Bedrock geology of the Ben Alder Massif: report of the 2005 field season

Landscape and Geology Programme

Internal Report IR/06/069

BRITISH GEOLOGICAL SURVEY

WHATEVER PROGRAMME

INTERNAL REPORT IR/06/069

Bedrock geology of the Ben Alder Massif: report of the 2005 field season

C J Banks, A G Leslie, J R Mendum

Keywords

Ben Alder, Dalradian, Grampian Highlands

Front cover

The Ben Alder Massif and Lancet Edge (Sgor Iutharn), as viewed from Culra Bothy [NN 523762] BGS registered photograph P605215.

Bibliographical reference

BANKS, C J, LESLIE, A G, AND MENDUM, J R. 2005. Bedrock geology of the Ben Alder Massif: report of the 2005 field season. *British Geological Survey Internal Report*, IR/06/069. 25pp.

Keyworth, Nottingham British Geological Survey 2006

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham, Edinburgh and London; see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-9363488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.geologyshop.com

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020-7589 4090 Fax 020-75848270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

☎ 028-9038 8462 Fax 028-9038 8461

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff, CF15 7NE

☎ 029–2052 1962 Fax 029–2052 1963

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

This report summarises bedrock data, collected by C J Banks, A G Leslie and J R Mendum, during the 2005 field season, which contributes to the resurvey of 1:50 000 Sheet 54E (Loch Rannoch). Geological mapping by C J Banks (Keele University) was completed under a BGS-UCAC consultancy agreement, contract number 2K04E007. Details of the superficial deposits are contained within an accompanying technical report by C J Fogwill (2005) who also provided a field safety back-up to C J Banks.

Contents

LIST OF FIGURES

LIST OF TABLES

Summary

This report presents a preliminary interpretation of the bedrock geology of Ben Alder, based on data collected during the 2005 field season. This work contributes to the resurvey of 1:50,000 scale Sheet 54E (Loch Rannoch). The principal aim of this report is to present a lithostratigraphical framework and structural model for testing during the 2006 field season.

The Ben Alder massif exposes polydeformed psammite and semipelite belonging to the Neoproterozoic Grampian Group, lower Dalradian Supergroup. It comprises essentially four formations locally termed, the Lethcois Semipelite (lowest), Ben Alder Psammite, Garbh Choire Semipelite and Gaick Psammite Formation. The lithological and stratigraphical character of these formations is compared and contrasted with that of the type-stratigraphies for the Strathtummel and Corrieyairack Basins. The Ben Alder Grampian Group has an unequivocal affinity with the Strathtummel Basin-fill.

In the Strathtummel Basin (east of the Geal-charn – Ossian Steep Belt), the resurvey of Sheet 63E (Dalwhinnie) utilised the Corrieyairack Basin's type-stratigraphy when naming new lithostratigraphical units. Some of these correlations are questioned and new correlations with the Strathtummel Basin stratigraphy are suggested.

The stratigraphical pile was progressively deformed by up to four phases of deformation (D1-D4). Early phase (D1) deformation is only represented by fabric development (S1). By contrast, the D2 main phase deformation folded the stratigraphy into a number of tight, almost isoclinal, SE-facing F2-fold structures (e.g. the Ben Alder Anticline) with associated penetrative fabric development (S2). Subsequently, these F2-structures were refolded by the co-axial and co-planar F3-folds, which have a more open nature. Late weak and upright folding (F4) served to 'kink' the stratigraphical units without altering their distribution, creating alternating steep and more gently dipping zones.

Displacement across major brittle faults (Ericht-Laidon, Inverpattack-Markie Faults) is relatively limited, enabling confidence in stratigraphical and structural correlations made between fault-bound blocks. These faults acted as conduits for late- and post-tectonic microdiorite, lamprophyre and pegmatite intrusions.

1 Introduction

The rugged Ben Alder massif (1148 m O.D.) is one of the most remote areas of the Grampian Highlands. Its grand corries and precipitous cliffs provide unsurpassed exposures through structurally complex metasediments belonging to the Neoproterozoic Grampian Group (Dalradian Supergroup)(figure 1, 2). However, due to its accessibility, the area has received only limited study during its primary geological survey (Hinxman *et al.* 1923) and subsequently during the structural mapping of Thomas (1979).

This report presents new data collected during a partial resurvey of the Ben Alder area in 2005. The main areas studied include Garbh Choire, Beinn Bheoil, Sron Coire na h-Iolaire, the southern side of Bealach Dhubh and the 200m high cliffs of Coire na Lethcois to Sron Bealach Beithe (figure 1, 3). The main aim of this work is to provide a preliminary lithostratigraphical framework and a structural model for the Grampian Group, which will be tested and refined during the 2006 field season. The data enables geological linkages between the Ben Alder area (Sheet 54E, Loch Rannoch) and Sheets 54W (Blackwater), 55W (Schiehallion) and 63E (Dalwhinnie) to be assessed.

Previous work in the area has concentrated on elucidating its geological structure. During the initial survey by Carruthers in 1913 and 1914, a number of "sharp folds' were identified but he concluded that it was 'impossible to decipher the structure of the Ben Alder plateau' (Carruthers in Hinxman *et al* 1923). Subsequently, Thomas (1979) provided a structural profile for Ben Alder and concluded that the metasediments were folded into early SE-facing nappes that were refolded by two further phases of folding. These SE-facing nappes contrast with the NE-facing folds on the opposite northwest side of the Geal-charn – Ossian Steep Belt. This observation led to the proposal that the steep belt was a root zone to the major, early Grampian nappes of the Central Highlands (Thomas 1979).

In recent decades, key advances in our understanding of the Grampian Group have been achieved through lithostratigraphical and sedimentological study (e.g. Haselock *et al.* 1982; Glover and Winchester 1989; Glover *et al.* 1995). This 'soft rock' perspective led to the Grampian Group being viewed as a dynamic basin-fill, and basin-architectural models have been proposed (Smith *et al.* 1999; Banks 2005). The Grampian Group was deposited into an eastern Strathtummel Basin and a western Corrieyairack Basin (Smith *et al.* 1999). These basins were defined in the Glen Banchor area (Sheet 63E), where they are separated by basement rocks that form an inter-basinal high (the Glen Banchor succession of Smith *et al.* 1999). Each basin has its own characteristic lithostratigraphical framework, indicating significant contrasts in the depositional evolution of the Grampian Group from west to east (Banks 2005).

The Geal-charn – Ossian Steep Belt flanks the Glen Banchor basement high on its northewest side. This relationship led Robertson and Smith (1999) to conclude that steep belt was generated by buttressing of SE-directed strain against the relatively competent basement high. The NE-SW trending steep belt has been mapped at the NW limit of the current study area (BGS 2002), but no lateral continuation of the Glen Banchor basement high is exposed. Consequently, it is unsure whether the Grampian Group in the Ben Alder area was deposited into the Corrieyairack or

Strathtummel Basin. It is a key objective of this project to compare the Ben Alder stratigraphy with the type stratigraphies for both basins, in order to assess its affinity.

Recently upgraded roads into the Loch Ericht estate have improved access to 4WD vehicles from Dalwhinnie, but many areas remain too remote to study within a day. Consequently, wild camping was necessary in order to examine the southern parts of Ben Alder. These areas receive poor to no network coverage for mobile phones enabling a full remote terrain test of satellite phones. The conclusions of this test are reported below.

2 Grampian Group lithostratigraphy of Ben Alder

The Grampian Group lithostratigraphy exposed in the Ben Alder area has similarities to that described for the Newtonmore area (Leslie *et al.* 2002; Banks 2005). These works describe essentially four formations: a basal semipelite overlain in turn by a thick succession of graded micaceous psammite, a thin semipelite and a thick succession of flaggy psammite and quartzite. The uppermost formation is structurally and stratigraphically overlain by the lowest Appin Group rocks in the Schiehallion area (BGS 2001; Treagus 2000). Exact correlations between formations will be discussed in section 2.3. As with the Grampian Group type-stratigraphies, the Ben Alder succession can be subdivided into a lower Corrieyairack Subgroup and an upper Glen Spean Subgroup (figure 4). Treagus (2000) divided the Grampian Group stratigraphy of Sheet 55W into the lithologically similar Atholl and Strathtummel Subgroups according to whether the psammites could be further divided into formations. Both these subgroups are lithological and stratigraphically similar to the Glen Spean Subgroup defined elsewhere (Glover and Winchester 1989) and it is recommended that Glen Spean Subgroup nomenclature be used as a matter of course.

2.1 THE CORRIEYAIRACK SUBGROUP

2.1.1 Lethcois Semipelite Formation

This formation is an along strike continuation of the semipelite recorded on the lower eastern slopes of Carn Dearg [Coire Sròn an Nid - NN 523 775] and in the Allt a’ Bhealaich Dhuibh [NN 5052 7457] on Sheet 63E (Dalwhinnie). On Sheet 63E, the semipelite is assigned to the Ardair Semipelite Formation (part of the Corrieyairack Basin type-stratigraphy) but doubts have been expressed over the reality of this correlation (Banks 2005) (see section 2.4). For the purposes of discussion the local mapping term, Lethcois Semipelite, is preferred.

The base of the Lethcois Semipelite is not exposed but a thickness of at least 180 m is preserved in the core of the D2 Ben Alder Anticline. The formation is best examined on either the long or short ridges bounding Coire na Lethcois [NN 5034 7355 and 5043 7295] (figure 1, 3). As its lower contact was not observed, the nature of its relationship with the presumably underlying Glen Banchor Succession is uncertain.

The Lethcois Semipelite comprises coarse-grained schistose semipelite (>90% of the formation), with subordinate beds of micaceous psammite (figure 4). The semipelite weathers to a distinctive rust-brown colour, but is dark grey to silver on fresh surfaces due to the high muscovite content. The rock consists of mm-scale quartzofeldspathic (plagioclase-bearing) microlithons enclosed by the dominant muscovitic fabric (figure 5a). In Coire na Lethcois, a ubiquitous coarse S3 crenulation is developed in the semipelite (figure 5 a, b), imparting a distinctive corrugated appearance to S0/S1 surfaces. Garnet poikiloblasts are abundant in the most pelitic parts of the formation but are rare elsewhere (figure 5c). Sporadically developed dark-grey micaceous psammite forms beds less than 25 cm thick. In contrast to the semipelite, in the micaceous psammites biotite is the main fabric-forming mica. These lithologies are most common close to the upper contact of the formation, giving the formation a ribbed appearance. No primary sedimentary structures were observed in any part of this formation.

2.1.2 Ben Alder Psammite Formation

The Ben Alder Psammite is exposed on both sides of the Inverpattack-Markie fault in the northern and eastern coires of both Ben Alder and Beinn Bheoil (figure 1). On Sheet 63E (Dalwhnnie), micaceous and feldspathic psammite-dominated successions were assigned either to The Fara Psammite Formation (east of the fault) or to the Creag Meagaidh Psammite Formation (west of the fault). These formations are lithologically and stratigraphically similar and there is little reason to treat them as separate units (Banks 2005). The name “Creag Meagaidh Psammite” is taken from the type-stratigraphy of the Corrieyairack Basin, but a correlation between the type-stratigraphy and Ben Alder remains unproven (see section 2.4). For the purposes of discussion, the local mapping term, Ben Alder Psammite, is preferred.

Micaceous psammite beds increase in abundance towards the upper part of the Lethcois Semipelite and its transitional contact with the overlying Ben Alder Psammite is defined where psammite accounts for over 50% of the succession. This contact is exposed on the long ridge of Coire na Lethcois at NN 50377373 (figure 1,3). The cliff section extending southwards from Coire na Lethcois to the Garbh Choire Fault exposes nearly the full thickness of the Ben Alder Psammite, which is measured at *c.* 1100 m.

The Ben Alder Psammite Formation is dominated by a monotonous succession of flaggy micaceous and feldspathic psammite (5-20 cm thick), interbedded with thin (0.5-2 cm) schistose semipelite (figure 4). The dark to light grey psammite beds are usually fine-grained, although feldspar porphyroblasts (albite) are locally abundant and weather out to give the rock a ‘gritty’ appearance (e.g. NN 50197257, figure 6a). Biotite is disseminated throughout the main quartz-plagioclase matrix and is the dominant fabric-forming mica (figure 6b and c). In thin section, plagioclase feldspars are sericitised and appear dusty in PPL.

The psammites commonly display an upward increase in the proportion of mica, representing normal sedimentary grading (figure 6 a, d-f). In the field, this grading imparts a characteristic ‘saw-tooth’ weathering profile to the outcrops. The only internal sedimentary structure noted is a weak planar lamination defined by mm-scale biotitic laminae. In relatively low strain exposures (e.g. NN 50817409), bed bases are commonly undulose and down-cut into the underlying beds in a manner reminiscent of loading. More rarely, small-scale scours between 5 and 15 cm deep are noted. The psammite beds commonly display amalgamation and bifurcation when traced laterally. On the limbs of the major folds, the formation takes on stripey ‘tram-line’ appearance that looks highly strained upon superficial examination (figure 6g). However, petrographically these micaceous psammites are indistinguishable from those taken from fold hinges where strain is generally low.

In the uppermost parts of the Ben Alder Psammite, the formation contains a thin (<75 m thick) heterolithic striped assemblage of quartzite, psammite, micaceous psammite and semipelite (e.g.

Allt a' Bhealaich Dhuibh, NN 4935 7295). These lithologies are thinly bedded on a 1-5 cm scale, with rare quartzite beds up to 20 cm. In the upper part of the Allt a' Bhealaich Dhuibh section, interbedded white quartzite and dark grey semipelite form a distinctive striped lithology with individual quartzite beds up to 2 m thick. The sequence shows complex fold patterns and the bed thicknesses are partly structurally controlled. On the Ben Alder crags ESE of Bealach Dhubh at [NN 4935 7295], feldspar porphyroblastesis is widespread and the heterolithic beds display abundant minor folding.

Normal grading, bed amalgamation, loading and scouring are all features common within submarine fan/ramp depositional settings (Reading and Richards 1996; Stow *et al.* 1996). The lack of internal sedimentary structures ('Bouma' divisions) precludes a more specific palaeoenvironmental interpretation. However, such features are sufficient to permit the assignment of the Ben Alder Psammite Formation to the Corrieyairack Subgroup, which is interpreted as 'turbiditic' elsewhere (Glover and Winchester 1989; Glover *et al.* 1996; Banks 2005).

The upper heterolithic beds are more problematic as they preserve little primary sedimentary information other than compositional layering. However, it can be speculated that the characteristic quartzites and clean psammites are more akin to 'typical' facies in the Glen Spean Subgroup. Hence, this succession may indicate submarine fan/ramp abandonment and herald the onset of shelf deposition. If this is correct, then they were deposited close to the shelf-slope break (both temporally and spatially).

2.1.3 Garbh Choire Semipelite Formation

The upper heterolithic beds of the Ben Alder Psammite are overlain by a massive semipelite unit, termed the Garbh Choire Semipelite. The contact is well exposed in Garbh Choire [NN 50567100] and in Coire Labhair [NN 4837 7257] and is a normal, rapid lithological transition. The formation forms a key stratigraphical marker, *c.* 160 m thick, which can be traced from Bealach Dhubh into Coire Labhair and is then picked up again on the Ben Alder plateau, from where it can also be mapped into Garbh Choire and east of the Inverpattack-Markie Fault onto Beinn Bheoil. The formation extends to Loch Ericht and hence may outcrop farther east in Talla Bheith Forest. The formation is best examined in its type-area in Garbh Choire [NN 4967 7134] (figure 7a).

The semipelite is a brown massive rock that weathers proud of the surrounding psammitic formations. Indeed, its is so homogenous that it weathers into large rounded blocks in a manner reminiscent of many igneous rocks. It can be differentiated from the older Lethcois Semipelite because of its coarse-grained nature and an intensely schistose to weakly gneissose fabric (figure 7b). It consists of elongate quartz-plagioclase lenticles (2-8 mm long) wrapped by a coarse, penetrative biotite and muscovite foliation (figure 7 b-d). Rare, ragged poikiloblasts of garnet occur up to 1mm across and rounded, detrital zircons (<0.5 mm) have been identified in thin section (figure 7c). No primary sedimentary structures have been identified in this formation.

2.2 THE GLEN SPEAN SUBGROUP

2.2.1 The Gaick Psammite Formation

A monotonous succession of quartzite, feldspathic psammite, micaceous psammite and subordinate semipelite overlies the Garbh Choire Semipelite. This succession is laterally continuous with, and lithologically similar to, the Bruar Psammite Formation identified on Sheet 55W (Schiehallion) (see Treagus, 2000). This formation was subsequently termed the 'Gaick Psammite Formation' during the re-survey of Sheet 64W (Newtonmore) and this nomenclature is followed here (Leslie *et al.* 2002).

A continuous section through the upper Garbh Choire Semipelite and basal part of the Gaick Psammite Formation is exposed on the south side of Garbh Choire, NN 50657088. The upper 5 metres of the Garbh Choire Semipelite contain thin (<5 cm thick) quartzite beds that thicken and become dominant upwards demonstrating a stratigraphical transition into the Gaick Psammite Formation. As the upper contact of the Gaick Psammite with the overlying Appin Group is not present in the current study area, its thickness cannot be measured. However, Leslie *et al.* (2002) estimated that the unit was 1-2 km thick on Sheet 64W, allowing for the effects of fold repetition.

Typical Gaick Psammite lithologies can be examined in the eastern coire of Sron Coire na h-lolaire [NN 515 708]. At this locality, an inverted succession of quartzite (structurally highest, stratigraphically lowest), micaceous psammite and feldspathic psammite is exposed.

The stratigraphically lowest lithologies comprise a *c.* 30 m sequence of thin-bedded (5-15 cm), pink to cream coloured quartzite and feldspathic psammite (e.g. at NN 49687114, figure 8a). These have a laminated appearance defined by parallel, sub-centimetre feldspar-rich, mica-rich and quartz-rich bands. These are stratigraphically overlain by a *c.* 50 m thick unit of relatively homogenous, massive to blocky, dark grey, micaceous psammite with poorly defined bedding surfaces.

The majority of the Gaick Psammite Formation consists of cream and grey, fine-grained quartzose and feldspathic psammite with a characteristic speckled "salt 'n' pepper" texture due to disseminated biotite flakes (figure 8 c and d). Bedding is normally 10-20 cm thick with bed thickness locally up to 1 m thick. As with the basal strata, these lithologies have a ubiquitous laminated appearance due to subtle compositional banding/layering. Hornblende-bearing calc-silicate pods and bands are present although rare. No primary sedimentary structures, other than the compositional layering were observed during the current study.

Petrographically, the Gaick Psammite differs from underlying formations because it is alkali-feldspar bearing. Potash-feldspar crystals are pristine, subhedral and display a distinctive wedge-shaped twinning; this contrasts with the highly altered/sericitised plagioclase feldspars present in the Corrieyairack Subgroup. The potash feldspars are interpreted as probably metamorphic in origin. Structural fabrics are poorly developed in this formation due to the general lack of platy minerals. However, weak foliations can be identified in thin section and are defined by stubby, discontinuous muscovite and subordinate biotite. Abundant detrital heavy minerals are concentrated in thin layers and are dominated by zircon, monazite and apatite (figure 8d). These concentrations reflect density sorting during sedimentation.

Lithologically, the Gaick Psammite Formation is assigned to the relatively clean psammite-dominated Glen Spean Subgroup, which has been interpreted as a shelf succession elsewhere (Glover and Winchester 1989; Glover *et al.* 1996). However, limited sedimentological interpretations can be made on the basis of the Ben Alder outcrops alone. The more quartzose nature of the metasediments indicates sediment reworking and winnowing. Heavy mineral concentrations and the general paucity of graded bedding are indicative that traction currents were the dominant hydrodynamic processes operating. This is consistent with a shelf environment, but is difficult to reconcile with the contrasting submarine fan/ramp environments such as those interpreted for the Corrieyairack Subgroup. Furthermore, exposures of the Gaick Psammite exposed along the A9 corridor (Sheet 55W, Treagus 2000) preserve pelite-draped dune bedding, lenticular bedding, channelisation and slumping, features indicative of deposition in a tidal-dominated shelf environment.

2.3 STRATIGRAPHICAL CORRELATION – A CORRIEYAIRACK OR STRATHTUMMEL BASIN AFFINITY?

The Corrieyairack Basin type-stratigraphy consists of seven formations with a cumulative thickness of over 8 km (Glover and Winchester 1989; Key *et al.* 1997) (figure 9). However, rapid lateral facies changes occur southeastwards towards the Geal-charn – Ossian Steep Belt (presumably reflecting the basin margin) and the succession thins with the Glen Spean Subgroup becoming entirely absent. Similar changes occur northwestwards away from the type-area, adjacent to the shelf-slope-break, where the Corrieyairack Subgroup becomes significantly thinned. Therefore, the Corrieyairack Basin type-stratigraphy defined in the Loch Laggan-Glen Spean area is the exception and certainly not the rule. Mainly due to the lack of stratigraphical work east of the Glen Banchor High, previous studies have relied on the type-stratigraphy of the Corrieyairack Basin for naming new units whilst mapping in the Strathtummel Basin (e.g. Robertson and Smith 1999; Smith *et al.* 1999; BGS 2002; Leslie *et al.* 2002). This has led to some confusion with formations being wrongly correlated to fit the type-stratigraphy and so incorrectly named.

Superficially, the stratigraphy of the Strathtummel Basin appears complicated because there are many stratigraphical names (Tables 1 and 2). This is a result of local mapping necessitating the attribution of different names to comparable stratigraphies outcropping on different fault-bounded blocks. However, a rationalisation of the stratigraphical nomenclature reveals that it consists of essentially four formations with an overall thickness of *c.* 5 km (Banks 2005). These formations form an essentially layer-cake stratigraphy extending from Kincraig to Schiehallion (figure 9, table 1). Lateral facies changes are rare and the four-fold stratigraphy can be used in a predictive sense.

NE **SW**

Sheet 74W	GLEN TRUIM FAULT	**Sheet 64W/74W**	CREAG LIATH FAULT	**Sheet 63E**	MASHIE FAULT	**Sheet 63E**	**Sheet 54E**	Recommended Nomenclature (Banks 2005)
Kincraig–Newtonmore		**Creag Dhubh – Creag na Sanais**		**Dalwhinnie**		**Loch Ericht Estate (east)**	**Ben Alder**	
Unnamed stratigraphy		Allt nam Biorag Psammite Member		The Fara Psammite		The Fara Psammite (undivided)	Gaick Psammite	Gaick Psammite
Pitmain Semipelite		Creag na Sanais Semipelite		Unnamed pelite			Garbh Choire Semipelite	Pitmain Semipelite
Loch Laggan Psammite		Creag Dhubh Psammite		The Fara Psammite			Ben Alder Psammite	Creag Dhubh Psammite
Kincraig Formation/ Coire nan Laogh Semipelite		Torr na Truim Semipelite		Mashie Semipelite		Unnamed pelite	Lethcois Semipelite	Coire Nan Laogh Semipelite

TABLE 1: Stratigraphical correlation of formations across major faults in the Strathtummel Basin, using the published nomenclature for each sheet (NE of Ericht-Laidon Fault, SE of Geal-Charn Ossian Steep Belt).

Several lines of evidence indicate that the Ben Alder Grampian Group has a Strathtummel Basin affinity (figure 9). Most importantly, it is lithologically and stratigraphically similar to the Strathtummel Basin stratigraphy elsewhere. The type-stratigraphy consists of a basal schistose semipelite (Coire nan Laogh Semipelite), which overlies gneissose arkosic psammite belonging to the Glen Banchor Succession. The Coire nan Laogh Semipelite is overlain in turn by 1-2 km of uniform, grey, graded micaceous psammites with subordinate semipelite (Creag Dhubh Psammite). In a similar manner, the Lethcois Semipelite is overlain by thick graded micaceous and feldspathic psammite and semipelite (Ben Alder Psammite). Therefore, it is reasonable to suggest that the Lethcois Semipelite correlates with the Coire nan Laogh Semipelite Formation and is the base of the Grampian Group. Hence, the Lethcois Semipelite should overlie rocks belonging to the Glen Banchor Succession at depth.

Recommended nomenclature (Banks 2005)	Ben Alder, Sheet 54 E	Previously also known as:
Gaick Psammite	Gaick Psammite	Allt nam Biorag Psammite Member, Atholl Subgroup, Bruar Psammite Formation, Ordhan Shios Psammite Formation, Strathtummel Subgroup, Strathtummel Succession (including the Kynachan Psammite, Kynachan Quartzite, Tummel Psammite and Tummel Quartzite formations).
Pitmain Semipelite	Garbh Choire Semipelite	Ardair Semipelite Formation, Creag na Sanais Semipelite Formation, Falls of Phones Semipelite Formation, Ordhan Shios Semipelite Formation, Tromie Semipelites.
Creag Dhubh Psammite	Ben Alder Psammite	Ben Alder Succession, Coylumbridge Psammite Formation, Creag Meagaidh Psammite Formation, Drumochter Succession, Etteridge Lodge Psammite Formation, Feshiebridge Psammite Formation, Loch Laggan Psammite Formation, Markie Micaceous Psammite, Raliabeg Psammite Formation, The Fara Psammite Formation.
Coire nan Laogh Semipelite	Lethcois Semipelite	Kincraig Limestone Formation, Mashie Semipelite Formation, Ord Ban Subgroup, Torr na Truim Semipelite.

TABLE 2: Stratigraphical jargon-buster for the Strathtummel Basin.

In the type stratigraphy, the graded micaceous psammite-dominated Creag Dhubh Psammite Formation passes transitionally upwards into a relatively thin (c.100m thick) gneissose semipelite that forms a key stratigraphical marker (termed the Pitmain Semipelite, Falls of Phones Semipelite, Creag na Sanais Semipelite e.t.c; table 2). The Garbh Choire Semipelite forms a similar stratigraphical marker unit overlying the Ben Alder Psammite Formation. It therefore follows that this gneissose semipelite is overlain by flaggy feldspathic psammite assigned to the Gaick Psammite Formation in both the Ben Alder Grampian Group and in the type stratigraphy. The following correlations with the Strathtummel Basin type-stratigraphy are suggested:

Ben Alder Stratigraphy:		**Type stratigraphy:**
Gaick Psammite	=	Gaick Psammite
Garbh Choire Semipelite	=	Pitmain Semipelite
Ben Alder Psammite	=	Creag Dhubh Psammite
Lethcois Semipelite	=	Coire nan Laogh Semipelite.

It is difficult to fit the Ben Alder lithostratigraphy into the more complicated stratigraphical framework documented in the Corrieyairack Basin.

Additional evidence for a Strathtummel Basin affinity lies in the fact that, despite occupying a number of different fault blocks, the nearby Drumochter, Dalwhinnie and Glen Truim areas all possess a ‘typical’ Strathtummel Basin stratigraphy (see Leslie *et al.*, 2002). Unless strike-slip displacement along the Mashie Fault was notably large, the adjacent Ben Alder area should also contain a Strathtummel Basin stratigraphy.

Robertson and Smith (1999) interpreted the Geal-charn – Ossian Steep Belt as a crumple-zone formed by focussing of strain onto a basement block comprising the Glen Banchor Succession. No basement is exposed in the study area and so the Ben Alder massif, lying to the south east, would either be sited on top of the submerged basement block or lie within the adjacent Strathtummel Basin.

For ease of discussion, the stratigraphy is treated using the local names (e.g. Ben Alder Psammite) for the remainder of this report. However, in order to rationalise the current plethora of stratigraphical names (see table 2), it is recommended that the final clean copies use the type-stratigraphy (Banks 2005).

2.4 RECOMMENDATIONS FOR RE-NAMING UNITS ON SHEET 63 E

The lithostratigraphy mapped at the southwest corner of Sheet 63E (Dalwhinnie) continues into the Ben Alder area. Although the linework fit between Sheet 63 E and the resurveyed areas of Sheet 54 E (Loch Rannoch) is good, there are significant inconsistencies in the stratigraphical nomenclature used. During the survey of Sheet 63E, new units were correlated with the Corrieyairack Basin type-stratigraphy and were named accordingly. At this time, little was known about Grampian Group stratigraphy elsewhere and the wider basin architecture in the Central Highlands was poorly understood.

The Corrieyairack Basin names used on Sheet 63E should be replaced with the appropriate Strathtummel Basin correlatives (figure 1). These are:

1) Ardair Semipelite Formation (SQ_{Ar}): This semipelite outcrops in the anticlinal core of the F2 Ben Alder Anticline between the Inverpattack-Markie Fault and the southern edge of Sheet 63E (e.g. NN 523775). If this formation was the Ardair Semipelite *sensu stricto* it should be much thicker (*c.* 700 m), containing many graded psammite beds (up to 50% of the formation) and should be underlain by a thick-bedded graded psammite sequence up to 3.6 km thick. When traced northeastwards across the fault, basement rocks belonging to the Glen Banchor Succession underlie the semipelite and it contains few psammite beds except near its upper contact. It is recommended that this semipelite be renamed to the Coire nan Laogh Semipelite Formation (= Lethcois Semipelite).

2) Creag Meagaidh Psammite Formation, (Q_{Cm}): This outcrops in two NE-SW trending bands flanking the ‘Ardair Semipelite’ (e.g. at NN 512748 and NN 501 746) and the summit area and main cliffs of Sgòr Iutharn [NN 489 745]. This graded feldspathic and micaceous psammite unit is lithologically indistinguishable and occupies a similar stratigraphical position to the more widely developed Creag Dhubh Psammite Formation (= Ben Alder Psammite). The Creag Dhubh Psammite is correlated with the Loch Laggan Psammite Formation in the Corrieyairack Basin NOT the Creag Meagaidh Formation that is *c.* 1.5 km higher up in the stratigraphy. This unit should be renamed the Creag Dhubh Psammite Formation on Sheet 63E.

3) Clachaig Semipelite Formation (SQ_{CG}): This semipelite outcrops on the eastern slopes of Sgòrr Iutharn [NN 4973 7454]. In the Corrieyairack Basin, the Clachaig Semipelite Formation only outcrops near the type area of Meall Clachaig [NN 3723 8262] (see Key *et al.* 1997). It is laterally impersistent and becomes absent when traced into the Geal-charn – Ossian Steep belt. It is therefore unlikely that this formation is continuous across the steep belt into the Ben Alder region. On Sheet 63E, the semipelite ± quartzite association overlies graded micaceous psammite beds assigned to the Creag Dhubh Psammite Formation (= Ben Alder Psammite). It is therefore a correlative of the Pitmain Semipelite Formation (= Garbh Choire Semipelite) and should be renamed accordingly.

The gneissose psammite assigned to the Inverlair Psammite Formation exposed in the Geal-charn – Ossian Steep [NN 485748] may also be incorrectly correlated and named. However, this unit is highly strained and migmatitic has not been examined in this study.

The Fara Psammite Formation (undivided) outcrops over large tracts adjacent to Loch Ericht. West of the Mashie Fault, it comprises similar graded micaceous psammite to, and its outcrop is laterally continuous with, the newly surveyed exposures of Ben Alder Psammite (Creag Dhubh Psammite in the type-stratigraphy). This correlation is unequivocal and The Fara Psammite should be renamed as the “Creag Dhubh Psammite” at least between the Mashie and Inverpattack-Markie Faults.

Adjacent to the Inverpattack-Markie Fault between Culra Bothy and Loch Pattack, ‘The Fara Psammite’ contacts an unnamed schistose semipelite. Consistent grading evidence on Beinn Bheoil [NN 52227410] indicates that the psammite is younger than this semipelite and so the latter is likely to correlate with the Lethcois Semipelite (Coire nan Laogh Semipelite in the type-stratigraphy). Therefore, this semipelite should be assigned to the Coire nan Laogh Semipelite Formation in line with the Strathtummel Basin type-stratigraphy.

2.5 IMPLICATIONS FOR GRAMPIAN GROUP BASIN ARCHITECTURE

The lithostratigraphical framework for the Grampian Group is fundamentally different either side of the Geal-charn – Ossian Steep Belt. Additionally, the facing of the major folds changes across the steep belt (Thomas 1979). These changes are not fortuitous and indicate that basin architecture exerted a major control on the stratigraphical and structural development of the Ben Alder area. Although no basement rocks units (Glen Banchor Succession) are exposed, they cannot be far from the present-day surface because an interbasinal high is required to separate the Corrieyairack (west) from Strathtummel (east) basin-fills. Furthermore, it would have provided a rigid buttress of basement material, onto which strain could be focussed, forming the steep belt.

3 Structure

3.1 DUCTILE DEFORMATION

The ductile deformational history of the Ben Alder stratigraphy can be divided into four phases (D1-D4). However, it is only the main phase deformations (D2-D3) that significantly control the regional distribution of stratigraphical units (figure 1, 2). The great eastern corrie sections of Ben

Alder (Garbh Choire, Garbh Choire Beag, Coire na Lethcois) are fortuitously orientated normal to the regional dip and fold axes trends and so effectively provide cross-sections across the structural profile (figures 2 and 10). The following structural nomenclature (D1, D2, D3, D4) is used in a local sense only and does not necessarily imply correlations with similarly numbered ductile structures elsewhere.

3.1.1 Early phase deformation (D1)

No major or minor F1 structures have been identified in the study area. This earliest phase of deformation is rarely evident and is only noted where later fabrics (S2-S4) crenulate an earlier planar fabric (S1). The S1 fabric is commonly parallel to sub-parallel with the compositional layering and is defined by the alignment of micas in semipelitic lithologies and by a preferential grain-shape fabric (quartz-feldspar) in psammites. S1 fabrics give little indication of F1 fold vergence or facing. Although Thomas (1979) identified D1 tight anticlines and synclines from the distribution of lithological units no evidence has been found that supports their existence in the Ben Alder area. Alternative structural and stratigraphical interpretations can account for the structure without recourse to F1 major folding. In the absence of evidence for F1 folds and other D1 tectonic features, it is plausible that this early fabric is related to layer-parallel lithostatic compaction.

3.1.2 Main phase deformation (D2)

The main regional phase of folding is characterised by tight, major and minor asymmetrical F2 folds, which have moderately inclined axial planes dipping to the northwest (figure 2, 10, 11). Major fold structures (Ben Alder Anticline, Coire Labhair Syncline) are kilometre-scale and consistently face to the southeast, verging away from the Geal-charn – Ossian Steep Belt. Minor F2 folds are abundant in the hinge zones of these major folds but are relatively uncommon on the limbs where later F3 minor structures are dominant (figure 10, 11). However, the effects of D2 are evident almost everywhere because of its strong, pervasive, penetrative S2 fabric. This fabric is defined by a strong mica alignment in the semipelites and micaceous psammites and by a preferred grain-shape orientation in the psammites and quartzites.

Thomas (1979) mapped out several major F2 structures across Ben Alder and Beinn Bheoil (with the help of R.H.S. Evans). This work was largely completed in the absence of a stratigraphical framework and without the use of way-up criteria such as graded bedding.

Ben Alder Anticline:

The geometry of the Ben Alder Anticline is best assessed by traversing up the long ridge of Coire na Lethcois [NN 5185 7414 to 5000 7360]. A complementary cross section is also exposed on the short ridge [NN 507 730 to 501 729] and seen in the fold closure in Garbh Choire Beag [NN 5000 7263] (figure 1, 2, 10a).

At the base of the long ridge, consistent grading evidence indicates that the Ben Alder Psammite is inverted and youngs northeastwards (e.g. NN 5075 7418). F2 Z-folds have a westerly to northwesterly vergence towards the anticlinal axis (figure 11 a and b). The Lethcois Semipelite outcrops on the long ridge between NN 5040 7370 and NN 5020 7360 and minor F4-structures dominate. Further up the ridge the Ben Alder Psammite outcrops again and grading evidence indicates that it is right-way-up [NN 5006 7363]. At this locality, S2 foliation/bedding relationships and northwestward verging F2 minor S-profile folds confirm that the anticlinal axis has been crossed.

A similar sequence is seen on the short ridge with the F2 hinge identified at [NN 5042 7300] where rare tight F2 minor folds with gentle northeasterly plunging axes are seen. In the upper part of the ridge, the Ben Alder Psammite is more attenuated and hence more thinly bedded. Grading evidence is not well seen.

In the Lethcois Semipelite exposed in the anticlinal closure in Garbh Choire Beag [NN 5000 7263], tight to isoclinal F2 M-profile folds with axial planes dipping at *c.* 60^{o} to the north are abundant. These folds plunge southwestwards by 10 to 20^{o}. Again, a traverse from the base of the coire to its upper lip, demonstrates that the Ben Alder Psammite is duplicated on both upper and lower limbs of the anticline.

A knowledge of the stratigraphical framework and utilisation of younging indicators has demonstrated that the Ben Alder Anticline is a tight, fundamental fold structure, which structurally repeats the Ben Alder Psammite Formation. This differs with the model of Thomas (1979), who interpreted the folds as a more open structure with different formations structurally above and below the Lethcois Semipelite Formation.

Coire Labhair Syncline:
This D2 structure is considered the complementary major F2 syncline to the Ben Alder Antiform. It is defined by the repetition of the stratigraphy and its mapped outcrop pattern rather than by the structural data. The section in the Allt a' Bhealaich Dhuibh traverses across the minor folded, northeastern closure of the syncline but as shown by Thomas (1979) there is much repetition of the stratigraphy and the simple structure is obscured by the local structural complexity. The lithologies that define the main fold include the Ben Alder Psammite, the Garbh Choire Semipelite and the Gaick Psammite Formation. Many of these are thinly banded and hence show an abundance of minor folding. Only rarely can signs of grading be recognised and the lack of detailed continuity and mappable marker bands precludes any coherent analysis of the structural profile. The outcrop pattern is typically complex with F2, F3 and F4 folds are all represented, obscuring the main synclinal structure. Although F2 and F3 minor folds can be distinguished from the later F4 structures by their general tightness and nature of related cleavages, the fold axes of many of these minor structures are roughly coaxial. F2 minor folds are invariably tight and recorded minor fold axes plunge some 15-30° to the southwest or WSW. F2 axial planes correspond to the S2 cleavage and are orientated at low angles to the regional bedding. An L2 quartz rodding lineation is locally developed, notably in the lower parts of the Gaick Psammite Formation. The penetrative fine S2 cleavage is seen to cross cut bedding at a high angle in F2 hinges but on the fold limbs the S2 cleavage-bedding angle is small and commonly cannot be resolved. An F2-F3 interference structure (type 3 of Ramsay, 1967) was clearly seen in the Allt a' Bhealaich Dhuibh at [NN 4836 7308] and a poorer example was recorded at [NN 48223 72692]. F3 minor folds are common and their axes plunge gently to moderately (5 to 30° typically) to the southwest and WSW. They vary from open to tight and locally in more pelitic rocks show a crenulation or even penetrative schistosity. F3 folds show both neutral and southeasterly vergence and control the outcrop-scale structural pattern. F4 folds are small to medium scale, open to close, near monoformal structures with gently WSW plunging axes and with a dominant SSE vergence (i.e downstep to NNE). They are best seen in the lower part of the Allt a' Bhealaich Dhuibh around [NH 4837 7311] where they exert significant control over the structure giving alternating steeply dipping and gently dipping zones.

3.1.3 Main phase deformation (D3)

Later F3 folds are commonly coaxial and coplanar to F2 structures. F3 folds were noted by their refolding of the pervasive S2 foliation and have a different structural style to F2 folds (cf figures

11and 12). Both minor and major F3 folds are generally more open than F2 structures and have moderately inclined to recumbent axial planes. F3 fold structures plunge gently between 5 to 20^o towards the west. A third axial planar, third foliation (S3) is only well developed in the hinge zones of major F3 fold structures where S3 crenulates the S2 foliation. In the areas currently studied, only one major F3 structure is noted:

Garbh Choire Synform:

The eastern face of Garbh Choire Beag [NN 502 727] provides superb exposures of this syncline which here folds the Ben Alder Psammite Formation (figure 2 and 12a). Note that the F3 synform and abundant related minor folding are only developed on the lower inverted limb of the Ben Alder Anticline (F2). The upper limb contains few F3 minor folds and D3 deformation seems to have merely attenuated the earlier D2 structure. Thus, while the Garbh Choire Synform appears to be complementary to the D2 Ben Alder Anticline and although there may be some elements inherited from an earlier D2 structure, F3 folds clearly refold the earlier D2 fabrics. At [NN 50133 72333] tight F2 folds are seen, refolded by more open F3 folds with L3 rodding well developed. However, there is no overall change in younging in the sequence and the local appearance of F2 structures is probably linked to the more local semipelitic and banded nature of the units here.

The Garbh Choire Synform is a relatively open fold with a broad hinge zone and an interlimb angle of *c.* 80^o. Its axial plane gently dips towards the northeast at *c.* 15^o. The trends of associated minor folds are remarkably consistent around the fold, plunging some 5 to 15 degrees to the WSW. F3 minor folds vary from open to close and are rarely tight. They commonly take the form of corrugations and have generated a pronounced ribbing on bedding surfaces (L3R) in the Ben Alder Psammite (figure 5.11b).

South of the Garbh Choire Fault, the Garbh Choire Synform is defined by the outcrop of the Garbh Choire Semipelite Formation (figure 10b). Steeply dipping semipelite strikes at c. 100^o from the Ben Alder summit plateau towards the base of Garbh Choire, where the formation forms a prominent band at the base of the cliffs. The semipelite is offset by the Inverpattack-Markie Fault and reappears on Beinn Bheoil [NN 51607140], where it structurally overlies inverted rocks of the Gaick Psammite Formation on the upper limb of the syncline. It is rare to find minor folds within the Garbh Choire Semipelite itself because it is essentially unbanded. However, intermediate-scale F3 minor folds that are co-axial to the major structure are exposed in the semipelite on Beinn Bheoil [NN 51647141] (figure 12c). By contrast, minor F3 folds are abundant in the stratigraphically overlying heterolithic basal beds of the Gaick Psammite Formation [NN 51507050], where they also show consistent axial plunges of 10-20^o to the west. They are co-axial to the major syncline, but are close to tight with interlimb angles of 30-50^o.

3.1.4 Late phase deformation (D4)

Late phase minor and major fold structures (F4) are distinctive from any earlier structures in being upright with steeply dipping axial planes. Minor folds and associated fabrics are abundant in pelitic lithologies, where an upright axial-planar cleavage is well developed (figure 6). S4 fabrics are generally not recorded in psammitic lithologies, which fold into larger wavelength intermediate-scale folds (e.g. figure 13). Several major F4 structures have been identified:

Lethcois Antiform and Synform

These F4 major folds have the effect of ‘kinking’ the stratigraphy. They alter the dip of bedding surfaces but have a limited affect on its strike direction. On the long ridge of Coire na Lethcois [NN 7370 8050], the Lethcois Antiform divides strata dipping at c. 30^{o}SE to the south from c.

70°NW to the north. The axis of the antiform consistently strikes eastwards and can be traced from the long ridge eastwards along the cliffs of Bealach Dhubh. The closure is well exposed as a series of intermediate folds in the fault controlled gulley at NN 4868 7280 (figure 13). Strong S4C fabrics are developing where the Lethcois Semipelite lies in the antiformal hinge on the long ridge.

Likewise, the Lethcois Synform divides strata dipping c. 50°NW to the south from c. 18°SW to the north. The hinge of this synform is exposed at the top of Coire na Lethcois around NN 5000 7315.

3.2 BRITTLE DEFORMATION

Several major faults cross the Ben Alder/Loch Ericht areas but have a relatively limited affect on the stratigraphical distribution (figure 1). All faults blocks contain similar stratigraphies and lithofacies, indicating that fault movements are entirely post-depositional. The major ductile structures can also be correlated between adjacent fault blocks.

3.2.1 Inverpattack-Markie Fault

The 010° trending Inverpattack-Markie Fault divides the study area into two fault blocks, the Ben Alder Massif and its satellite Beinn Bheoil. It runs through the hanging valley of Bealach Bheithe and meets up with Ericht-Laidon Fault in Ben Alder Bay [NN 500675]. The fault is one of a number 010° faults (e.g. Glen Truim Fault, Creag Liath Fault) associated with the transfer of strain between the major late-Caledonian Sronlairig and Ericht-Laidon Faults.

The fault zone is not directly exposed in the area but its displacement can be well constrained by the offset of the Garbh Choire Semipelite Formation. In Bealach Bheithe, the semipelite is offset sinistrally by approximately 500 m. This is considered a more reliable estimate that the c. 1.5 km dextral offset mapped in the poorly exposed area near Culra Bothy on Sheet 63E [NN 518763]. Around the fault zone, thick pegmatite intrusions are common indicating that it acted as a conduit for late-stage pneumatolytic fluids.

3.2.2 Garbh Choire Fault

The Garbh Choire Fault is represented by a prominent gully in Garbh Choire [NN 4963 7130] (figure 10b). At this locality, the fault plane dips at 090/74°S and vein-quartz covers these polished surfaces. It is a dip-slip fault downthrowing to the south and juxtaposing the Ben Alder Psammite Formation (footwall) with the Garbh Choire Semipelite and Gaick Psammite Formations (hangingwall).

On the map of Thomas (1979), the Garbh Choire Fault cuts the Inverpattack-Markie Fault and continues eastwards across Beinn Bheoil. The current survey has found no evidence for this continuation and Bheinn Bheoil is considered to have a continuous stratigraphical succession across its summit ridge.

3.2.3 Ericht-Laidon Fault

The northeast-trending Ericht-Laidon Fault is a major fault running through Loch Ericht and is one of the major late-Caledonian sinistral strike-slip faults in the Grampian Highlands. The fault extends for about 170 km from the Tayvallich area where it has a dip-slip component of about 2 km. It was estimated that the fault has a sinistral displacement of about 7 km in the Moor of

Rannoch (Hinxman *et al.*, 1923) area. The trace of the Ericht-Laidon Fault is entirely underwater in the study area but many minor parallel fractures occur on the eastern faces of Beinn Bheoil. It is plausible that these fractures exerted a structural control on the failure of the steep eastern slopes. Slipped blocks that are several hundred metres across occur at NN 527 718, 528 722 and 523 713.

4 Igneous Rocks

North of the Moor of Rannoch Granite, the Ben Alder Area is relatively devoid of igneous intrusions. The minor intrusions that are exposed occur in close to brittle faults and can be classified into three groups:

4.1 PEGMATITES

Pink and white megacrystic pegmatite (grain size commonly between 1 and 8 cm) is notably common immediately adjacent to the Inverpattack-Markie and Ericht-Laidon Faults becoming less abundant eastwards towards Ben Alder itself (figure 14a). They are well exposed in Sròn Coire na h-Iolaire [NN 51207090], where a set of east-west trending discordant pegmatite sheets form the steep east-facing back wall of the coire. In Sròn Coire na h-Iolaire, pegmatite bodies are up to 25 metres across and have a broadly granitic composition, being dominated by K-feldspar-quartz-muscovite. Elsewhere, pegmatite bodies more commonly occur as sub-metre-scale discordant and concordant sheets, veins and dykes. No deformational fabrics were noted in any of the exposures indicating their late- to post-tectonic generation.

4.2 LAMPROPHYRES

Many small appinite and lamprophyre intrusions occur throughout the Grampian Highlands and the Ben Alder area is no exception. Several lamprophyre sheets up to 1 m across are exposed adjacent to the Garbh Choire Fault [NN 49637130]. These are buff-coloured on fresh surfaces, weathering to brick red and are porphyrytic with black and white phenocrysts scattered throughout a fine-grained groundmass. In thin section, the rock is highly altered with white-mica and chlorite replacing and pseudomorphing the original mineralogy (figure 14). Sericite pseudomorphs reveal euhedral, lath-shaped phenocrysts up to 0.5 mm, which are interpreted as plagioclase. Darker, mafic phenocrysts are up to 5 mm in length and are pale green in PPL with iron staining and opaque inclusions. Berlin-blue interference colours indicate secondary fine-grained chlorite replacement of the original phenocrysts. These dark phenocrysts are tentatively interpreted as altered amphiboles, although no vestige of pleochroism remains. The absence of preferential mineralogical alignment demonstrates their post-tectonic genesis.

The mineralogy described above classifies these intrusions as spessartites (hornblende-plagioclase), which are the most common lamprophyric intrusions in the highlands (Stephenson and Gould 1995).

4.3 MICROGRANITES

The presence of microgranite is only noted by its occurrence in scree downslope of prominent gulleys (e.g. NN 5000 7350), where dykes have preferentially weathered out. Microgranite is red to orange, fine grained with biotite phenocrysts between 1-4 mm across. Euhedral plagioclase phenocrysts also occur but are rarer. The dyke gulleys have a variety of trends but are mostly orientated N-S.

5 Field test of satellite phones

In Ben Alder, mobile phones will only work where there is a clear line of sight towards the A9, which is where the phone network booster masts are located. A clear signal was detected on the high and eastern parts of the area (especially Beinn Bheoil) but mobile phones were useless elsewhere. Therefore, satellite phones were deemed a necessary piece of safety equipment. Two models were field tested:

5.1 THURAYA

The Thuraya system works on a single operational satellite (the Thuraya 2) positioned in Geosynchronous Orbit, 35,786 km above the Earth, at 44^{o} East Longitude (source: www.thuraya.com). Whilst this provides superb coverage to low to mid latitude countries in the Northern Hemisphere, Scotland lies at the periphery of its published coverage area. Poor to no satellite signal could be detected in either Edinburgh or in the highlands. It only functioned when it was able to connect to a mobile phone network.

5.2 IRIDIUM

Iridium Satellite LLC is currently the only company to offer complete satellite phone coverage of the earth (including oceans, airways and polar regions). Iridium delivers communication services via a constellation of 66 evenly-distributed, low-earth orbiting (LEO), cross-linked satellites, which is the largest commercial satellite constellation in the world (source: www.iridium.com). The Iridium satellite was tested at the field camp in Garbh Choire [NN 50007125] and had no problems finding a signal despite being surrounded by three sheer rock walls. However, the system had several minor faults. Firstly, the signal was occasionally lost mid-conversation when the LEO satellite that the phone was connected to moved out of range. However, the Iridium system could always be relied upon to reconnect moments later. Secondly and most importantly, the battery life was short and would be fully discharged after around 15 minutes. It is therefore recommended that anybody using these phones in remote-terrain should carry at least one spare battery.

References

BANKS, C.J. 2005. Neoproterozoic Basin Analysis: *A combined sedimentological and provenance study in the Grampian Group, Central Highlands Scotland*. Unpublished Ph.D. thesis. Keele University.

BRITISH GEOLOGICAL SURVEY. 2001. Schiehallion. Scotland Sheet 55W. Solid Geology. 1:50 000 *HMSO*.

BRITISH GEOLOGICAL SURVEY. 2002. Dalwhinnie. Scotland Sheet 63E. Solid Geology. 1:50 000. *HMSO*.

GLOVER, B.W., KEY, R.M., MAY, F., CLARK, G.C., PHILLIPS, E.R. and CHACKSFIELD, B.C. 1995. A Neoproterozoic multi-phase rift sequence: the Grampian and Appin Groups of the southwestern Monadhliath Mountains of Scotland. *Journal of the Geological Society, London*, 152**,** 391-406.

GLOVER, B.W. and WINCHESTER, J.A. 1989. The Grampian group: a major Late Proterozoic clastic sequence in the Central Highlands of Scotland. J*ournal of the Geological Society*, London, 146**,** 85-96.

HASELOCK, P.J., WINCHESTER, J.A. and WHITTLES, K.H. 1982. The stratigraphy and structure of the southern Monadhliath Mountains between Loch Killin and Upper Glen Roy. *Scottish Journal of Geology*, 18**,** 275-290.

HINXMAN, L.W, CARRUTHERS, R.G. and MACGREGOR, M. 1923. The Geology of Corrour and the Moor of Rannoch. *Memoir of the Geological Survey of Great Britain*, Sheet 54 (Scotland).

KEY, R.M., CLARK, G.C., MAY, F., CHACKFIELD, B.C. and PEACOCK, J.D. 1997. Geology of the Glen Roy District. *Memoir of the British Geological Survey*, Sheet 63W (Scotland). *HMSO*.

LESLIE, A.G., KRABBENDAM, M and SMITH, R.A. 2002. Progress report on the Geology of 1:50 k Sheet 64W (Newtonmore). *British Geological Survey, Internal report*.

RAMSAY, J.G. 1967. *Folding and fracturing of rocks*. McGraw-Hill, New York-London. 568pp.

READING, H.G. and RICHARDS, M. 1996. Turbidite Systems in Deep-Water Basin Margins Classified by Grain Size and Feeder System. *American Association of Petroleum Geologists*. 78**,** 792-822.

ROBERTSON, S and SMITH, M. 1999. The significance of the Geal Charn-Ossian Steep Belt in Basin development in the Central Scottish Highlands. *Journal of the Geological Society*, London, 156, 1175-1182

SMITH, M., ROBERTSON, S. and ROLLIN, K.E. 1999. Rift basin architecture and stratigraphical implications for basement-cover relationships in the Neoproterozoic Grampian of the Scottish Caledonides. *Journal of the Geological Society*, London. 156**,** 1163-1173, 291-299.

STEPHENSON, D. and GOULD, D. 1995. British Regional Geology: The Grampian Highlands (4th Edition). British Geological Survey. *HMSO.*

STOW, D.A.V., READING, H.G. and COLLINSON, J.D. 1996. Deep seas. In: READING, H.G. (ed.), Sedimentary Environments: *Processes, Facies and Stratigraphy*. Blackwell Scientific, Oxford. 395-453.

THOMAS, P.R. 1979. New evidence for a Central highland Root Zone. In: HARRIS, A.L., HOLLAND, C.H. and LEAKE, B.E. (eds) The Caledonides of the British Isles Reviewed. *Geological Society, London, Special Publications*, 8**,** 205-211.

TREAGUS, J.E. 2000. *Solid geology of the Schiehallion district. Memoir of the British Geological Survey*. Sheet 55W (Scotland). *HMSO.*

INTRUSIVE IGNEOUS ROCKS

L — Lamprophyre, highly altered.

π — Pegmatite of granitic composition (qtz-Kspr-musc ± bio)

STRATIGRAPHICAL SUCCESSION - Grampian Group, Dalradian Supergroup (Neoproterozoic).

BASE NOT SEEN

GAICK PSAMMITE FORMATION (^{Q}GK)
(c. 160 m)
Monotonous, stacked, feldspathic psammite, psammite and subordinate quartzite in medium beds (15-25 cm thick). Psammite typically has a speckled appearance due to disseminated biotite flakes (^{Q}GK).

A basal succession of quartzite (^{Qq}GK) and micaceous psammite (^{QS}GK) is locally divisible.

GARBH CHOIRE SEMIPELITE FORMATION (^{SQ}GC)
(c. 160 m)
Massive, intensely schistose to weakly gneissose semipelite (^{SQ}GC).

$^{SQ}GC(^{SQ}CG)$ where formerly termed "The Clachaig Semipelite Formation".

BEN ALDER PSAMMITE FORMATION (^{Q}BA)
(c. 1100 m)
Medium to thinly bedded micaceous psammite, feldspathic psammite and subordinate semipelite with abundant normal palaeo-grading indicating way-up (^{Q}BA).

$^{Q}BA(^{Q}TF)$, where formerly termed "The Fara Psammite Formation".

$^{Q}BA(^{Q}CM)$, where formerly termed "Creag Meagaidh Psammite Formation".

A distinctive, thinly bedded striped succession of psammite, feldspathic psammite, semipelite and rare quartzite is noted in the formations' upper part. K-feldspar porphyroblasts are locally developed ($^{Qstriped}BA$).

LETHCOIS SEMIPELITE FORMATION (^{SQ}LC)
(c. 180 m)
Schistose semipelite with subordinate micaceous psammite. Well developed crenulation cleavage (^{SQ}LC).

$^{SQ}LC(^{SQ}AR)$ where formerly termed "Ardair Semipelite Formation".

$^{SQ}LC(^{SQ}UN)$ where formerly undivided.

Scale to stratigraphical succession: 100 m

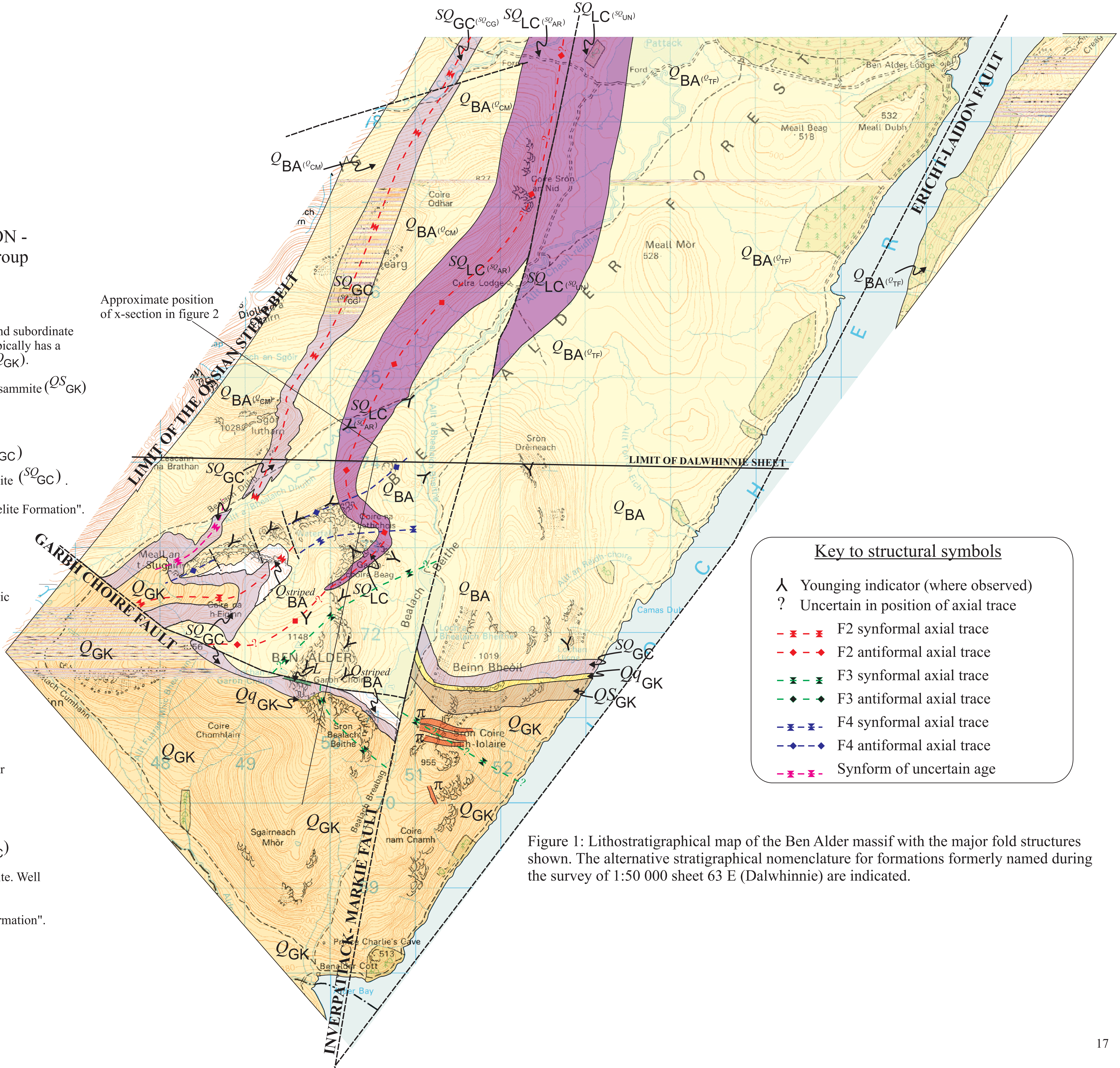


Figure 1: Lithostratigraphical map of the Ben Alder massif with the major fold structures shown. The alternative stratigraphical nomenclature for formations formerly named during the survey of 1:50 000 sheet 63 E (Dalwhinnie) are indicated.

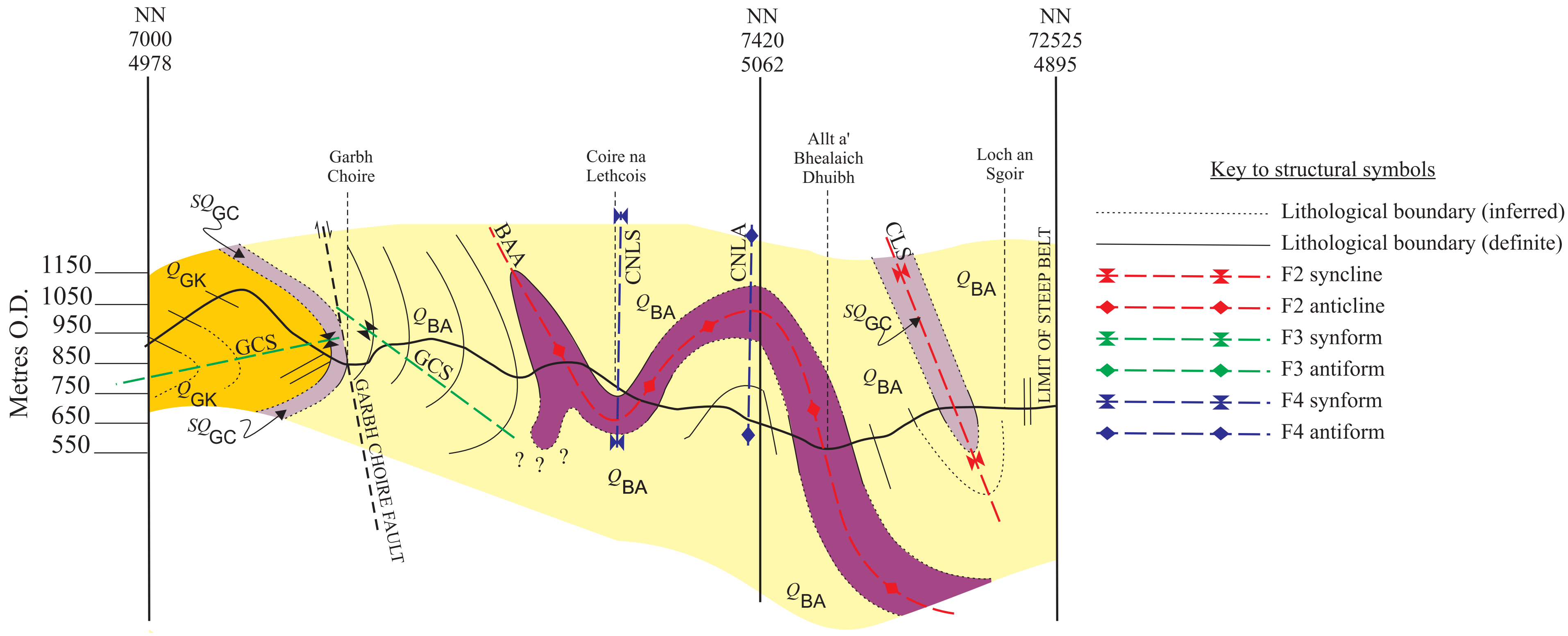


Figure 2: Structural cross-section through the Ben Alder Massif (position of section is indicated on figure 1).
Abbreviations used: BAA = Ben Alder Anticline; CLS = Coire Labhair Syncline; CNLA = Coire na Lethcois Antiform; CNLS = Coire na Lethcois Synform; GCS = Garbh Choire Synform.

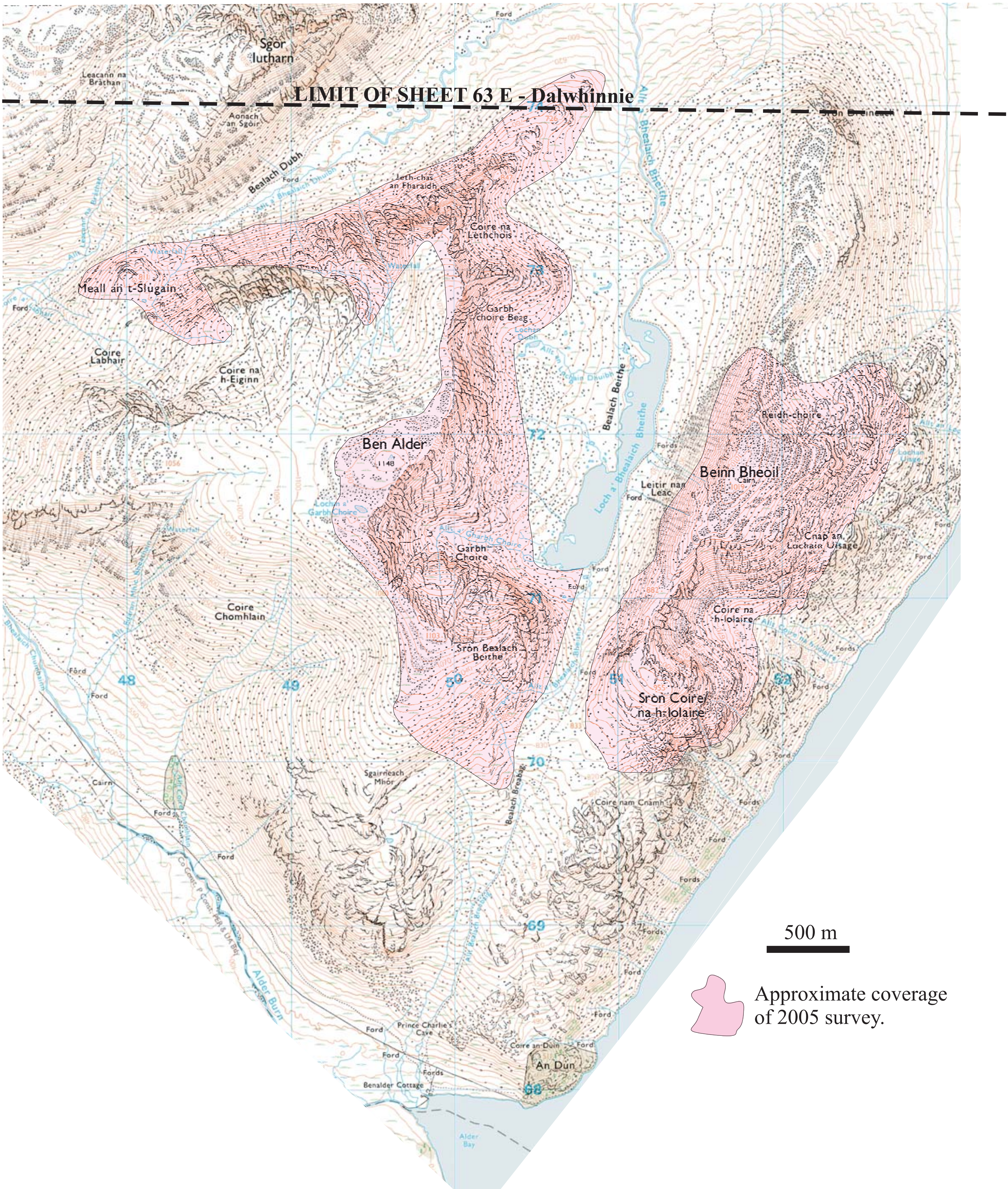


Figure 3: Topographical overview of the study area. The approximate area that was survey during 2005 is indicated. Map base courtesy of Digimap using data supplied by the Ordnance Survey.

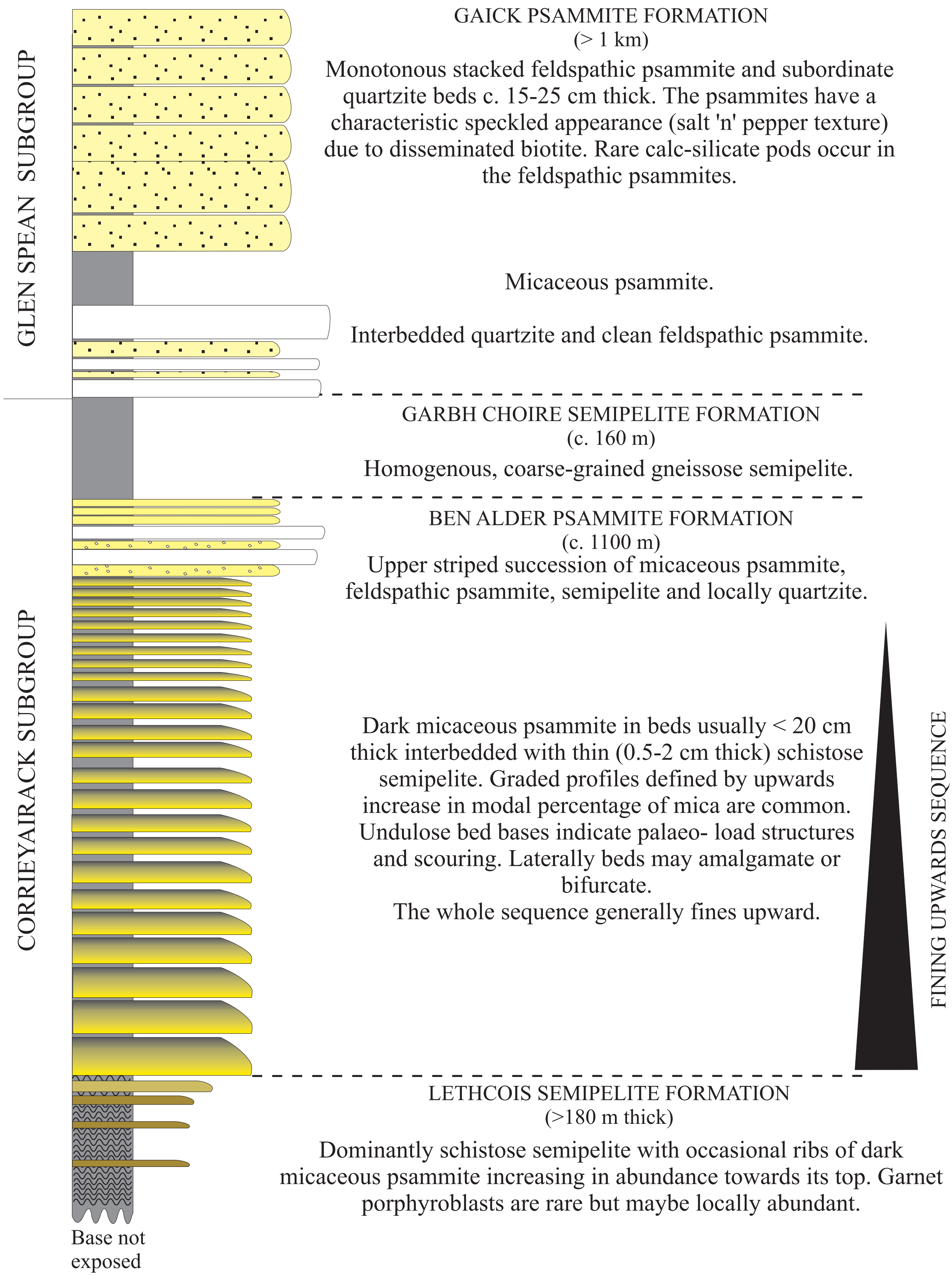
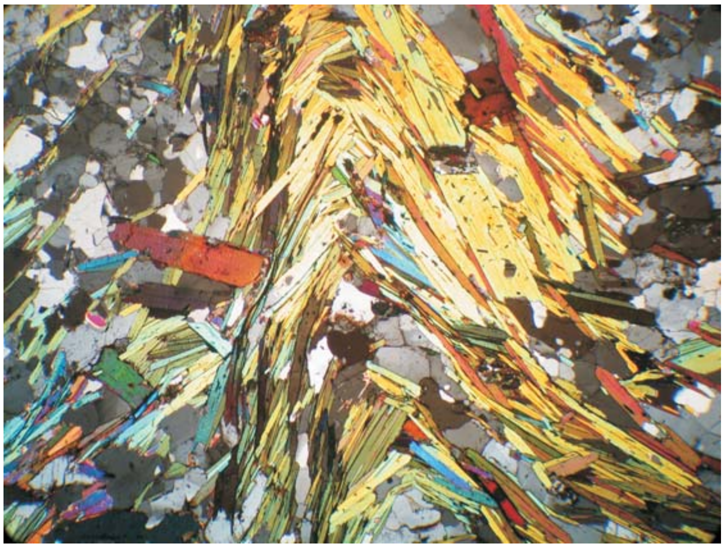


Figure 4: Diagrammatic summary of the Ben Alder stratigraphy.

a)

b)



c)

Figure 5: The Lethcois Semipelite Formation,
a) Crenulated schistose semipelite from Coire na Lethcois, long ridge, NN 50377365, (BGS registered photograph, P605177). Pencil is approximately 1 cm in diameter;
b) Cross-polarised image of a well-developed F4 crenulation cleavage within schistose semipelite, NN 50377365 (BGS thin section, N7969);
c) Plane polarised light image of ragged garnet poikiloblasts within quartz-plagioclase-biotite matrix, NN 5025 7367 (BGS thin section, N7972).
The field of view in b) & c) is 5mm.

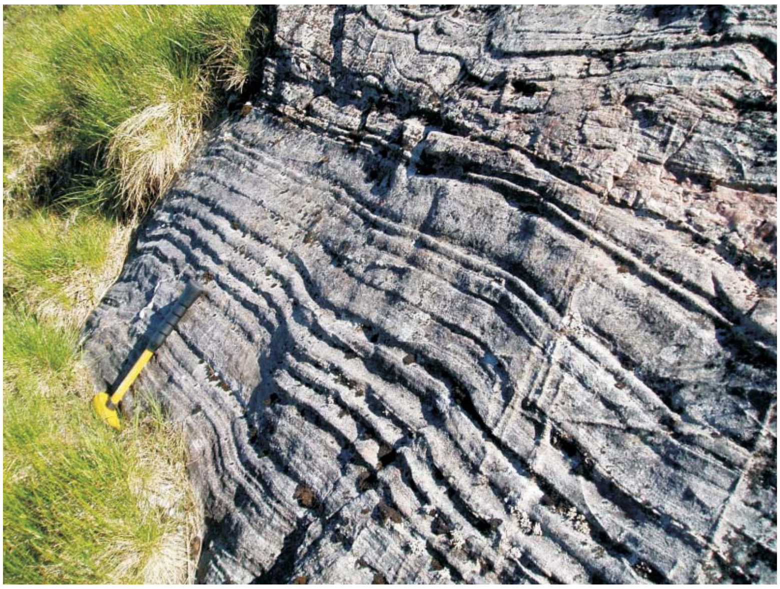
a)

b)

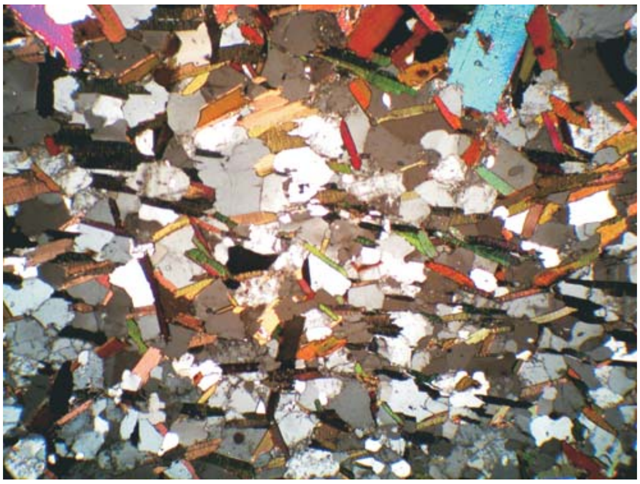
c)

Figure 6: The Ben Alder Psammite Formation:
a) Micaceous psammite grading upwards into thin schistose semipelite. Note the gritty texture imparted by feldspar porphyroblasts. The pencil is 15 cm long. Garbh Choire Beag, NN 50197257 (BGS registered photograph, P605159).
b) Penetrative biotite fabric within a micaceous psammite. Plagioclase shows dusty weathering due to sericitisation. Width of the field of view is 5 mm. (BGS thin section, N7962).
c) Micaceous psammite displaying a quartz-plagioclase matrix cut by biotite fabric. Width of the field of view is 2 mm. (BGS thin section, N7962).

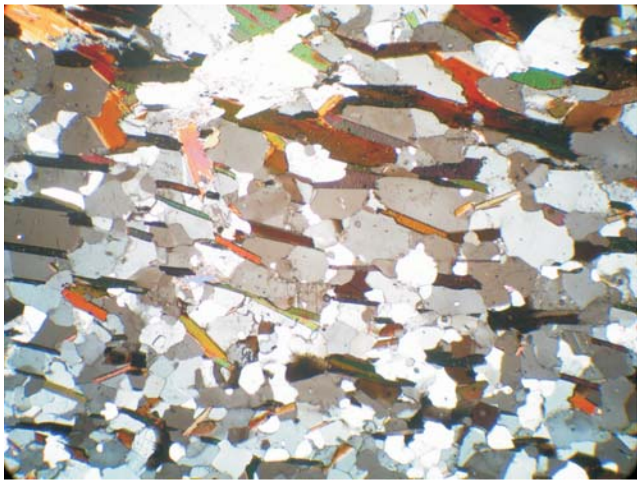
d)



e)



f)



g)

Figure 6 continued: The Ben Alder Psammite Formation:
d) Well-developed graded profiles within micaceous psammites. Hammer is 40 cm long. Bealach Dhubh, NN 49347333. (BGS registered photograph, P605180).
e & f) Graded bedding preserved by an upward modal increase in the proportion of mica. Width of the field of view is 5 mm. (BGS thin section, N7974 & N7964 respectively).
g) Striped micaceous psammite and semipelite on the upper, right way-up limb of the Ben Alder Anticline. Compass plate is 20 cm long. Coire na Lethcois, NN 50027328 (BGS registered photograph, P605178).

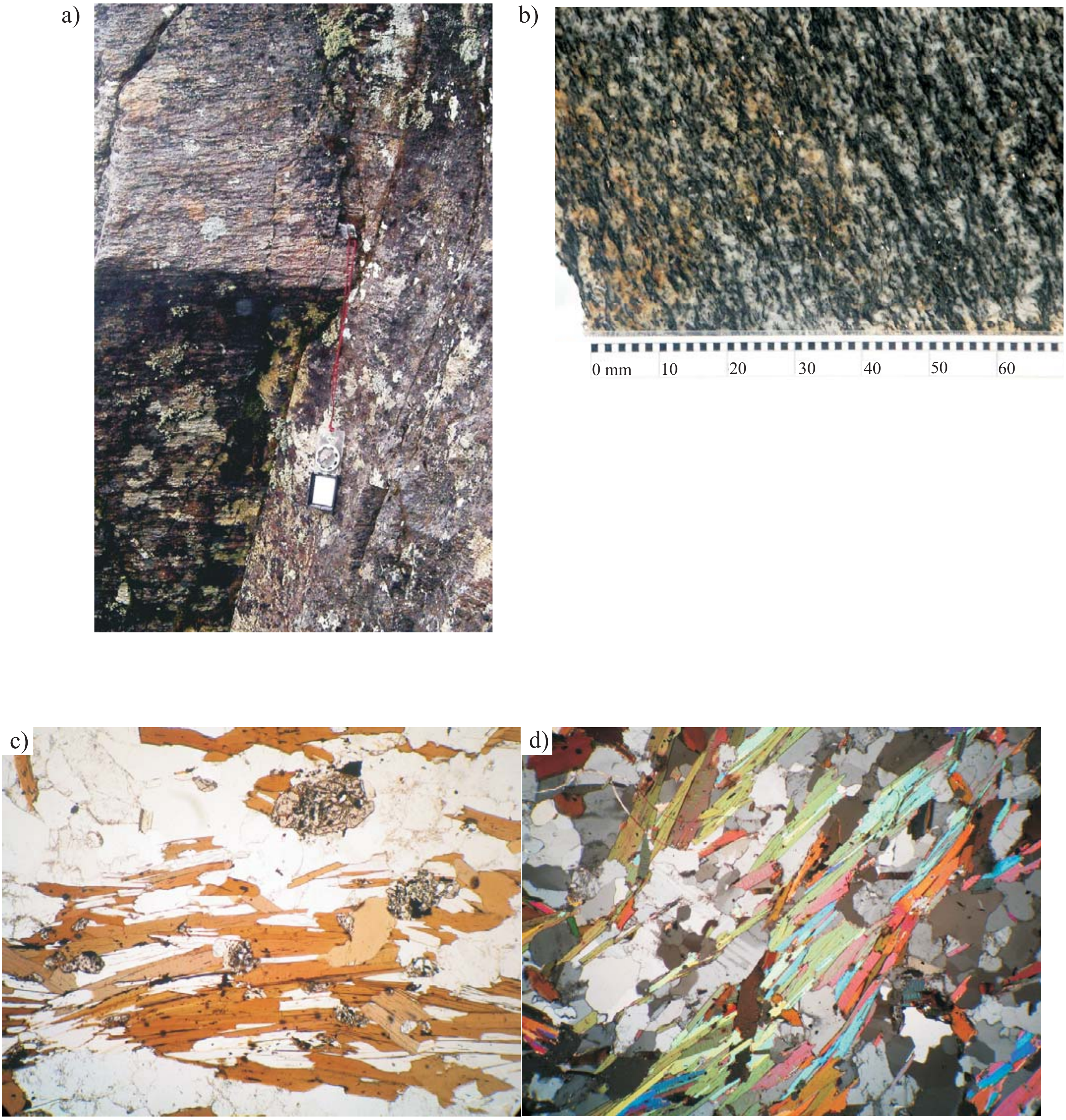


Figure 7: The Garbh Choire Semipelite Formation,
a) Massive gneissose semipelite displaying S3 crenulations on an S0/S1, adjacent to the Garbh Choire Fault, Garbh Choire, NN 49677134 (BGS registered photograph, P609269). Compass plate is 20 cm long.
b) Coarsely schistose/weakly gneissose texture in semipelite, NN 49327287 (sample CJB14).
c) Ragged garnet poikiloblasts associated with a penetrative biotite fabric. Width of field of view is 5 mm. (BGS thin section, N7975).
d) Penetrative mica fabric within a quartz- plagioclase matrix. Width of field of view is 5 mm. (BGS thin section, N7966).

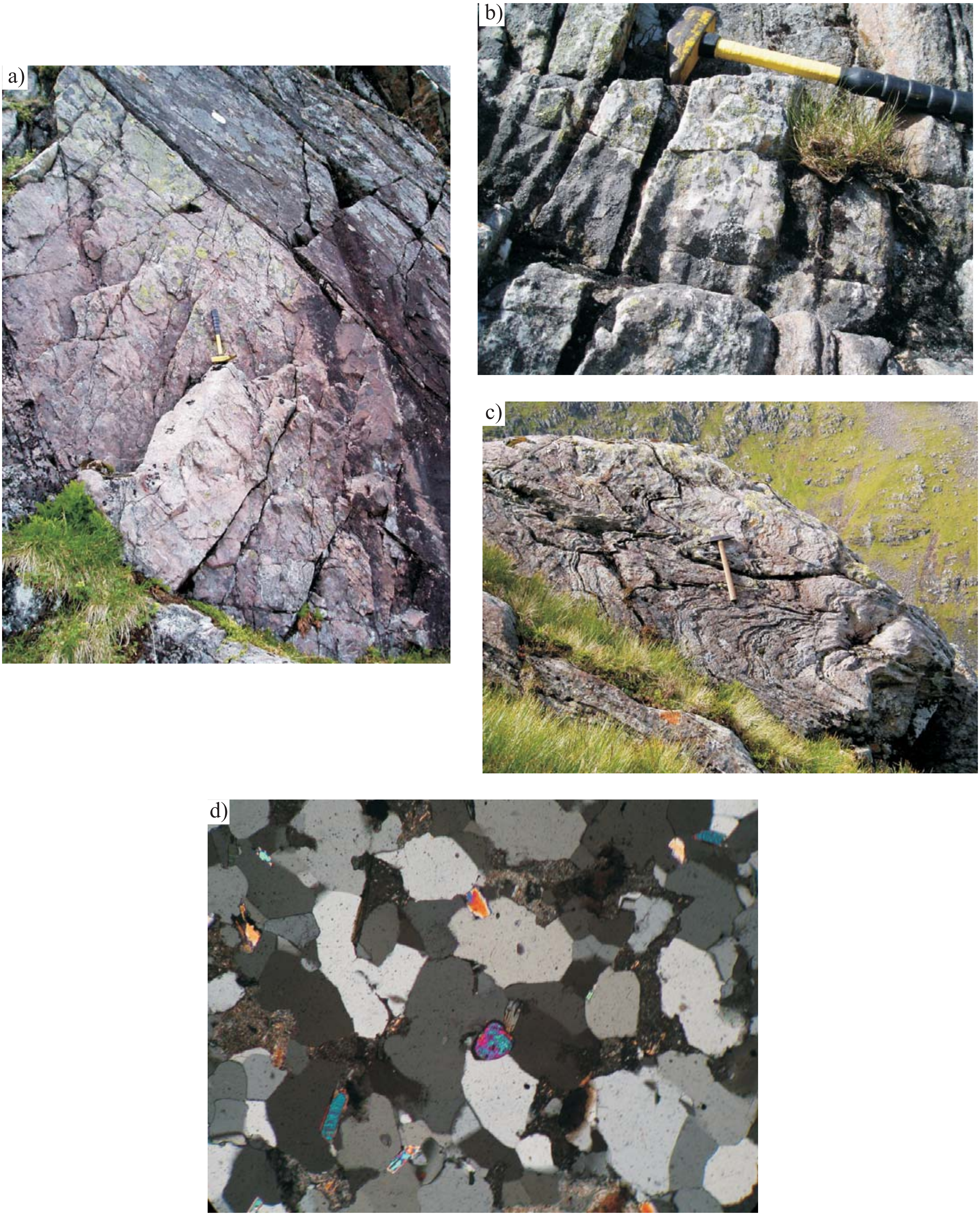


Figure 8: The Gaick Psammite Formation:
a) Inverted basal quartzite beds of the Gaick Psammite structurally underlying gneissose semipelites assigned to the Garbh Choire Semipelite Formation, Garbh Choire, NN 49687114 . Hammer is 40 cm long. (BGS registered photograph, P605198).
b) 'Typical' Gaick lithologies, flaggy feldspathic psammite interbedded with quartzite. Bealach a' Bheithe, NN 50657070. Hammer is 40 cm long. (BGS registered photograph, P599545).
c) Heterolithic feldspathic psammite and quartzite with minor D2 folds, Garbh Choire, NN 50137110. Hammer is 40 cm long. (BGS registered photograph, P605201).
d) Quartz-plagioclase psammite with stubby muscovite in a poorly developed fabric. Note the high relief detrital zircon. Width of field of view is 2 mm. (BGS thin section, N7977).

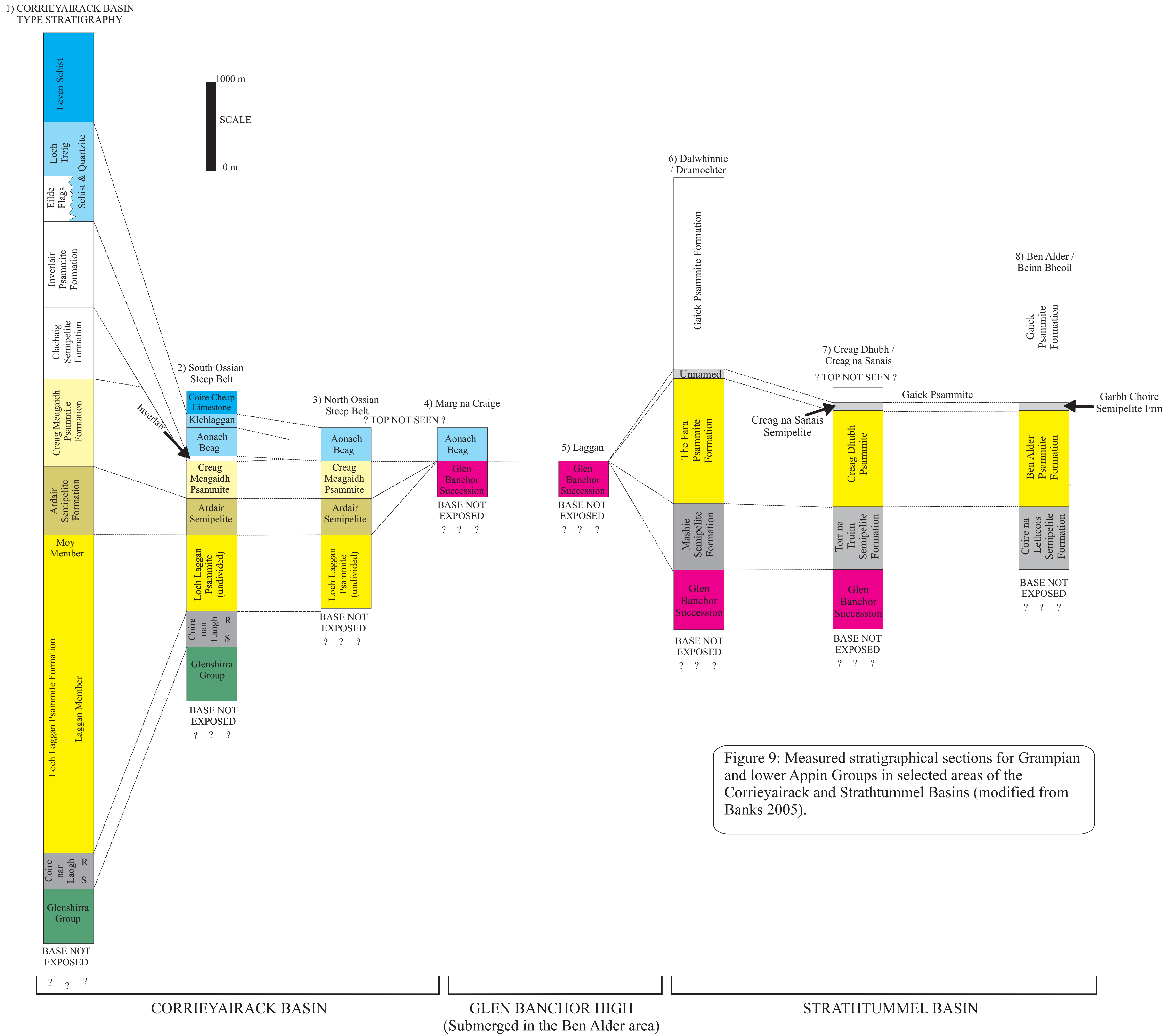


Figure 9: Measured stratigraphical sections for Grampian and lower Appin Groups in selected areas of the Corrieyairack and Strathtummel Basins (modified from Banks 2005).

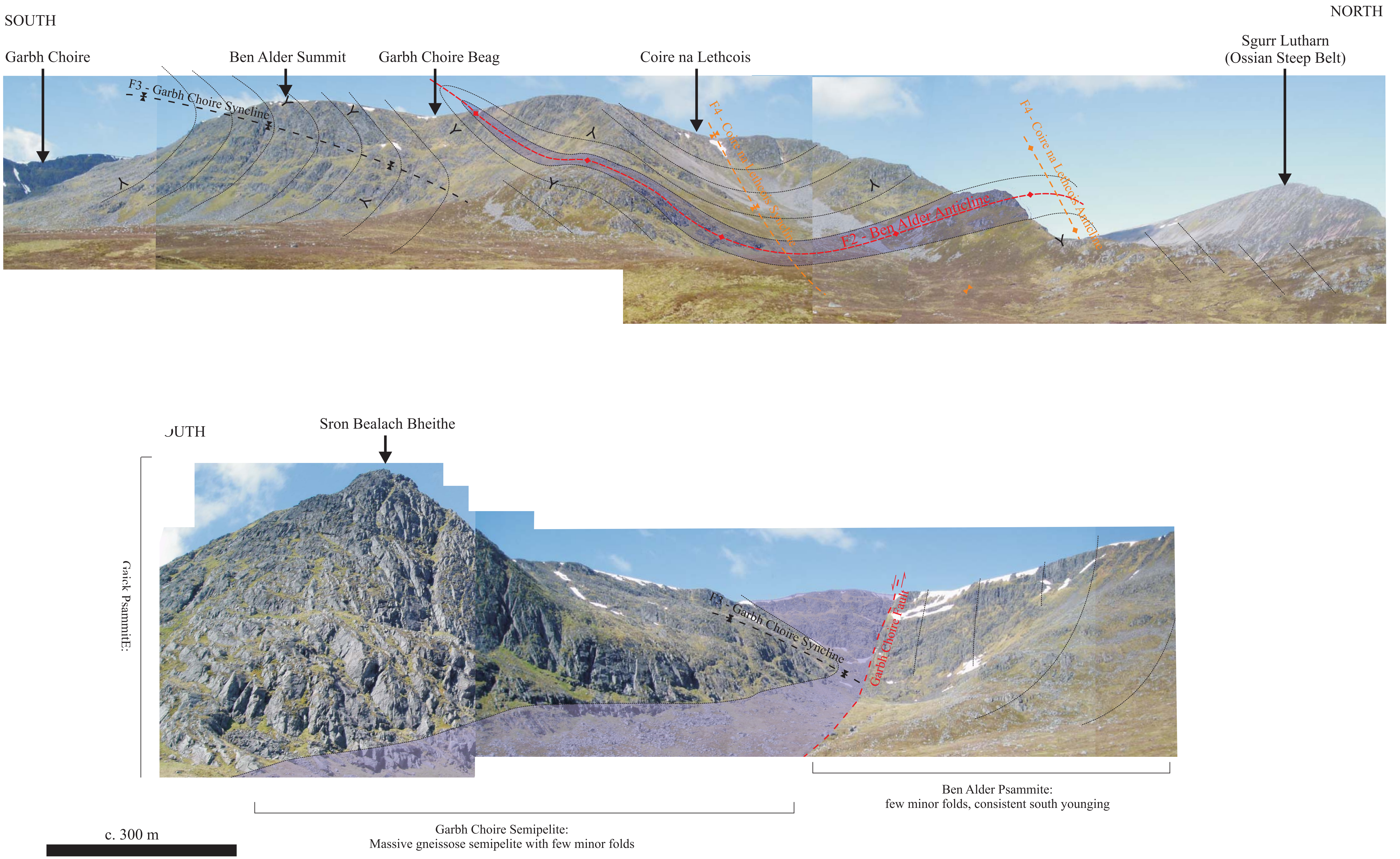


Figure 10: Panoramas of the eastern coires of Ben Alder. Bedding traces and the major fold structures are highlighted. The outcrop of the semipelite formations are shown in purple.
a) Coire na Lethcois to Ben Alder summit; b) Ben Alder summit to Sron Bealach Bheithe.

a)

b)

c)

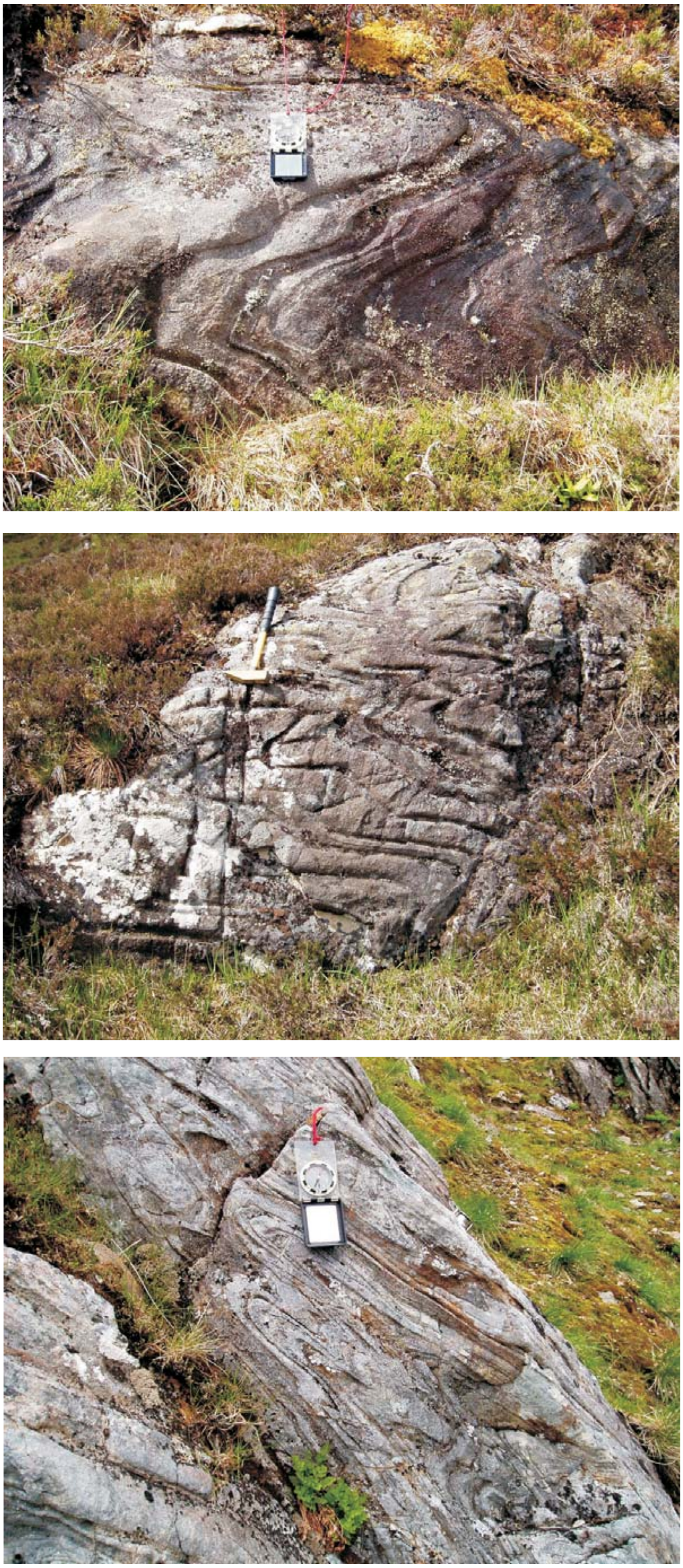


Figure 11: The style of F2 minor fold structures in different Grampian Group formations:
a & b) Larger wavelength folds in relatively homogenous psammites, Ben Alder Psammite Formation (NN 50947406 & 50817409 respectively). BGS registered photographs, P605172 and P605173).
c) Isoclinal folds in the heterolithic, striped beds of the Ben Alder Psammite Formation, Bealach Dhubh [NN 49147288]. BGS registered photograph, P605190.

Continued overleaf.

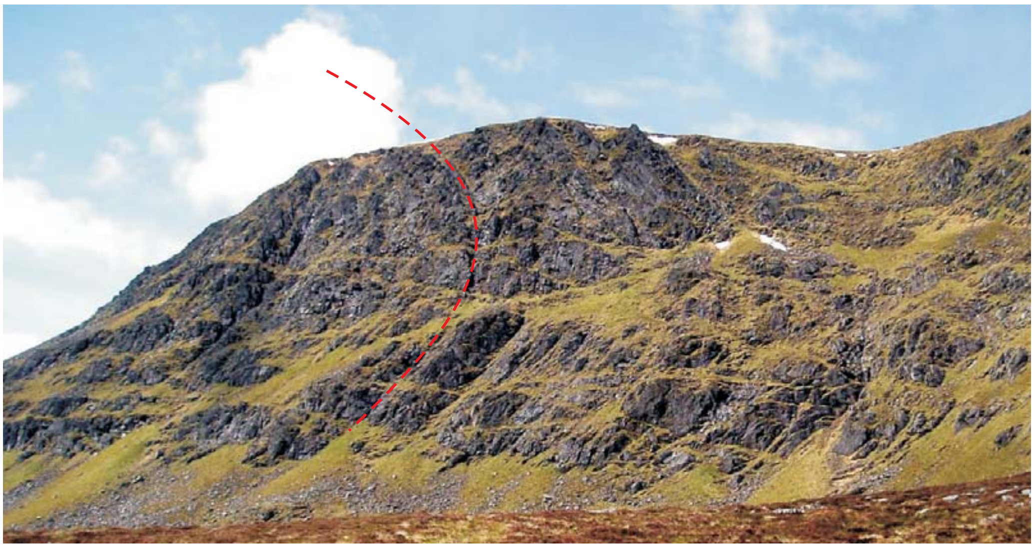
d)

e)

f)

Figure 11 continued:
d) Parasitic, tight F2 Z-fold in striped lithologies at the top of the Ben Alder Psammite Formation [NN 49147288]. BGS registered photograph, P605192.
e) Tight F2 folds of a quartzite band within the Garbh Choire Semipelite [NN 49147288]. BGS registered photograph, P605194.
f) F2 tight minor fold, refolded by upright F4 fold, basal Gaick Psammite Formation [NN 51647141]. BGS registered photograph, P605205.

a)



b)

c)

Figure 12: Examples of F3 folding:
a) Exposed closure of the F3 Garbh Choire Syncline, Garbh Choire. Cliffs are c. 200m. Taken looking west from NN 5100 7300. BGS registered photograph, P605156.
b) F3-corrugations on the lower limb of the F3 Garbh Choire Synform, Garbh Choire, NN 50207230. BGS registered photograph, P605160.
c) Tight F3 folding in the Garbh Choire Semipelite, Beinn Bheoil, NN 51647141. BGS registered photograph, P605205.

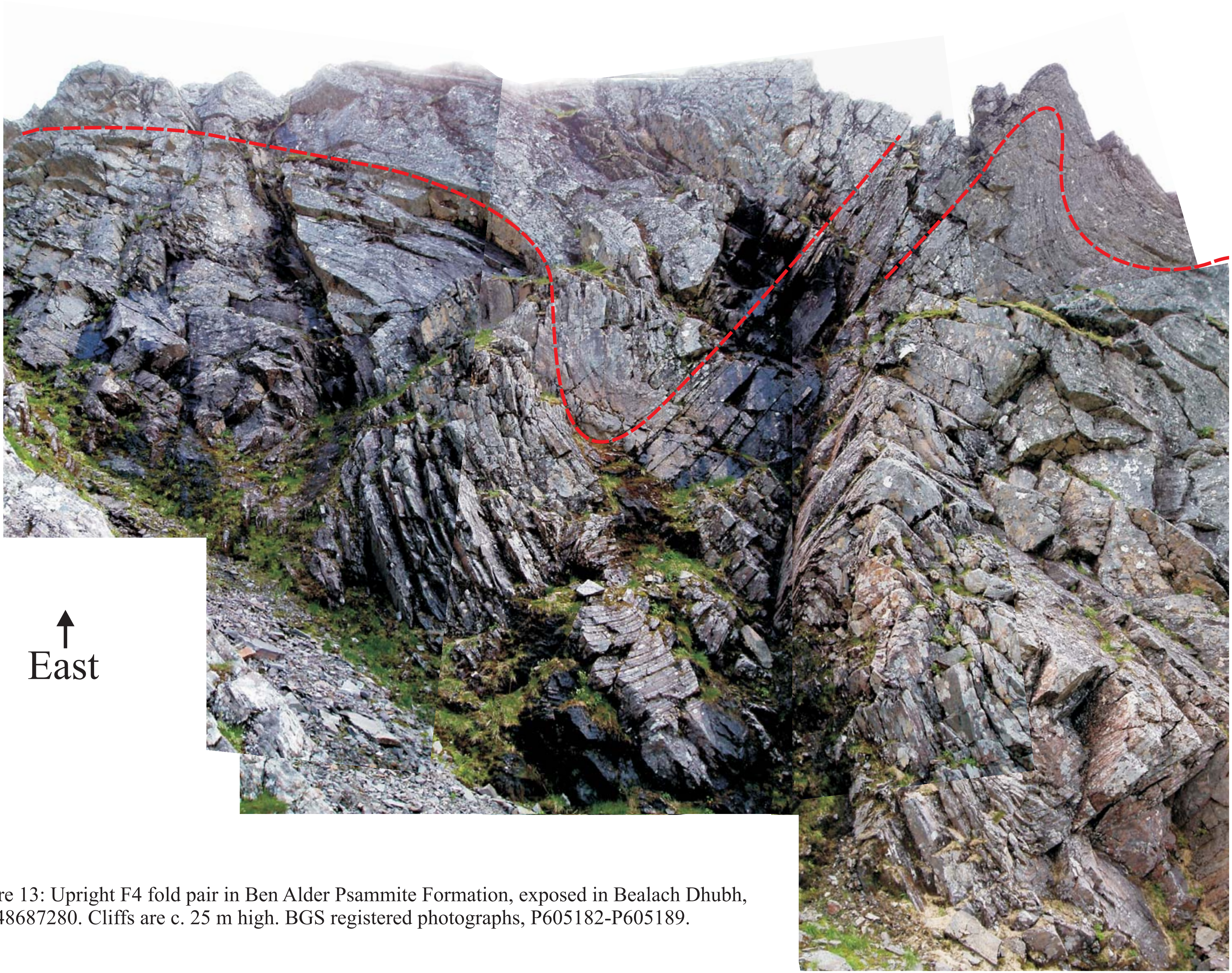
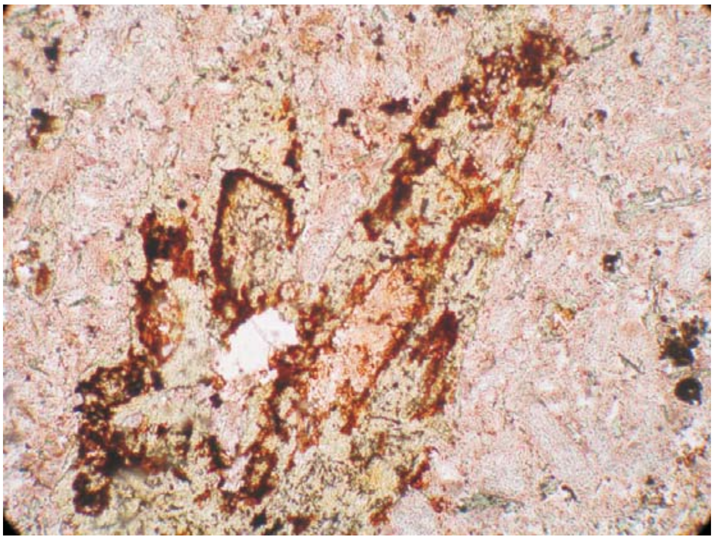


Figure 13: Upright F4 fold pair in Ben Alder Psammite Formation, exposed in Bealach Dhubh, NN 48687280. Cliffs are c. 25 m high. BGS registered photographs, P605182-P605189.

a)

b)



c)

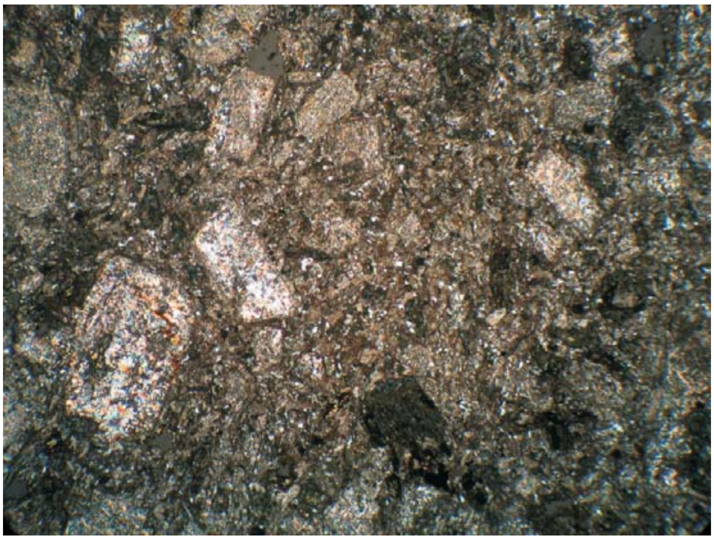


Figure 14: Minor intrusions in the Ben Alder area:
a) Concordant, granitic pegmatite sheets in the Ben Alder Psammite Formation, NN 50357163. BGS registered photograph, P605162.
b & c) Photomicrographs of amphibole (b) and plagioclase (c) phenocrysts within a highly altered lamprophyre, Garbh Choire, NN 49637130. BGS thin section, N7967.