the Moine and Dalradian successions. The site contains excellent examples of highly contrasting rock types and clear, easily accessible exposures of their contacts. Migmatitized and gneissose semipelites are juxtaposed across a zone of relatively high strain against variably gneissose psammite and quartzite containing abundant sedimentary structures. The sedimentary structures confirm that that the psammites and quartzites are everywhere structurally and stratigraphically below the semipelite. The contact zone is a zone of high strain but is distinctly different from the Grampian Shear-zone as described at *The Slochd* and *An Suidhe* GCR sites in that it lies along the common limb linking two major fold structures and it does not contain deformed pegmatitic granite veins, quartz veining, pods of garnet amphibolite or books of muscovite.

The nature of the contact between these two contrasting rock types was first described in the Strath Errick area in an abstract by Harris *et al.* (1981), who noted the presence of a zone of strong deformation marked by platy quartzite. They considered the contact to be a modified unconformity between the 'Newer Moine' rocks, which pass upwards into the Dalradian, and an 'Old Moine' basement. Highton (1986) provided a more-detailed description and re-interpreted the contact zone as a ductile thrust carrying the 'older' migmatites over younger Dalradian metasedimentary rocks. The primary survey of the area was completed in 1989 by P Haselock under contract to BGS (1:10 000 Sheet NH62SW), and this was included in the BGS 1:50 000 Sheet 73E (Foyers, 1996).

4.2 Description

Within the Lochan Uaine area, the contrasting lithologies can be studied in the craggy outcrops around the summit and eastern flanks of Beinn Mheadhoin (NH 6045 2175) and on Garbhal Mor (NH 6260 2344). Their contact relations are best observed in the prominent meltwater channel and jokallhaup basin, which includes Lochan Uaine, between NH 6122 2276 and NH 6124 2257. The rocks, all at amphibolite-facies metamorphic grade, dip steeply eastwards and are overturned locally. A series of map-scale reclined folds (F2) trend north-west—south-east and are refolded about N-S-trending axes of later upright folds (F3).

Two lithostratigraphical units have been defined. The stratigraphically and structurally lowest strata are represented by the variably gneissose Gairbeinn Pebbly Psammite Member of the Garva Bridge Psammite Formation in the Glenshirra Subgroup (Smith *et al.,* 1999). These are the lowest strata recognized in the Grampian Group and form a geochemically distinct metasedimentary unit across the Northern Grampian Highlands (Haselock, 1994; Banks and Winchester, 2004). The uppermost and younger lithological unit, the Ruthven Semipelite Formation, comprises intensely migmatized semipelite with thin units of psammite and calcsilicate rock. This unit was considered to be older by early workers, and was correlated with the Moine rocks of the Northern Highlands Terrane, mainly on textural grounds and the presence of additional deformation phases. However, it is now correlated with the Coire nan Laogh and Kincraig formations which together form the basal units of the Corrieyairack Subgroup (Smith *et al.*, 1999).

The Gairbeinn Pebbly Psammite Member comprises medium-grained, typically grey- to pink-weathering psammite and micaceous psammite, with subordinate quartzite and distinctive thin pebbly units. It is comparable to the strata described at the *River E* GCR site. In thin section the psammites are dominated by plagioclase, K-feldspar, quartz and mica. Highton (1986) separated the pebbly and magnetite-bearing rocks of Beinn Mheadhoin from the variably gneissose psammites on Garbhal Mor (his Can Ban Psammite), largely on the basis of degree of metamorphic recrystallization. However, subsequent recognition of pebbly bands and sedimentary structures on Garbhal Mor and on the nearby hills of Carn Poullachie and Carn Ban, has confirmed a correlation with the Beinn Mheadhoin outcrop and this suggests that the development of gneissose textures was controlled by intra-formational variations in bulk chemistry.

Bedding is generally 5–20 cm but locally up to 50 cm thick and is defined by variations in grain size, the proportion of mica and by magnetite-rich laminae. Semipelite is rare but bands up to 0.4 m thick were noted by Highton (1986). Evidence for stratigraphical younging is common and includes graded bedding, cross-bedding, small-scale ripple drift and flaser lamination, ripple lamination, convolute lamination and slump folds (Figure 12). Younging is everywhere towards the contacts with the structurally overlying semipelite. Laterally impersistent pebble beds, up to 30 cm thick, are seen immediately south of Lochan Uaine at NH 6117 2241 and on Garbhal Beag (NH6224 2418). The clasts, up to 10 cm in diameter and composed of microcline and quartz-feldspar aggregates, are dispersed within the matrix of the rock but are sufficiently abundant locally for the rock to be clast supported. The pebble beds and heavy-mineral seams contain magnetite, titanite and epidote. These impart a detectable magnetic signature to the formation and have been used to map out its outcrop throughout the district (e.g. Haselock and Leslie, 1991) (Figure 11). Farther to the north-east, on Garbhal Mor at NH 621 238 and on the hill of Carn Ban, the formation is variably gneissose with units containing abundant granitic segregations rimmed by biotite-rich selvidges.

Highton (1986), Haselock and Gibbons (1990) and the summary of geology accompanying the BGS 1:50 000 Sheet 73E (Foyers, 1996) have all described a transitional junction between the two formations south of Garbhal Mor at NH 6225 2274 (Figure 11). The transition is marked by the incoming of bands of siliceous psammite, passing upwards into interbanded impure quartzite and psammite; the proportion of semipelite decreases but thin seams of semipelite are still present up to 200 m from the contact. Individual units of quartzite reach 50 m in thickness locally. Elsewhere in the area, the contact relations are less clear due to the focussing and overprint of ductile shear along the contact zone. However, despite the high strain and resultant attenuation, the transitional nature of the junction has now been well established by several authors and major excision of strata along the line of the shear-zone is unlikely.

The Ruthven Semipelite Formation is characterized by medium- to coarse-grained gneissose and migmatitic semipelite and pelite. Rare thin units of psammite, layers of calcsilicate rock and variations in the frequency of quartzofeldspathic segregations define original lithological variation. In thin section the semipelite contains the assemblage biotite, muscovite, quartz, garnet and plagioclase. Pelites containing kyanite, fibrolite and

K-feldspar are recorded elsewhere in the district. At Lochan Uaine, the formation is spectacularly exposed in large boulders at the southern end of the loch and in the crags to the east (e.g. at NH 6128 2275). The migmatites are stromatic (lit-par-lit) and comprise quartzofeldspathic leucosomes, up to 10 cm thick, surrounded by screens of biotite and muscovite. Layering, commonly accentuated by effects of later deformation, becomes more schistose locally. No sedimentary structures have been observed.

The metasedimentary rocks at Lochan Uaine are affected by three phases of deformation and associated amphibolite-grade metamorphism. An early tectonic event produced a near-bedding-parallel foliation in the psammites, which is transitional into the coarser grained migmatitic fabrics in the micaceous psammite and the semipelite. Earlier workers separated these two fabrics into two distinct events, with the gneissosity predating the foliation (Harris *et al.*, 1981; Highton, 1986). In the Gairbeinn Pebbly Psammite Member this early fabric, probably a composite of S0 and S1, is defined by aligned micas. The main D2 deformation produced a series of NW-trending steep to reclined folds with steep NE-dipping axial planes, a strong axial planar crenulation cleavage in the hinge-zones and transposition of the earlier gneissoity. An antiform-synform pair controls the disposition of lithologies and the early fabrics at the GCR site and the common limb, which runs close to Lochan Uaine, is strongly attenuated and faulted. Garnets within the semipelite show two-stage growth, typically with inclusion-free rims around a core rich in quartz and magnetite. The final and weakest phase of deformation (D3) produced regional upright tight N-S-trending folds with an axial planar crenulation overprint; these features are not well developed at the GCR site.

At Lochan Uaine, the boundary between the Gairbeinn Pebbly Psammite Member and Ruthven Semipelite Formation lies on the right way-up limb of the F2 fold-pair and is marked by a zone of deformation previously termed the Lochan Uaine or Gairbeinn slide (Highton, 1986; Haselock and Gibbons, 1990). Haselock and Gibbons (1990) correlated this structure with a slide-zone that marks the upper boundary of the Glenshirra Subgroup with younger rocks throughout the western part of the Northern Grampian Highlands. The zone of deformation is well exposed in the crags at the northern and southern ends of Lochan Uaine, where the transition from feldspathic pebbly psammite to pelite occurs over a distance of *c.* 2 m. It is marked by platy psammite and quartzite and by schistose semipelite in which the original bedding and coarse gneissose fabrics have been obliterated and transposed into the main shear fabric. Highton (1986) described the progressive deformation of pebbles and sedimentary structures that define a strain gradient consistent with simple-shear and minimal horizontal extension. Above the contact, the rapid fall off in strain and the presence of ribboned quartz grains in thin section led Highton (1986) to interpret these rocks as the products of a ductile thrust or zone of decollement, synchronous with D2 in the gneissose semipelites and with his first deformation in the psammites. A shape fabric in the pebbly bands, together with mineral fabrics, defines a lineation that plunges gently to the north. This is progressively re-orientated into steep plunges in the shear-zone.

Shear-sense indicators have not been recorded, although Highton (1986) noted an anticlockwise sense of rotation from augen of restite grains and muscovite in the semipelite. The BGS 1:10 000 Sheet indicates a top-to-the-west sense of shear, though the basis for this interpretation is not clear.

4.3 Interpretation

The startling contrast between the Gairbeinn Pebbly Psammite Member and Ruthven Semipelite Formation, as highlighted by a variety of features including sedimentary environment, metamorphic fabric and structural history, has led previous workers to consider the Lochan Uaine GCR site as a candidate for the elusive Moine–Dalradian contact, a zone of major ductile thrusting or a local zone of attenuation on the common limb between two major folds.

In sedimentary terms, the presence of superb sedimentary structures and grain-size variation with local development of pebble bands indicates high-velocity, rapid rates of sedimentation for the Gairbeinn Pebbly Psammite Member. The psammites are texturally and mineralogically immature and this, combined with the nature of the sedimentary structures, indicates deposition within an alluvial to shallow marine environment (Banks and Winchester, 2004). The pebbly beds might indicate shallow marine fan-type deposits whilst the presence of slump folds suggests liquifaction and rapid sedimentation. Regionally, the Gairbeinn Pebbly Psammite is interpreted as having been deposited within a SE-thining fan-delta clastic wedge (Banks and Winchester, 2004). The presence of clasts and pebbles suggest proximity to an uplifted block of granitoid basement (Smith *et al.*, 1999).

In contrast, the Ruthven Semipelite Formation formed in a wholly marine environment and passes stratigraphically upwards into a thick sequence of rift-related turbiditic metasedimentary rocks. The base of the formation, like the Coire nan Laogh Semipelite Formation elsewhere (see the *Garva Bridge* GCR report), represents an important sequence boundary and defines the base of the Corrieyairack Subgroup (Banks and Winchester, 2004; Banks, 2005). This base is marked by the transitional unit of interbedded quartzite and semipelite seen on Garbhal Mor and at Lochan Uaine.

Superficially the two formations appear to record distinct metamorphic histories, with a major gneiss-forming event preserved in the semipelites but not in the psammites in which bedding is commonly well preseserved. This has now been re-interpreted as a response to differences in primary composition. During deformation, the plagioclase-bearing psammites on Beinn Mheadhoin were essentially unreactive and thus preserve their original primary structures, whereas the stratigraphically equivalent K-feldspar-bearing micaceous psammites and semipelites on Garbhal Mor developed gneissose and migmatitic fabrics. Similarly the mica-rich pelites of the Ruthven Semipelite Formation were readily migmatized during deformation and metamorphism. On this basis the strata on either side of the postulated shear-zone share a common tectonothermal history and hence there is no evidence for an orogenic unconformity as was proposed by Harris *et al.* (1981).

The nature of the contact and the amount of translation across the shear-zone remain debateable. If the correlation of the psammites on Beinn Mheadhoin and Garbhal Mor is accepted then there is little requirement for a significant break, and the deformation zone can be explained in terms of attenuation along major rheological contrasts on the long limb of a fold during the D2 event. Shear-zones propagating on minor F2 fold limbs were noted by Highton (1986) in Strathnairn and are common throughout the Northern Grampian Highlands. Alternatively, if stratigraphical excision is envisaged then the shear-zone, with a presumed top-to-the-west sense of movement, contravenes the first rule of thrusting as it brings younger rocks over older.

4.4 Conclusions

Interest in the Lochan Uaine GCR site was first aroused because the exposed contact between two distinctly different metasedimentary units, one gneissose and the other non-gneissose with good sedimentary structures, was thought to be a possible junction between the Moine and Dalradian successions. Subsequent contrasting interpretations of the contact have varied from an unconformity overprinted by a shear-zone, to a thrust and, more recently, to a zone of attenuation along the long limb of an F2 fold. Such variance highlights the need for care in the interpretation of stratigraphical contacts and metamorphic fabrics in such lithologies. This historical site now provides an exceptional example of how contrasts in physical properties and differences in bulk-rock chemistry can produce markedly different looking rocks.

Superbly exposed psammites and quartzites with abundant sedimentary structures (the Gairbeinn Pebbly Psammite) young upwards towards a transitional contact with strongly migmatitic semipelite (the Ruthven Semipelite). The two units share a common tectonothermal history and both are now assigned to the Grampian Group of the Dalradian. During the main phase of deformation (D2), rheological contrasts across the contact zone have provided the focus for ductile strain to produce platy, mylonitic fabrics along the long limbs of major fold structures.

5 BLARGIE CRAIG (NN 587 938–NN 608 955)

M. Smith and S. Robertson

5.1 Introduction

The Blargie Craig GCR site contains one of two recently discovered exposures, where there is evidence for the existence of an unconformity separating Grampian and Appin group Dalradian strata from an underlying crystalline basement of Moine-like affinity. The major break in sedimentation that this represents is critical to the elucidation of both the geometry of Dalradian sedimentary basins in the Northern Grampian Highlands and their subsequent deformation during the Caledonian Orogeny (Harris *et al*., 1994; Smith *et al*., 1999; Strachan *et al*., 2002). Additionally, the site preserves features of the Grampian Shear-zone.

Variably gneissose rocks at Blargie Craig that have been deformed in the Grampian Shear-zone (previously termed the Blargie Slide), are cut by veins of pegmatitic granite that have yielded radiometric ages of *c.* 750 Ma. These have been interpreted as recording a Neoproterozoic deformation episode (Temperley, 1990). The recognition of Neoproterozoic deformation here and elsewhere in the Northern Grampian Highlands has been fundamental to the delineation of a series of inliers of older 'basement' to the Dalradian 'cover', previously referred to as the Central Highland Division (Piasecki, 1980), the Central Highland Migmatite Complex (Stephenson and Gould, 1995) or the Glen Banchor and Dava successions (Smith *et al*., 1999). Those 'successions' have now been formalized as subgroups of the Badenoch Group. The Blargie Craig GCR site includes part of the Laggan Inlier, which is the largest and most southerly of these 'basement' inliers.

The basement-cover interpretation did not gain widespread acceptance; Lindsay *et al.* (1989) considered that a 'metamorphic front' separated the purported basement from its 'cover' and thereby envisaged a single continuous Dalradian succession. More recently however, Smith *et al.* (1999) and Robertson and Smith (1999) have shown that the lower part of the Dalradian, namely the Grampian Group and parts of the Appin Group were deposited unconformably on a pre-Dalradian sedimentary succession, which is now exposed in upstanding interbasin 'highs'. The Laggan Inlier exposes one of these 'highs' and is comparable to the Kincraig Inlier, which includes the *An Suidhe* GCR site.

The GCR site includes a wide range of lithologies, which are well exposed in glaciated SE-facing crags and small cliffs rising to an elevation of 750 m in the upper Spey Valley (Figure 13a). A consistent sub-parallel outcrop pattern, steep to vertical strata and large-scale, upright, tight to isoclinal folds with highly attenuated limbs indicate that the site lies within the NE-trending deformation zone termed the Geal-charn–Ossian Steep Belt (see 1.4.2 in *Introduction*). The youngest strata are assigned to the Appin Group and include metalimestone and quartzite, amphibolite and semipelite. In many places across the Grampian Highlands (e.g. Kinlochleven, Bridge of Brown), these strata rest conformably on psammite and semipelite of the Grampian Group. In contrast, in the lower ground around Coull Farm, south-west of Blargie Craig, glaciated mounds and roches moutonées preserve Appin Group strata resting unconformably on the older Glen Banchor Subgroup, with no intervening zone of shearing or high strain. In this area, the Grampian Shear-zone, including the dated pegmatitic granite veins, occurs wholly *within* the Glen Banchor Subgroup rocks.

The regional geology of the area was described briefly by Anderson (1956) and Temperley (1990) and a description of Blargie Craig is included in an excursion guide (Piasecki and Temperley, 1988b). The primary survey of the area was completed between 1996 and 1999 (BGS 1:10 000 sheets NN59NE, NN59SE, NN69NW and NN69SW) and is included in the BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002) but, other than the maps, little information has been published. This site report is based upon the authors' observations and acknowledges numerous discussions with J.R. Mendum.

5.2 Description

The GCR site extends from Coul Farm north-eastwards for about 3 km to Gergask Craig and includes key sections at Blargie Craig and Coull Farm (Figure 13a).

The site contains three principal lithostratigraphical units (Figure 13a). The oldest comprises variably gneissose interbanded semipelites, psammites and quartzites of the Glen Banchor Subgroup. These are separated from grey flaggy non- to weakly-gneissose psammites and semipelites of the Corrieyairack Subgroup of the Grampian Group to the north-west by a narrow outcrop of semipelite, quartzite, amphibolite and metalimestone assigned to the Aonach Beag Semipelite and Coire Cheap formations of the Appin Group (Robertson and Smith, 1999). The effects of recrystallization during amphibolite-facies metamorphism have largely obliterated the original sedimentary textures in the older rocks and no way-up evidence has been found in the Glen Banchor Subgroup. In the Grampian and Appin group rocks, bedding profiles and rare sedimentary structures provide reliable younging evidence. Within the GCR site, the Appin Group strata young consistently away from the Glen Banchor Subgroup strata (Figure 13b).

In its type area, farther north-east in Glen Banchor, the Glen Banchor Subgroup comprises four informal units, all of which are present in the area around Blargie Craig. These units are similar to lithologies described at the *An Suidhe* and *The Slochd* GCR sites but detailed correlations have yet to be established. The structurally lowest unit is the Creag an Loin Psammite, which is exposed south of the River Spey around Dalchully House (NN 5945 9375). It comprises medium- to coarse-grained gneissose and migmatized interbanded psammite and semipelite. Granitic leucosomes of quartz and feldspar are sheathed with biotite-rich melanosomes imparting a stromatic texture. The semipelite is biotite, mucovite and garnet bearing. In Glen Banchor, these strata are in conformable contact with the An Stac Semipelite, e.g. on Sron Mor na h-Uamhaidh (NN 638 977). The An Stac Semipelite, clearly displayed in cliff sections at Gergask Craig (NN 6121 9535) and north of Blargie (NN 6008 9512), consists of medium-grained gneissose muscovite-and-garnet-bearing semipelite with thin ribs of quartzite and calcsilicate rock and is intensely veined by granite and quartzofeldspathic pegmatite. Banding is defined by rare bands of dark-grey micaceous psammite. Close to contacts with adjacent units, the semipelite is finer grained, interbanded with micaceous psammite and more schistose in appearance. It contains the assemblage, garnet-muscovite-kyanite-fibrolite and, where strongly sheared, for example near Coul Farm and on Blargie Craig, it has lenticular ribbons of silvery muscovite, quartz-feldspar augen and plates and veins of quartz. This unit everywhere hosts the pegmatitic granite veins that characterize the Grampian Shear-zone.

The structurally highest unit in the Glen Banchor Subgroup is the Creag Liath Psammite, comprising K-feldspar-bearing medium-grained gneissose banded psammite and siliceous psammite. Minor lithologies include quartzite. Porphyroblasts of microcline up to 0.5 cm in diameter are common and impart a pebbly appearance to the rock and along joint faces. A minor but very distinctive unit of gneissose feldspathic quartzite, referred to as the Blargie Quartzite Member, generally occurs at the lower boundary of the Creag Liath Psammite Formation, although thin developments of this lithology are also noted within the An Stac Semipelite Formation. The quartzite is typically white to pale brown, well jointed, feldspathic and migmatitic with abundant microcline and thin interbeds of banded gneissose psammite and rare semipelite. Elongate irregular lensoid bodies of medium-grained amphibolite are developed sporadically throughout the Glen Banchor Subgroup. They are generally a few tens of metres in diameter but can reach up to 100 m in length e.g. at Blargie Farm (NN 6018 9465).

The Grampian Group strata include metasedimentary rocks assigned to the Loch Laggan Psammite, Ardair Semipelite and Creag Meagaidh Psammite formations of the Corrieyarack Subgroup, which are poorly exposed to the north-west of the site e.g. in the Allt Tarsuinn Mor (NN 5873 9622) and Allt Tarsuinn Beag (NN 5840 9530). These strata comprise, in varying proportions, well-bedded blocky grey psammite with thin semipelite and ribs of calcsilicate rock. Grading profiles defined by weathering of muscovite-rich semipelite bands indicate a consistent regional sense of right way-up and stratigraphical younging away from the underlying Glen Banchor Subgroup. The *Rubha na Magach* GCR site report contains further descriptions of these lithologies.

The youngest strata in the Blargie area are assigned to the Aonach Beag Semipelite and Coire Cheap formations of the Appin Group on a combination of lithological and geochemical criteria (see 'Interpretation'). They are in mappable continuity with strata farther west, which include the Kinlochlaggan Boulder Bed and Quartzite and are of undoubted Appin Group affinities (see the *Allt Mhainisteir* and *Kinloch Laggan Road* GCR site reports) (Evans and Tanner 1996; Robertson and Smith 1999). The Aonach Beag Semipelite Formation is dominated by interbanded rusty-weathering schistose semipelite and micaceous psammite but also includes blocky white quartzite and quartzose psammites, some of which are pebbly. Concordant thin sheets of garnet amphibolite are abundant, particularly close to the boundary with the Glen Banchor Subgroup. At NN 5915 9524, a small outcrop of metacarbonate rock, calcsilicate rock and semipelite is well exposed in and around three small quarries where limestone has previously been extracted. These rocks are assigned to the Coire Cheap Formation on the basis of their whole-rock geochemistry and $^{87}Sr/^{86}Sr$ initial isotopic ratios, which are consistent with younger Appin and Argyll group metacarbonate rocks (Thomas *et al.*, 1997; Thomas *et al.*, 2004). Minor exposures of white quartzite occur in the vicinity of the contact with the Aonach Beag Semipelite Formation. The quartzite, which might be the Kinlochlaggan Quartzite Formation, is only a few metres thick compared with up to 160 m seen at the *Allt Mhainisteir* GCR site.

The contacts between the above strata are generally poorly exposed and are commonly highly attenuated by deformation. However, north of Coul Farm (at NN 5870 9425) the critical contact between Appin

Group and Glen Banchor Subgroup strata is well exposed in a series of roche moutonée exposures (Figure 14). A sharp and concordant boundary separates striped gneissose psammite with micaceous laminae and thin layers of quartzose psammite of the Creag Liath Psammite from schistose semipelite and micaceous psammite with abundant garnet amphibolite sheets of the Aonach Beag Semipelite Formation. Thin calcsilicate layers occur at the contact. The outcrop of this contact is repeated a number of times by upright isoclinal folds (Figure 13b) and is also well exposed some 5 km to the north-east at Margie na Craig in upper Glen Banchor (NN 6202 9780).

Zones of high ductile strain typical of the Grampian Shear-zone are present within the An Stac Semipelite *c.* 30–40 m below the unconformity at the locality described above. Similar features are also well exposed at Blargie Craig along the contact between the An Stac Semipelite and the Blargie Quartzite (Paisecki and Temperley, 1988b). As at the *An Suidhe* and *The Slochd* GCR sites, the Grampian Shear-zone is characterized by the progressive attenuation of lithologies with transposition into parallelism of all lithological and structural features. Mylonites are also present and exhibit grain-size reduction and segregation of quartz into subconcordant 'plates' together with the development of tabular garnets. Porphyroblasts of quartz, K-feldspar, muscovite and garnet have grown within the zones of quartz 'plates'. Thin sheets and thicker veins of pegmatitic granite are developed within the high-strain zones and Rb-Sr dates on muscovite books within these indicate ages of *c.* 750 Ma (Piasecki and van Breemen, 1983).

Throughout the GCR site the lithological layering, axial surfaces of folds and associated tectonic fabrics are coplanar due to deformation within the Geal-charn–Ossian Steep Belt (Robertson and Smith, 1999). Overall the structure is one of a syncline–anticline pair with numerous parasitic folds on the limbs, many with sheared long limbs. The main gneissosity of the Glen Banchor Subgroup strata probably reflects an early compositional variation and is in places deformed by isoclinal folds, some of which are rootless. This gneissosity and the early bedding fabrics (S0) of the Grampian and Appin group strata are overprinted, transposed and re-orientated into the main S2 foliation, which is axial planar to the numerous minor tight to isoclinal folds that are commonly seen in exposures. An upright S3 crenulation records the final deformation event to have affected all strata. Mineral assemblages, particularly in the semipelitic strata, indicate that both the early gneissosity and the S2 deformation occurred under amphibolite-facies metamorphic conditions.

5.3 Interpretation

Blargie Craig, originally recognized for the preservation of high-strain lithologies and features of the Grampian Shear-zone (Piasecki and van Breemen, 1983; Piasecki and Temperley, 1988b), can now be placed in a wider lithological and structural context.

Following the completion of the primary survey, the lithologies of the Laggan Inlier and its surrounding strata can now be fitted into the regional framework. On the BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002), definite Grampian Group strata are spatially separated from an older basement succession by a heterolithic sequence containing quartzites and metalimestones (Figure 13b). This sequence has lithological similarities to the Kincraig Formation of the Corrieyairack Subgroup at the *An Suidhe* GCR site. Accepting such a correlation would place an emphasis and focus on the Aonach Beag Slide as an important discontinuity or thrust structure juxtaposing basement rocks against a thin cover of upward-facing and locally overturned basal Grampian Group strata (Figure 13b). However, the quartzites are distinctively thicker and whiter in colour and the semipelites are rusty weathered and less segregated than those in the Kincraig Formation and, most significantly, the metalimestones have chemical signatures consistent with those in the Appin Group (Thomas *et al.*, 1997). The sequence was therefore assigned to the Appin Group by Robertson and Smith (1999).

If the above correlation is accepted, then there is good evidence along the north-western margin of the Laggan Inlier for major stratigraphical omission across an unconformity between the Appin Group strata and an older 'basement'. Although less clearly evidenced than at the *An Suidhe* GCR site, due to the intensity of the regional deformation, the basement Glen Banchor Subgroup strata are affected by a gneiss-forming event prior to deposition of the Grampian and Appin groups and thus the contact is an orogenic unconformity. The actual plane of the unconformity, as exposed north of Coul Farm, is unremarkable. There is no evidence for an angular discordance, or for conglomerates at the base of the younger succession. But across the contact, some 5–6 km of Grampian Group strata are absent. Structurally, there is no evidence (i.e. down-dip lineations, mylonites, veining etc) for the contact being a major thrust. High ductile strains associated with the Grampian Shear-zone are preserved only within Glen Banchor Subgroup strata.

Regionally the Blargie Craig GCR site lies within the Geal-charn–Ossian Steep Belt. On the basis of opposing facing directions, Thomas (1979) originally interpreted this major structure as a primary root-zone to the major nappes of the Central and Northern Grampian Highlands. It forms the boundary between two contrasting structural domains, with primary upright structures to the north-west and recumbent folding to the south-east and has been re-interpreted as a zone of partitioned strain, where shortening during the Caledonian Orogeny was focused along an intrabasinal high (Smith *et al.*, 1999; Robertson and Smith, 1999). The steep belt has overprinted and transposed all minor structures and fabrics within all strata. Evidence cited by Piasecki (1980) from elsewhere in the Northern Grampian Highlands, which suggests that the Glen Banchor Subgroup rocks experienced a more-complex tectonothermal history, is difficult to confirm, although the presence of an early gneisossity contrasting with the preservation of bedding in Grampian Group strata supports a tectonic break. The Grampian Shear-zone, as at other GCR sites, is represented by thin zones of enhanced ductile strain and fluid-enhanced metamorphism and mineral growth within the Glen Banchor Subgroup only. The timing of fabric-forming events, as evidenced by zircon and monazite growth, is uncertain and remains to be proven conclusively.

5.4 Conclusions

The Laggan Inlier, represented by the Blargie Craig GCR site, is possibly unique in the Proterozoic record of Scotland in that it preserves one of the few recorded exposures of the contact between a 'basement' of essentially Moine-like rocks and a 'cover' of Grampian and Appin group metasedimentary rocks. The stratigraphical omission of more than 5 km of Grampian Group strata is interpreted as resulting from non-deposition on an intrabasinal high during Neoproterozoic rifting events (post 800–750 Ma). Subsequent deformation during the Grampian Event of the Caledonian Orogeny (470–450 Ma) partitioned strain between the basin and its margin. The site therefore highlights the challenges involved in identifying primary lithological, orogenic and structural relations in a zone of intense strain in which all fabrics have been transposed into a common upright orientation.

This GCR site is representative of the basement Glen Banchor Subgroup of the Badenoch Group and preserves excellent examples of the key lithologies of both this and its Dalradian cover. Sheets of pegmatitic granite within the Grampian Shear-zone have yielded key radiometric dates, which were crucial in the initial identification of the older basement.

If the Badenoch Group successions described in *The Slochd, An Suidhe,* and *Blargie Craig* GCR site reports are to be correlated with the Moine Supergroup of the Northern Highlands Terrane, then the present understanding of their contact with Dalradian strata could question the validity of identifying separate Northern Highlands and Grampian terranes.

6 RIVER E
(NH 541 150–554 136)

C.J. Banks

6.1 Introduction

The River E, which flows from the Monadhliath Mountains into the south end of Loch Mhor, some 4 km south-east of Foyers, contains excellent exposures of Grampian Group strata. The river section provides a transect across the Glen Buck Pebbly Psammite Formation of the Glenshirra Subgroup, exposed as a structural inlier in the core of an upright F2 anticline (Figure 15). Clean-washed exposures of feldspathic pebbly psammites, psammites and less abundant pelites, exhibit abundant well-preserved sedimentary structures, a rarity in this part of the Northern Grampian Highlands due to ubiquitous metamorphism and deformation (see also the *Rubha na Magach* and *Garva Bridge* GCR site reports). Slumped horizons, load casts, rip-up clasts, trough and tabular cross-lamination, planar lamination, grading and dewatering structures are all preserved due to low strain in the hinge-zone of the major fold (Figure 16). Indeed, the detail exhibited allows palaeoenvironmental interpretations to be made with a resolution comparable to that in undeformed Phanerozoic successions.

The base of the Glen Buck Pebbly Psammite Formation is nowhere exposed and hence its relationship with postulated basement rocks of the Badenoch Group is unknown. The upper contact, with schistose semipelite and micaceous psammite of the Corrieyairack Subgroup, defines the inlier but it is not exposed in the river section described here (see the BGS 1:50 000 Sheet 73E (Foyers, 1996). Where seen, the contact is sharp, but it is strongly deformed by a ductile shear-zone that exploited competency contrasts between lithologies of the Corrieyairack and Glenshirra subgroups.

On the BGS 1:50 000 Sheet 73E (Foyers, 1996) the rocks of the inlier were included within the Gairbeinn Pebbly Psammite Formation, now reassigned to member status within the Garva Bridge Psammite Formation (see the *Lochain Uaine* and *Garva Bridge* GCR site reports). However, a recent re-interpretation of the relationships indicates a correlation with the Glen Buck Pebbly Psammite Formation to the south-west (Banks and Winchester, 2004; Banks, 2005).

6.2 Description

An estate track provides easy access and the best sections occur in the River E, east and north of the ruins at NH 5556 1370. The most common lithology within the Glen Buck Pebbly Psammite Formation is a medium-grained feldspathic psammite that occupies *c.* 75% of the river section. Scattered angular clasts of quartz and/or K-feldspar form less than 5% of the rock. This lithology varies in colour from salmon pink (reflecting oxidation of iron minerals), through cream (quartzose lithologies) to dark grey (more micaceous lithologies).

These beds of feldspathic psammite have a lens, sheet or wedge morphology up to 50 cm in thickness (Figure 16a). They display excellent tabular and trough lamination with multiple re-activation surfaces. Cross-laminated beds commonly have a pebbly lag or heavy mineral concentration at their base (Figure 16b). Sets usually attain *c.* 0.1 - 0.15 m in thickness with co-sets *c.* 0.2 - 0.3 m thick. Ripple cross-lamination is very common and occurs at the top of cross-laminated beds of psammite or pebbly psammite. Psammite beds at NH 546 136 preserve low-angle (<10°) cross-sets with migration directions opposite to the surrounding background tabular cross-laminae. Some rare beds thin and display a reduction in clast abundance and size in a direction opposite to foreset migration.

Common erosional scour-and-fill structures are developed at the base of the feldspathic psammite units and have a deep (*c.* 0.05 m) and narrow (*c.* 0.1 m) morphology with intraclasts scattered throughout the scour fill. Well-developed examples occur at NH 5445 1410. A variety of load casts, flame structures, sand volcanoes and injection structures are well developed; good exposures of injection structures can be viewed at NH 5445 1410 (Figure 16c).

Pebbly psammite occupies approximately 25% of the section, and is commonly matrix supported, with granule- to pebble-sized clasts of single mineral grains (K-feldspar or quartz) or of quartzofeldspathic aggregates, which are rarely pegmatitic. The clasts are always angular, which might reflect either original immature depositional texture or the synmetamorphic overgrowth of detrital grains. The pebbly psammites can be divided into two groups–beds that are internally massive (disorganized) and beds that show well-developed sedimentary structures (organized).

Massive beds of pebbly psammite tend to form sharp, parallel-sided sheets between 0.1 and 1.0 m thick, with erosive bases. Bed tops may show cross-stratification, indicating later reworking. Some thicker units show inverse grading from granule- to pebble-sized clasts (NH 5463 1363). These massive sheets are stacked and interbedded with organized beds of pebbly psammite (Figure 17).

Organized pebbly psammite beds are discontinuous laterally and have lensoid morphologies. They can have gradational lower contacts with more-massive pebbly sheets (Figure 17). Intricate tabular and trough cross-stratification is well preserved. Cross-strata form co-sets *c.* 0.1 - 0.3 m thick with sets ranging from 0.05 - 0.1 m thick (NH 5463 1363).

Semipelite forms a very minor constituent of the River E succession. Where developed, it is rarely extensive, either laterally or vertically. It most commonly occurs as micaceous drapes on psammitic cross-laminae or as thicker lenses between psammitic macroforms. No internal sedimentary fabric or texture is preserved in this lithology as a consequence of coarse-grained recrystallization during regional metamorphism.

Slumped bedding forms a relatively minor, but locally important, component of the stratigraphical succession described here. Beautifully preserved, contorted and folded slumped layers up to 2 m thick occur at NH 5460 1367. These slump folds occur within layers that are demonstrably stratabound by planar beds; the slump structures have no systematic axial trend and are disharmonic to the regional fabric.

6.3 Interpretation

The metasedimentary rocks exposed within the River E inlier, are interpreted as having been deposited within alluvial and fluvial environments. The assemblages of sedimentary structures indicate that two depositional processes were dominant: sediment gravity flows (debris flows and slumps) and traction currents.

Disorganized and massive, matrix-supported pebbly psammite sheets indicate deposition by cohesive debris flows (Miall, 1992). Rare inverse grading suggests that significant dispersive pressures (probably from grain collision) operated within these flows (the density-modified-grain flow of Lowe, 1976). Flows eroded the underlying substrate but were gradational with, and reworked by, stream flows as is suggested by the development of cross-lamination in pebbly sheet tops.

Sediment gravity flows are also represented by slumped units. These indicate failure and collapse of a topographical high (a bank or cliff) perhaps by fluvial undercutting. The intensity and ductile nature of the slumped folding suggest that these sediments were unlithified and water saturated when this occurred.

Well-developed tabular and trough cross-lamination within organized pebbly psammite and psammite indicate deposition by traction currents. Considering the palaeo-grain size of the sediment, these traction currents would have been almost certainly subaqueous; no indication of aeolian processes has been found. The dominance of tabular cross-stratification indicates the common accretion of straight-crested ripples and dunes. The rarer occurence of trough cross-bedding is the result of higher velocity flows creating more-linguoid ripples and lunate dunes (Allen, 1963). Weaker, dilute traction currents are indicated by developments of ripple lamination within non-pebbly units. The unidirectional nature of the tabular cross-sets indicates a consistent migration direction of these fluvial sand bodies, which could be either downstream or lateral. Rare low-angle cross-sets with palaeocurrents opposite to the general trend indicate the development of antidunes, where standing waves promote upstream migration of bedforms.

Common scour-and-fill structures suggest very high current velocities eroding the substrate. Deep, narrow scours and intraclast-rich scour-fills suggest coarse bedload abrasion rather than fluid erosion of the substrate (Collinson and Thompson, 1988). Rapid deposition onto a water-saturated substrate is recorded by common dewatering structures.

The pebbly and feldspathic psammites exposed in the River E therefore represent a variety of lateral and downstream accretion architectural elements (sensu Miall, 1985). However, due to poor lateral continuity of exposure away from the river section, three-dimensional control on the geometry of these sand bodies is difficult to establish.

The pebbly deposits are interpreted as longitudinal gravel bars, point bars, thoroughly reworked debris flows or sheet-flood deposits. The non-pebbly deposits represent a spectrum of sand bars, sand waves, dunes and ripples. Some of these non-pebbly psammite beds represent point bars as is suggested by lateral grain-size reduction in the opposite direction to palaeocurrents. Palaeocurrents reflect lateral migration of bars, whilst lateral grain-size reduction indicates flows becoming weaker up the bar (Miall, 1992).

The quartz-K-feldspar-dominated clast population indicates that both the debris flows and the river systems were fed from a quartzofeldspathic gneissose or granitic hinterland.

6.4 Conclusions

This near-continuous section in the River E exhibits some of the most spectacular Neoproterozoic sedimentary structures in Britain. Here, feldspathic pebbly psammites crop out in the core of an upright F2 antiform, where the amount of strain is far less than is usual in the Northern Grampian Highlands, preserving excellent examples of sedimentary slumping, load casts, rip-up clasts, trough and tabular cross-lamination, planar lamination, grading and dewatering structures.

The strata are representative of the Glenshirra Subgroup, the lowest division of the Grampian Group and the detailed evidence at this site indicates that the original sediments were deposited within continental alluvial and fluvial environments. Traction deposition of a mixed sandy and gravely bedload took place in braided river systems. This palaeoenvironment was subject to influx of debris flows that introduced coarse clastic sediment sourced from a nearby quartzofeldspathic gneissose or granitic terrane.

7 GARVA BRIDGE (NN 524 953)

S. Robertson

7.1 Introduction

The environs of Garva Bridge, in the upper catchment of the River Spey, are the type area for the Glenshirra Subgroup, the oldest part of the Dalradian Supergroup. The sedimentological detail preserved at this GCR site in the lower stretch of the Allt Coire Iain Oig, together with the lithological features observed in the surrounding area, are highly pertinent to interpretations of basin evolution for the lower part of the Grampian Group.

The Glenshirra Subgroup crops out in a near-circular inlier covering approximately 30 km^2 and informally referred to as the Glenshirra Dome (Figures 18, 19). This dome dominates the outcrop pattern in the north-west corner of the BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002). It is cut by The Allt Crom Complex in the north-east and by the Corrieyairack Pluton in the south-west. The stratigraphy was originally described by Haselock *et al.* (1982), who recognized four formations in the north of the dome, and Okonkwo (1988) who recognized two formations in the south. Recent detailed surveying has replaced these with a single formation, the Garva Bridge Psammite Formation, containing a distinctive pebbly psammite (the Gairbeinn Pebbly Psammite Member). Haselock and Leslie (1992) demonstrated the distinctively strong magnetic nature of the Gairbeinn Pebbly Psammite Member and used that characteristic to help define lithological boundaries in unexposed ground. Any discrepancies between the published map and the earlier studies result largely from previously unrecognized fold repetition.

The boundary between the Garva Bridge Psammite Formation and the overlying Coire nan Laogh Semipelite Formation of the Corrieyairack Subgroup was recognized as a zone of high strain referred to as the Gairbeinn Slide (Haselock *et al.*, 1982; Okonkwo, 1988). However, recent investigations have concluded that the high strain is focused at the boundary between contrasting lithologies within a conformable succession (Smith *et al.*, 1999). Comparative geochemical studies (Haselock, 1984) and sedimentological analysis (Glover *et al.*, 1995; Glover, 1998; Banks and Winchester, 2004) have emphasized the distinctive immature fluviatile to shallow-marine nature of the Glenshirra Subgroup, which is in sharp contrast to the deeper marine, turbiditic nature of the succeeding Corrieyairack Subgroup. Banks and Winchester (2004) identified this change in sedimentary environment as a sharp sequence boundary, recording a major reorganization of basin architecture. They considered this to be so significant as to warrant elevation of the Glenshirra sequence from subgroup to group status. However, this has not been adopted in this special issue.

7.2 Description

The Garva Bridge Psammite Formation consists mainly of psammite with lesser amounts of micaceous psammite and thin beds of semipelite. The formation is well exposed in the north bank tributaries to the River Spey, including the Allt Coire Iain Oig and Allt a' Ghamnha, and in hillside exposures around Gairbeinn (NN 46 98). On Creag Mhor (NN 488 974) the succession is relatively more micaceous with common thin beds of semipelite. The base of the formation is not exposed and therefore the 2 km observed thickness provides a minimum estimate only. The following detailed descriptions are based largely on those of Glover (1998).

The formation comprises two lithological associations; a psammite association that occurs near the base of the succession and a heterolithic association of psammite, micaceous psammite and semipelite. The heterolithic association is dominant and, while it occurs both above and below the psammite association, it broadly overlies the psammite association; the relationships are well exposed in the Allt Coire Iain Oig section (NN 519 979 to NN 524 949), which includes the designated Garva Bridge GCR site at NN 524 953.

Rocks of the psammite association are typically pink and range from well bedded with cross-bedding in the Allt a' Ghamnha section (NN 491 958 to NN 483 975), to massive and, in places, flaggy and coarse grained with increasing deformation and recrystallization in the Allt Coire Iain Oig (NN 519 979 to NN 524 949). In the Allt a' Ghamnha, where the association is approximately 500 m thick, individual gently lensoid psammite bodies up to several metres thick are stacked vertically and are inferred to overlap laterally. Each psammite body is made up of a number of cross-bedded sets arranged into thinning upwards packages. Tectonic flattening has greatly reduced intersection angles, both at set-bounding surfaces such that cross-bedding is not prominent and at psammite body boundaries (Glover, 1998).

The heterolithic association in the Allt Coire Iain Oig shows interdigitation of psammite, micaceous psammite and semipelite on centimetre to metre scales (Figure 20a). Sedimentary structures are widely preserved in spite of the metamorphic recrystallization, largely as a result of original mud drapes which, as thin semipelitic or pelitic selvedges, now accentuate relict bedding structures. Psammite-dominated parts of the association show small-scale cross-bedding and planar bedding, ripple cross-lamination and local features thought to be hummocky cross-stratification. Feldspar augen are interpreted as metamorphic overgrowths on originally smaller detrital grains. In the muddier parts of the association, sharp-based white or pale-grey psammites pass gradually upwards and downwards into progressively more-micaceous (originally muddier) lithologies in stacked metre-scale cycles. The gradual change occurs through a series of sharp-based thin and medium beds (3 to 50 cm). These show a variety of sedimentary structures including ripple cross-lamination and cross-bedding, scour and gutter casts, convolute laminations and local normally graded bedding.

The Gairbeinn Pebbly Psammite Member is restricted to the north-western part of the Glenshirra Dome and is best seen on the slopes of Gairbeinn (NN 464 985). The member is lithologically similar to the remainder of the formation but also includes coarser grained beds, which become pebbly towards the top of the formation (Figure 20b). The pebbles are composed entirely of quartz and, whilst now significantly flattened, are interpreted to have been originally up to 3 cm in diameter. Pebbles occur within beds of micaceous psammite and less commonly in psammite, with bed thickness typically less than 0.3 m but locally up to 1 m. Pebbly beds typically account for 10% of the member.

The Garva Bridge Psammite Formation thickens markedly towards the north-west. This is largely a result of the much greater thickness of the psammite association and is enhanced by the spatial restriction of the pebbly psammite member referred to above. The heterolithic association generally overlies the psammite association, albeit with some possible interdigitation in the south-east.

The contact between the Gairbeinn Pebbly Psammite Member and the overlying Coire nan Laogh Semipelite Formation is almost continuously exposed along the eastern slopes of Gairbeinn (NN 462 986). Within 60 m of the contact, the Gairbeinn Pebbly Psammite is platy with both intense flattening and elongation of pebbles down dip to the north-west. The base of the Coire nan Laogh Semipelite Formation is represented by an abrupt change to schistose to gneissose semipelite with quartzofeldspathic layers and lenses up to a few millimetres across. A few lenses of quartzite occur in the lower few metres of the formation, but otherwise the semipelite is homogeneous. The upper parts of the formation are marked by an increase in the proportion of psammite layers. These form the lower parts of composite psammite-semipelite beds which reflect graded bedding. The incoming of psammite layers marks a progressive transition into the overlying dominantly psammitic Loch Laggan Psammite Formation (see the *Rubha na Magach* GCR site report).

Deformation and amphibolite-facies metamorphic recrystallization are variably intense. The succession is generally the right way up, although SE-verging small-scale fold structures are present locally, and a SW-closing and SE-verging medium-scale reclined fold-pair in the Creag Mhor area (NN 486 970) repeats part of the succession.

Structures related to three phases of deformation can be recognized across the area. An intense schistosity is developed parallel to bedding planes in micaceous lithologies during the D1 phase and, although no discrete F1 folds have been recognized, this bedding-parallel schistosity is crenulated in the hinge-zone of F2 folds. The majority of the minor F2 folds have a consistent southeasterly vergence; where abundant as on Creag Mhor, the F2 folding is accompanied by intense crenulation of the S1 schistosity. These crenulations, and a rodding in quartzofeldspathic segregations, give rise to a prominent L2 lineation; the dominant planar schistosity is probably in reality a composite D1-D2 structure and lies parallel to lithological layering. The shape of the Glenshirra Dome is controlled by a major antiformal F3 fold. Minor open folds of probable D3 age occur at NN 4936 9660 and intersecting crenulations occur in many semipelite exposures. Distinguishing S2 and S3 crenulations is however difficult due to the variable orientation of the S2 axial surfaces and the lack of any significant development of a crenulation cleavage in either the D2 or the D3 phase of deformation.

7.3 Interpretation

A combination of lithological associations, bedforms and sedimentary structures, albeit modified by deformation and metamorphic recrystallization, allow an interpretation of the depositional environment of the Glenshirra Subgroup. Cross-bedding within the psammite association demonstrates that these strata were deposited largely from traction-dominated currents. The stacking of sandstone bodies, each comprising thinning upward sets, is consistent with deposition as bedforms and barforms within a fluvial setting. The absence of intervening primary mud deposition suggests little preservation of overbank material. This could have been due either to a braided-river environment or the lack of vegetation available in the Neoproterozoic to bind overbank material.

The variety of sedimentary structures in the heterolithic association, including ripple cross-lamination and cross-bedding, scour and gutter casts, hummocky cross-stratification, convolute laminations and local normally graded bedding point to deposition in a shallow-marine storm-influenced environment. The cleaning and muddying upward cycles are interpreted as having been controlled by changes in relative sea level (Glover, 1998).

The depositional environment of the Gairbeinn Pebbly Psammite Member cannot be well constrained because of the absence of well-preserved sedimentary structures. It is inferred to have been dominantly fluvial, with the muddy pebbly rocks possibly the product of mass flow rather than traction (Glover, 1998).

The overall geometry of the depositional basin (Figure 21) can be inferred from the gross disposition and thickness of the lithological associations outlined in Figure 19. A number of features suggest that the north-western part of the dome represents a more-proximal environment. These include a greater thickness of both the psammite association and of the succession as a whole. Additionally, the Gairbeinn Pebbly Psammite Member is only present in the north-west, whereas the heterolithic association is dominant in the south-east. These observations reflect a lateral facies change from dominantly fluvial in the north-west to shallow-marine, storm-dominated facies in the south-east.

The overall evolution of the Glenshirra Subgroup is interpreted as a gradual north-westwards backstepping of fluvial facies and a concomitant increase in the distribution of shallow-marine sedimentation (Glover, 1998) with a renewed phase of more-extensive fluvial deposition close to the top of the formation.

The abrupt change from psammites that represent fluvial deposits to semipelite derived from muddy sediments at the base of the Coire nan Laogh Semipelite Formation, is interpreted as representing a major basin-flooding event (Banks and Winchester, 2004). This starved the basin of coarse clastic material and led to the deposition of offshore mud. Progressive basin deepening led to the onset of deposition by turbidity currents in the upper part of the formation. Quartz-rich lenses near the base of the semipelite may represent reworking of the underlying originally sandy deposits in an offshore environment.

7.4 Conclusions

The Garva Bridge GCR site represents the original type-area for the Glenshirra Subgroup and preserves evidence relating to the depositional environment and basin geometry of the lowest exposed part of the Dalradian succession. The combination of lithological associations and sedimentary structures in the Garva Bridge Psammite Formation demonstrate that fluvial sediments passed laterally to the south-east into shallow-marine, storm-influenced sediments. Through time, the area of fluvial deposition back-stepped towards the north, to be replaced by more-extensive shallow-marine deposition. A major flooding event marked by an abrupt change of lithology at the base of the Coire nan Laogh Semipelite Formation cut off the sand-grade sediment supply. This was probably related to basin deepening, which resulted in the onset of deposition from turbidity currents.

8 RUBHA NA MAGACH (NN 4603 8495–NN 4660 8522)

C.J. Banks

8.1 Introduction

The Grampian Group rocks that underlie much of the Northern Grampian Highlands have been divided by Harris *et al.* (1994) into the Glenshirra (oldest), Corrieyairack and Glen Spean (youngest) subgroups. The Corrieyairack Subgroup attains its greatest thickness (*c.* 5.5 km) in the area surrounding Loch Laggan (Figure 22). Smith *et al.* (1999) postulated that this might represent the depocentre of an intercratonic rift basin, which they termed the Corrieyairack Basin.

Clean water-washed sections on the north shore of Loch Laggan at Rubha na Magach, provide some of the most informative exposures of the Loch Laggan Psammite Formation, which account for some 3.6 km thickness of the Corrieyairack Subgroup. Details of primary sedimentological features are commonly preserved in the micaceous psammites and semipelites of this formation, despite simple upright F2 folding and the effects of metamorphic recrystallization under amphibolite-facies conditions (*c.* 500–600°C, 5–8 kbar, Phillips *et al.*, 1999). Sedimentological analysis of excellent exposures in an area of low tectonic strain at Rubha na Magach allows characterization of the depositional systems for the postulated basin depocentre.

The exposures at Rubha na Magach (NN 4618 8492) were first described by Winchester and Glover (1988), who noted the extraordinarily detailed preservation of such sedimentary structures as cross-bedding, rip-up clasts and convolute bedding. Subsequent descriptions by Glover (1989) and by Glover and Winchester (1989) incorporated palaeo-environmental interpretations. A useful field description with maps and photographs was provided by Winchester and Glover (1991). The site is included within BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002).

8.2 Description

The Loch Laggan Psammite Formation comprises grey psammite and micaceous psammite with subordinate thin semipelite. These lithologies occur in the form of massive and graded beds. The graded bedding and several observation of cross-lamination indicate that the formation is the right way up.

The most-informative localities can be seen on the Rubha na Magach promontory (NN 4618 8492) and at a lochside exposure 300 m to the east at NN 4653 8516. Both exposures lie on the south-east limb of the F2 Laggan Antiform; bedding and a bedding-parallel foliation dip at *c.* 60° to the south-east and bedding is the right way up. Measured logs of both exposures are provided in Figure 23. A heterolithic association of interbedded psammite, micaceous psammite, and dark micaceous psammite with semipelite is exposed. Beds commonly have tabular, parallel-bedded forms and are laterally persistent on the scale of the exposures. Coarse-grained metamorphic recrystallization of the semipelitic component has resulted in scant preservation of sedimentary detail so that it is only possible to infer that it is likely to represent original mudstone. In contrast, the micaceous psammite has well-preserved and commonly very intricate sedimentary structures (Figure 24).

The most-common sedimentary structure is normal grading. Recrystallization during metamorphism has affected the mineralogy and grain size so that original grading is defined by an upward increase in mica content. Psammitic beds consequently have a pseudo-coarsening-upward appearance as they grade into semipelite. Most psammitic beds have graded tops but some massive psammite does occur. A discontinuous planar lamination is also very common and is usually confined to the micaceous psammites.

Climbing ripple (ripple-drift) cross-lamination is beautifully preserved in the micaceous psammites at Rubha na Magach (Figure 24a). Both stoss-side preservation (so that cross-laminae are continuous) and stoss-side erosion surfaces are preserved. Packets of cross-laminae are commonly *c.* 10 cm thick and occur at discrete horizons in individual beds. As with the planar lamination, these are most commonly found in the micaceous psammites.

Convolute lamination can be viewed where thick psammite beds overlie originally planar-laminated micaceous psammite (Figure

24b). Rare beds of micaceous psammite with convolute lamination show bulbous basal projections thought to be load structures (best seen at NN 4653 8516). Such structures are only very rarely preserved in the Loch Laggan Psammite Formation, any such basal projections typically having been removed by shearing along bedding surfaces during folding.

Low-angle scours that cut off the underlying sedimentary structures occur in a number of places and many beds have a very sharp base. The scours are also marked in places by lines of rip-up clasts. Small rip-up clasts, 5-10 cm long and several centimetres thick, have been found at NN 4618 8492. The clasts are usually of dark micaceous psammite or semipelite within more-psammitic beds. Some clasts show original lamination, twisted concordantly with the shape of the clast. These are usually seen at the interface between two psammite or micaceous psammite beds suggesting that significant amounts of bed amalgamation might have occurred.

Okonkwo (1985) noted a common repetitive sequence of sedimentary structures, similar to that reported by Bouma (1962) for the deposits of turbidity currents. Okonkwo (1985) described a basal massive sandy layer overlain in turn by a lower planar laminated horizon, then a cross-laminated horizon, then an upper planar laminated horizon and finally by a mud corresponding respectively to the Ta, Tb, Tc, Td and Te divisions of the Bouma sequence (Bouma, 1962).

Two principal lithofacies associations are present at Rubha na Magach and are shown in the sedimentary logs of Figure 23. The first consists of thick-bedded massive psammite, micaceous psammite and thin semipelite, forming complete Bouma (i.e. Ta–e) and base-missing Bouma (i.e. Tb–e, Tc–e, Td–e) sequences. These have very well-developed sedimentary structures and are well graded. The second lithofacies consists of thin-bedded micaceous to highly micaceous psammite interbedded with more-thickly developed semipelite. This second lithofacies usually shows planar lamination and good grading. Taken together, the two lithofacies form *c.* 15 m-thick packages. The thick-bedded lithofacies association commonly shows a crude thinning and fining upwards into the thinner bedded one.

These localities have several other notable features. Prominent white calcsilicate pods, originally diagenetic calcareous concretions, have the assemblage garnet-hornblende-clinozoisite-andesine-quartz, thus indicating that amphibolite-facies conditions were attained during regional metamorphism (Winchester, 1974). The metasedimentary rocks are cut by several suites of pegmatitic veins and felsic dykes (the Loch Laggan Vein-complex), some of which are quite spectacular, as in the road cuttings at NN 4760 8615 and NN 4721 8593.

8.3 Interpretation

The abundant sedimentary structures in the psammites and micaceous psammites suggest deposition by high-energy, fast-flowing and turbulent currents. In contrast, the semipelitic lithologies suggest a quieter environment of deposition dominated by the settling out of suspended fine sediment. These interpretations, along with the identification of Bouma sequences, support the interpretation of Okonkwo (1985), that these sediments were deposited by turbidity currents.

The grain size of the original sediment (sand to mud grade) and the sedimentary structures present are consistent with a turbidity current origin. The thicker bedded, coarser grained lithofacies association represents relatively high-density, sand-laden turbidity currents and possible tractional processes. As these high-density turbidity currents could scour the existing substrate and deposit sand on top of it, the resultant beds are sharp based and commonly show amalgamation with the underlying sand beds. Rapid deposition is suggested at Rubha na Magach by scouring, rip-up clasts and convoluted lamination. The overlying, thinner bedded and muddier lithofacies association was deposited by much less-dense turbidity flows. Between periods of turbidity flow, periods of quiescence allowed sediment to fall out of suspension and form a silt or mud layer (now semipelite).

Glover (1989) and Glover *et al.* (1995) assigned these metasedimentary rocks to more-specific turbidite elements (*sensu* Mutti and Normark, 1987) and concluded that the Loch Laggan Psammite Formation represents an inner fan channel system. Mutti and Normark (1987), comparing multiple examples of ancient and modern turbidite successions, decribed similar lithofacies associations to the Loch Laggan Psammite Formation in channel systems where erosional and depositional processes took place. Such channels acted as conduits for powerful high-density turbidity currents, such as those inferred here for the thicker lithofacies association in the Loch Laggan Psammite Formation. More-dilute and less-powerful flows dominated the inter-channel areas. Inter-flow times were marked by a laterally persistent mud blanket (semipelite). Thus, in broad agreement with Glover *et al.* (1995), the lithofacies associations observed at Rubha na Magach are interpreted here as inner fan in-channel- and channel-related deposition. The complex channel systems were of mixed erosional-depositional type.

8.4 Conclusions

Rubha na Magach is a nationally important site for its excellent exposures of Neoproterozoic turbiditic sequences in the Grampian Group. These are the most-instructive exposures of the Loch Laggan Formation, the dominant formation of the Corrieyairack Subgroup and are particularly important in developing an understanding of the overall palaeo-environment of the basin depocentre, which was situated in the Loch Laggan area. The more-typical complex deformation and metamorphism of the Northern Grampian Highlands are less well developed here, enabling the application of sedimentological techniques that are more readily applied to undeformed Phanerozoic successions.

A vertical sequence of sedimentary structures, comparable with that of Bouma (1962), is well preserved. This consists of a basal massive division (Ta) overlain in turn by a lower planar-laminated division (Tb), a cross-laminated division (Tc), an upper planar-laminated division (Td) and is capped by semipelite (mud, Te). The preservation of rip-up clasts, scours and the sharp-based nature of the beds indicate that these turbiity currents were of very high density and it is concluded that the Loch Laggan Psammite Formation was deposited by turbidity currents in a sub-marine channel system.

9 KINLOCH LAGGAN ROAD A86 (NN 5440 8975–NN 5500 8980)

S. Robertson

9.1 Introduction

A number of boulder beds interpreted to be of glacial origin have been recognized within the Grampian Highlands. Their significance lies not only in their record of the Earth's past glacial history but also in their potential value as chronostratigraphical markers. The thickest and most extensively developed is the Port Askaig Tillite, which can be traced from the type area on the Isle of Islay, north-eastwards through Perthshire and into the North-east Grampian Highlands (see the *Garvellach Isles*, *Tempar Burn* and *Muckle Fergie Burn* GCR site reports in Tanner et al., 2013a, Treagus et al., 2013 and Stephenson et al., 2013b respectively). Other boulder beds are much more restricted in their geographical occurrence. The Kinloch Laggan road section contains the type locality for the Kinlochlaggan Boulder Bed. Here, adjacent lithologies allow the stratigraphical position of the boulder bed to be determined and the excellent glacially smoothed exposures have prompted some re-assessment of the nature of the deposit. The results of recent mapping by the British Geological Survey on 1:50 000 Sheet 63E (Dalwhinnie, 2002) have traced lenticular occurrences of boulder bed to the south-west along the west-north-west limb and around the hinge of the major Kinlochlaggan Syncline (see the *Aonach Beag and Geal-charn* GCR site report).

The Kinlochlaggan Boulder Bed was first recognized and interpreted as glacial in origin by Treagus (1969). The unit occurs within a sequence of quartzites, pelites and metacarbonate rocks that were attributed by Treagus to the lower part of the 'Ballachulish succession' of the Dalradian. The succession was thought to occur within the core of the Kinlochlaggan Syncline and to be surrounded by older rocks of the 'Moine Series' (Anderson, 1947b, 1956; Smith, 1968), the latter now assigned to the Grampian Group. Subsequent work has generally assigned the boulder bed more precisely to the Lochaber Subgroup of the Appin Group (Thomas, 1979; Treagus, 1981; Robertson and Smith, 1999). However, Piasecki and Temperley (1988a) equated the succession at Kinloch Laggan, including the boulder bed, with the 'Ord Ban Subgroup', now the Kincraig Formation at the base of the Corrieyairack Subgroup of the Grampian Group. At the opposite extreme, Evans and Tanner (1996) suggested that the boulder bed is equivalent to the Port Askaig Tillite at the base of the Islay Subgroup of the Argyll Group.

9.2 Description

The type locality for the Kinlochlaggan Boulder Bed is a small roche moutonnée beside the A86 road at Kinloch Laggan (NN 548 897) (Figure 25). The boulder bed occurs within a near-vertical, NNE-striking succession of quartzite, semipelite, metacarbonate-rock and calcsilicate rock exposed on the west-north-west limb of the upright Kinlochlaggan Syncline (Anderson, 1947b).

The boulder bed consists of a sequence, over 20 m thick, of quartzite and psammite. The north-western part comprises 7 m of massive pebbly quartzose psammite or quartzite that is apparently unbedded apart from some poorly developed micaceous partings and colour lamination. Clasts are relatively abundant, poorly sorted, matrix supported and unevenly distributed (Figure 26). Treagus (1969, 1981) recognized 'several thousand stones' per square metre within the size range 3 to 30 mm. Most clasts are less than 3 cm long and many are less than 1 cm with only 20 counted in the range 8 to 10 cm. Treagus reported that approximately 75% of the 'stones' are of alkali granite with the remainder being quartzite, pelite or semipelite. Numerous pink feldspars could be either clasts or porphyroblasts, whereas quartz-feldspar aggregates are thought to be clasts. Numerous weathered-out hollows on exposed surfaces are thought to indicate former positions of clasts. One clast of semipelite is 9 cm long and 1.5 cm across and contains two tectonic fabrics, the later of which is parallel to both the long axis of the clast and the fabric in the host quartzite. Only one large boulder is present. This is 40 cm by 16 cm, subrounded and composed of granite. It contains a foliation parallel to both the long axis of the boulder and the fabric in the host quartzite.

The clast-bearing lithology is succeeded to the south-east by 6 m of non-pebbly psammite and then by 7 m of psammite containing scattered clasts that are lithologically similar to those in the first unit. Only 6 clasts in the size range 8 to 10 cm have been recognized; smaller 3 to 30 mm clasts are more abundant but widely scattered. Treagus (1969) reported traces of bedding lamination and that the bedding planes are deformed locally in the matrix beneath some of the clasts. Thin granite veins cross-cut the second clast-bearing unit.

The contacts between the boulder bed and the adjacent lithologies are not exposed in the road section. The nearest exposures of the Kinlochlaggan Quartzite Formation are 60 m away to the west, forming the prominent cliffs behind Kinloch Laggan village hall and smaller exposures on the roadside. There are no exposures in the intervening ground. However, 16 km to the south-west, both in Coire Cheap (NN 4176 7566) and near Aonach Beag (NN 4554 7375), the boulder bed is seen to be conformable with the quartzite. Furthermore, preserved cross-bedding in the Coire Cheap area clearly shows that the quartzite underlies the boulder bed.

At Kinloch Laggan, the Kinlochlaggan Quartzite comprises 150-200 m of massive white quartzite with bedding defined only by variations in colour. Large, white to pink feldspar crystals are a widespread feature. Two subangular granitic clasts 15 mm long occur in roadside exposures at NN 5459 8976. Younging evidence is sparse and is confined to possible examples of cross-bedding, which do not give a conclusive answer.

The quartzite is well exposed and forms numerous glacially smoothed surfaces on the hillside along strike to the north-east. Vertical faces at NN 556 906 show prominent gently plunging rodding lineations. Some surfaces show two slightly oblique linear structures, an earlier rodding lineation, which is co-axial with the large-scale folds such as the Kinlochlaggan Syncline, and a later lineation marked by the hinges of small-scale crenulations or corrugations.

The Kinlochlaggan Quartzite overlies a dominantly semipelitic unit referred to as the Aonach Beag Semipelite Formation. The contact between the semipelite and the quartzite is gradational through a zone of interbedded quartzite and semipelite that is well exposed on the hillslope to the north-west of Kinloch Laggan around NN 551 904. The contact between the lowest exposed part of the semipelite and the Grampian Group to the north-west is interpreted as a slide (Figure 25). However, to the south-west, in the Coire Cheap area, the contact is locally conformable and transitional (Robertson and Smith, 1999).

To the east of the boulder bed, the overlying succession is dominated by metacarbonate rocks, calcsilicate rocks and semipelites assigned to the Coire Cheap Formation. Amphibolite sheets are widespread. The nearest exposures to the boulder bed, less than 10 m away across strike, occur in a small disused limestone quarry. On the west wall of this quarry, stratigraphically closest to the boulder bed, 1 m of schistose biotite-muscovite semipelite is succeeded to the east by approximately 1 m of biotite semipelite composed of biotite, plagioclase, quartz, clinozoisite and accessory tourmaline. Some 20 to 30 cm of vein quartz separates this from *c.* 16 m of metacarbonate rock. The lowest part of the metacarbonate rock is pale grey and contains both dolomite and calcite. The remainder is massive, coarsely crystalline and grey-blue with brown-weathering surfaces. Micaceous partings separate metre-thick units of metacarbonate rock. Brown-weathering upstanding ribs, resulting from a greater abundance of calcsilicate minerals, show tight to isoclinal folds with a strong co-axial ribbing lineation. Approximately 1 m of rusty-weathering biotite semipelite occurs on the east wall of the quarry. A second quarry immediately to the east contains 13 m of metacarbonate rock that is lithologically similar to the bulk of the first quarry. Farther to the east, schistose semipelite to pelite contains a 3 m-wide sheet of garnet amphibolite; the garnets are largely replaced by feldspar.

9.3 Interpretation

The Kinlochlaggan Boulder Bed has been interpreted as glacial in origin on the basis of the occurrence of matrix-supported extrabasinal granite clasts, and the unbedded psammite units containing the clasts were originally interpreted as tillites (Treagus 1969, 1981). However, the quartz-rich and mica-poor character of the sequence indicates that it was derived from a relatively mature sandy sediment, more typical of a clastic waterlain origin than a subglacial till. The immediately underlying quartzites of the Kinlochlaggan Quartzite are likely to have originated on a shallow marine shelf. Therefore the extrabasinal clasts are best interpreted as ice-rafted dropstones, a feature supported by the apparent deformed bedding lamination beneath some clasts reported by Treagus (1969). These features are preserved in spite of intense folding and metamorphic recrystallization at kyanite to sillimanite grade.

The boulder bed occurs within a heterogeneous succession of semipelites, quartzites and metacarbonate rocks, which stratigraphically overlies the Grampian Group. Therefore the suggested correlation with the 'Ord Ban Subgroup' (now the Kincraig Formation at the base of the Corrieyairack Subgroup) is untenable. The boulder bed occurs above and in stratigraphical continuity with the Aonach Beag Semipelite Formation and Kinlochlaggan Quartzite Formation. Collectively, these two units are lithologically similar to the Loch Treig Schist and Quartzite Formation, which forms the lower part of the Lochaber Subgroup in the Loch Treig area to the south-west of this GCR site (Key *et al.*, 1997). The boulder bed is therefore assigned to the Lochaber Subgroup of the Appin Group (Figure 27). The overlying metacarbonate-bearing succession of the Coire Cheap Formation, which is separated from the boulder bed by some 10 m of unexposed strata, has no correlative in the Loch Treig area. However, there are similarities in terms of the lithologies and the geochemistry of the metacarbonate rocks with the upper part of the Ballachulish Subgroup in the Schiehallion area, which represents the closest Appin Group rocks to the south (Thomas *et al.*, 1997). Such a correlation requires that the upper part of the Lochaber Subgroup and the lower part of the Ballachulish Subgroup are absent from the Kinloch Laggan area (Robertson and Smith, 1999). The much more-extensive Port Askaig Tillite occurs at the base of the Islay Subgroup, stratigraphically well above the metacarbonate-bearing successions of the Ballachulish Subgroup.

9.4 Conclusions

The Kinloch Laggan Road GCR Site contains the type locality for the Kinlochlaggan Boulder Bed, which represents one of a number of boulder beds containing extrabasinal clasts within the Dalradian succession. The clasts of granite, together with quartzite, semipelite, pelite and feldspar are interpreted as dropstones from floating ice rather than being derived from till beneath a grounded ice-sheet. The boulder bed occurs within a conformable stratigraphical succession that can be correlated with the Lochaber Subgroup of the Appin Group. It lies beneath a significant intra-Appin Group unconformity in the local succession where the upper parts of the Lochaber and lower parts of the Ballachulish Subgroup are absent. The site is of national importance in demonstrating the earliest recorded glacial influence within the Dalradian. When combined with the Port Askaig Tillite and the boulder beds in the upper parts of the Dalradian, it demonstrates a repeated glacial influence during Neoproterozoic and Early Palaeozoic times.

10 ALLT MHAINISTEIR
(NN 546 861–NN 524 847)

S. Robertson

10.1 Introduction

The Allt Mhainisteir and Allt Liath nam Badan river sections, in the Ardverikie Forest area south of Loch Laggan, contain a near-continuous section through the lithologically diverse Kinlochlaggan succession of the Appin Group (Figure 28). The Kinlochlaggan succession is separated from the Grampian Group lying stratigraphically beneath it by spectacular shear-zones and tectonic slides, with resulting local omission of lithological units. Nevertheless, strain is low in places and this GCR site provides the framework against which to place elements of the succession recorded elsewhere in the Kinloch Laggan district (see for example the *Aonach Beag and Geal-charn* GCR site report).

The Allt Mhainisteir GCR site lies within the Geal-charn–Ossian Steep Belt, a major composite D1 synclinal structure focussed upon the Kinlochlaggan Syncline (Thomas, 1979; Robertson and Smith, 1999) (Figures 30, 31). Details of the stratigraphical and structural architecture of the steep belt are included in the report for the *Aonach Beag and Geal-charn* GCR site, which lies some 10–12 km to the south-south-west of the Allt Mhainisteir. The steep belt comprises a narrow, elongate zone of steeply dipping, varied lithologies of the Kinlochlaggan succession, which include metalimestone, kyanite semipelite, quartzite and the Kinlochlaggan Boulder Bed (see the *Kinloch Laggan Road* GCR site report). These lithologies contrast markedly with the surrounding psammites and semipelites of the Grampian Group. The Allt Mhainisteir GCR site also includes gneissose 'basement' rocks belonging to the Glen Banchor Subgroup of the Badenoch Group (Smith *et al*., 1999). In addition, a well-exposed section through the NNE-trending Inverpattack Fault-zone reveals both early ductile and later brittle deformation

The results of new mapping in the area by the British Geological Survey are represented on the 1:50 000 Sheet 63E (Dalwhinnie, 2002).

10.2 Description

Within the area of the GCR site there are three major tectonostratigraphical units (Figure 28); the Kinlochlaggan succession occupying the core of the Kinlochlaggan Syncline is bound to both the east and west by Grampian Group psammites. The boundaries are defined by high-strain ductile shearing expressed as tectonic slides, the Allt Mhainisteir Slide to the east of the Kinlochlaggan succession and the northward continuation of the Aonach Beag Slide to the west. Rocks of the Glen Banchor Subgroup crop out in the eastern part of the GCR site, where they are juxtaposed against the Grampian Group by the Inverpattack Fault.

10.2.1 Lithologies east of the Allt Mhainisteir Slide

Grampian Group rocks assigned to the Creag Meagaidh Psammite Formation of the Corrieyairack Subgroup are well exposed in the lower part of the Allt Mhainisteir section, immediately west of the Inverpattack Fault-zone (NN 544 859). A succession of graded beds, typically 20 cm thick, are composed dominantly of psammite in which thin micaceous bed tops represent original muddier sediment. The rocks dip steeply to the south-east but young to the west towards the trace of the Kinlochlaggan Syncline; hence they are inverted.

The published BGS 1:50 000 sheet indicates that rocks of the Appin Group, Sron Garbh Semipelite Formation extend north-north-eastwards from the valley of the Allt Cam (NN 50 78) towards an unexposed section at NN 542 859 in the Allt Mhainisteir, to the west of the outcrop just described. The formation is very well exposed on Sron Garbh (NN 514 814) and on the ice-scoured slopes between Sron Garbh and Meall na Brachdlach (NN 518 824). Across these locations, the formation comprises almost entirely gneissose magnetite semipelite with rare gradations towards micaceous psammite. The outcrop width ranges from at least 750 m immediately north-east of Sron Garbh to less than 200 m 5.5 km to the north-east around NN 538 856. The formation is not exposed north of the Allt Mhainisteir and has been interpreted as a local facies development within the Kinlochlaggan succession (Robertson and Smith, 1999). The formation is juxtaposed against the Creag Meagaidh Formation in the north and east of its outcrop, with no intervening older elements of the Kinlochlaggan succession (Figure 27). Although contacts are not clearly exposed, loose debris in the form of regolith can be traced across the boundary near Meall na Brachdlach. No highly strained material can be seen; the contacts are therefore regarded as preserving the original depositional relationships and hence provide evidence of onlap of the Sron Garbh Semipelite Formation onto the underlying Grampian Group (Robertson and Smith, 1999).

Returning to the river section, the next exposures to the north-west (at NN 5371 8559) comprise further graded psammites that are also assigned to the Creag Meagaidh Formation, albeit a rather coarser grained lithology than that seen to the east. At NN 5351 8541, abundant close folds deforming the lithological banding are particularly well seen. The folds die out over short distances along their axial surfaces but a coarse schistosity, axial planar to the folds and strongly oblique to the bedding, is prominent even where there are no folds. Remnants of graded bedding are locally recognizable, although the increase in grain size due to metamorphism has modified most primary features.

Over the 80 m that intervenes between the last locality and the Allt Mhainisteir Slide, the folds become progressively tighter with the local development of discontinuities along fold limbs. Some of these discontinuities host metamorphic quartzofeldspathic segregations. Within 30 m of the slide (at NN 5343 8535) isoclinal folds, some of which are rootless, are exposed in the bed of the Allt Mhainisteir (Figure 29). Quartzofeldspathic leucosomes and thin pegmatitic veins up to 1 cm thick are also present within the pervasive gneissose foliation. At NN 5339 8532, the slide contact is marked by an abrupt change from flaggy psammite and micaceous psammite of the Creag Meagaidh Psammite Formation to the Aonach Beag Semipelite Formation of the Kinlochlaggan succession, which here comprises micaceous psammite and psammite with 10 cm-thick, brown-weathering schistose semipelites and concordant homogeneous to banded amphibolites.

10.2.2 Grampian Group lithologies west of the Kinlochlaggan succession and the Aonach Beag Slide

The Aonach Beag Slide is not exposed in the Allt Liath nam Badan but a continuous section through the contact of the Kinlochlaggan succession with the Grampian Group is exposed nearby at NN 522 851 on the eastern slope of Meall Each. There, a medium-scale asymmetrical fold hinge preserves a low-strain area in the Creag Meagaidh Psammite Formation. The main tectonic fabric is at a high angle to bedding. Graded beds, typically up to 10 to 15 cm (and locally 30 cm) thick, range from massive psammite to micaceous psammite with thin semipelitic tops. The stratigraphy youngs to the east towards a slide that forms the contact with the Kinlochlaggan succession. Much of the Creag Meagaidh Psammite Formation to the west is flaggy and strongly attenuated with very tight or isoclinal folds. Gneissose semipelites and psammites of the Inverlair Psammite Formation form a unit a few tens of metres thick adjacent to the trace of the Aonach Beag Slide (NN 526 852). To the east of the slide, schistose to platy semipelite with some psammite and abundant amphibolite represent the Aonach Beag Semipelite Formation of the Kinlochlaggan succession.

10.2.3 The Kinlochlaggan succession in the Allt Mhainisteir and Allt Liath nam Badan

The Kinlochlaggan succession comprises a heterogeneous association of quartzite, schistose to gneissose semipelite, micaceous psammite, metacarbonate rock, calcsilicate rock and abundant amphibolite. The succession is represented by three formations in the area of this GCR site.

The oldest formation, the Aonach Beag Semipelite Formation, is well exposed in the Allt Liath nam Badan between NN 5240 8475 and NN 5260 8490. It comprises a mixed succession of interlayered schistose and commonly platy semipelite and micaceous psammite with ribs of psammite. At NN 5251 8487, more than 18 m of massive and locally gneissose psammite with streaked-out feldspar megacrysts occurs between flaggy schistose semipelite and fissile, intensely deformed psammite and micaceous psammite. Amphibolites, many of which carry garnet, account for less than 5% to over 30% of any particular exposure and occur in concordant sheets ranging from less than 1 cm to 100 cm thick. Quartz seams and lenses together with coarse-grained quartzofeldspathic lenses are widely developed. Quartzites, which are a prominent feature of the upper part of the formation both to the south-west (see the *Aonach Beag and Geal-charn* GCR site report) and to the north-east, are not present here.

The Aonach Beag Semipelite Formation is overlain by the Kinlochlaggan Quartzite Formation. The contact is not exposed in this section, although elsewhere it is gradational, with either an increase in the proportion of interbedded quartzite or a change to more-psammitic lithologies. The formation is very well exposed in the Allt Liath nam Badan around NN 5267 8492 and close to its confluence with the Allt Mhainisteir around NN 5312 8513, where pebbly layers and relics of cross-bedding can be seen. It comprises massive white quartzite up to 160 m thick (see also the *Kinloch Laggan Road* GCR site report). No representative of the Kinlochlaggan Boulder Bed has been recognized in this section. At NN 5271 8491, the quartzite is cut by an amphibolite lens, at least 35 m thick and probably less than 100 m long. This amphibolite has a sharp contact with the quartzite.

The Kinlochlaggan Quartzite Formation is overlain abruptly by the Coire Cheap Formation in the Allt Liath nam Badan at NN 5280 8505; pale-coloured metacarbonate rock occurs close to the base of the Coire Cheap Formation at this contact. Here, the Sron Garbh Semipelite Formation is absent, most likely as the result of original depositional variations rather than the effect of any tectonic excision. The Coire Cheap Formation is dominated by semipelite but is distinguished by the presence of calcsilicate rocks and metacarbonate rocks (e.g. at NN 5290 8507). The latter range up to 45 m in outcrop width.

Between NN 5318 8516 and the Allt Mhainisteir Slide, each of the three constituent formations of the Kinlochlaggan succession are present in the stream section. However, relationships are complicated by a combination of faulting, very tight folds that repeat the succession, and a stratigraphically attenuated succession. The Aonach Beag Semipelite Formation is approximately 25 m thick adjacent to the Aonach Beag Slide (compared with 170 m on the opposite limb of the Kinlochlaggan Syncline), and the Kinlochlaggan Quartzite is only 5 m thick at NN 5335 8527 and 7 m thick at NN 5323 8516 where it crops out in an antiformal closure. The Coire Cheap Formation is marked by metacarbonate-rock units up to 6 m thick. At NN 5327 8518, metacarbonate rock contains pods of cross-cutting pegmatite and is separated by 1 m of micaceous psammite from gneissose semipelite with leucosomes up to 1 cm across and 2 cm-long kyanites.

10.2.4 The Inverpattack Fault

The Inverpattack Fault is well exposed in the Allt Mhainisteir around NN 5454 8591, where it juxtaposes Grampian Group lithologies against the Glen Banchor Subgroup. East of the fault and into the River Pattack (NN 546 861), small- to medium-scale asymmetrical and chevron folds (several metres in amplitude) occur together with fractures, many of which dip steeply to the west. Some fold limbs are truncated by the fractures, whereas in other examples semipelitic lithologies are crumpled and crenulated adjacent to discontinuities. The geometry of crumple folds suggests that displacement across the fractures has a normal sense (i.e. downthrow to the west). Microdiorite dykes cut some folds, whereas a dyke at NN 5461 8612 might be deformed by a fold; other dykes are deformed in fracture-zones.

A zone of mixed cataclasitic and mylonitic rock at least 8 m across crops out to the west of the folded and fractured zone (NN 5456 8592), deforming interbanded psammite and semipelite that is cut by microdiorite and pegmatitic dykes. The rock is typically dark grey, fissile, friable and very fine grained, with the foliation typically inclined at 70° to the east-south-east. It contains porphyroclasts of psammitic and pegmatitic lithologies up to 10 cm across that are wrapped by the foliation. In thin section, numerous angular to subrounded quartz and plagioclase grains and bent biotite flakes form both monominerallic and lithic clasts within a very fine-grained foliated groundmass in which larger clasts are cemented by carbonate minerals. Deformation might also post-date emplacement of the microdiorite dykes, as microdiorite clasts are thought to occur within the zone. Both anastomosing shear fabrics (S-C fabrics) and tails developed on porphyroclasts indicate a sinistral reverse sense of displacement (i.e. downthrow to the west). Immediately to the west, the cataclasite-mylonite zone is succeeded by 90 m of brecciated psammite. The psammite forms massive exposures, which on close examination consist of angular psammite fragments within a psammitic matrix. Thin zones of mylonite and discontinuities, some of which are gently inclined, occur throughout this brecciated zone, all of which has been recemented and is therefore cohesive.

10.3 Interpretation

The Kinlochlaggan succession strata are preserved in the core of the Kinlochlaggan Syncline in the centre of the Geal-charn–Ossian Steep Belt (Figures 30, 31). The contacts with the underlying Grampian Group are affected by high-strain ductile shearing, with the Aonach Beag Slide marking the boundary in the west and the Allt Mhainisteir Slide acting similarly in the east. Grampian and Appin group rocks share a common deformational history. Good evidence for increasingly high non-co-axial strain as each of the slide contacts is approached is preserved in the lithostratigraphy. However strain is sufficiently low in places for the essential stratigraphical continuity of the sequence to be maintained.

The Lochaber Subgroup, Sron Garbh Semipelite Formation, resting directly on the Grampian Group, Creag Meagaidh Psammite Formation east of the Allt Mhainisteir Slide, represents a local facies development within the Kinlochlaggan succession. In the absence of any highly strained material at the contact this relationship is interpreted to mean that the original depositional relationships are preserved. Since distinctive older elements of the Kinlochlaggan succession are not present here e.g. the Kinlochlaggan Quartzite Formation, such details constitute an important part of the overall evidence for onlap relationships and the complex depositional framework in Appin Group times proposed for the region now disposed within the Geal-charn–Ossian Steep Belt by Robertson and Smith (1999) (see the *Aonach Beag and Geal-charn* GCR site report).

The Inverpattack Fault is one of a number of NNE-trending faults that link major NE-trending transcurrent faults in the Northern Grampian Highlands. It links the Markie Fault and the Ericht–Laidon Fault and cuts across the trace of the Geal-charn–Ossian Steep Belt. The fault separates the Grampian and Appin groups of the Dalradian from the older Glen Banchor Subgroup of the Badenoch Group, which is exposed on the east side of the steep belt. The microfabric relationships in the fault rocks are consistent with the left-lateral displacement of lithological units across the fault; *c.* 2.5 km of sinistral offset is observed farther north (NN 58 96). Observed fault fabrics display evidence for both early brittle–ductile deformation and later brittle faulting, demonstating the likely long-lived nature of this fault system.

10.4 Conclusions

The Allt Mhainisteir GCR site provides a coherent *c.* 4 km-long traverse across the Geal-charn–Ossian Steep Belt, which here includes a distinctive succession of metalimestone, quartzite, semipelite and amphibolite known as the Kinlochlaggan succession. This provides the most-complete correlative framework for other sections within the steep belt. Despite the presence of high ductile strain on both the north-west and the south-east sides of the Kinlochlaggan succession, Grampian Group psammites can be seen to young consistently towards it. Hence the Kinlochlaggan succession lies stratigraphically above the Grampian Group and can be readily assigned to the Appin Group. Local stratigraphical omissions in both the Grampian and Appin group successions provide evidence for the punctuated nature of the depositional record in this sector of the Dalradian basin.

This GCR site also provides a well-exposed section through the Inverpattack Fault, revealing a complex history of ductile and brittle deformation associated with one of the sinistral strike-slip faults that have a major effect upon the outcrop pattern in the Northern Grampian Highlands, and whose effects must be compensated for in any attempt to reconstruct a depositional framework for the region.

11 AONACH BEAG AND GEAL-CHARN (NN 454 735–NN 470 747 and NN 475 761–NN 497 746)

S. Robertson, J.R. Mendum and A.G. Leslie

11.1 Introduction

The Aonach Beag and Geal-charn GCR site provides one of the best cross-sections through the zone of sheared and tightly folded, steeply dipping metasedimentary rocks termed the Geal-charn-Ossian Steep Belt. Exposures around Aonach Beag (NN 457 743) and in the NE-facing corries of Coire Cheap (NN 476 754) and Coire Sgòir (NN 487 747) provide an excellent near three-dimensional section across this complex zone. The site includes a number of spectacularly developed ductile shear-zones or slides and associated isoclinal folds, elegantly first described by Thomas (1979). The stratigraphy, structure and metamorphism of the area have been most recently re-assessed by Robertson and Smith (1999), and details are incorporated within the BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002), this report draws extensively upon that work.

The Geal-charn-Ossian Steep Belt comprises a narrow zone of steeply dipping rocks that can be traced north-eastwards for more than 50 km from Aonach Beag (Figures 18 and 30). A varied association of lithologies, including metacarbonate rock, kyanite-bearing pelite and semipelite, quartzite and the Kinlochlaggan Boulder Bed, occur in the core of the steep belt and are collectively referred to as the Kinlochlaggan succession in the Appin Group (Robertson and Smith, 1999). These lithologies contrast markedly with the surrounding psammites and semipelites of the Grampian Group.

To the west of the steep belt, in the Loch Laggan-Glen Roy area, the Grampian Group succession is at least 8 km thick (Key *et al*., 1997). There the sand- and silt-dominated succession is divided into three subgroups, which broadly reflect their depositional environment; the fluvial and shallow marine Glenshirra Subgroup is overlain by deeper water sediments of the Corrieyairack Subgroup that were deposited largely from turbidity currents. These are overlain in turn by the shallow marine to estuarine Glen Spean Subgroup in a basin-shoaling succession. The overlying Appin Group represents an overall transgressive system with a silt- and mud-dominated succession contrasting with the mainly sandy Glen Spean Subgroup.

To the south-east of the steep belt, much of the Grampian Group is assigned to the Fara Psammite Formation of the Strathtummel succession. It is less well known than the succession of the Loch Laggan–Glen Roy area, although it was described by Thomas (1979, 1980). Robertson and Smith (1999) made only tentative correlations with the Corrieyairack Subgroup. Gneissose rocks of the Glen Banchor Subgroup, which are thought to form a basement to the Grampian Group (Robertson and Smith, 1999), extend partway along the south-east side of the steep belt from the north-east to within 12 km of this GCR site. They are exposed on the eastern side of the *Allt Mhainisteir* GCR site.

11.2 Description

The site is remote and mountainous. Aonach Beag (1116 m) and Geal-charn (1107 m) form a dramatic ridge to the north-west of the Ben Alder massif. Coire Cheap and Coire Sgòir both face north-east along the continuation of that ridge (Figure 32). A lithostratigraphical column for the area within and west of the steep belt is shown in Figure 27. Within the GCR site, Grampian Group rocks form the flanks of the steep belt whereas the Appin Group rocks occupy the core in the Kinlochlaggan Syncline and related folds. The broad disposition of these lithologies is illustrated in the cross-section (Figure 31).

11.2.1 Structural setting of the steep belt

The Geal-charn-Ossian Steep Belt is defined as a zone of steeply inclined rocks (dips of over 60°) up to 4 km wide (Robertson and Smith, 1999). The overall attitude of lithological layering, the axial surfaces of isoclinal folds and associated tectonic fabrics are approximately coplanar.

The Grampian Group in the Loch Laggan area, north-west of the steep belt, has an apparently simple structural history. Strata in the Loch Laggan-Glen Roy area are generally moderately to steeply inclined, with a preponderance of upright early structures (Key *et al.*, 1997). An early schistosity, steeper than bedding, occurs in semipelitic rocks and in the micaceous tops to graded beds. This is modified in places by a steeply inclined crenulation. Minor folds are rare and strain is generally low, as is indicated by the widespread preservation of sedimentary structures (e.g. Glover *et al.*, 1995).

The structural history is more varied to the south-east of the steep belt. A large area of gently inclined, albeit strongly flattened, rocks with recumbent early folds, extends for several tens of kilometres east of Kinloch Laggan to beyond Dalwhinnie (Robertson and Smith, 1999). In this area, the Glen Banchor Subgroup of the Badenoch Group preserves a protracted tectonothermal history in which an early gneissose foliation is deformed by at least one generation of isoclinal folds. That early gneissose foliation is deformed by shear-zones with associated syntectonic veins of quartz and quartzofeldspathic pegmatite yielding Rb-Sr muscovite ages of *c.* 750 Ma (Piasecki and van Breemen, 1983). In contrast, much of the adjacent eastern outcrop of Grampian Group strata shows evidence of only a relatively simple history. A single bedding-parallel schistosity is pervasive and is the result of strong flattening strain. Small-scale recumbent and asymmetrical folds are rare over a large area of the Grampian Group outcrop between the steep belt and the A9 road section north of Drumochter and no large-scale folds have been recognized to date. An upright open crenulation is developed locally. In contrast, Thomas (1979) recorded that the Ben Alder area preserves evidence of major changes in facing of early recumbent structures south-east of the Geal-charn-Ossian Steep Belt (see the *Ben Alder* GCR site report). The model proposed by Thomas (1979) has early SE-facing nappe structures refolded by two further phases of folding, with the major nappes divergent from the upward-facing steep belt.

The steep belt separates these contrasting north-western and south-eastern structural domains (Figure 31). A progressive increase in inclination of strata into the steep belt from the north-west culminates in a zone, mostly less than 2 km wide, where inclination is over 75°. The south-eastern margin of the steep belt is more abrupt with steeply inclined and near flat-lying rocks closely juxtaposed.

The intensity and complexity of deformation within the steep belt is striking when compared with patterns to the north-west and south-east. Robertson and Smith (1999) recognized three main phases of deformation in the steep belt, which broadly equate with those described by Thomas (1979). The first phase produced large-scale tight to isoclinal folds with amplitudes of several kilometres and a penetrative axial planar schistosity. This deformation resulted in extreme attenuation of fold limbs and the development of slides. Adjacent to the slides, there is a marked decrease in the wavelength and increase in frequency of tight to isoclinal folds with minor dislocations on some fold limbs (see also the *Allt Mhainisteir* GCR site report). The main dislocations are generally marked by zones with intense platy fabrics, varying in width from about a metre up to 20 m. Both small- and large-scale dislocations generally show excision of strata with only rare repetition.

The first phase structures were modified and attenuated during a second phase of close to isoclinal folding. In the north, the first and second phase structures are co-axial and coplanar and therefore difficult to distinguish but in the southern part of the steep belt (e.g. around this GCR site), the second deformation is less intense and is oblique to the first phase. Thus, interference structures are widely developed and in psammites a coarse secondary biotite foliation is commonly discordant to the first fabric. Re-activation of some of the slide-zones is indicated by intensification of the second fabric, which is rotated into parallelism with the first. Elsewhere, the slide-zones are clearly cut by the coarsely spaced biotite fabric. Kyanite-grade metamorphism developed during the second phase of deformation. Later in this phase, fluid movements along the sheared and deformed zones of high strain resulted in local sillimanite replacement of kyanite (Phillips *et al.*, 1999).

The overall geometry of the steep belt is that of a major upright synform (Figure 31). The facing and vergence of small- and medium-scale structures indicates that much of the structural pattern developed during second-phase tightening and intensification of earlier first-phase structures. Few significant changes in the large-scale pattern of fold vergence occurred during the second phase and primary facing relationships were largely preserved from the onset of deformation in the steep belt. The most important major fold structure, the Kinlochlaggan Syncline, constrains the main outcrop of the Kinlochlaggan succession to a zone generally less than 1 km wide. Critical exposure of the fold hinge can be traced in detail on the south-west ridge of Aonach Beag (NN 454 735) (Figure 30). The Aonach Beag Slide lies on the western limb of the syncline (Thomas, 1979). This important dislocation has the same lateral extent as the main syncline and defines the north-western limit of the Kinlochlaggan succession. South-east of the trace of the main syncline, the Cheap slides separate the Kinlochlaggan Syncline from the Sron Garbh anticlinal fold-complex and associated slides to the east (Figures 30). The Kinlochlaggan succession is also present within parts of this latter fold complex, the eastern limit of which is defined by the Sgòir Slide, which was first recognized as separating contrasting stratigraphical successions by Thomas (1979). The Cheap and Sgòir slides die out gradually farther to the north-east.

The second phase folds are refolded by sporadically developed third phase structures. These occur primarily close to the eastern edge of the steep belt, although they are also prominent around Aonach Beag (NN 458 742) where they have nucleated on the earlier folds. Open to close SE-verging folds are typical, with axial planes inclined moderately or steeply to the east-south-east. Crenulation cleavages are developed in semipelite but are generally confined to fold hinges. The absence of penetrative fabrics, even in the tightest folds, and of new metamorphic mineral growth or recrystallization, readily distinguishes the third phase structures.

11.2.2 Grampian Group lithostratigraphy

Within this GCR site, the units of the Grampian Group range from near-undeformed sequences with well-preserved sedimentary structures to migmatitic gneissose and highly sheared equivalents. The stratigraphy is summarized in Figure 27.

The Creag Meagaidh Psammite Formation comprises thin- to medium-bedded psammite and micaceous psammite with little lithological variation; the field appearance is largely controlled by the degree of strain. On the cliffs of Sgòr Iutharn (NN 490 744), the formation is generally preserved in a low-strain state (Figure 32). Beds are typically 10 to 15 cm thick and are rarely 25 to 30 cm. These mostly comprise grey to white, rather massive feldspathic psammite that grades into thin (mostly less than 3 cm) micaceous psammite, semipelite or even pelite. The local presence of sharp bases and gradations in the tops of the beds into more-micaceous lithologies is considered to reflect primary graded bedding. Differential erosion across these graded units produces distinctive 'sharks teeth' profiles with preferential weathering inwards of the more-micaceous tops. High-strain areas are very flaggy to fissile with fine-scale (several millimetres) interbanding of platy psammite and micaceous psammite.

The Creag Meagaidh Formation is overlain stratigraphically by the Clachaig Semipelite and Psammite Formation and in places by the Inverlair Psammite Formation. The boundary with the latter is tectonic (the Sgòir slides)–see below.

The Clachaig Semipelite and Psammite Formation comprises a varied succession dominated by semipelite. On the north-east ridge of Sgòr Iutharn, the Lancet Edge (NN 495 746), the Clachaig Formation forms the core of an isoclinal syncline (?F1) on the eastern edge of the steep belt. Here there is a transitional contact with the underlying psammite of the Creag Meagaidh Formation. The basal part of the Clachaig Formation is a massive, coarsely foliated, garnetiferous biotite-rich semipelite and pelite with minor thin beds of micaceous psammite. Higher in the succession, quartzose and feldspathic psammite beds are seen within thin- to medium-bedded semipelite, micaceous psammite and feldspathic psammite. Spectacular minor folds and refolded folds are present. Minor calcsilicate-rock lenses occur in these lithologies.

The Inverlair Psammite Formation is particularly well seen around Coire Cheap (Figure 30) in massive exposures showing transitions from psammite to micaceous psammite on scales ranging from a few centimetres to a metre or so (e.g. around NN 478 755). Micaceous psammite beds are typically only a few centimetres thick. Boundaries are commonly subtle as a result of extensive recrystallization and grain coarsening, a characteristic feature of this formation. The formation is generally gneissose, particularly the micaceous psammites, which carry a coarsely spaced fabric within leucosomes that are pegmatitic in places.

On the north-west side of the steep belt, the degree of gneissification and deformation increases towards the Aonach Beag Slide and related ductile dislocation structures (Figure 30). The psammite is correspondingly more massive and gneissose with interbanded quartzite units in places. The slide-zone is marked by lithologies from the Inverlair Psammite Formation and Aonach Beag Semipelite Formation interleaved in an imbricate zone. Immediately north of a small col on the north-north-west ridge of Aonach Beag at NN 452 751, notably striped migmatitic psammite and subsidiary semipelite show abundant segregation veins, tight folding and a gently ENE-plunging quartz-rodding lineation. These rocks lie within a slide-zone structurally just below the main Aonach Beag Slide that is exposed on the ridge.

Folded gneissose, and locally migmatitic, psammites and minor semipelites of the Inverlair Psammite Formation also occur extensively in the north-western part of Coire Sgòir (NN 485 750), east of the Kinlochlaggan succession in the core of the steep belt. The sequence is tightly folded and is cut by several ductile slide-zones (the Sgòir slides, Figure 31); slivers of the Aonach Beag Semipelite Formation (including amphibolite) occur in this high-strain zone. Contacts with folded and locally sheared psammite of the Clachaig, Creag Meagaidh and Aonach Beag formations are all steeply inclined ductile slides. Units of foliated gneissose semipelite, quartzite and quartzose psammite also occur locally.

11.2.3 Appin Group lithostratigraphy

Within the steep belt, the boundary of Grampian Group rocks with those of the overlying Appin Group is generally tectonic and is marked by platy zones of interbanded psammite and quartzite. These are seen spectacularly at NN 477 756 in Coire Cheap (the Cheap slides). However, transitional stratigraphical boundaries are also preserved in Coire Cheap to the west of Aisre Ghobhainn (NN 478 753) and locally north-west of Aonach Beag (NN 45 74). At the former locality, psammite and gneissose micaceous psammite pass into platy micaceous psammite with quartz segregations and then schistose semipelite and micaceous psammite of the Aonach Beag Semipelite Formation.

The Aonach Beag Semipelite Formation is well developed on the north-west ridge of Aonach Beag (NN 457 743) and in Coire Cheap (NN 478 752), where the transitional boundary with the Grampian Group Inverlair Psammite Formation reveals the lowest parts of the formation. The formation dominantly comprises semipelite but contains progressively more psammite in its upper part. Units of tremolitic rock and thin white quartzites occur in the lower part. Abundant amphibolite sheets generally lie parallel to bedding but are discordant locally. These range from 15 cm to several metres thick, and are generally thicker adjacent to the overlying Kinlochlaggan Quartzite Formation and to thicker psammite units.

The Kinlochlaggan Quartzite Formation comprises massive white quartzite with large, locally prominent, white to pink feldspar crystals. Partings in the quartzite, which probably reflect bedding, are typically 5 to 60 cm apart and are controlled locally by micaceous psammite layers up to 2 cm thick. The feldspars are up to 5 mm long and are either scattered or are concentrated within layers, indicating a clastic origin. The formation has an outcrop width of between 5 and 160 m, a range that probably reflects both tectonic attenuation and original variation in depositional thickness. South-west of Aonach Beag (NN 455 740), in the hinge-zone of the Kinlochlaggan Syncline, the quartzite is 100 to 120 m thick, is well exposed in clean crags and exhibits only minor deformation. Pink feldspar clasts are scattered throughout individual white to pale-grey packets of dominantly quartz sand 1 to 20 cm thick. Minor coarser grained bases to these units are seen and in places more-micaceous tops are present. Grading shows that the formation youngs and faces upwards. No cross-bedding has been recorded here. However, minor cross-bedding and small-scale slump folds can be seen in the craggy exposures on the north-west ridge of Geal-charn at NN 4715 7563 and in exposures farther north-east at NN 4798 7667. In the central part of the steep belt, to the west of Coire Cheap (NN 475 750), outcrop of the formation is repeated up to three times by upright isoclinal folding. Pebbly layers, 1 to 10 cm thick with rounded quartz and feldspar pebbles up to 6 mm across, occur in the quartzite in Coire Cheap at NN 474 753. Amphibolites, typically up to 2 m thick, are widespread and are commonly concentrated at the margins of the formation; examples in Coire Cheap and south-west of Aonach Beag are locally discordant and are clearly dykes.

The Kinlochlaggan Boulder Bed (see also the *Kinlochlaggan Road* GCR site report) is represented on the west wall of Coire Cheap (NN 4776 7566), by massive grey psammite containing scattered granite clasts up to 5 cm across and with a few discontinuous slightly micaceous layers. This occurrence has a gradational boundary over 20 or 30 cm with the underlying quartzite, is approximately 2 m thick and forms a lens about 20 m long. The lensoid nature is considered to be representative of the other occurrences in the region, thereby accounting for the discontinuous nature of the 'boulder bed'.

To the west of and stratigraphically upwards from the Kinlochlaggan Quartzite Formation in Coire Cheap, a 20 m-thick mixed unit of metacarbonate rock, calcsilicate rock, micaceous psammite and garnet amphibolite represents an attenuated Coire Cheap Formation. This is succeeded by a *c.* 100 m-thick semipelite unit forming the prominent peak of Sron Gharbh (NN 473 754). The semipelite is characteristically dark grey, homogeneous and generally schistose, with widespread scattered small garnets; quartzofeldspathic segregations are rare whereas quartz segregations are widespread. This semipelite is not recognized 1 km to the north-east in the Allt Coire Cheap section but can be traced south-westwards into Coire na Coichille (NN 469 750) where it apparently lenses out; it is apparently a local facies development (Robertson and Smith, 1999). Kyanite-bearing semipelite occurs at the western boundary of the semipelite in Coire Cheap, and is succeeded to the west (at NN 4754 7588) by 16 m of flaggy, platy, very fine-grained, grey micaceous psammite.

This platy psammite marks the return to a heterogeneous succession of semipelite, calcsilicate rock and metacarbonate rock, all cut by amphibolite sheets, which extends north-eastwards from Aonach Beag (NN 455 740) through superb exposures in Coire Cheap and Allt Coire Cheap, the type area for the Coire Cheap Formation. The semipelitic units are gneissose and/or kyanite-rich in parts and locally they are graphitic. In Coire Cheap, the micaceous psammite referred to above is succeeded to the west by fine-grained platy micaceous psammite with thin quartzite ribs interbanded with thin layers (up to 1 m) of calcsilicate rock and metacarbonate rock. Lines of solution hollows up to a few metres deep, along with some resurgence and limited along-strike exposures might represent unexposed metacarbonate rocks. Locally (e.g. at NN 4740 7571), rusty-weathering micaceous psammite is cut by discordant amphibolite sheets up to 3 m thick. The discordance with schistosity in the micaceous psammite is up to 30° and the amphibolite is unfoliated. Rather fine-grained margins could reflect original chills, whereas relics of ophitic texture and blue-green amphibole are preserved in the central parts of the sheets. At NN 4717 7541, graphitic schist with partially replaced kyanite occurs in loose blocks; contacts with adjacent lithologies are not exposed.

In the west wall of the corrie (NN 473 755), the graphitic schist is succeeded by *c.* 45 m of thinly bedded, cream- to buff-weathering metacarbonate rock, referred to as the Coire Cheap Limestone. The metacarbonate rock appears particularly thick here; no major fold closures have been identified but there are tight internal minor folds. A few amphibolite sheets and pods up to 2 to 3 m across occur, mostly near the western boundary. Farther west the metacarbonate rock is succeeded by *c.* 5 m of platy calcsilicate rock with thin beds of metacarbonate rock and then by a 50-70 m-thick gneissose kyanite semipelite referred to as the Coire Cheap Kyanite Gneiss. Kyanite is abundant throughout this unit and commonly comprises some 25% of the rock. Much of the kyanite is coarse (over 1 cm and rarely up to 5 cm long) and although many crystals are randomly arranged, some show subhorizontal alignment on the steep schistosity surfaces. A few garnet amphibolite layers up to 30 cm thick are present. The kyanite gneiss is succeeded to the north-west by a thin metacarbonate-rock layer in the corrie wall and then by approximately 20 m or so of rusty-weathering micaceous psammite with some layers of semipelite. The latter contain tourmaline and relics of kyanite largely replaced by muscovite. This is succeeded in turn in the corrie wall by several metres of calcsilicate rock, which is in contact to the west with the Kinlochlaggan Boulder Bed and the Kinlochlaggan Quartzite Formation. The repetition of the underlying Kinlochlaggan Quartzite indicates that the trace of the Kinlochlaggan Syncline is crossed in Coire Cheap; the most likely place for the closure is in either the semipelite unit on Sron Garbh or in the Coire Cheap Limestone, although there is no obvious repetiton of the surrounding lithologies. This indicates either original facies changes or structural dislocation preferentially on one limb of the structure. Facies changes over short distances seem more likely given the significant lateral changes in the succession within a kilometre as indicated by the succession in the Allt Coire Cheap and to the south-west in Coire na Coichille.

11.3 Interpretation

11.3.1 Stratigraphical relationships

The Kinlochlaggan succession has generally been interpreted as an upward-facing succession within the core of the Geal-charn-Ossian Steep Belt, with the Grampian-Appin group boundary modified locally by sliding (Hinxman *et al.*, 1923; Anderson, 1947b, 1956; Smith, 1968; Treagus, 1969, 1997; Thomas, 1979). However, Evans and Tanner (1996, 1997) speculated that the Kinlochlaggan succession contains an allochthonous, inverted and downward-facing upper Appin Group–lower Argyll Group stratigraphy, separated from the Grampian Group by a major structural discontinuity. In marked contrast, Piasecki and Temperley (1988b) equated the Kinlochlaggan succession with semipelites and metalimestones at the base of the Grampian Group that are exposed at Kincraig and Ord Ban (see the *An Suidhe* GCR site report).

In the steep belt, a gradational stratigraphical boundary is preserved locally between the Grampian Group and the Aonach Beag Semipelite Formation; the latter must therefore lie at the base of the Appin Group. The Kinlochlaggan Quartzite Formation is in stratigraphical succession above the Aonach Beag Semipelite Formation and, while the boundary between the Kinlochlaggan Quartzite and Coire Cheap formations is marked locally by *c.* 70 cm of platy psammite, this is not thought to represent a major tectonic discontinuity. The Kinlochlaggan Boulder Bed occurs locally in lenticular form on top of the Kinlochlaggan Quartzite Formation and cannot on that basis be correlated with the Port Askaig Tillite (basal Islay Subgroup) and its equivalents.

The Aonach Beag Semipelite Formation is lithologically similar to the Loch Treig Schist and Quartzite Formation of the Glen Roy district, which also lies stratigraphically on top of the Grampian Group and is assigned to the Lochaber Subgroup. The Kinlochlaggan Quartzite Formation is lithologically similar to the Binnein Quartzite Formation in the Loch Leven area and hence it too is assigned to the Lochaber Subgroup. The Sron Garbh Semipelite Formation is correlated with the Leven Schist Formation of the Glen Roy district on the basis of lithological similarities, particularly its magnetic character, and its stratigraphical position. It is therefore assigned to the upper part of the Lochaber Subgroup although the correlation is tentative (Robertson and Smith, 1999).

Pale metalimestone in the Coire Cheap Formation, located above the Kinlochlaggan Quartzite, has a geochemical signature typical of the middle part of the Ballachulish Subgroup, while the remainder of the metalimestones have geochemical signatures similar to Blair Atholl Subgroup metalimestones elsewhere in the Grampian Highlands (Thomas, 1995; Thomas *et al.*, 1997; Thomas and Aitchison, 1998). These correlations indicate that well-known segments of the Appin Group stratigraphy are missing from the exposed sections at this site. There is no representative of the Appin Quartzite and the uppermost parts of the Lochaber Subgroup are also absent. It is not known whether this is the result of non-deposition or erosion. Any erosion must have pre-dated deposition of the upper parts of the Ballachulish Subgroup, since this rests without a major structural discontinuity on the Kinlochlaggan Quartzite. Significant facies changes and thickness changes have been reported in the Appin Group in the South-west Grampian Highlands with possible uplift and erosion at the time of deposition of the Appin Quartzite (Litherland, 1970, 1980), supporting such interpretations.

Robertson and Smith (1999) argued that within the steep belt as a whole, component parts of the Kinlochlaggan succession show major onlap relationships. North of Laggan (NN 600 965), stratigraphical relationships show the progressive overstep of the Kinlochlaggan succession onto the Creag Meagaidh and Ardair formations and ultimately directly onto the Glen Banchor Subgroup. For 10 km along strike to the north-east of the River Spey, the entire Grampian Group is absent on the eastern limb of the Kinlochlaggan Syncline. This therefore represents one of the most significant stratigraphical breaks in the Grampian Highlands, but nowhere is it marked by an angular discordance or by exposed conglomerates. Based upon the regional stratigraphical considerations, Robertson and Smith (1999) argued for an original basin architecture in which the Glen Banchor Subgroup occured in a structural ‘high’ that formed the eastern wall of a west-facing basin during deposition of the Grampian Group and continued to influence depositional systems throughout Appin Group time. Metalimestones of the Blair Atholl Subgroup are the youngest parts of the sequence to overstep the Glen Banchor ‘high’.

11.3.2 Structural framework

Thomas (1979) interpreted the Geal-charn-Ossian Steep Belt as a fundamental root-zone because the major recumbent folds on opposite sides of the steep belt face in opposite directions i.e. to the north-west on the north-west side and to the south-east on the south-east side (see Stephenson et al., 2013a, fig 10a). In contrast, Temperley (1990) argued for a late structural development for the steep belt with folding and shearing superimposed upon a zone that had already experienced a protracted tectonothermal history.

The overall geometry of the steep belt is that of a major upright synform (Figure 31). The facing and vergence of small- and medium-scale structures indicates that much of the structural pattern developed during the first deformation phase, with few significant changes in architecture resulting from the subsequent deformation (Figure 4); the vergence of second-phase folds shows no large-scale systematic changes across the belt (Smith *et al.*, 1999). The steep belt forms the boundary between contrasting structural domains with primary upright structures to the north-west and recumbent folding to the south-east. The original orientation of the structures in the steep belt has previously been envisaged as either upright (Anderson, 1947b, 1956; Thomas, 1979, 1980) or recumbent (Temperley, 1990; Evans and Tanner, 1996).

On the basis on the overall structural geometry and the stratigraphical relationships, Robertson and Smith (1999) argued that the Geal-charn-Ossian Steep Belt is a major composite synclinal structure focussed upon the Kinlochlaggan Syncline. According to their model, the steep belt originated as a primary feature located at the eastern margin of a major west-facing sedimentary basin in which more than 8 km of Grampian Group sediment had been deposited. This basin was adjacent to an intrabasin structural 'high' composed mainly of gneissose metasedimentary rocks of the Glen Banchor Subgroup and acting as the local basement to the Grampian and Appin group rocks. Major unconformities recognized at more than one stratigraphical level reflect onlap of the basin successions onto the 'high'.

The primary major upright folds and associated slides of the steep belt developed when considerable shortening was focused along the basin margin during the Caledonian Orogeny (Figure 4). The deformation patterns were interpreted by Robertson and Smith (1999) as the result of buttressing and inversion of the depositional sequence against the more-rigid upstanding structural 'high'. A similar origin has been suggested for the upright Stob Ban–Craig a' Chail Synform which reflects deformation of the western edge of both the deep water Corrieyairack Subgroup basin and Appin Group half grabens (Glover *et al.*, 1995).

11.4 Conclusions

The Aonach Beag and Geal-charn GCR site is of national importance for the way in which the complex Caledonian deformation pattern in a crucial central area of the Grampian Highlands can be related to the original geometry and subsequent development of early Dalradian sedimentary basins.

The site preserves excellent exposures of the stratigraphical relationships between the local Kinlochlaggan succession of the Appin Group and the underlying Grampian Group in a regional zone of steeply dipping rocks known as the Geal-charn–Ossian Steep Belt. The mountainous nature of the site is such that truly three-dimensional observations can be made of the structural geometry of the steep belt, which includes the complex upward-facing

Kinlochlaggan Syncline and other complementary tight folds in its core.

The Geal-charn–Ossian Steep Belt occurs at the boundary between contrasting structural and stratigraphical domains. Distinct but coeval sedimentary successions in each domain responded in fundamentally different ways to later deformation, with primary upright structures to the west and recumbent structures to the east. The steep belt is a zone of primary major upright folds with associated slides, developed on severely attenuated fold limbs as originally stated by Thomas (1979). However, it is not a root-zone to divergent nappes as envisaged by Thomas, nor is it the product of a late monoform or late upright shearing as proposed by Temperley (1990). It occurs at the eastern margin of a thick composite sedimentary basin where deformation was focused against a footwall 'high'. Subsequent deformation was then influenced by the distribution of half-graben fills and intrabasinal 'highs'.

12 BEN ALDER
(NN 477 722–NN 483 722 and NN 495 733–NN 499 708)

A.G. Leslie and C.J. Banks

12.1 Introduction

The Ben Alder GCR site comprises the whole of the eastern flank of the mountain (Figure 33, 34), from Garbh Coire (NN 498 715) to Coire na Lethchois (NN 502 734), together with the western corrie of Coire Labhair (NN 483 722). Its national importance arises from the architecture of large-scale polyphase folding of a varied Grampian Group metasedimentary succession, adjacent to the Geal-charn–Ossian Steep Belt that is exposed in the *Aonach Beag and Geal-charn* GCR site.

The summit of Ben Alder stands at 1148 m in the midst of an extensive plateau with much ground above 970 m, some 10 km from the nearest 4-wheel-drive track and 15 km from the nearest road. The cliffs on the north-western flank and in the imposing eastern corries are over 200 m high. The remote and mountainous nature of the terrain has no doubt led to the paucity of geological investigations. The area was originally surveyed by the Geological Survey, who identified a number of 'sharp folds' whose 'true nature and value are unknown', deforming 'quartz-biotite-granulites of the Moine Series'. It was concluded that it was 'impossible to decipher the structure of the Ben Alder plateau' (Carruthers in Hinxman *et al*., 1923). Thomas (1979) provided the first detailed account of the country between Loch Ericht and Loch Treig, which includes the great corries on the north-east face of Geal-charn (the *Aonach Beag and Geal-charn* GCR site) and those of Ben Alder. Much of the structure relevant to the Ben Alder area is represented on the BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002), although this GCR site lies along strike to the south-west, entirely within the adjacent Sheet 54E (Loch Rannoch).

Thomas (1979, 1980) recognized major changes in facing across early recumbent structures affecting a 'Moine' succession in the

Ben Alder area to the south-east of the Geal-charn-Ossian Steep Belt. He regarded the area as critical to any understanding of potential stratigraphical and structural linkages between the NW-facing nappes that had by then been recognized in the Loch Leven district (Treagus, 1974; Roberts, 1976) and the SE-facing nappes of Glen Orchy (Thomas and Treagus, 1968), Strathtummel (Thomas, 1980) and the Southern Highlands (Harris *et al.*, 1976; Bradbury *et al.*, 1979). The model proposed by Thomas (1979) had major nappes diverging to the north-west and south-east from either side of the upward-facing Geal-charn-Ossian Steep Belt, which in effect acted as a fundamental root-zone (see Stephenson et al., 2013a, fig. 10a). In the Ben Alder area, the early SE-facing nappe structures were refolded by two further phases of folding.

Robertson and Smith (1999) examined many of the critical sections across the Geal-charn–Ossian Steep Belt in Coire Cheap and Coire Sgòir. That work essentially confirmed the presence of Appin Group lithostratigraphy in the core of the upward-facing Kinlochlaggan Syncline (F1) and the importance of ductile slide structures in Coire Cheap, Coire Sgòir and on Aonach Beag. Three main penetrative deformation phases were recognized; the resultant structures and fabrics equate broadly with those described by Thomas (1979), while recognizing that the strict timing of deformation might be diachronous in structural domains across the region. The facing and vergence of small- and medium-scale structures is such that the structural pattern must have developed to a large extent during the first main deformation, there being few significant changes in secondary-phase fold vergence across the steep belt. Robertson and Smith (1999) thus regarded the steep belt as a zone of primary major upright folds with associated slides developed on severely attenuated fold limbs, as originally stated by Thomas (1979).

12.2 Description

The following description is drawn largely from the maps and comments within publications by Thomas (1979, 1980), supplemented where appropriate by more-recent work by the British Geological Survey, mainly on the adjacent 1:50 000 Sheet 63W (Dalwhinnie, 2002) (Robertson and Smith, 1999). The most-recent BGS work (2005–2006) extended that re-assessment southwards onto the Ben Alder massif itself and will rationalize the regional stratigraphical relationships within current understanding of the Grampian Group (c.f. Banks, 2005). The structural chronology referred to here is that of Thomas (1979).

Thomas (1979) referred to a ‘Moine succession’ rich in strongly striped and banded schistose semipelite and psammite, interleaved with much thicker units of schistose pelite and gneissose psammite. A few pods and lenses of calcsilicate rock occur throughout. These lithologies are likely to be assigned eventually to the sequence of Grampian Group formations recognized within Sheet 63E (Dalwhinnie, 2002) immediately to the north and by Banks (2005); namely the Coire nan Laogh Semipelite Formation, Creag Dhubh Psammite Formation, Pitmain Semipelite Formation and the Gaick Psammite Formation.

Thomas (1979, 1980) considered that the upright pattern of folds in the Geal-charn-Ossian Steep Belt is transformed to the south-east, over 2-3 km across strike, into broadly recumbent nappe structures, which have been refolded by second and third generation upright structures (Figure 35) that he termed the 'Ben Alder folds'. Details of the distribution and suggested way up of this sequence are reproduced in Figure 34; Figure 36 is a structural profile extending south-eastwards from the Geal-charn-Ossian Steep Belt through Ben Alder (both after Thomas, 1979).

The Sgòir Slide lies along the south-east margin of the steep belt. This slide lies on the north-western limb of the F1 Coire Sgòir Anticline and is marked by tight folding, migmatization, and loss of good bedding features. The slide juxtaposes Inverlair Psammite Formation rocks to the north-west against folded, strained and mobilized Creag Dhubh Psammite Formation in the south-east (referred to as the Creag Meagaidh Psammite on BGS Sheet 63E). Earlier slide structures are affected by refolding locally and, at a larger scale, the Coire Sgòir Anticline and the structurally lower level F1 Coire Labhair Syncline are re-orientated across the trace of the F3 Lancet Edge Antiform, so that the upright axial surfaces of both folds adjacent to the steep belt become NW-dipping to the south-east, across the trace of the F3 fold.

In the upright core of the Coire Labhair Syncline, where it crosses Lancet Edge (NN 495 745), are pelites, banded semipelites and psammites, which have been assigned to the Clachaig Semipelite and Psammite Formation by Robertson and Smith (1999) (see also BGS Sheet 63E). Thomas (1979) mapped these schistose semipelites and pelites from Lancet Edge along the trace of the Coire Labhair Syncline, south across the Bealach Dubh and then south-westwards through the crags to Coire Labhair, where the syncline closure is very well exposed in the south face of the corrie (NN 481 722). At this point, schistose psammites are revealed in the core of the fold; semipelite and pelite on the lower limb extend eastwards across much of the summit plateau of Ben Alder and the cliffs and crags farther to the east around Garbh Coire (NN 500 715).

The closure of the complementary F1 Ben Alder Anticline is less clear and is dependent upon assessment of lithological repetition eastwards towards Coire na Lethchois and Garbh-choire Beag (Figure 34). Thomas (1979) placed the closure on the cliffs just south of Garbh-choire Beag (NN 501 724), within a unit of schistose psammite. From there, a repetition of the semipelite and pelite formations mapped at the Bealach Dubh is shown northwards from the closure towards Coire na Lethchois (NN 503 734). From Garbh-choire Beag the Ben Alder Anticline was traced west and then north across the northern flank of the summit massif of Ben Alder to the crags at NN 497 734; here too the closure is within schistose psammite with schistose semipelite and pelite to the west and east on opposite limbs.

According to Thomas (1979), the major change in trend of the F1 Ben Alder Anticline occurs across the trace of the NE-trending F2 Ben Alder Antiform; the latter structure was identified in cross-section in the cliffs in Garbh-choire Beag (NN 503 726). The complementary F2 Ben Alder Synform is less clear, being 'barely exposed' in a section around NN 509 730, above the hanging valley of the Bealach Beithe.

Rather symmetrical open F3 folds, which deform both the D1 and D2 structures, are present as a fold-pair in Coire na Lethchois (NN 501 734) (the Coire na Lethchois Antiform and Synform) and as more-asymmetrical folds stepping down to the north-west on the southern edge of the Bealach Dubh (NN 498 737) (the Bealach Dubh Synform) and on Lancet Edge (NN 496 745) (the Lancet Edge Antiform). These are open to tight folds with a crenulation cleavage developed locally, especially in the hinge areas.

South of the Garbh Coire Fault (NN 497 715), Thomas (1979) recorded that several F1 isoclines become truly recumbent over the broad symmetrical hinge of the F3 Coire na h'Iolaire Antiform (NN 513 705), so that in general terms the attitude of the earliest isoclinal folds is upright in the steep belt to the north-west and recumbent on the Ben Alder massif and to the south-east.

12.3 Interpretation

Thomas (1979, 1980) described local successions of what is now termed the Grampian Group from both the Ben Alder area and farther to the south-east across Strath Tummel. Tentative correlations, in the area of Sheet 63E (Dalwhinnie), of the psammite and semipelite successions immediately south-east of the steep belt with the Corrieyairack Subgroup succession of the Loch Laggan–Glen Roy area (Robertson and Smith, 1999) have been further rationalized by Banks (2005).

Thomas' succession for the Ben Alder area comprised three psammite-dominated, and two semipelite-and-pelite-dominated units. Whilst Robertson and Smith (1999) recorded a strikingly similar sequence for their Grampian Group lithostratigraphy in the steep belt, detailed correlation is an ongoing concern. Adopting the most-recent analysis of Grampian Group lithostratigraphy (Banks, 2005) will mean, for example, that the pelite, banded semipelite and psammite in the core of the Coire Labhair Syncline should be correlated with the Pitmain Semipelite Formation, and the younger schistose psammites should be correlated with the Gaick Psammite. Banded and graded schistose psammites that enclose these two formations are correlated with the Creag Dhubh Psammite Formation.

Establishing the lithostratigraphical succession on Ben Alder, and hence the structural architecture, was apparently more problematical than it was in the steep belt (Thomas, 1979). This was largely due to the apparent lack of sedimentary structures and evidence of younging, compounded by the superimposition of polyphase folding on a major scale. More-recent work farther to the north and north-west, notably on Loch Laggan side and in Glen Roy has recognized sedimentary rocks of the Corrieyairack Subgroup that were deposited in deep water, largely by turbidity currents (see the *Rubha na Magach* GCR site report). These are overlain in turn by the Glen Spean Subgroup, which represents a basin-shoaling succession from shallow marine to estuarine (Glover and Winchester, 1989; Glover *et al.*, 1995; Glover and McKie, 1996). Such documentation of the stratigraphy and sedimentary history has transformed understanding of the Grampian Group depositional record. The lithostratigraphy of the Ben Alder massif is now known to straddle the boundary between the Corrieyairack and Glen Spean subgroups of the Grampian Group, with the Pitmain Semipelite Formation deposited on the flooding surface that defines the base of the Glean Spean Subgroup.

The Ben Alder GCR site is centred upon the northern part of the Ben Alder massif where Thomas (1979) recorded his evidence for D2 and D3 refolding of the primary nappe structure on the south-east flank of the steep belt. The earliest folds were considered to change from an upward-facing, upright form in the steep belt to more-recumbent SE-facing structures, (ultimately downwards-facing to the south-east) as they were traced south-eastwards away from the steep belt, across the Drumochter Dome and into the Atholl Nappe-complex in the footwall of the Boundary Slide in the Blair Atholl district (see 1.4.1 in *Introduction*). The NW-facing structures in the Appin and Lochaber districts were represented as a 'mirror-image' emerging from the steep belt to the north-west. Thus the Geal-charn-Ossian Steep Belt was envisaged as a root-zone to both the SE-facing and the NW-facing nappes of the Central Grampian Highlands.

In this scenario, Thomas regarded the Drumochter Dome as an F2 structure (Thomas, 1979, figure 6). However, Lindsay *et al.* (1989) demonstrated that S2 axial planes and cleavages are folded across the dome, which is consequently now generally accepted as a later structure, possibly F3 as originally proposed by Roberts and Treagus (1977c, 1979) for the related domes of Glen Orchy and Glen Lyon or F4 of other authors. Thomas (1980, 1988) regarded the Meall Reamhar Synform of the Blair Atholl district as the F1 closure of the SE-facing Atholl Nappe but in the light of work by Treagus (1987, 2000) this fold is now regarded as an F2 structure. The most-recent structural interpretations of the Grampian Highlands emphasize the importance of the D2 deformation (rather than D1) in relation to the generation of the major nappes (Krabbendam *et al*., 1997; Treagus, 1987, 2000) and it seems likely that a similar modification of the structural chronology of the polyphase folding displayed on the Ben Alder massif will be appropriate, with the major recumbent folds essentially D2 in age rather than D1. However, the presence of F1 folds of significant magnitude cannot be discounted at this stage.

Robertson and Smith (1999) broadly agreed with Thomas (1979) on the structural architecture within the steep belt but dismissed the idea of a root-zone for emergent nappes. Instead they argued that the steep belt forms the boundary between contrasting structural domains, with primary upright structures to the north and west and recumbent folding to the south and east (Figure 31). In this model, the steep belt itself is believed to have formed at the eastern margin of a major Grampian Group basin with partitioned (and possibly diachronous) deformation patterns interpreted to be the result of buttressing of the sedimentary rocks of the basin against a rigid upstanding block of 'basement' to the east composed of the Glen Banchor Subgroup (see the *Aonach Beag and Geal-charn* GCR site report). In this respect, the steep belt would have a similar origin to the upright Stob Ban-Craig a'Chail Synform, which reflects deformation of the western edge of both the deep water

Corrieyairack Subgroup basin and Appin Group half grabens (Glover *et al.*, 1995). Current syntheses of the structure of the Central Grampian Highlands do not therefore invoke the D1/D2 'fountain of nappes' emanating in opposing directions from a root-zone as was envisaged (Thomas, 1979) in earlier structural models (see discussion in 1.4 in *Introduction*).

12.4 Conclusions

The area around Ben Alder has been central to debates concerning the existence or otherwise of a root-zone for the regional nappe-complexes of the Central Grampian Highlands. It was believed that the nappes were 'squeezed out' on both sides of a zone of steeply dipping rocks, now called the Geal-charn–Ossian Steep Belt, which is well exposed in the adjacent *Aonach Beag and Geal-charn* GCR site. This in effect created a mushroom-shaped 'fountain' of nappes in which individual nappes were separated by ductile dislocations termed slides. Away from the steep belt to the south-east the primary F1 nappes became highly inclined, SE-facing, and all of the structures were subsequently refolded by more-upright folds of at least two generations (F2 and F3), resulting in the observed pattern of recumbent structures.

The Ben Alder GCR site is situated on the south-east side of the steep belt and has been crucial to any interpretation of the steep belt and of the nappes between there and the Boundary Slide at Blair Atholl. This in turn is fundamental to theories for the origin and evolution of the Grampian nappe-complexes in general.

The most recent published work has emphasized the influence of the original depositional framework of the Grampian Group sediments, and in particlar the basin geometry, on the subsequent structural architecture. Hence the Geal-charn–Ossian Steep Belt is no longer regarded as a root-zone to the major nappes and has been attributed to compression of the sediments against a basement 'high' that forms the basin margin, with the SE-facing nappes attributable largely to the D2 deformation phase. The ongoing debate will continue to draw heavily upon evidence from the Ben Alder area, emphasizing still further the national importance of the *Aonach Beag to Geal-charn* and *Ben Alder* GCR sites.

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Figure 1 Map of the Northern Grampian Highlands showing distribution of subgroups (after Smith *et al*., 1999). Circled letters on the map refer to stratigraphical columns in Figure 3.
GCR Sites: 1 An Suidhe, Kincraig 2 The Slochd, 3 Lochan Uaine, 4 Blargie Craig, 5 River E, 6 Garva Bridge, 7 Rubha na Magach, 8 Kinloch Laggan Road A86, 9 Allt Mhainisteir, 10 Aonach Beag and Geal-charn, 11 Ben Alder.
Abbreviations: BS Boundary Slide, ESZ Eilrig Shear-zone, ELF Ericht–Laidon Fault, FSSZ Flichity–Slochd Shear-zone, GB Glen Banchor, GOSB Geal-charn–Ossian Steep Belt, IMF Inverpattack–Markie Fault, KC Kincraig, LSZ Lochindorb Shear-zone, SF Sronlairig Fault.

Figure 2 Rift basins and their bounding lineaments in the Northern Grampian Highlands (after Smith *et al*., 1999). Based on a simplified geological map after restoration and removal of major faults and intrusions. Solid linework shows the outline of the main subgroups (see Figure 1).
Abbreviations: MPH Meall Ptarmigan High, SOL Strath Ossian Lineament.

Figure 3 Stratigraphical correlations in the Northern Grampian Highlands (after Smith *et al*., 1999) for the areas shown by circled letters in Figure 1. Thicknesses are relative but not to scale. Blank areas in columns indicate stratigraphical breaks.
Abbreviations: AB Aonach Beag Semipelite Fm, ACH Achneim Striped Psammite Fm, AD Ardair Semipelite Fm, AP Appin Group, undivided, BAS Ben Alder succession, BSZ Blargie Shear-zone, CC Coire Cheap Semipelite Fm, CM Creag Meagaidh Psammite Fm, CNL Coire nan Laogh

Semipelite Fm, CS Clachaig Semipelite Fm, DRS Drumochter succession, DS Dava Subgroup, EF Eilde Flag Formation, EL Elrick Formation, ESZ Eilrig Shear-zone, FSSZ Flichity–Slochd Shear-zone, GB Glen Buck Psammite Fm, GBS Glen Banchor Subgroup, GS Glenshirra Subgroup (undivided), IL Inverlair Psammite Fm, K Kincraig Formation, KLQ Kinlochlaggan Quartzite Fm, LL Loch Laggan Psammite Fm, LSZ Lochindorb Shear-zone, LTQ Loch Treig Schist and Quartzite Fm, NB Nethybridge Fm, PT Pitmain Semipelite Fm, PY Pityoulish Semipelite Fm, RS Ruthven Semipelite Fm, STS Strathtummel succession, TB Tarff Banded Semipelite Fm, TP Tormore Psammite Fm.

Figure 4 Opposed verging fold-pairs separated by a vertical high-strain zone in psammites of the Glen Spean Subgroup in the Geal-charn–Ossian Steep Belt. North-east of Loch a'Bhealaich Leamhain, Ardverikie Forest (NN 5060 7960, 5 km north-east of the Aonach Beag and Geal-charn GCR site). S. Robertson provides a scale. (Photo: BGS No. P 508351, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 5 Map of the area around the An Suidhe, Kincraig GCR site (after BGS 1:10 000 Sheet NH80NW, 1998)

Figure 6 Generalized vertical section of strata at the An Suidhe, Kincraig GCR site.

Figure 7 Interbanded metacarbonate rock and phyllitic calcareous semipelite overlain by semipelite of the Kincraig Formation, Leault Limestone Quarry (NH 8210 0638), An Suidhe, Kincraig GCR site. Hammer shaft is 35 cm long. (Photo: BGS No. P220941, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 8 Map of the area around The Slochd GCR site(after BGS 1:10 000 sheets NH82NW and NH82SW, 1998).

Figure 9 Migmatized gneissose psammite with leucosomes and incipient melt segregations, Slochd Psammite Formation, south-east of the road and rail summit at The Slochd at NH 8370 2516. Hammer head is 16.5 cm long. (Photo: BGS No. D 5586, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 10
(a) The A9 roadcut at The Slochd (NH 8366 2548). (Photo: BGS No. D 5582, reproduced with the permission of the Director, British Geological Survey, © NERC.)
(b) Sketch of the geology seen in the A9 roadcut at The Slochd (after Piasecki and Temperley, 1988b).

Figure 11 Map of the Lochan Uaine area, Strath Errick (after BGS 1:10 000 Sheet NH62SW).

Figure 12 Convolute lamination and cross-lamination in the Gairbeinn Pebbly Psammite Formation, east flank of Beinn Mheadhoin (NH 607 217), near the Lochan Uaine GCR site. Lens cap is 7 cm in diameter. (Photo: BGS No. P 518573, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 13

(a) Map of the area around the Blargie Craig GCR site, incorporating part of the Laggan Inlier after BGS 1:10 000 sheets NN59NE NN59SE, NN69NW and NN69SW (1997).

(b) Generalized cross-section across the Laggan Inlier showing general distribution of lithologies and structure, drawn 4 km north-east of Blargie Craig, from BGS 1:50 000 Sheet 63E (Dalwhinnie, 2002).

Figure 14 Glacially smoothed exposure in the Blargie Craig GCR site, showing contact between the Aonach Beag Semipelite Formation of the Appin Group (left) and the Creag Liath Psammite of the Glen Banchor Subgroup (right). The hammer shaft (35 cm long) lies along the inferred unconformity. Locality 250 m north-west of Coul Farm at NN 5870 9425. (Photo: BGS No. P 611930, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 15 Map of the River E section.

Figure 16

(a) Inversely graded, matrix-supported pebbly psammite overlain by a psammite displaying a variety of cross-lamination and some dewatering structures. Beds young upwards in the photo. River E (NH 5463 1363). Open compass is 17.5 cm long.

(b) Pebbly lag at the base of trough cross-laminated psammite. Beds young upwards in the photo. River E (NH 5458 1375). Tape measure is 10 cm in diameter.

(c) Well-preserved sand volcano in heterolithic pink and grey psammite showing ripple lamination. Beds young upwards in the photo. River E (NH 5445 1410). Pencil is 14 cm long.

(Photos: C.J. Banks.)

Figure 17 Sedimentary log for the section in the River E at NH 5460 1367, illustrating facies stacking pattern in pebbly psammite-dominated parts of the succession. Gms matrix-supported pebbly psammite (debris flow), Gt trough cross-laminated pebbly psammite (stream-flow reworking or longitudinal bars), Sp planar laminated psammite (sandy bar form), St trough cross-laminated psammite (sandy bar form), Cl slumped layer, E erosive base.

Figure 18 Map of the area around the Geal Charn–Ossian Steep Belt after Robertson and Smith (1999), with GCR sites superimposed. B Blargie Craig, Ch Coire Cheap, G Garva Bridge, Ki Kinloch Laggan, Mh Allt Mhainisteir, RM Rubha na Magach.

Figure 19 Map of the Glenshirra Dome and the area of the Garva Bridge GCR site. The overall geological setting is given in Figure 18.

Figure 20

(a) Heterolithic association, Garva Bridge Psammite Formation, Allt Coire Iain Oig. Cleaning and muddying upwards cycles. The clean sand component of each cycle is invariably ripple cross-laminated. The more-muddy parts of each cycle contain thin planar beds of psammite (originally clean sand) or small gutter casts filled with heterolithic sand and mud.

(b) Numerous elongate quartz pebbles within micaceous psammite in the Gairbeinn Pebbly Psammite Member of the Garva Bridge Psammite Formation, Gairbeinn. The parting present in the psammite above this pebbly bed is tectonic rather than original bedding.
(Photos: B.W. Glover.)

Figure 21 Schematic cross-section through the Glenshirra Subgroup illustrating the proposed lateral facies changes and the possible basin configuration. After Glover (1998).

Figure 22 Map showing the location of the Rubha na Magach localities and the general geology of the area to the north-west of Loch Laggan. The overall geological setting is given in Figure 18.

Figure 23 Measured sedimentary logs for:
(a) Rubha na Magach (NN 4618 8492).
(b) lochside exposures at NN 4653 8516. Note the crude thinning and fining-upward cycles from thick-bedded psammite, micaceous psammite and semipelite up into thinner bedded micaceous psammite and semipelite, shown to illustrate the lithofacies present. Log (a) is *c*. 50 m higher in the stratigraphy than log (b).

Figure 24
(a) Complex ripple-drift cross-lamination in a thick bed of micaceous psammite at Rubha na Magach (NN 4618 8492). Open compass is 17.5 cm long. (Photo: C.J. Banks.)
(b) Loading and convolute lamination on a thick micaceous psammite grading into semipelite. Also shows a calcsilicate pod below the notebook. Lochside exposure at NN 4653 8516. Notebook is 20 cm long. (Photo: C.J. Banks.)
(c) Bouma units Ta to Te in a thick psammite to semipelite bed on the Rubha na Magach promontory at NN 4618 8492. A basal massive psammite (Ta) passes into a lower plane bed (Tb), a cross-laminated horizon (Tc), an upper plane bed (Td) and is finally capped by semipelite (Te). Pen is 15 cm long. (Photo: J.A. Winchester.)

Figure 25 Map of the area around the Kinloch Laggan Road A86 GCR site. After Robertson and Smith (1999). The wider geological setting is shown on Figure 18. KLS, Kinlochlaggan Syncline.

Figure 26 Typical lithofacies of the Kinlochlaggan Boulder Bed with 40 x 16 cm granite boulder in centre of view (NN 548 897). Hammer head is 16.5 cm long. (Photo: BGS No. P 221180, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 27 Lithostratigraphy of the area within and west of the Geal-charn–Ossian Steep Belt in the vicinity of the Kinloch Laggan Road, Allt Mhainisteir and Aonach Beag and Geal-charn GCR sites. After Robertson and Smith (1999).

Figure 28 Map of the Allt Mhainisteir and Allt Liath nam Badan sections, south of Loch Laggan. The overall geological setting is shown in Figure 18.

Figure 29 Intense isoclinal folding in the Creag Meagaidh Psammite Formation adjacent to the Allt Mhainisteir Slide, NN 5343

8535. Hammer head is 16.5 cm long. (Photo: BGS No. P 221176, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 30 Map of the area around the Allt Mhainisteir, Rubha na Magach and Aonach Beag and Geal-charn GCR sites. After Robertson and Smith (1999). The line of cross-section in Figure 31 is shown as A–A'. AG Aonach Beag and Geal-charn GCR site, KLS Kinlochlaggan Syncline, Mh Allt Mhainisteir GCR site, RM Rubha na Magach GCR site.

Figure 31 Schematic cross-section across the Geal-charn–Ossian Steep Belt along the line A–A' indicated on Figure 30. ABS Aonach Beag Slide, CC Coire Cheap, CS Coire Sgoir, SGF Sron Garbh Fold-complex, SS Sgoir slides. After Robertson and Smith (1999). Ornaments as on Figure 30.

Figure 32 Annotated view south-south-west from below Diollaid a'Chairn (NN 4920 7540) to Coire Sgòir, Loch an Sgòir and Sgòr Iutharn in the Aonach Beag and Geal-charn GCR site, showing structures on the south-east edge of the Geal-charn–Ossian Steep Belt. The smaller folds are diagrammatic. Migmatization increases north-westwards in the steep belt. gPs gneissose psammite, gSp gneissose semipelite, Pe pelite, Ps psammite, Sp semipelite, LEA Lancet Edge Antiform (plunges steeply into the hillside). (Photo: BGS No. P 001217, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 33 Looking south-west from the Allt a'Chaoil-reidhe by Culra Bothy (NN 5230 7600) to Ben Alder, Sgor Iutharn and Geal-charn. The prominent gap between Ben Alder and Sgor Iutharn is the Bealach Dubh; the Ben Alder GCR site lies to the left of the bealach and the Aonach Beag and Geal-charn GCR site is to the right. (Photo: BGS No. P 001218, reproduced with the permission of the Director, British Geological Survey, © NERC.)

Figure 34 Map of the area around the Aonach Beag and Geal-charn and Ben Alder GCR sites (after Thomas, 1979). ABA Aonach Beag Anticline (F1), ABS Alder Bay Synform (F2), ACA Aisre Cham Anticline (F1), BAA Ben Alder Antiform (F2), BAAn Ben Alder Anticline (F1), BAS Ben Alder Synform (F2), BDS Bealach Dubh Synform (F3), CCA Coire Cheap Anticline (F1), CIA Coire na h' Iolaire Antiform (F3), CLS Coire Labhair Syncline (F1), CNLA Coire na Lethchois Antiform (F3), CNLS Coire na Lethchois Synform (F3), CSA Coire Sgoir Anticline (F1), GCF Garbh Coire Fault, GCS Geal Charn Syncline (F1), KLS Kinlochlaggan Syncline (F1), LEA Lancet Edge Antiform (F3), SMA Sgairneach Mhor Antiform (F2).

Figure 35 Secondary upright folding superimposed on earlier tight to isoclinal folds in Grampian Group psammites. Structural architecture is typical of that developed within the 'Ben Alder folds' (*sensu* Thomas, 1979). South-east side of Bealach Dubh, NN 5014 7120. Hammer shaft is 35 cm long. (Photo: C.J. Banks, BGS No. P605207.)

Figure 36 Schematic cross-section, approximately true-scale, across the Aonach Beag and Geal-charn and Ben Alder GCR sites (after Thomas, 1979).

Figure 5.1

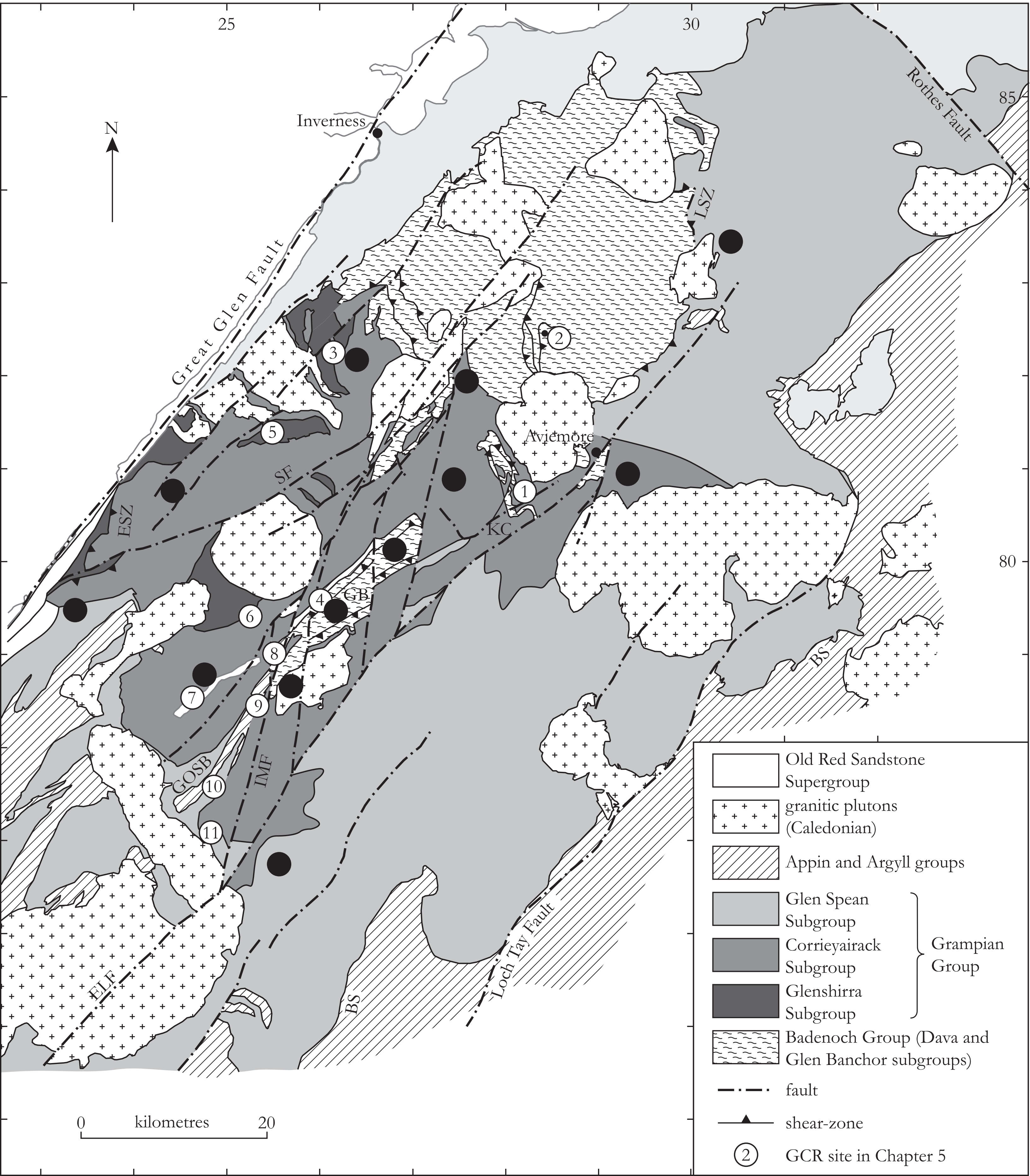
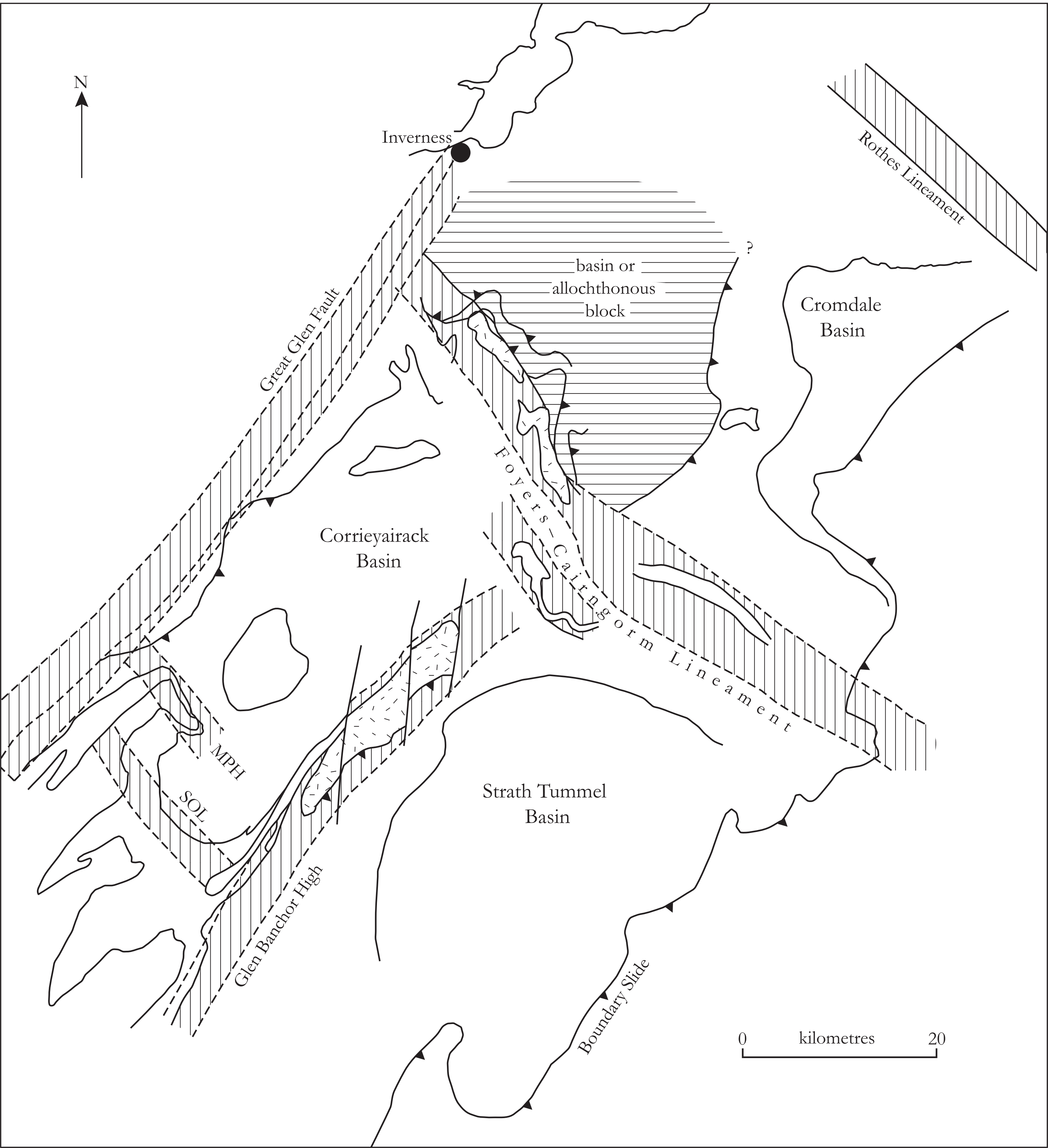

25
30
85
80
N
Inverness
Great Glen Fault
Rothes Fault
LSZ
Aviemore
SF
ESZ
KC
GB
GOSB
IMF
ELF
BS
Loch Tay Fault
1
2
3
4
5
6
7
8
9
10
11
0 kilometres 20
Old Red Sandstone Supergroup
granitic plutons (Caledonian)
Appin and Argyll groups
Glen Spean Subgroup
Corrieyairack Subgroup
Glenshirra Subgroup
Grampian Group
Badenoch Group (Dava and Glen Banchor subgroups)
fault
shear-zone
GCR site in Chapter 5

Figure 5.2



N
Inverness
Rothes Lineament
?
basin or
allochthonous
block
Cromdale
Basin
Great Glen Fault
Foyers–Cairngorm Lineament
Corrieyairack
Basin
MPH
SOL
Strath Tummel
Basin
Glen Banchor High
Boundary Slide
0
kilometres
20

Figure 5.3

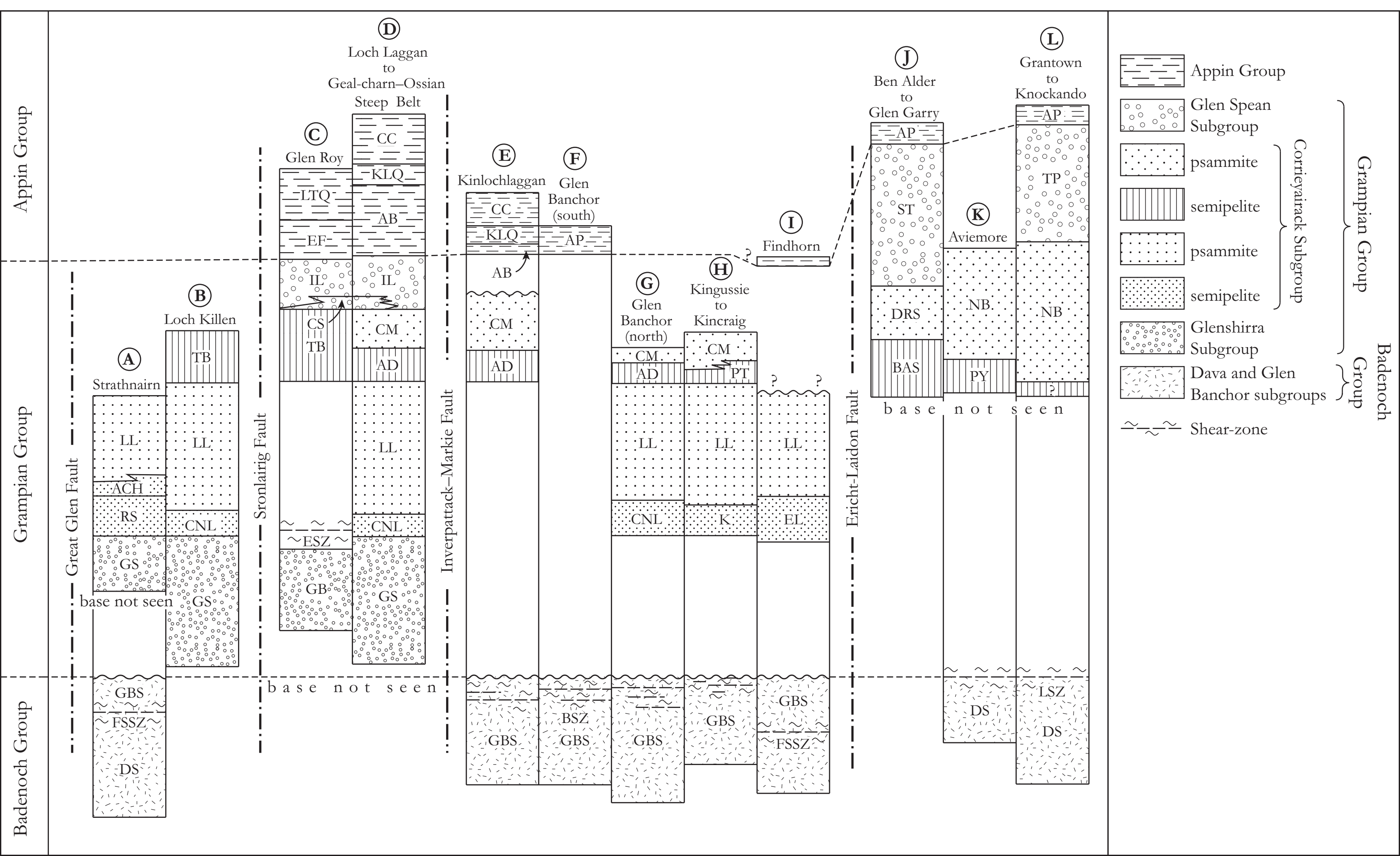
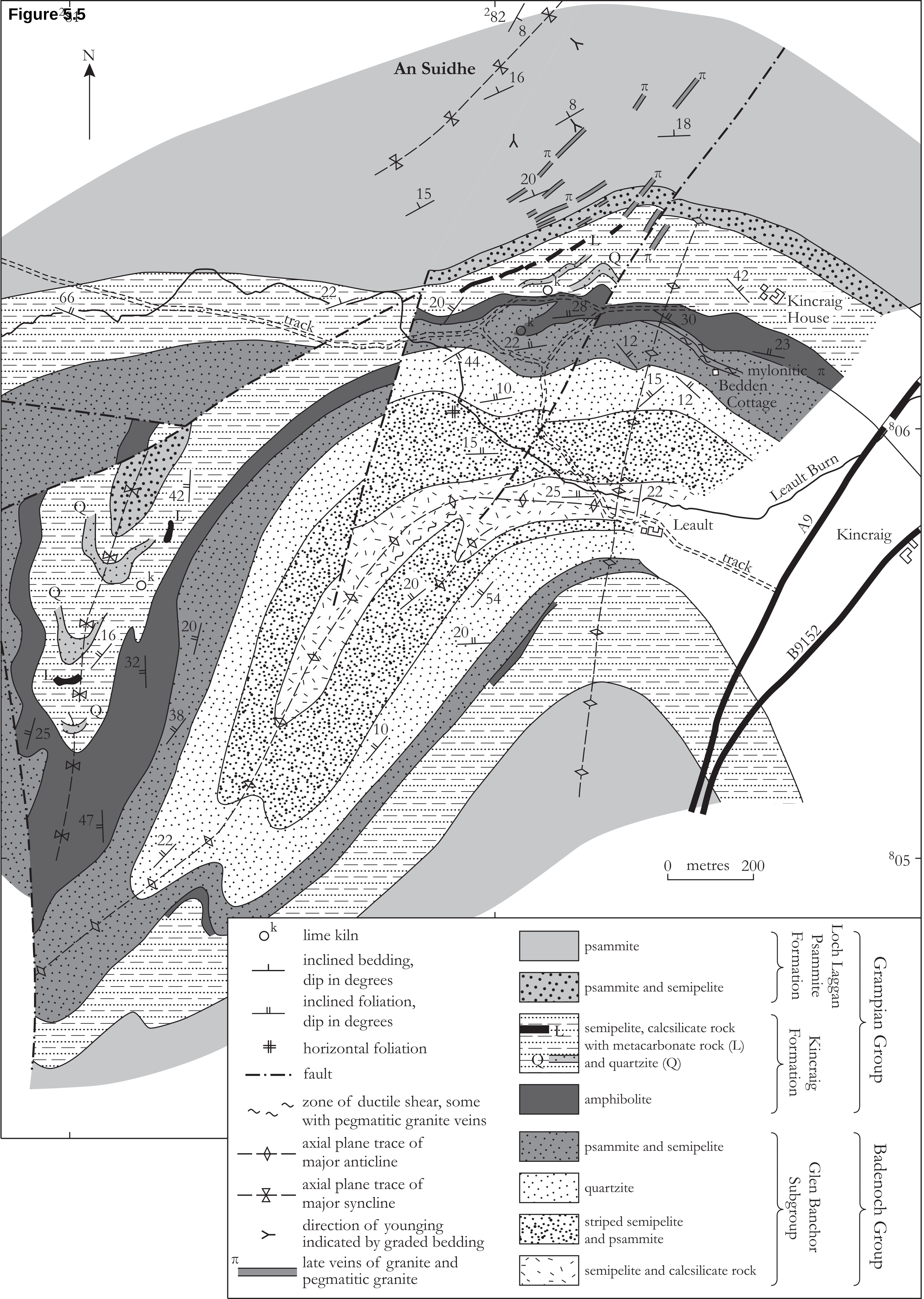

Appin Group
Grampian Group
Badenoch Group
Great Glen Fault
Sronlairig Fault
Inverpattack–Markie Fault
Ericht-Laidon Fault
A
Strathnairn
LL
ACH
RS
GS
base not seen
GBS
FSSZ
DS
B
Loch Killen
TB
LL
CNL
GS
C
Glen Roy
LTQ
EF
IL
CS
TB
ESZ
GB
base not seen
D
Loch Laggan to Geal-charn–Ossian Steep Belt
CC
KLQ
AB
IL
CM
AD
LL
CNL
GS
E
Kinlochlaggan
CC
KLQ
AB
CM
AD
GBS
F
Glen Banchor (south)
AP
BSZ
GBS
G
Glen Banchor (north)
CM
AD
LL
CNL
GBS
H
Kingussie to Kincraig
CM
PT
LL
K
GBS
I
Findhorn
LL
EL
GBS
FSSZ
J
Ben Alder to Glen Garry
AP
ST
DRS
BAS
base not seen
K
Aviemore
NB
PY
DS
L
Grantown to Knockando
AP
TP
NB
LSZ
DS
Appin Group
Glen Spean Subgroup
psammite
semipelite
psammite
semipelite
Corrieyairack Subgroup
Glenshirra Subgroup
Grampian Group
Dava and Glen Banchor subgroups
Badenoch Group
Shear-zone

Figure 5.5



N
An Suidhe
Kincraig House
mylonitic
Bedden Cottage
Leault Burn
Leault
Kincraig
track
A9
B9152
L
Q
π
k
0 metres 200
806
805
282
lime kiln
inclined bedding, dip in degrees
inclined foliation, dip in degrees
horizontal foliation
fault
zone of ductile shear, some with pegmatitic granite veins
axial plane trace of major anticline
axial plane trace of major syncline
direction of younging indicated by graded bedding
late veins of granite and pegmatitic granite
psammite
psammite and semipelite
Loch Laggan Psammite Formation
semipelite, calcsilicate rock with metacarbonate rock (L) and quartzite (Q)
amphibolite
Kincraig Formation
Grampian Group
psammite and semipelite
quartzite
striped semipelite and psammite
semipelite and calcsilicate rock
Glen Banchor Subgroup
Badenoch Group

Figure 5.6

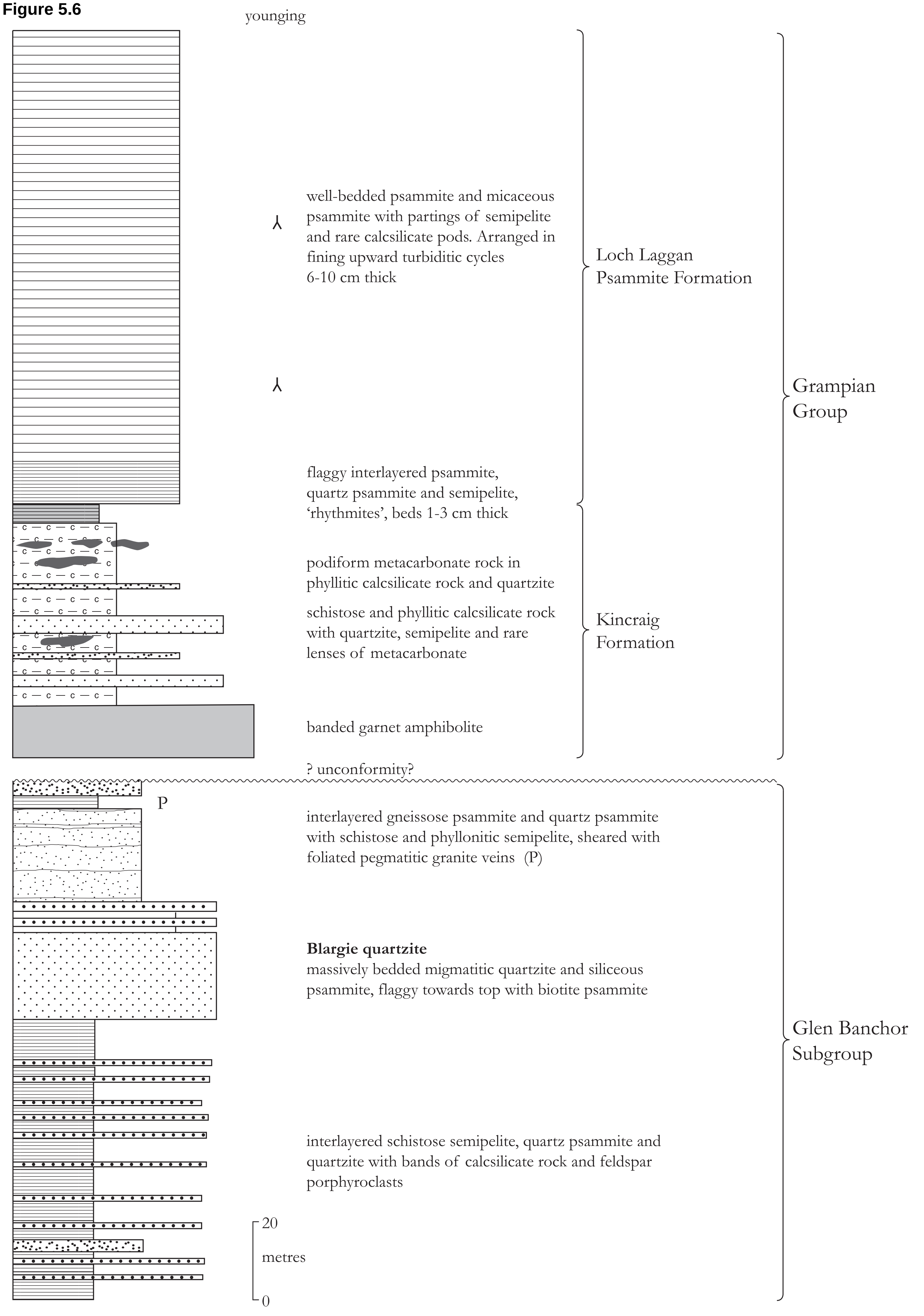
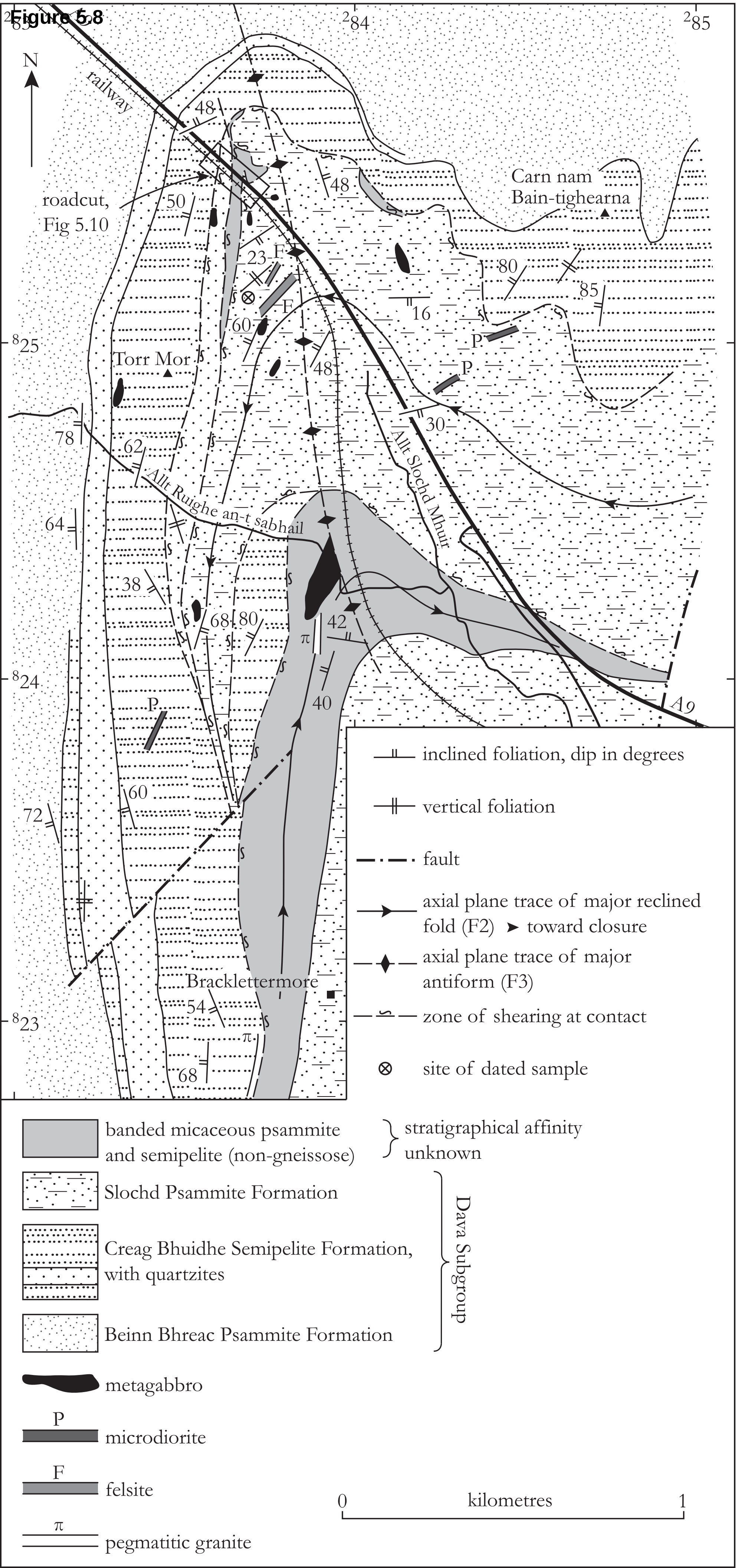
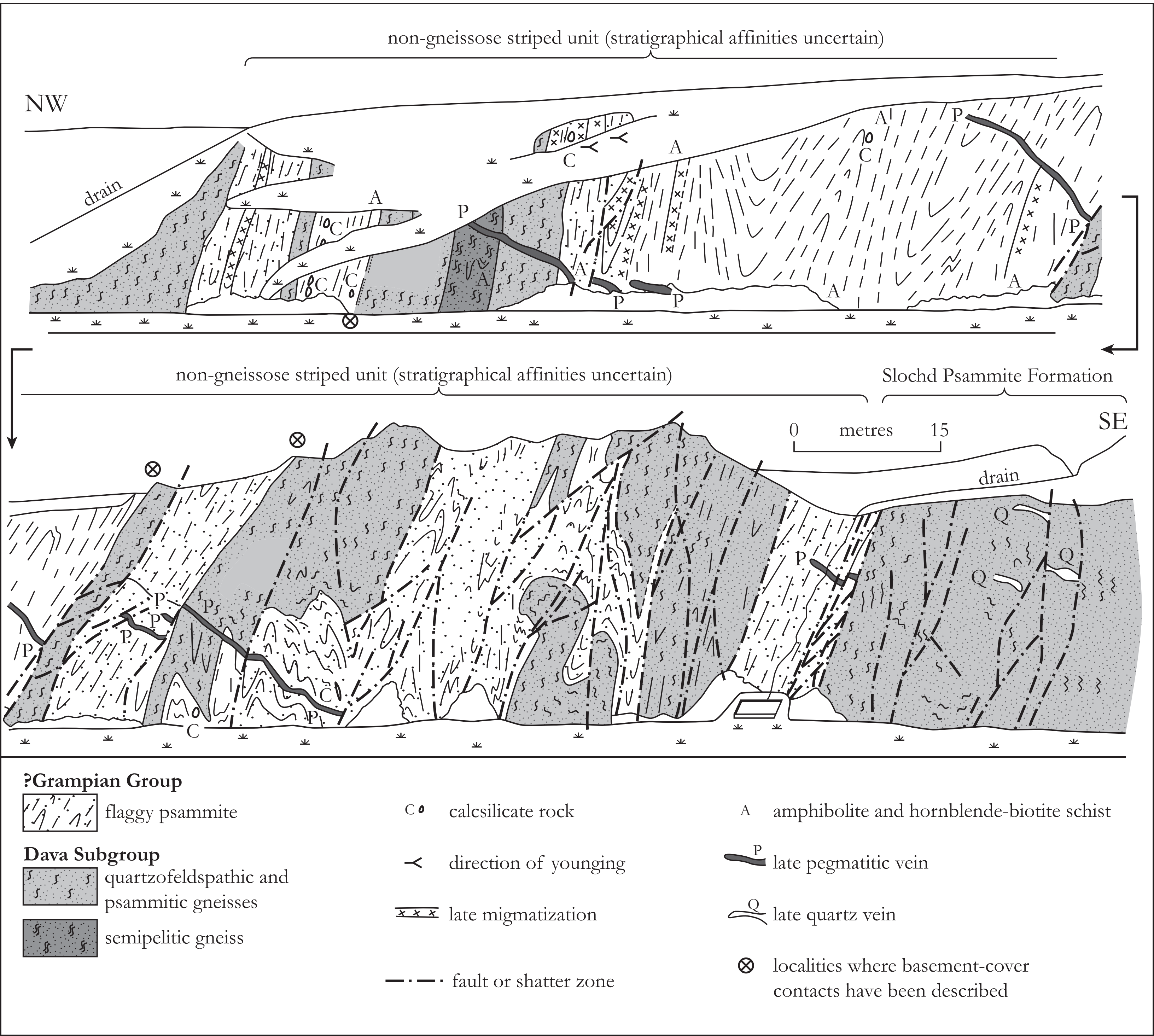

younging
well-bedded psammite and micaceous psammite with partings of semipelite and rare calcsilicate pods. Arranged in fining upward turbiditic cycles 6-10 cm thick
flaggy interlayered psammite, quartz psammite and semipelite, 'rhythmites', beds 1-3 cm thick
Loch Laggan Psammite Formation
podiform metacarbonate rock in phyllitic calcsilicate rock and quartzite
schistose and phyllitic calcsilicate rock with quartzite, semipelite and rare lenses of metacarbonate
Kincraig Formation
banded garnet amphibolite
Grampian Group
? unconformity?
P
interlayered gneissose psammite and quartz psammite with schistose and phyllonitic semipelite, sheared with foliated pegmatitic granite veins (P)
Blargie quartzite
massively bedded migmatitic quartzite and siliceous psammite, flaggy towards top with biotite psammite
interlayered schistose semipelite, quartz psammite and quartzite with bands of calcsilicate rock and feldspar porphyroclasts
Glen Banchor Subgroup
20
metres
0

Figure 5.8



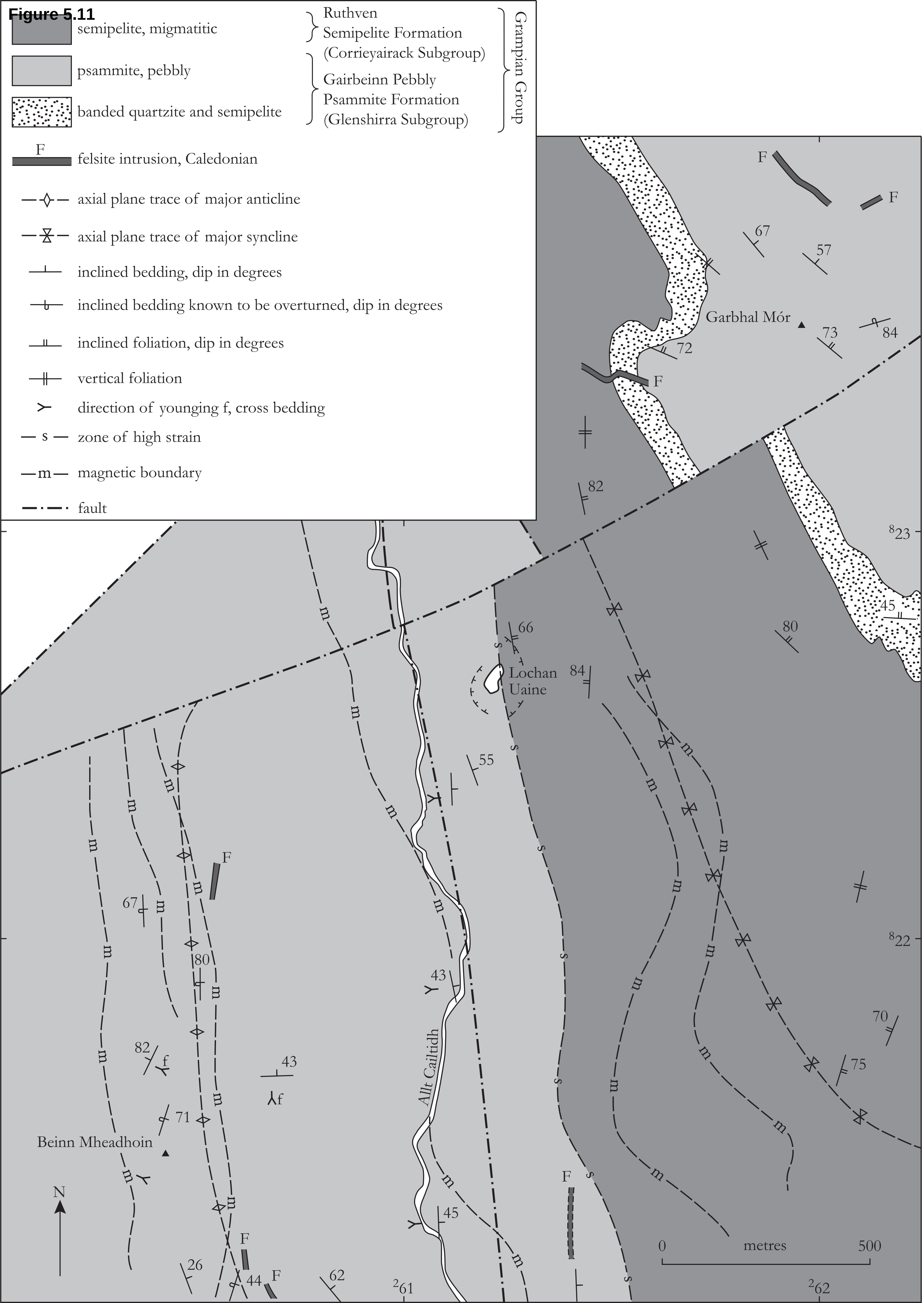
N
railway
roadcut, Fig 5.10
Carn nam Bain-tighearna
Torr Mor
Allt Ruighe an-t sabhail
Allt Slochd Mhuir
Bracklettermore
A9
84
85
825
824
823
48
50
23
60
16
80
85
48
30
78
62
64
38
68
80
42
40
60
72
54
68
F
P
π
inclined foliation, dip in degrees
vertical foliation
fault
axial plane trace of major reclined fold (F2) ➤ toward closure
axial plane trace of major antiform (F3)
zone of shearing at contact
site of dated sample
banded micaceous psammite and semipelite (non-gneissose)
stratigraphical affinity unknown
Slochd Psammite Formation
Creag Bhuidhe Semipelite Formation, with quartzites
Beinn Bhreac Psammite Formation
Dava Subgroup
metagabbro
microdiorite
felsite
pegmatitic granite
0
kilometres
1

Figure 5.10b



non-gneissose striped unit (stratigraphical affinities uncertain)
NW
drain
A
C
P
non-gneissose striped unit (stratigraphical affinities uncertain)
Slochd Psammite Formation
SE
0 metres 15
drain
Q
?Grampian Group
flaggy psammite
Dava Subgroup
quartzofeldspathic and psammitic gneisses
semipelitic gneiss
C o calcsilicate rock
direction of younging
late migmatization
fault or shatter zone
A amphibolite and hornblende-biotite schist
P late pegmatitic vein
Q late quartz vein
localities where basement-cover contacts have been described

Figure 5.11



semipelite, migmatitic
psammite, pebbly
banded quartzite and semipelite
Ruthven
Semipelite Formation
(Corrieyairack Subgroup)
Gairbeinn Pebbly
Psammite Formation
(Glenshirra Subgroup)
Grampian Group
F
felsite intrusion, Caledonian
axial plane trace of major anticline
axial plane trace of major syncline
inclined bedding, dip in degrees
inclined bedding known to be overturned, dip in degrees
inclined foliation, dip in degrees
vertical foliation
direction of younging f, cross bedding
s
zone of high strain
m
magnetic boundary
fault
Garbhal Mór
Lochan
Uaine
Allt Cailtidh
Beinn Mheadhoin
N
0
metres
500
823
822
261
262

Figure 5.13a

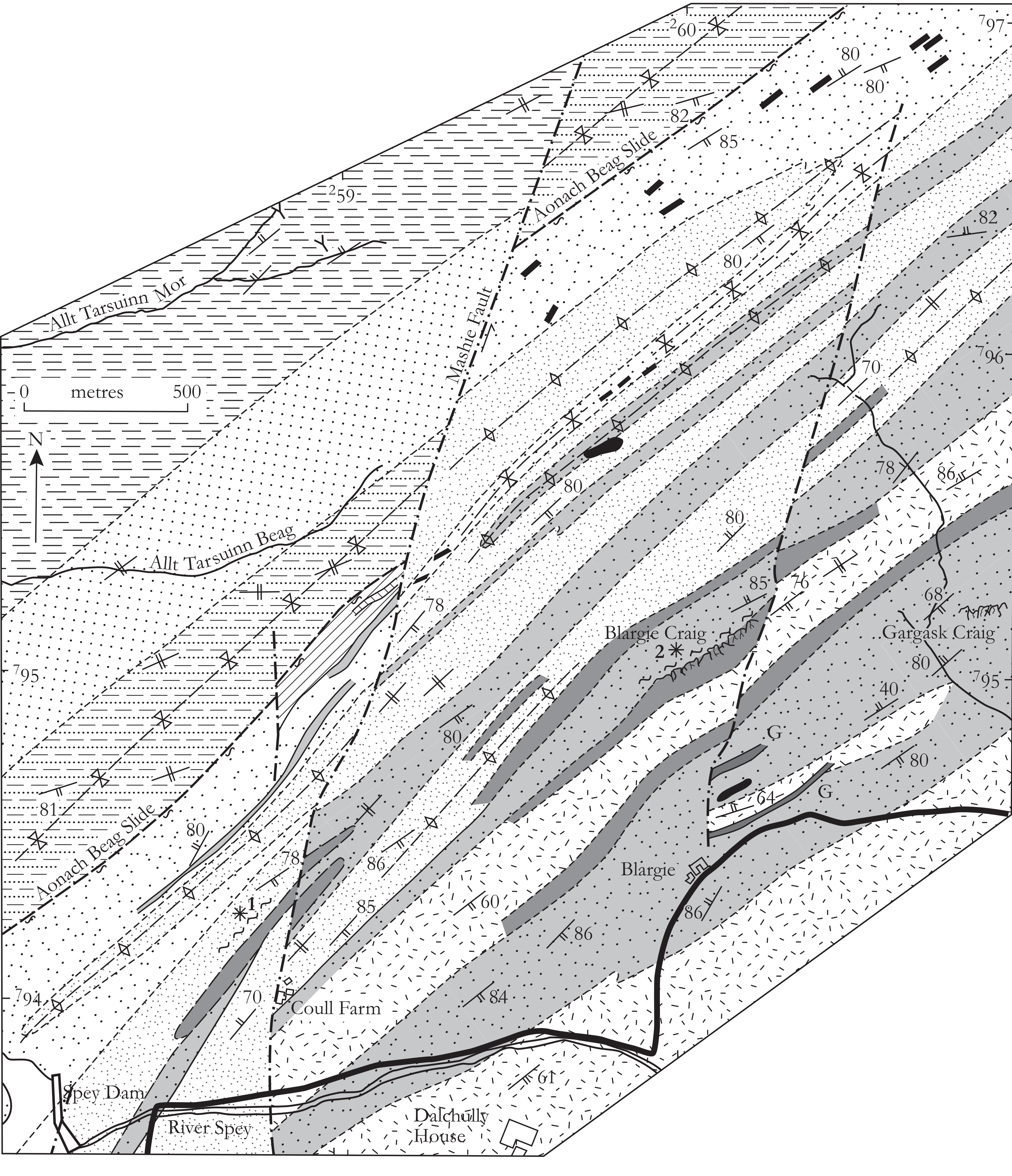

0 metres 500
N
Allt Tarsuinn Mor
Allt Tarsuinn Beag
Aonach Beag Slide
Aonach Beag Slide
Mashie Fault
Blargie Craig
Gargask Craig
Blargie
Coull Farm
Spey Dam
River Spey
Dalchully House
G
G
1
2
[2]60
[2]59
[7]97
[7]96
[7]95
[7]95
[7]94
80
80
82
85
82
80
70
78
86
80
80
85
76
78
68
80
40
80
64
80
86
78
86
60
85
86
84
70
61
81
80

Figure 5.13b

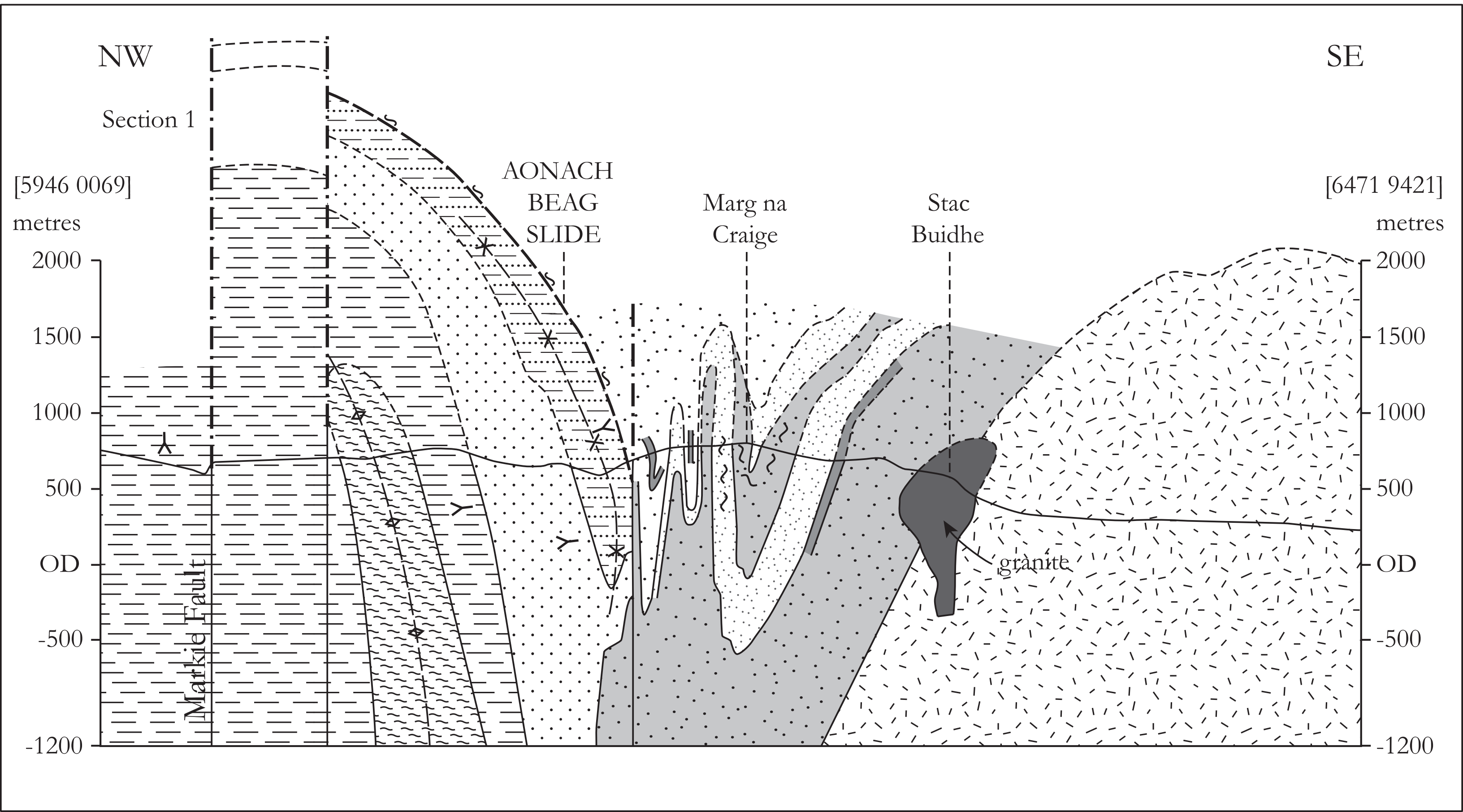

NW
SE
Section 1
[5946 0069]
metres
[6471 9421]
metres
AONACH
BEAG
SLIDE
Marg na
Craige
Stac
Buidhe
granite
Markie Fault
2000
1500
1000
500
OD
-500
-1200

Figure 5.13 key

Figure 5.15

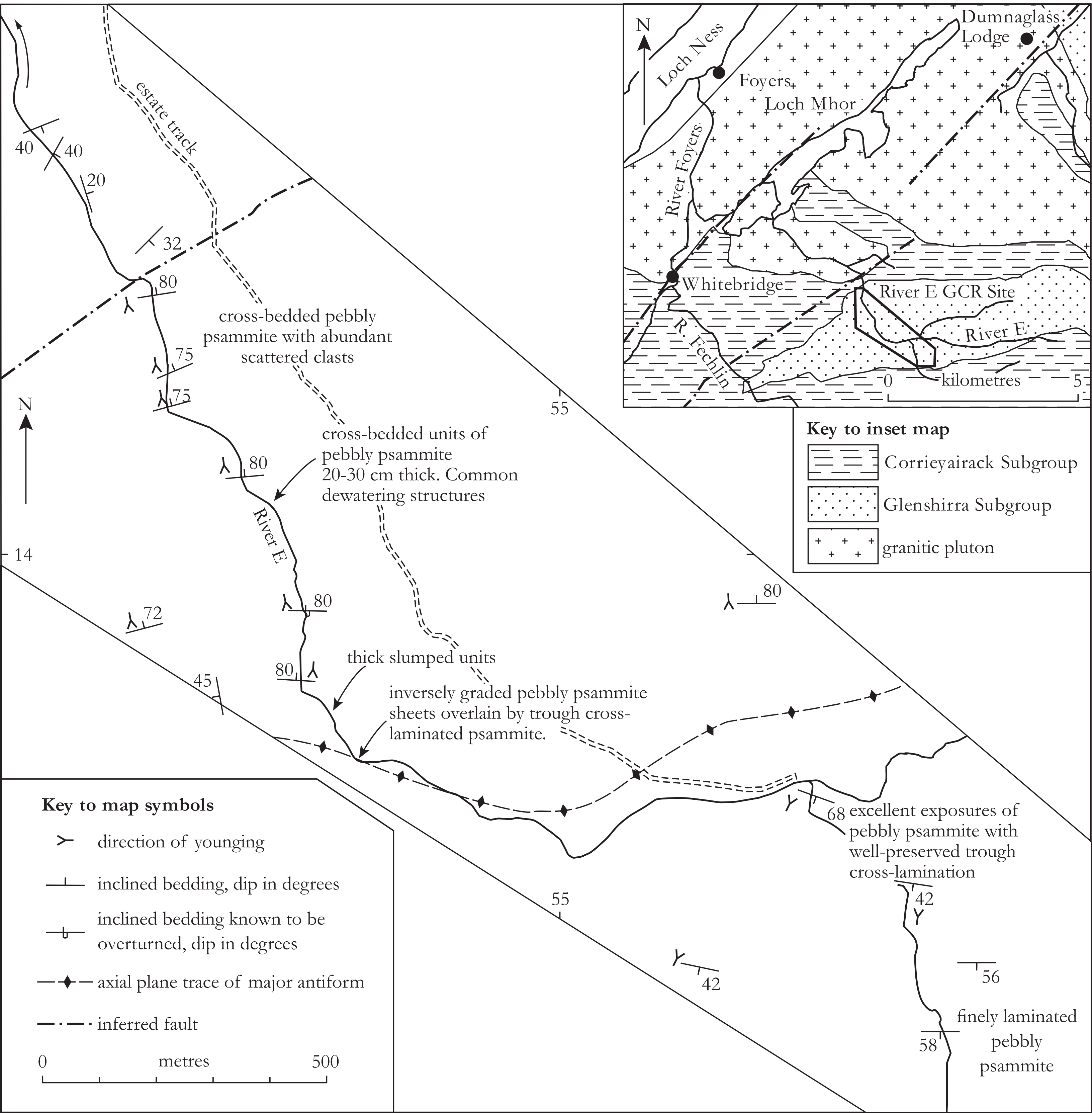
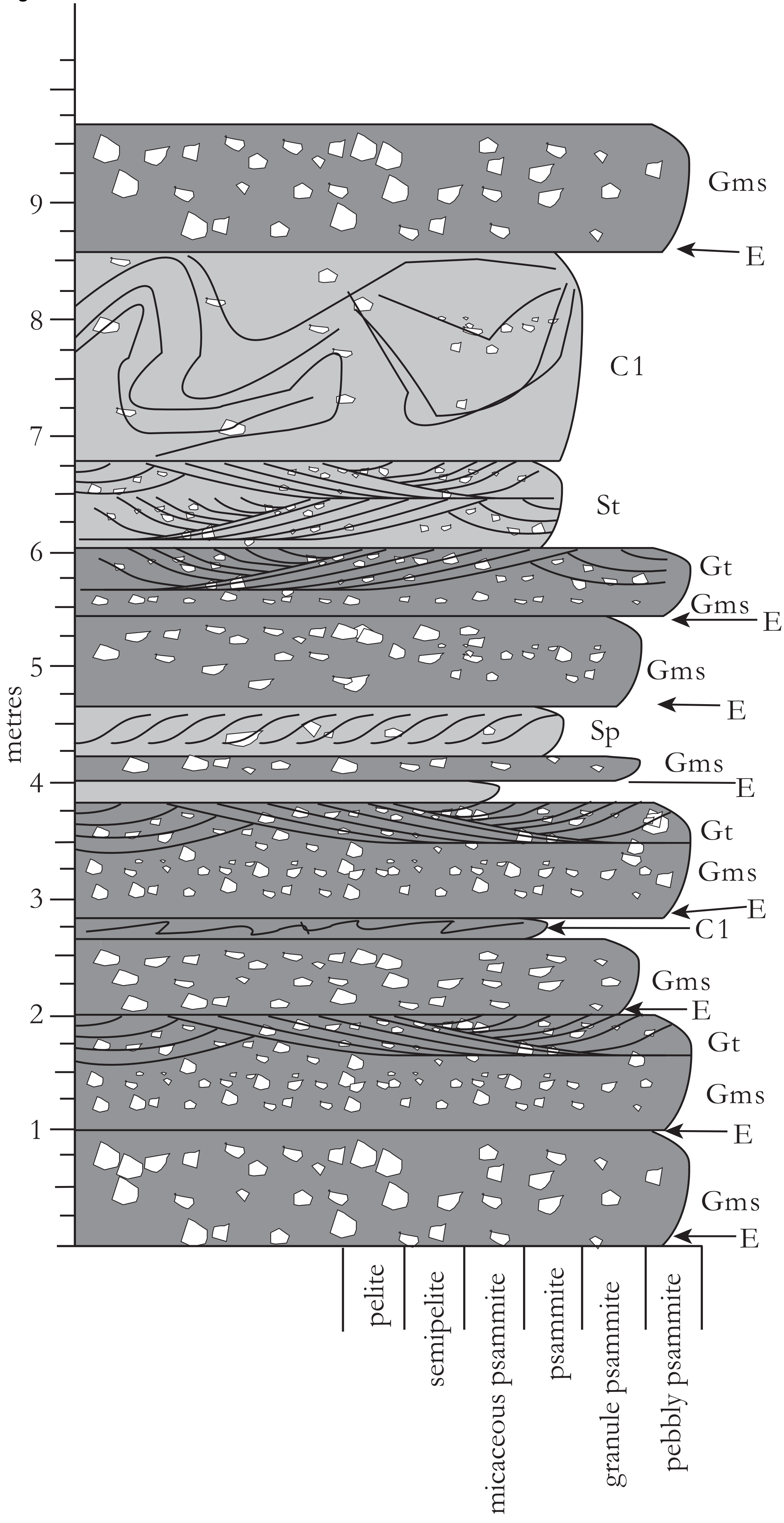
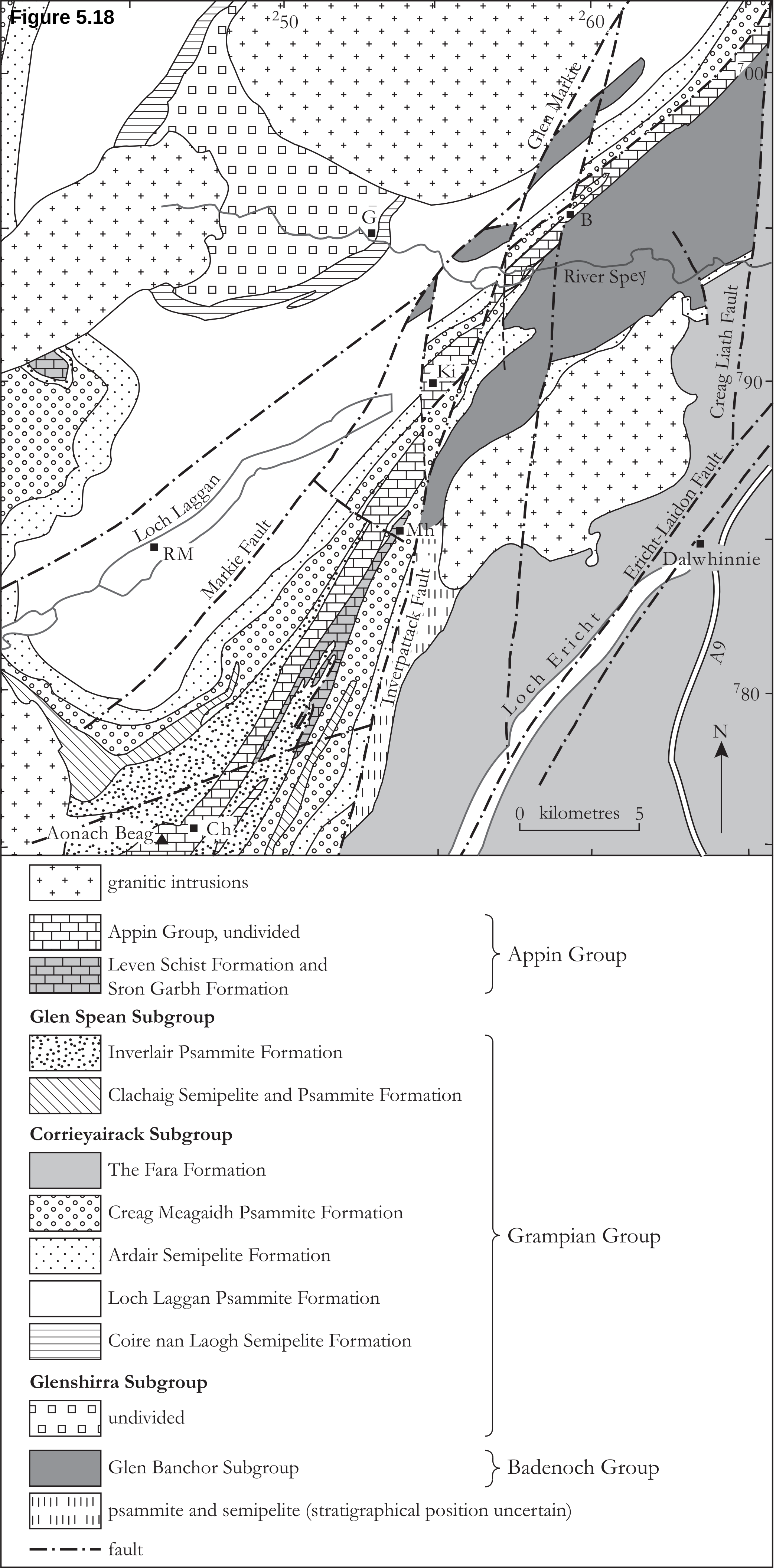

estate track
40
40
20
32
80
cross-bedded pebbly psammite with abundant scattered clasts
75
75
N
55
cross-bedded units of pebbly psammite 20-30 cm thick. Common dewatering structures
80
River E
14
80
72
80
thick slumped units
45
inversely graded pebbly psammite sheets overlain by trough cross-laminated psammite.
68
excellent exposures of pebbly psammite with well-preserved trough cross-lamination
42
55
42
56
finely laminated pebbly psammite
58
Key to map symbols
direction of younging
inclined bedding, dip in degrees
inclined bedding known to be overturned, dip in degrees
axial plane trace of major antiform
inferred fault
0
metres
500
Loch Ness
Foyers
Loch Mhor
Dumnaglass Lodge
River Foyers
Whitebridge
River E GCR Site
River E
R. Fechlin
0
kilometres
5
Key to inset map
Corrieyairack Subgroup
Glenshirra Subgroup
granitic pluton

Figure 5.17



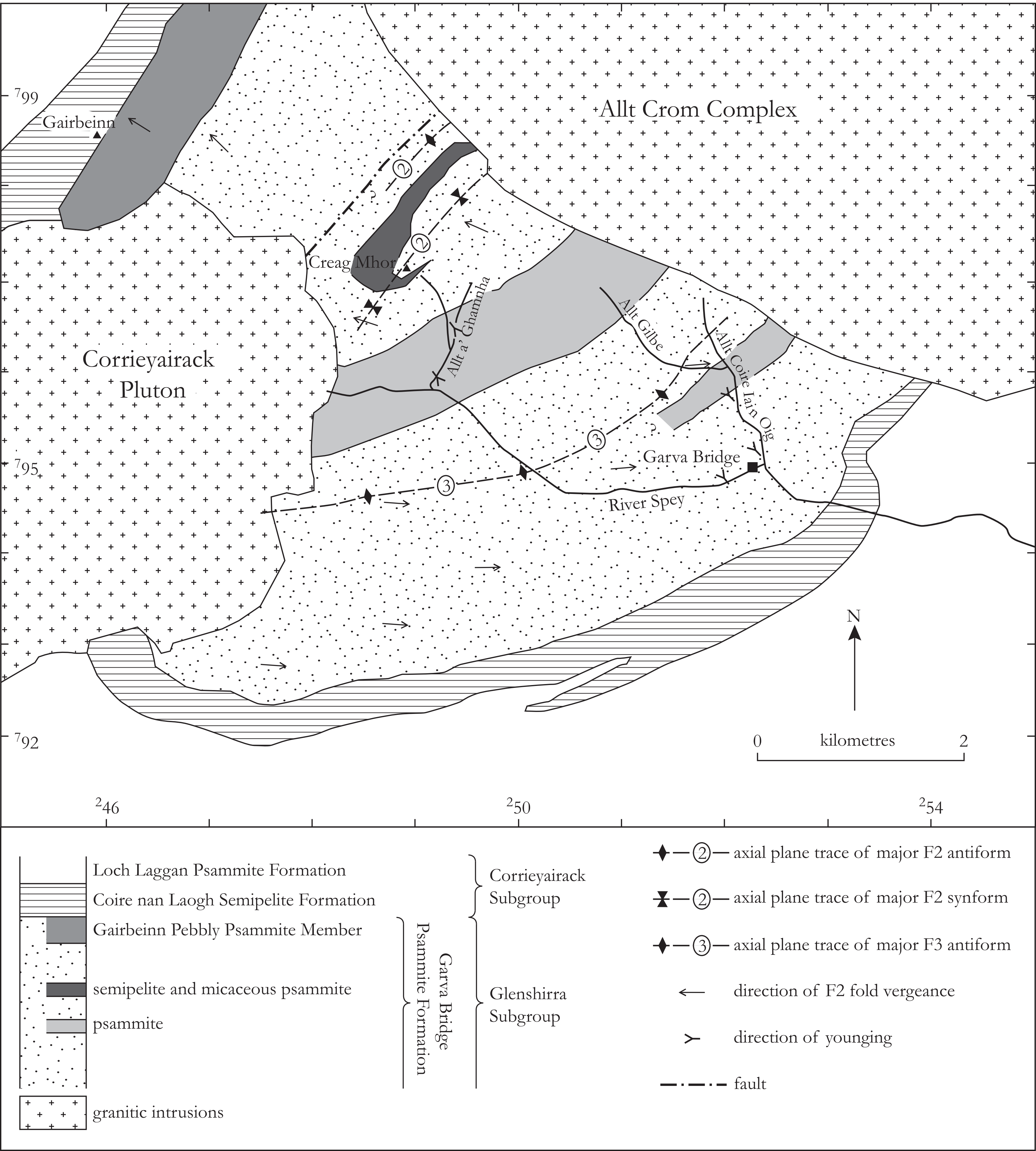
metres
9
8
7
6
5
4
3
2
1
Gms
E
C1
St
Gt
Gms
E
Gms
E
Sp
Gms
E
Gt
Gms
E
C1
Gms
E
Gt
Gms
E
Gms
E
pelite
semipelite
micaceous psammite
psammite
granule psammite
pebbly psammite

Figure 5.18



²50
²60
⁷00
⁷90
⁷80
Glen Markie
G
B
River Spey
Ki
Creag Liath Fault
Loch Laggan
RM
Markie Fault
Mh
Inverpattack Fault
Ericht-Laidon Fault
Dalwhinnie
Loch Ericht
A9
N
0 kilometres 5
Aonach Beag
Ch
granitic intrusions
Appin Group, undivided
Leven Schist Formation and Sron Garbh Formation
Appin Group
Glen Spean Subgroup
Inverlair Psammite Formation
Clachaig Semipelite and Psammite Formation
Corrieyairack Subgroup
The Fara Formation
Creag Meagaidh Psammite Formation
Ardair Semipelite Formation
Loch Laggan Psammite Formation
Coire nan Laogh Semipelite Formation
Grampian Group
Glenshirra Subgroup
undivided
Glen Banchor Subgroup
Badenoch Group
psammite and semipelite (stratigraphical position uncertain)
fault

Figure 5.19



Allt Crom Complex
Gairbeinn
Creag Mhor
Corrieyairack
Pluton
Allt a' Ghamnha
Allt Gilbe
Allt Coire Iain Oig
Garva Bridge
River Spey
N
0
kilometres
2
799
795
792
246
250
254
Loch Laggan Psammite Formation
Coire nan Laogh Semipelite Formation
Gairbeinn Pebbly Psammite Member
semipelite and micaceous psammite
psammite
granitic intrusions
Garva Bridge Psammite Formation
Corrieyairack Subgroup
Glenshirra Subgroup
axial plane trace of major F2 antiform
axial plane trace of major F2 synform
axial plane trace of major F3 antiform
direction of F2 fold vergeance
direction of younging
fault

Figure 5.21

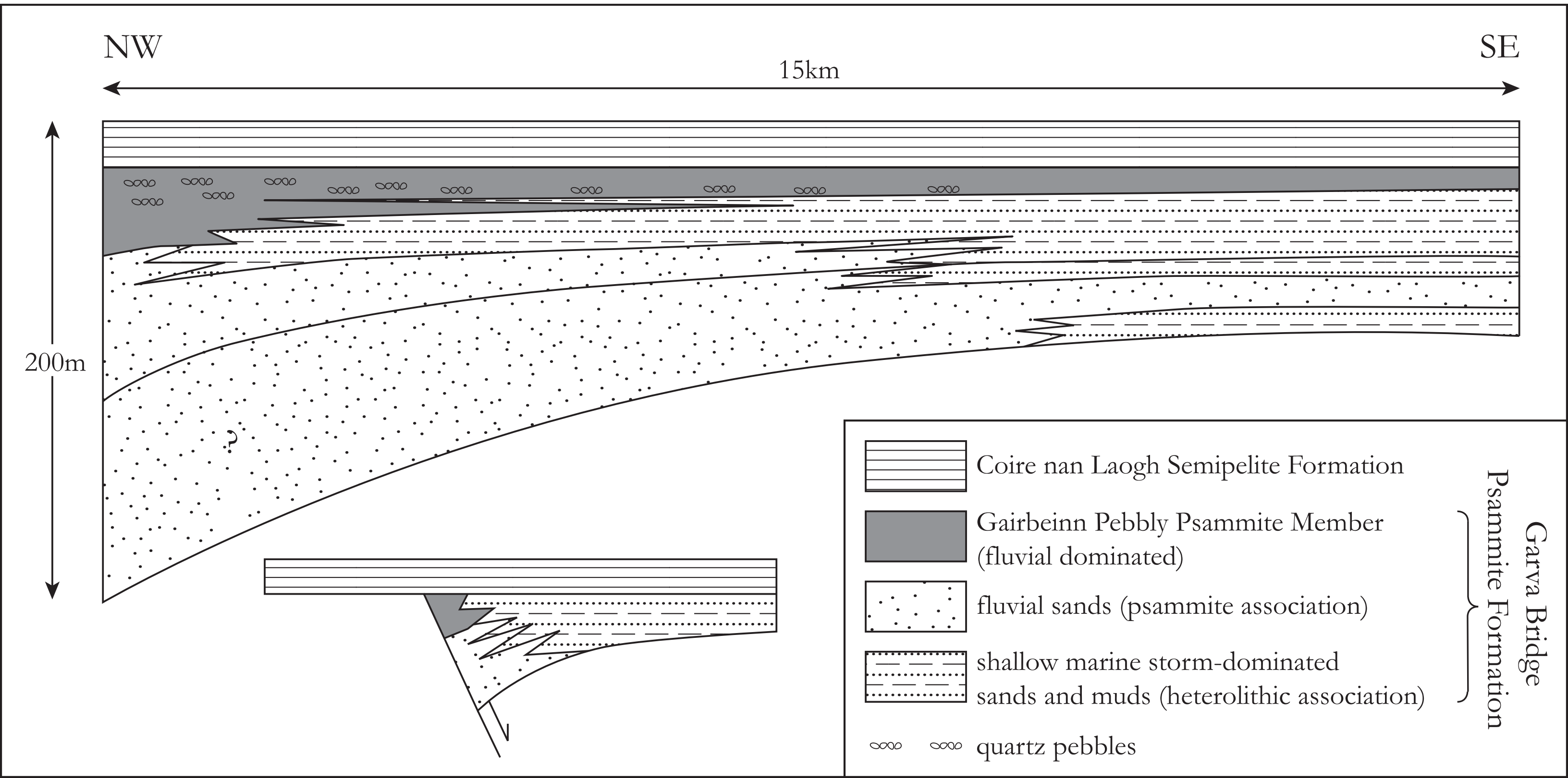
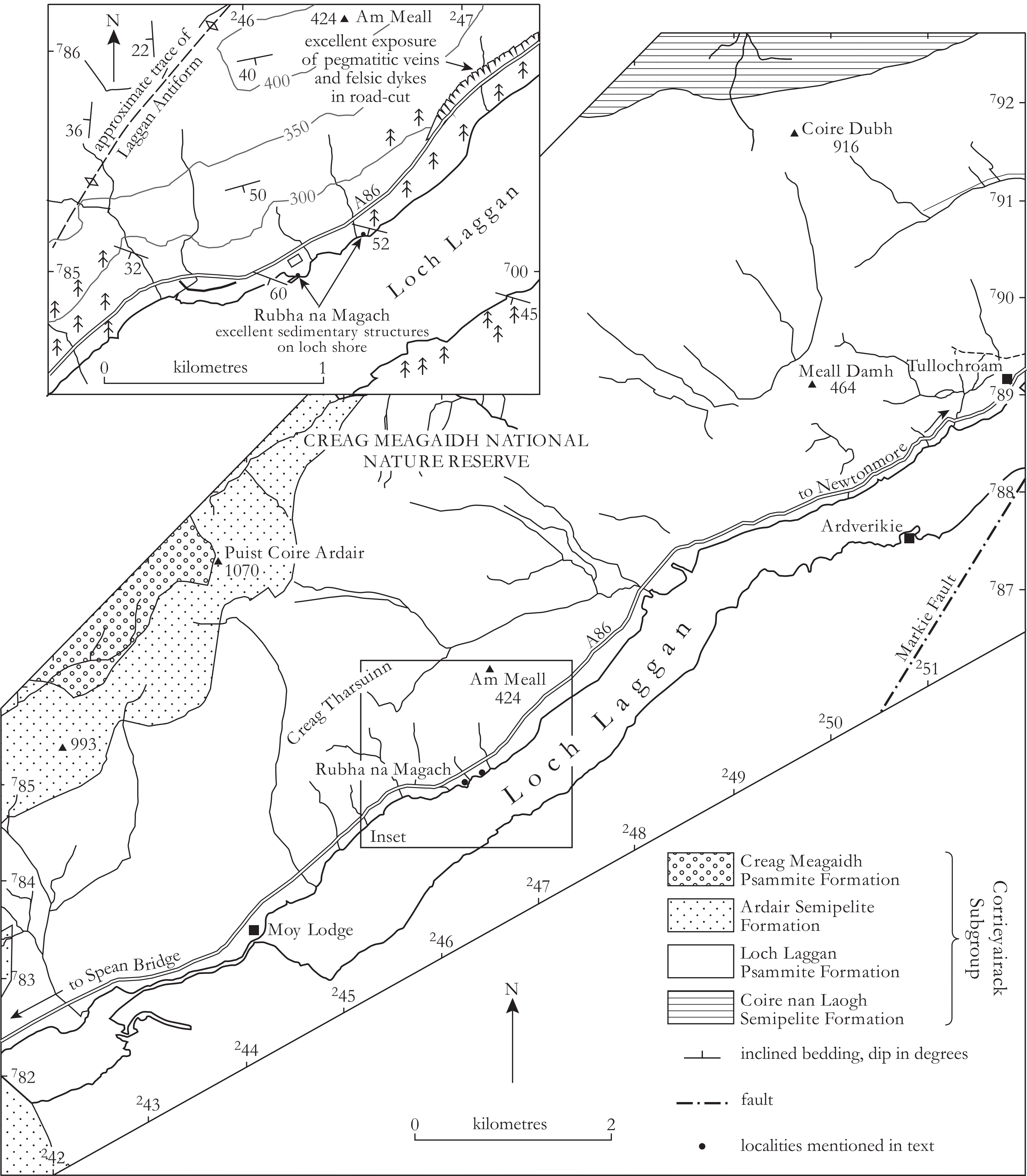
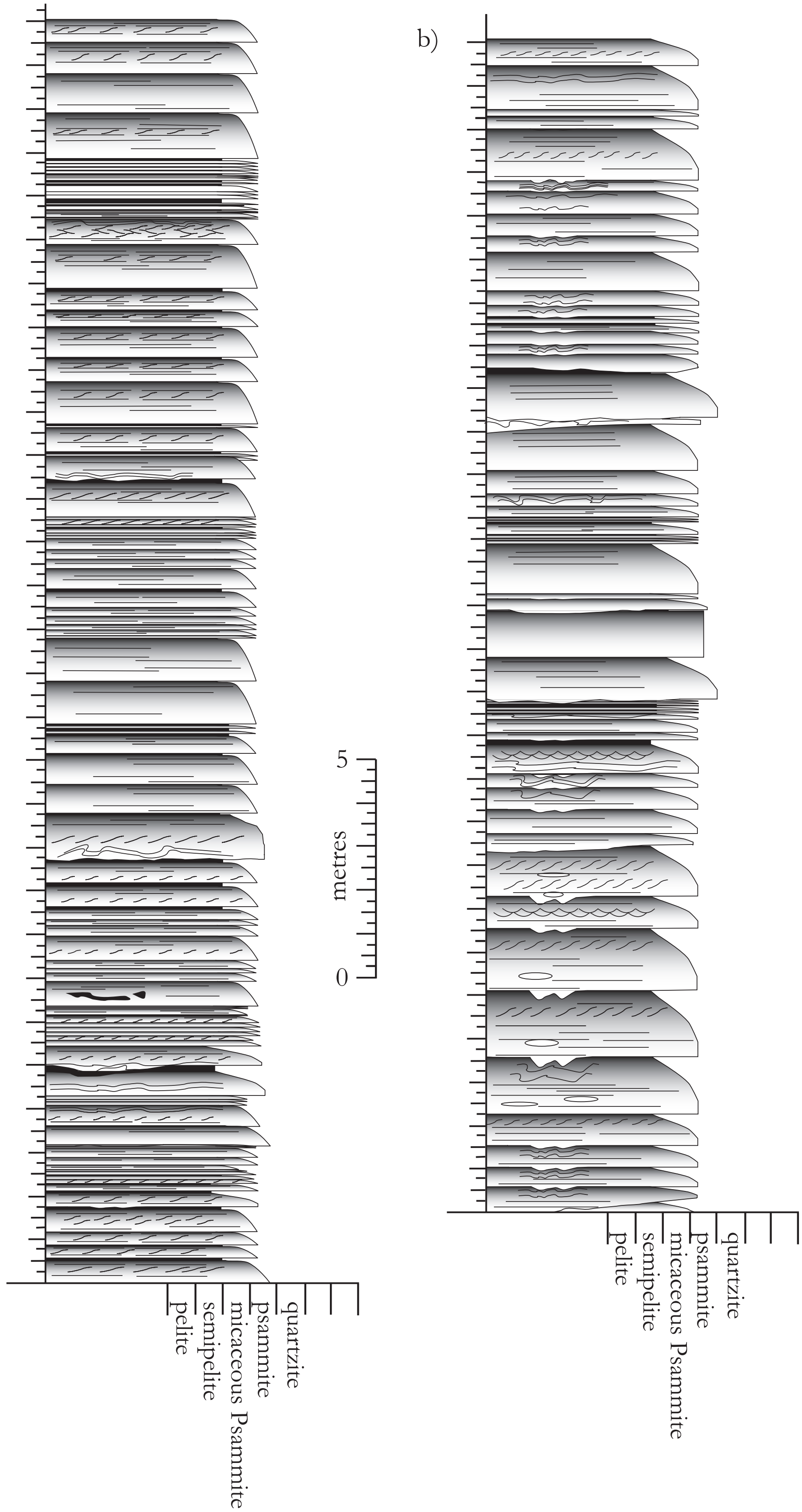

NW
SE
15km
200m
?
Coire nan Laogh Semipelite Formation
Gairbeinn Pebbly Psammite Member
(fluvial dominated)
fluvial sands (psammite association)
shallow marine storm-dominated
sands and muds (heterolithic association)
quartz pebbles
Garva Bridge
Psammite Formation

Figure 5.22

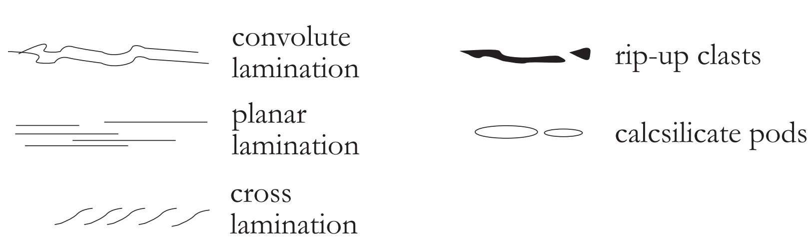


N
786
22
approximate trace of Laggan Antiform
246
424 Am Meall
247
excellent exposure of pegmatitic veins and felsic dykes in road-cut
40
400
36
350
50
300
A86
52
Loch Laggan
785
32
60
700
Rubha na Magach
excellent sedimentary structures on loch shore
45
0 kilometres 1
792
Coire Dubh
916
791
790
Meall Damh
464
Tullochroam
789
CREAG MEAGAIDH NATIONAL NATURE RESERVE
to Newtonmore
788
Ardverikie
Puist Coire Ardair
1070
787
A86
Markie Fault
251
Am Meall
424
Creag Tharsuinn
Loch Laggan
250
993
Rubha na Magach
249
785
Inset
248
784
247
Moy Lodge
246
to Spean Bridge
783
245
N
244
782
243
0 kilometres 2
242
Creag Meagaidh Psammite Formation
Ardair Semipelite Formation
Loch Laggan Psammite Formation
Coire nan Laogh Semipelite Formation
Corrieyairack Subgroup
inclined bedding, dip in degrees
fault
localities mentioned in text

Figure 5.23

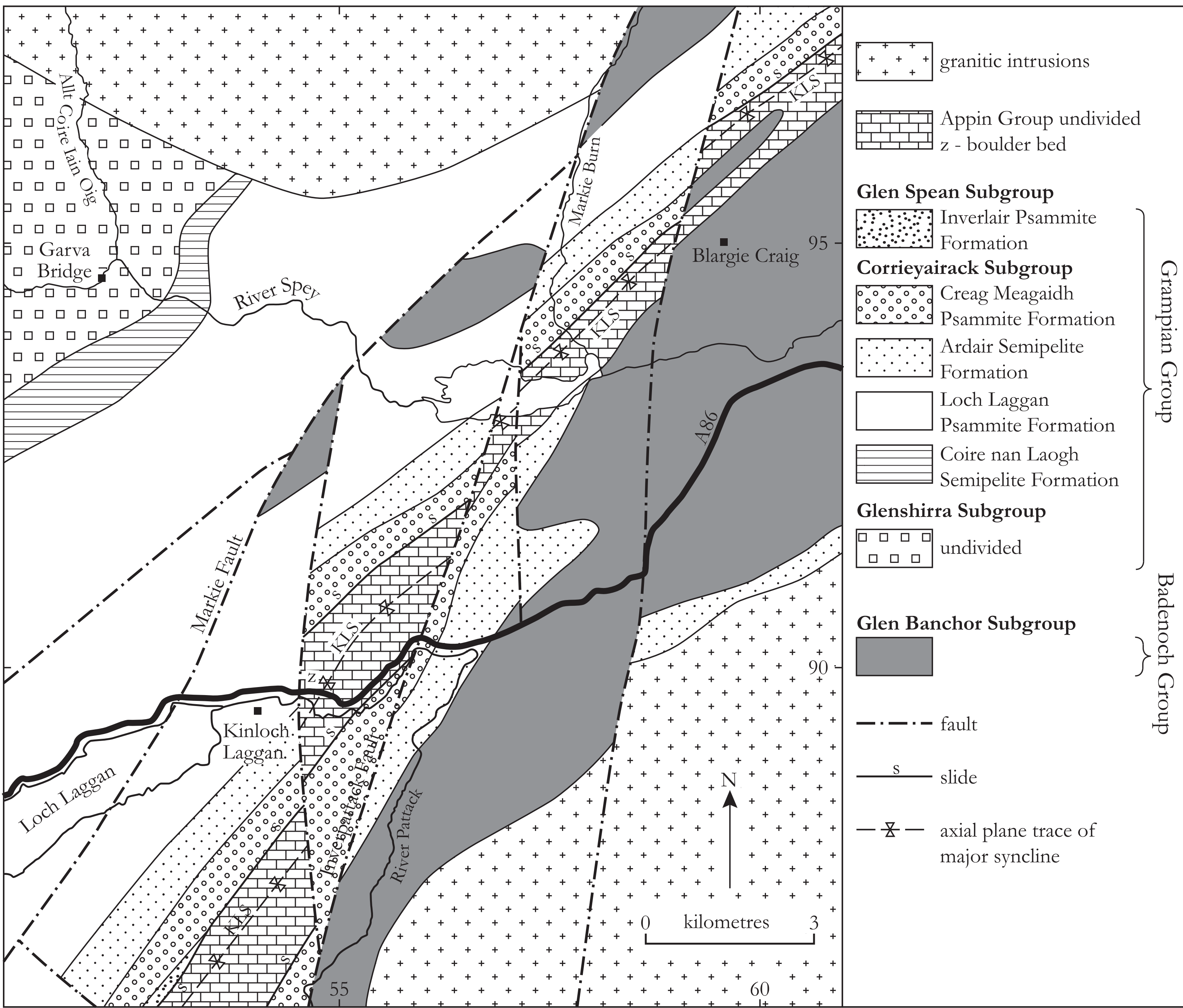


a)
b)
5
metres
0
pelite
semipelite
micaceous Psammite
psammite
quartzite
pelite
semipelite
micaceous Psammite
psammite
quartzite



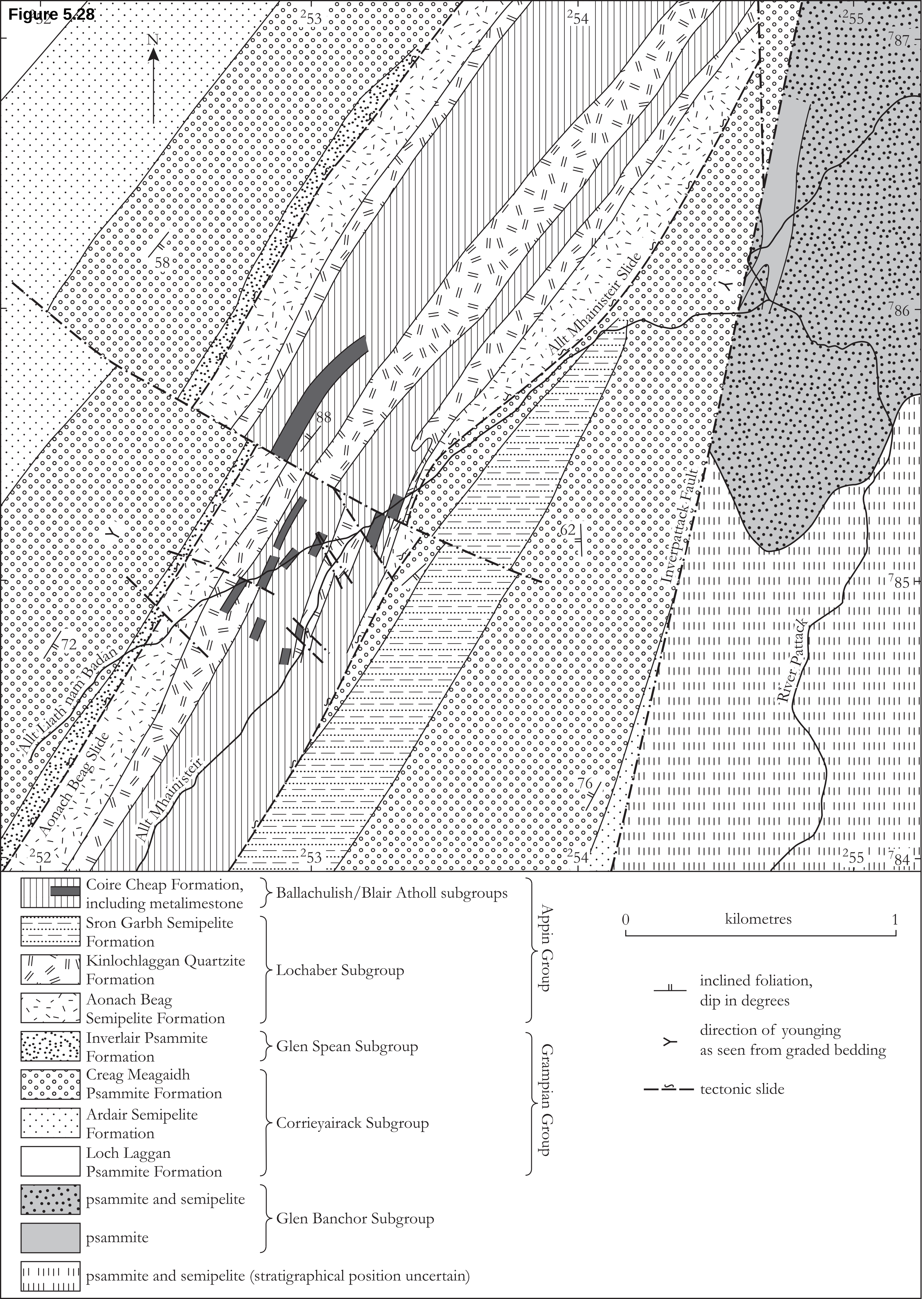
convolute lamination
planar lamination
cross lamination
rip-up clasts
calcsilicate pods

Figure 5.25



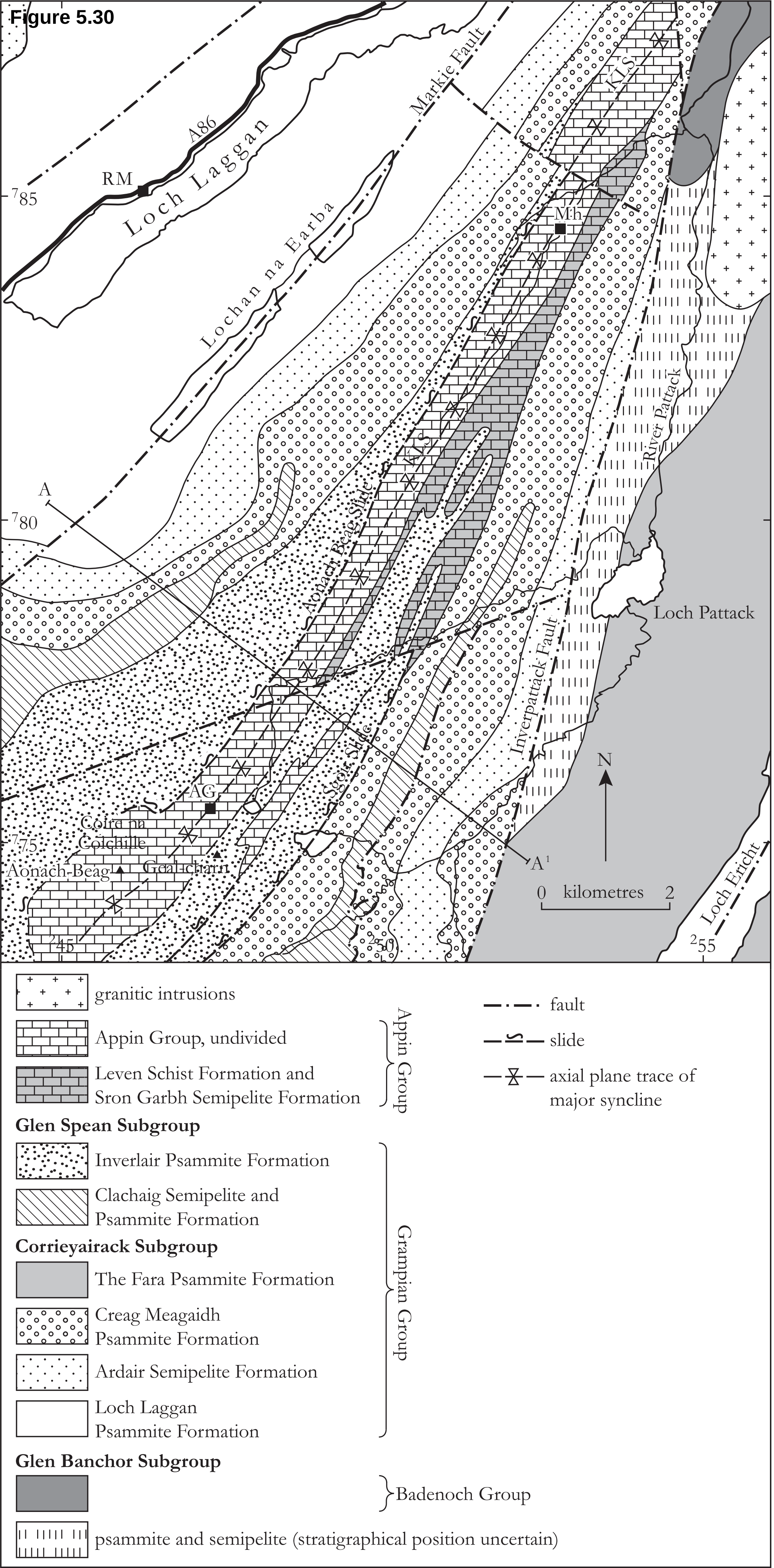
Allt Coire Iain Oig
Garva Bridge
River Spey
Markie Burn
Blargie Craig
95
Markie Fault
KLS
z
Kinloch Laggan
Loch Laggan
Inverpattack Fault
River Pattack
A86
90
N
0 kilometres 3
55
60
granitic intrusions
Appin Group undivided
z - boulder bed
Glen Spean Subgroup
Inverlair Psammite Formation
Corrieyairack Subgroup
Creag Meagaidh Psammite Formation
Ardair Semipelite Formation
Loch Laggan Psammite Formation
Coire nan Laogh Semipelite Formation
Glenshirra Subgroup
undivided
Grampian Group
Glen Banchor Subgroup
Badenoch Group
fault
slide
axial plane trace of major syncline

Figure 5.28



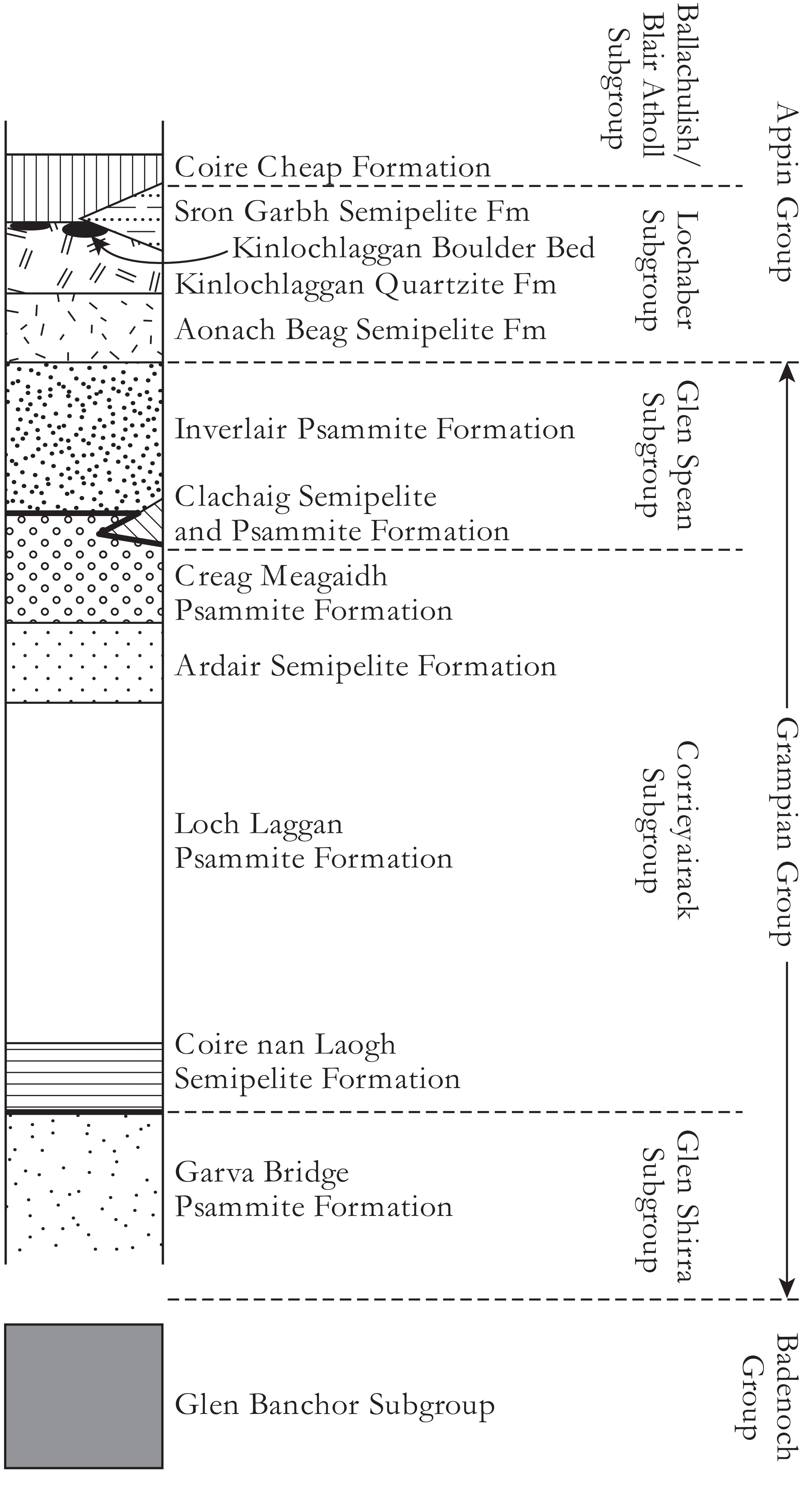
N
252
253
254
255
787
786
785
784
58
88
62
72
76
Allt Mhainisteir Slide
Inverpattack Fault
River Pattack
Allt Liath nam Badan
Aonach Beag Slide
Allt Mhainisteir
Coire Cheap Formation, including metalimestone
Ballachulish/Blair Atholl subgroups
Sron Garbh Semipelite Formation
Kinlochlaggan Quartzite Formation
Aonach Beag Semipelite Formation
Lochaber Subgroup
Appin Group
Inverlair Psammite Formation
Glen Spean Subgroup
Creag Meagaidh Psammite Formation
Ardair Semipelite Formation
Loch Laggan Psammite Formation
Corrieyairack Subgroup
Grampian Group
psammite and semipelite
psammite
Glen Banchor Subgroup
psammite and semipelite (stratigraphical position uncertain)
0
kilometres
1
inclined foliation, dip in degrees
direction of younging as seen from graded bedding
tectonic slide

Figure 5.30



Markie Fault
A86
RM
Loch Laggan
Lochan na Earba
KLS
Mh
River Pattack
A
A[1]
780
785
775
Aonach Beag Slide
Sgòr Slide
Inverpattack Fault
Loch Pattack
N
AG
Coire na Coichille
Aonach Beag
Geal-charn
0 kilometres 2
Loch Ericht
245
250
255
granitic intrusions
Appin Group, undivided
Leven Schist Formation and
Sron Garbh Semipelite Formation
Appin Group
Glen Spean Subgroup
Inverlair Psammite Formation
Clachaig Semipelite and
Psammite Formation
Corrieyairack Subgroup
The Fara Psammite Formation
Creag Meagaidh
Psammite Formation
Ardair Semipelite Formation
Loch Laggan
Psammite Formation
Grampian Group
Glen Banchor Subgroup
Badenoch Group
psammite and semipelite (stratigraphical position uncertain)
fault
slide
axial plane trace of
major syncline

Figure 5.27



Coire Cheap Formation
Sron Garbh Semipelite Fm
Kinlochlaggan Boulder Bed
Kinlochlaggan Quartzite Fm
Aonach Beag Semipelite Fm
Inverlair Psammite Formation
Clachaig Semipelite
and Psammite Formation
Creag Meagaidh
Psammite Formation
Ardair Semipelite Formation
Loch Laggan
Psammite Formation
Coire nan Laogh
Semipelite Formation
Garva Bridge
Psammite Formation
Glen Banchor Subgroup
Ballachulish/
Blair Atholl
Subgroup
Lochaber
Subgroup
Glen Spean
Subgroup
Corrieyairack
Subgroup
Glen Shirra
Subgroup
Appin Group
Grampian Group
Badenoch
Group

Figure 5.31

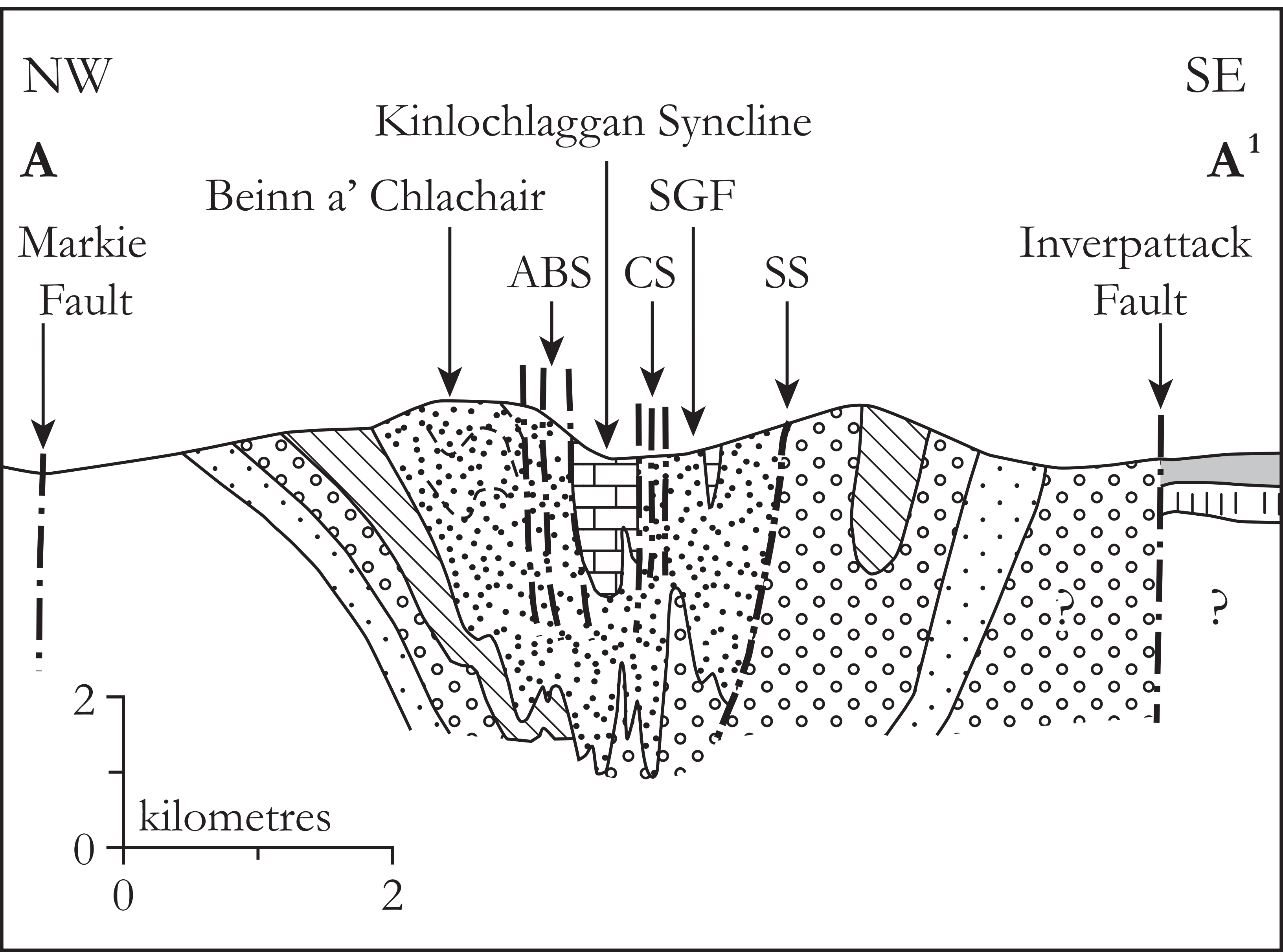

NW
SE
Kinlochlaggan Syncline
A
A1
Beinn a' Chlachair
SGF
Markie
Fault
ABS
CS
SS
Inverpattack
Fault
?
?
2
0
kilometres
0
2

Figure 5.34

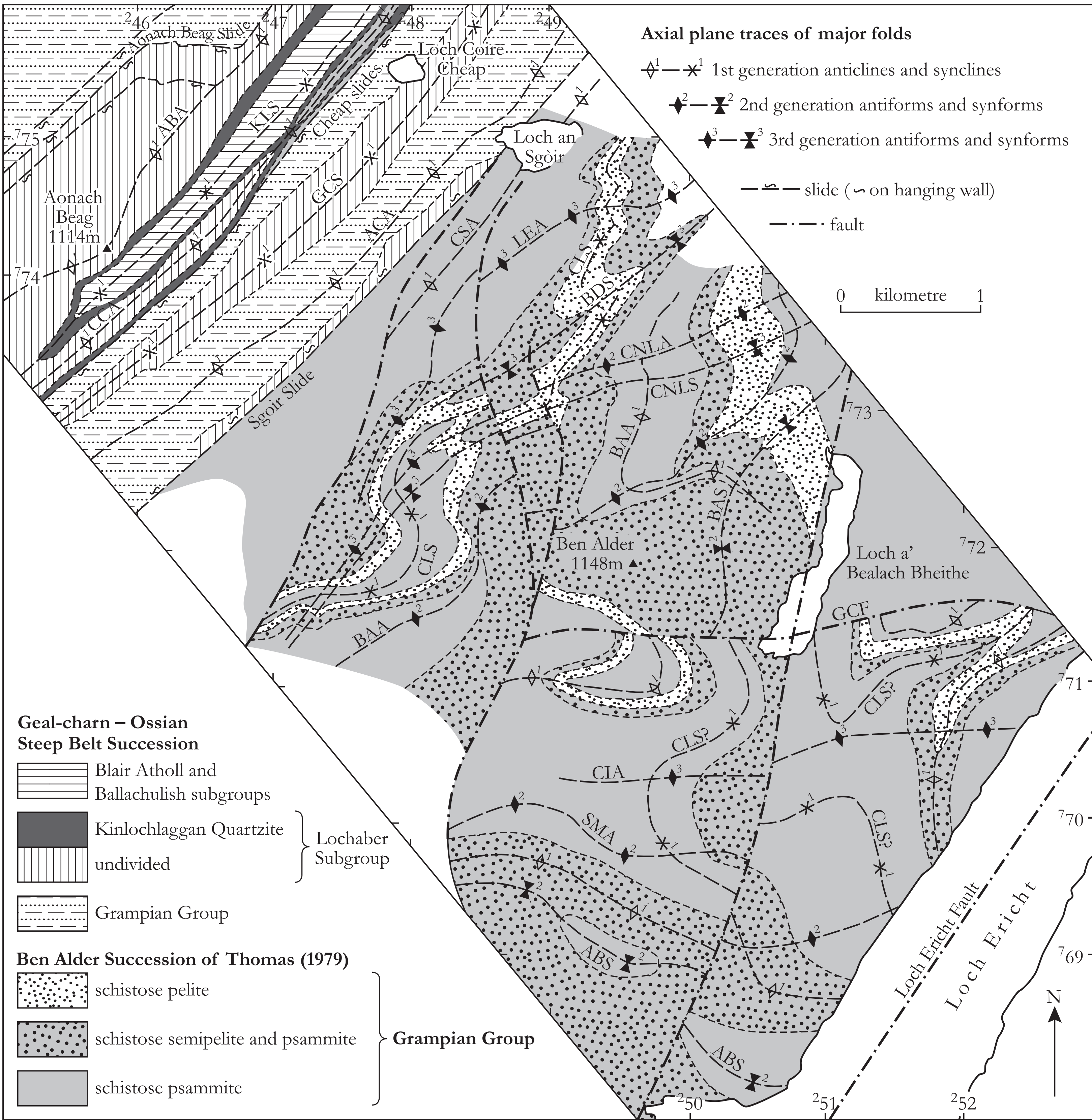
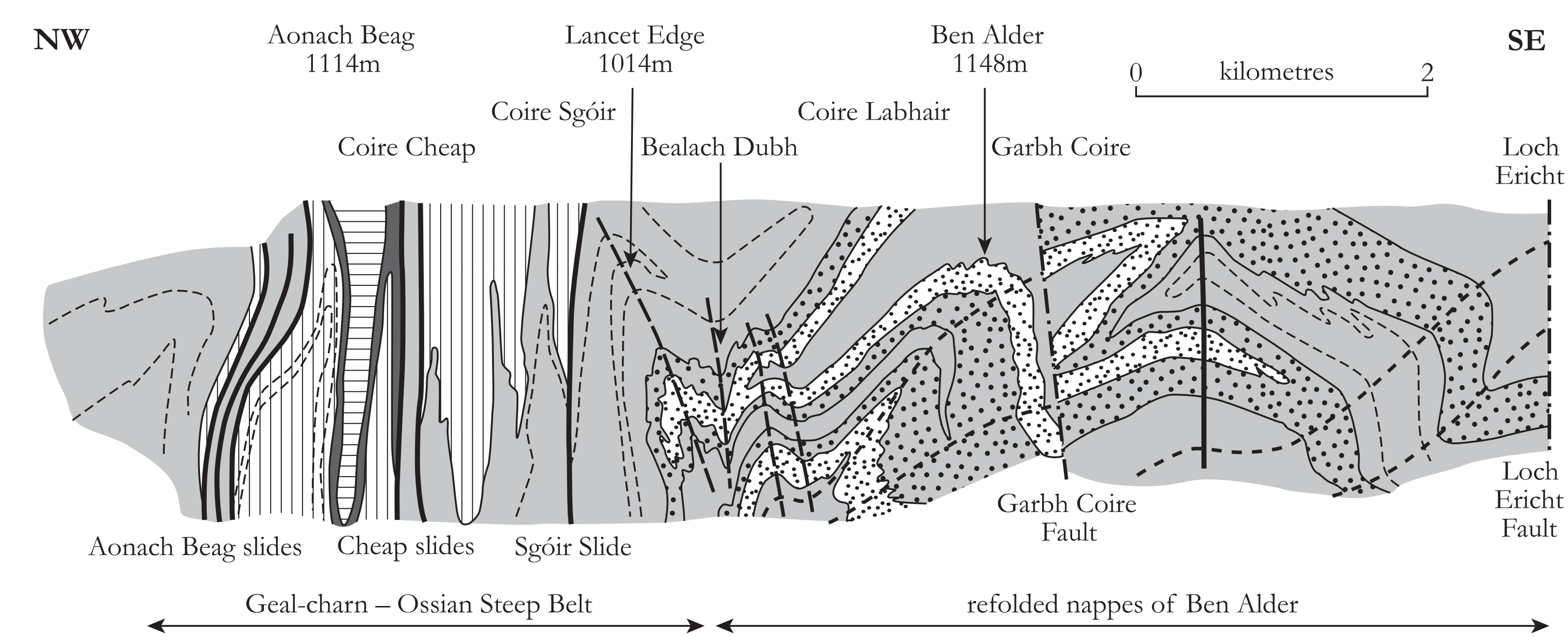

Axial plane traces of major folds
1st generation anticlines and synclines
2nd generation antiforms and synforms
3rd generation antiforms and synforms
slide (on hanging wall)
fault
0 kilometre 1
Geal-charn – Ossian Steep Belt Succession
Blair Atholl and Ballachulish subgroups
Kinlochlaggan Quartzite
undivided
Lochaber Subgroup
Grampian Group
Ben Alder Succession of Thomas (1979)
schistose pelite
schistose semipelite and psammite
schistose psammite
Grampian Group
Aonach Beag Slide
Loch Coire Cheap
Cheap slides
Loch an Sgòir
Aonach Beag 1114m
Sgoir Slide
Ben Alder 1148m
Loch a' Bealach Bheithe
Loch Ericht Fault
Loch Ericht
N
ABA
KLS
GCS
ACA
CCA
CSA
LEA
CLS
BDS
CNLA
CNLS
BAA
BAS
GCF
CLS?
CIA
SMA
ABS
246
247
248
249
250
251
252
775
774
773
772
771
770
769

Figure 5.36



F1	anticlines →	Aonach Beag; Coire Cheap; Aisre Cham; Coire Sgóir; Ben Alder
	synclines →	Kinlochlaggan; Geal Charn; Coire Labhair
F2		Ben Alder Antiform; Ben Alder Synform; Sgairneach Mhor Antiform; Alder Bay Synform
F3		Lancet Edge Antiform; Bealach Dubh Synform; Coire na Lethchois open folds; Coire na h'Iolaire Antiform

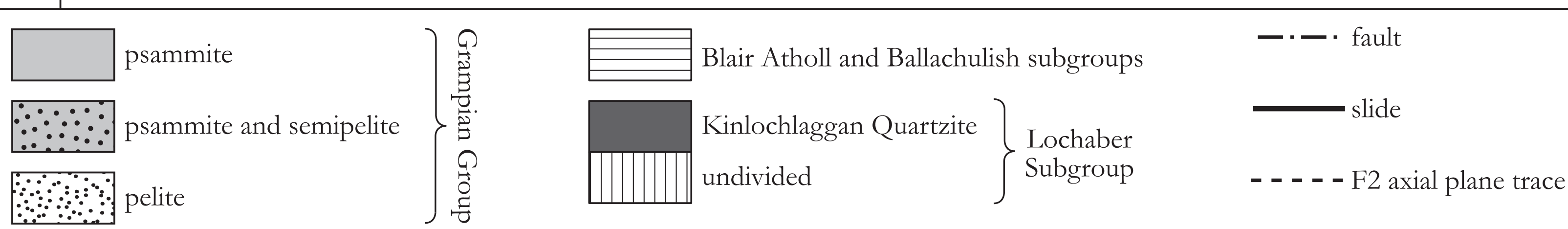


Figure 5.4 colour
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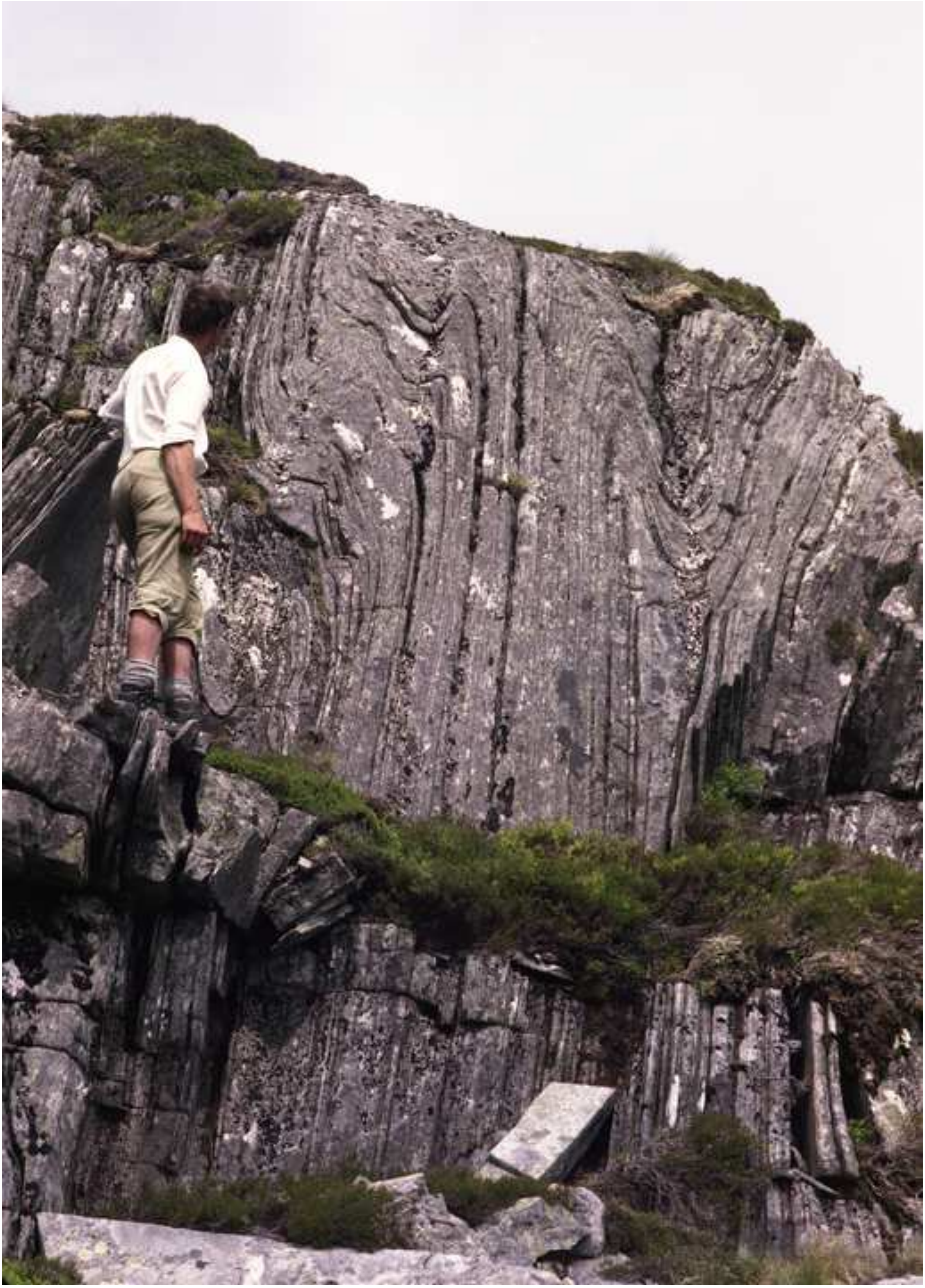

Figure 5.7 colour

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Figure 5.9 colour
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Figure 5.10a colour
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Figure 5.12 colour

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Figure 5.14 colour

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Figure 5.16a colour
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Figure 5.16b colour

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Figure 5.16c colour

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Figure 5.20a colour

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Figure 5.20b
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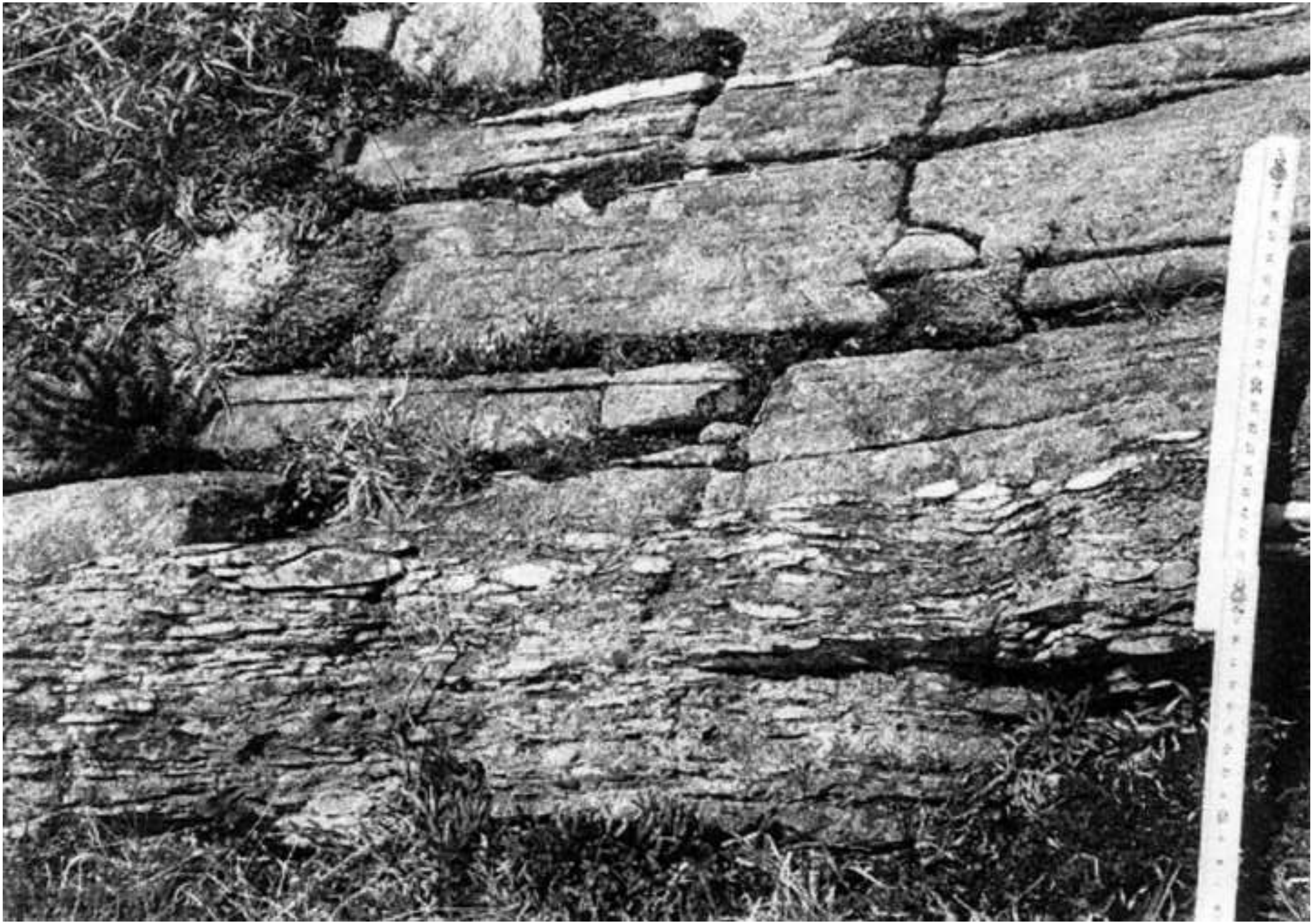

Figure 5.24a colour

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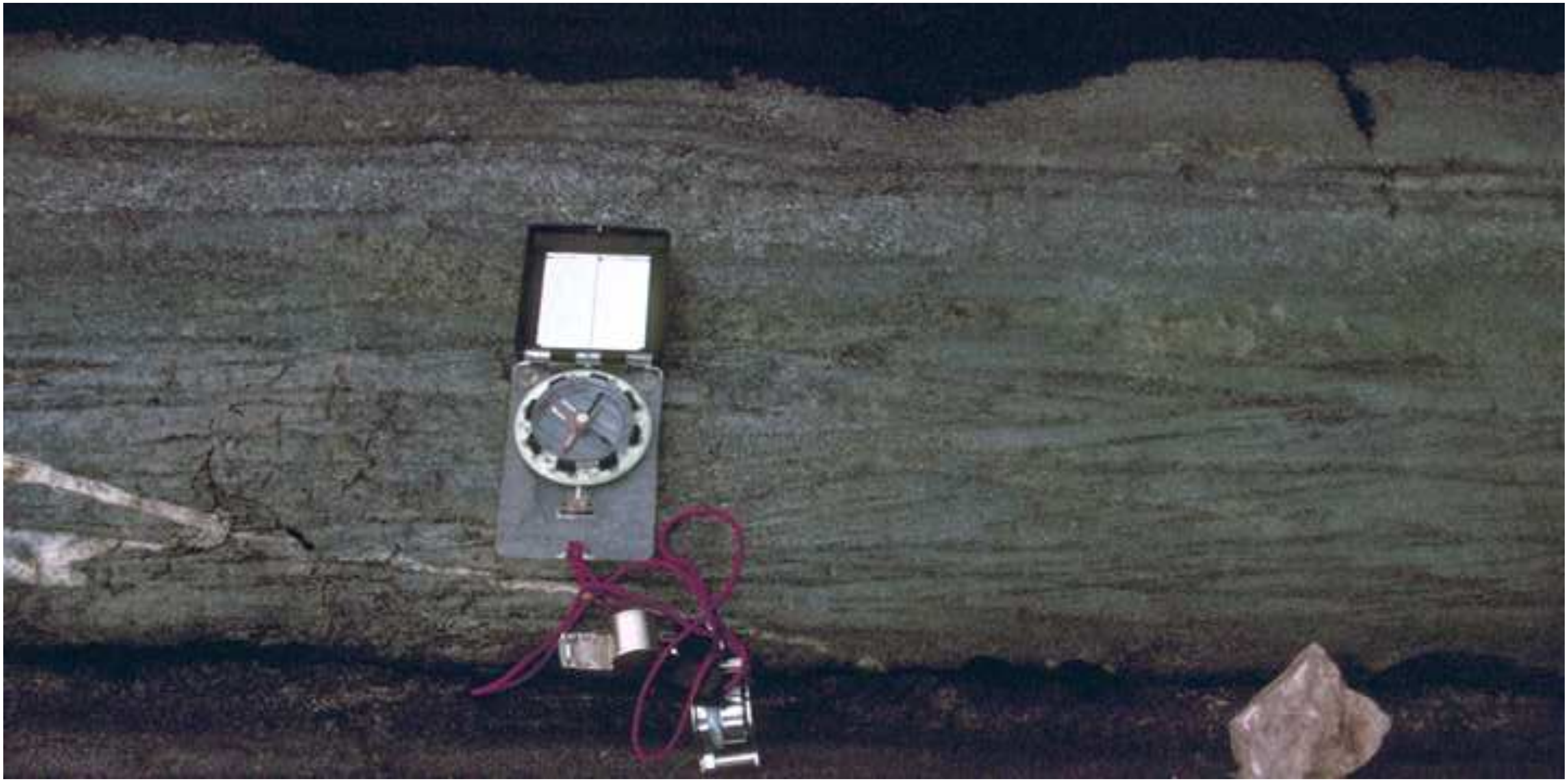

Figure 5.24b colour
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Figure 5.24c colour

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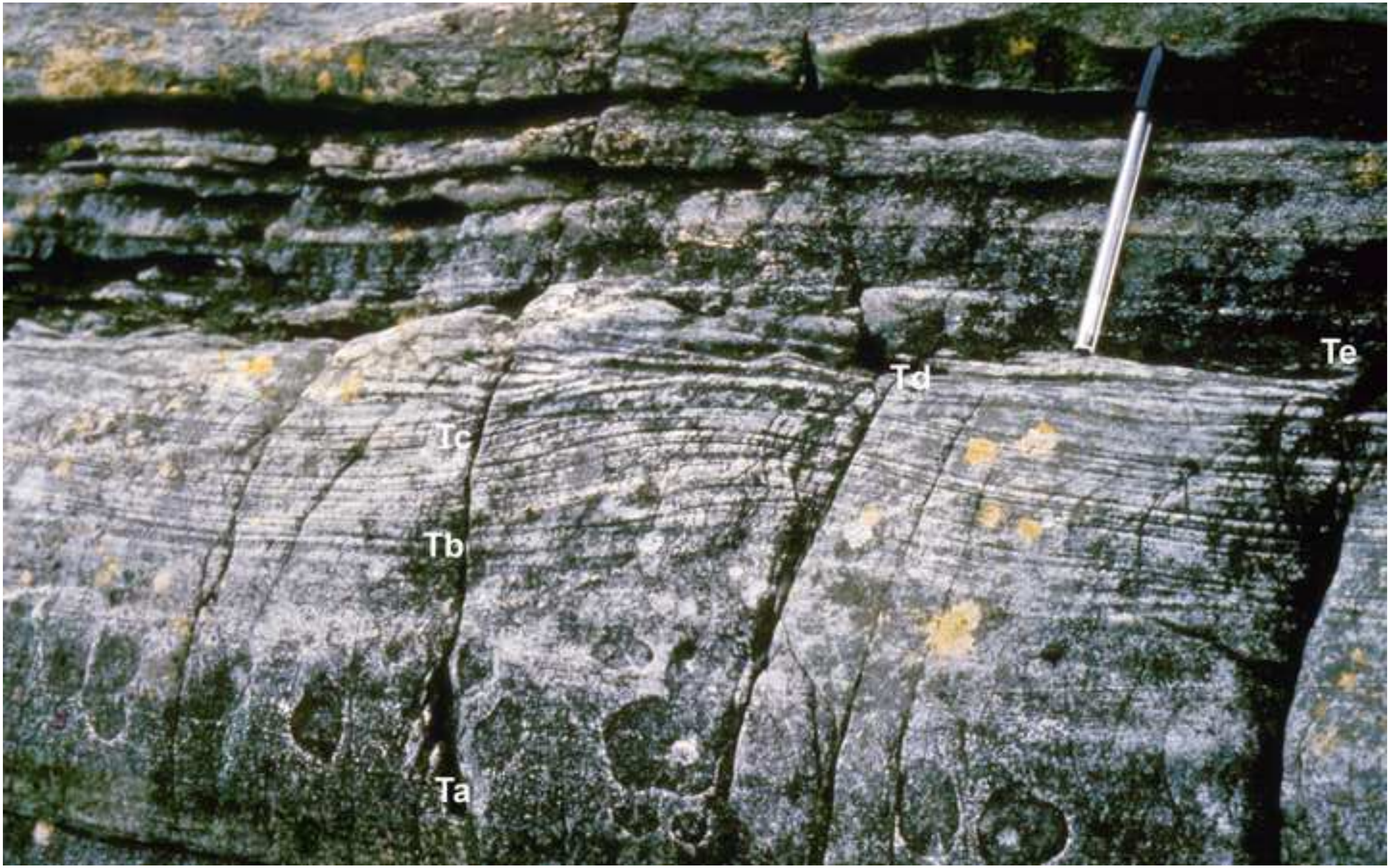

Figure 5.26 colour

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Figure 5.29 colour
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Figure 5.32 colour
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Figure 5.33 colour

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Figure 5.35 colour
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Figure 5.4 B&W
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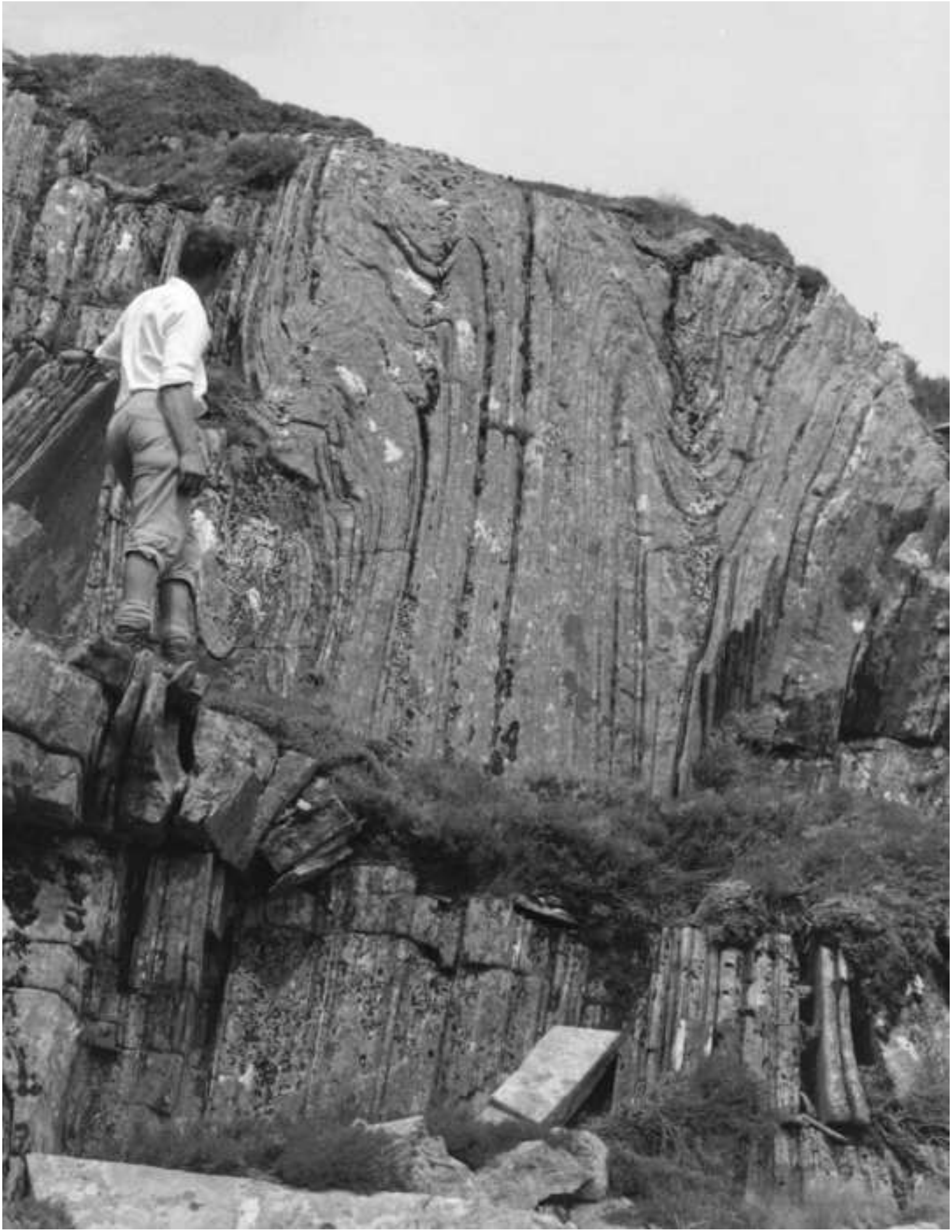

Figure 5.7 B&W

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Figure 5.9 B&W

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Figure 5.10a B&W

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Figure 5.12 B&W
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Figure 5.14 B&W
Click here to download high resolution image

Figure 5.16a B&W

Click here to download high resolution image

Figure 5.16b B&W

Click here to download high resolution image

Figure 5.16c B&W
Click here to download high resolution image

Figure 5.20a B&W

Click here to download high resolution image

Figure 5.24a B&W

Click here to download high resolution image

Figure 5.24b B&W
Click here to download high resolution image

Figure 5.26 B&W
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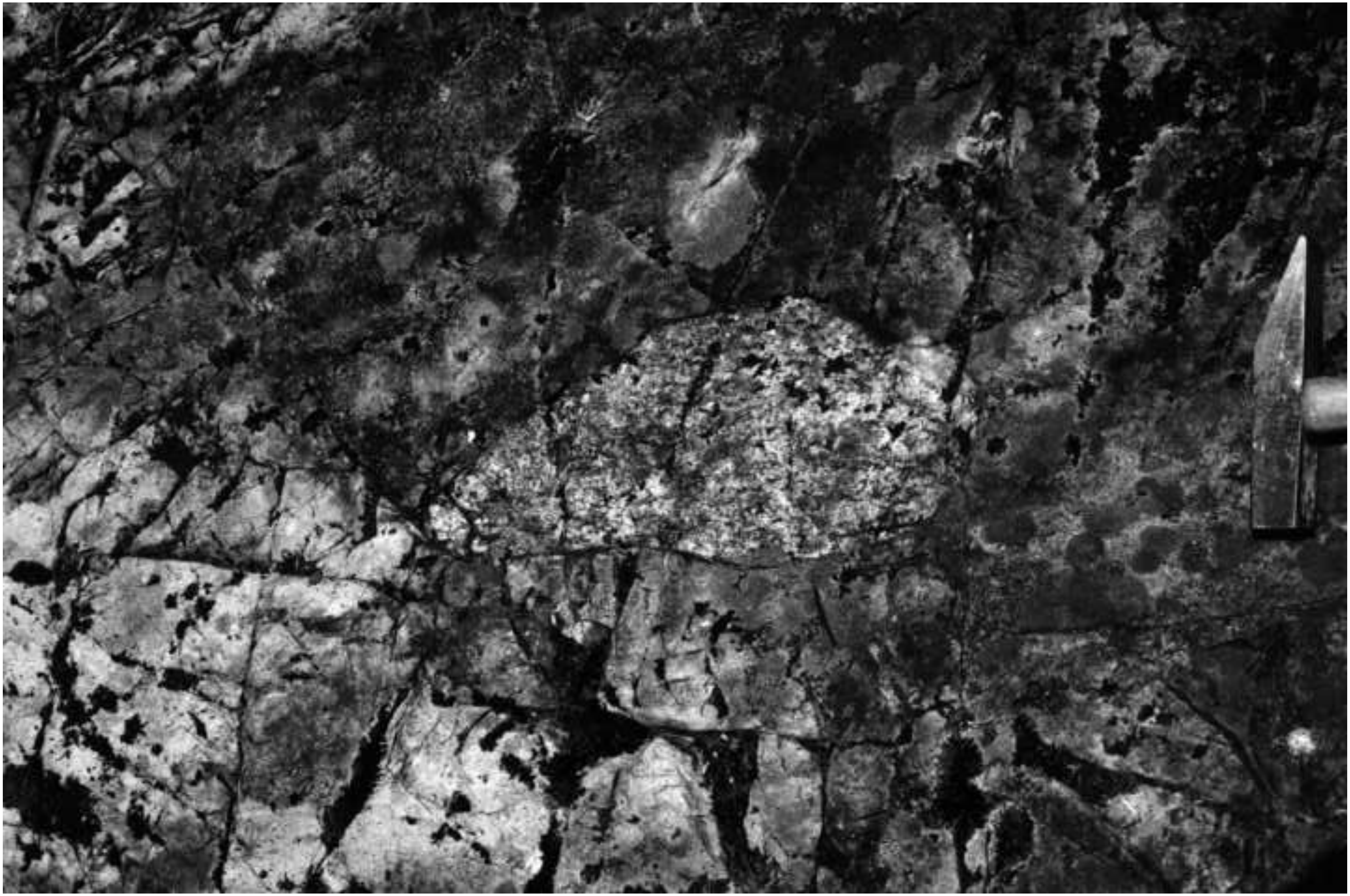

Figure 5.29 B&W

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Figure 5.33 B&W
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Figure 5.35 B&W
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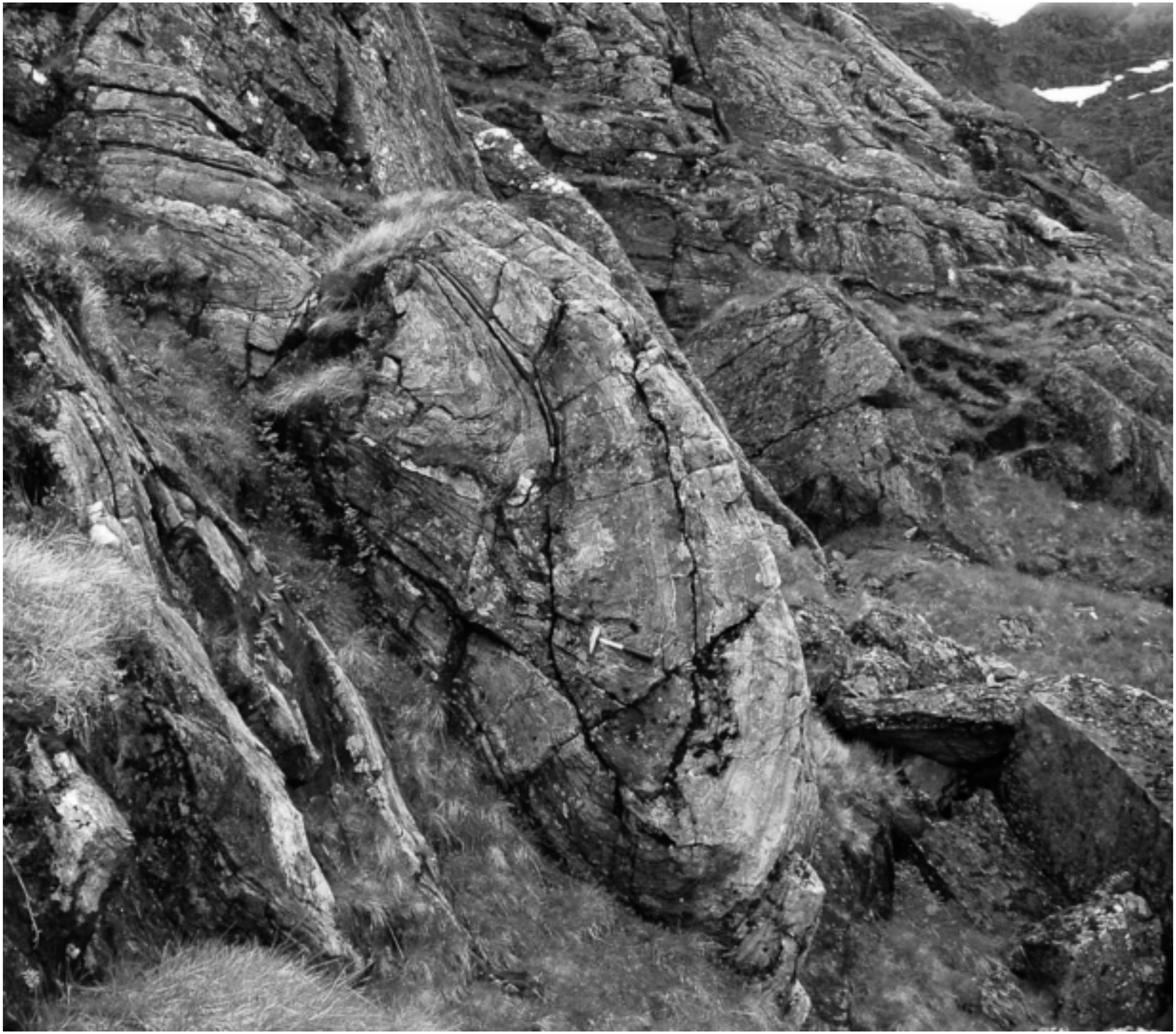

Figure 5.24c B&W

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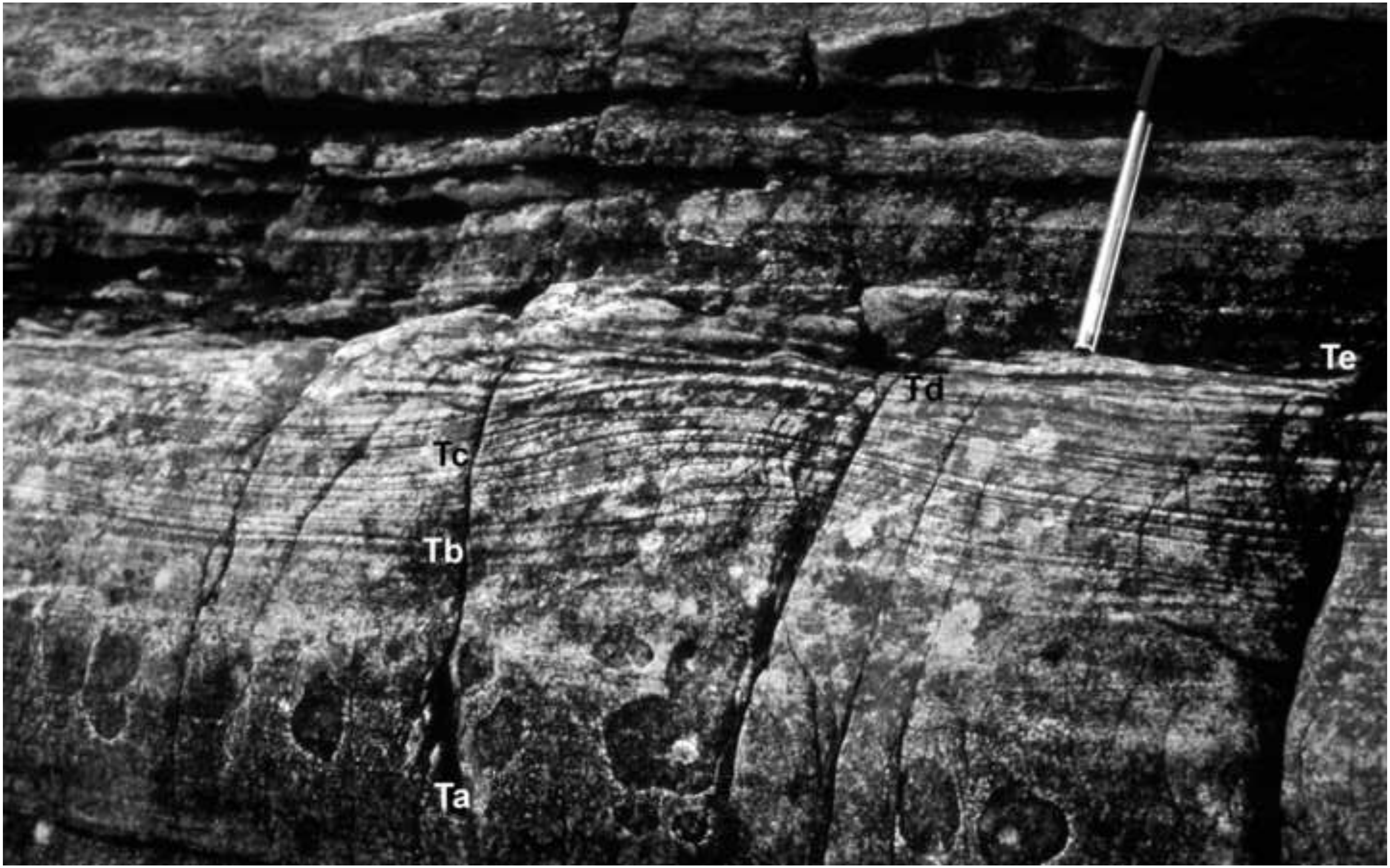

Figure 5.32 B&W

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