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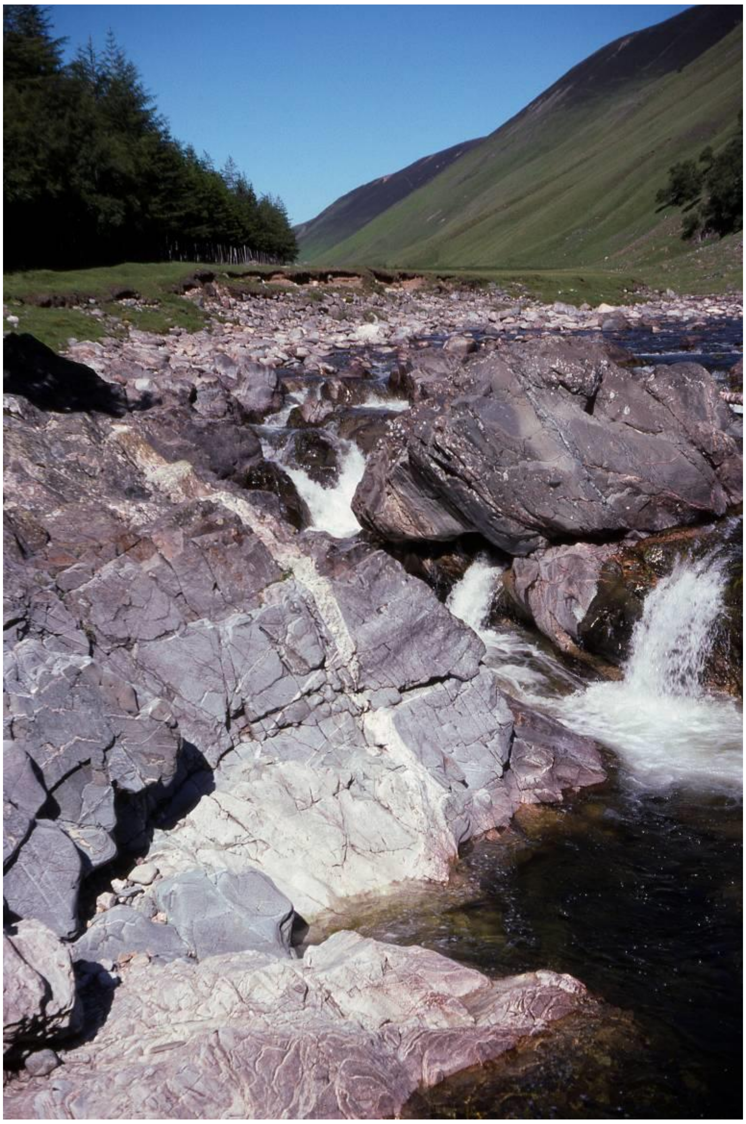
Geology of the Newtonmore – Ben Macdui district

Geology and Landscape

Open Report OR/11/055



BRITISH GEOLOGICAL SURVEY

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Front cover

James Hutton's Locality above Dail-an-Eas Bridge [NN 9388 7467], looking north-east up Glen Tilt whose trend is largely controlled by the Loch Tay Fault. Here Hutton observed granite veins cutting and recrystallising Dalradian metasedimentary rocks and deduced that granite crystallised from a hot liquid.

BGS Imagebase P601616.

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Bedrock and Superficial Geology of the Newtonmore – Ben Macdui district: Description for Sheet 64 (Scotland)

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Keyworth, Nottingham British Geological Survey 2011

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Foreword

This report, and the 1:50 000 Series geological maps that it describes, is the published product of a programme funded by central Government to improve the understanding of the geology of the UK. The information that these publications provide underpins the exploration of earth-based resources, assessment of natural hazards and ground conditions, and land-use planning. A major part of this report provides comprehensive knowledge and understanding of the geological, geomorphological and environmental changes that have occurred over the past few million years, and which were responsible for the present distribution of superficial deposits and landforms. The Newtonmore and Ben Macdui districts lie within the Cairngorm National Park, which is one of the most popular tourist locations in Britain. This places particular focus on land-use and development decisions within the area, but also enhances opportunities for developing geotourism and academic research. The description of the bedrock geology reviews the earlier published and unpublished work on the area while the Quaternary section is essentially the first comprehensive description of the region.

Acknowledgements

The accompanying bedrock 1:50 000 geological maps were compiled mainly from 1:10 000 and 1:25 000 maps produced by B Beddoe-Stephens, J E Cavill, A Crane, T P Fletcher, S Goodman, M Krabbendam, A G Leslie, S Robertson, C G Smith, M Smith, R A Smith and D Stephenson. In addition information on the Cairngorm Pluton was taken from published work of T N Harrison and information on the Grampian Group lithostratigraphy and sedimentology was taken from the PhD thesis of C J Banks.

The Quaternary geology of the 1:50 000 maps was compiled from 1:10 000 and 1:25 000 maps of the superficial deposits produced mainly by N R Golledge and J W Merritt, with contributions from B Beddoe-Stephens, T Bradwell, J E Merritt, T P Fletcher, A J Highton, S Robertson, M Smith, R A Smith and D Stephenson.

The first draft of this Sheet Description was written by R A Smith (Bedrock) and J W Merritt (Quaternary), with contributions from N R Golledge, A G Leslie, M Krabbendam and D Stephenson. Information on the concealed geology was provided by B C Chacksfield and on the petrology by E R Phillips. The final draft was prepared by R A Smith and J W Merritt and scientifically edited by N R Golledge and D Stephenson.

NOTES

The word 'district' is used in this description to refer to the area covered by Sheets 64W (Newtonmore) and 64E (Ben Macdui) of the 1:50 000 geological map of Scotland. The Newtonmore and Ben Macdui maps are published separately, as Bedrock and Superficial Deposits with simplified bedrock editions.

The Newtonmore and Ben Macdui sheets are the western and eastern halves respectively of the area which was formerly covered by Sheet 64 (Kingussie) of the Geological Map of Scotland.

National Grid references in the text are given in the form [NN 951 744] depending on which 100 km square they refer to (NN, NO, NH, or NJ). Numbers proceeded by S or N refer to the Scottish BGS sliced rock/thin section collection held at BGS, Edinburgh.

BGS services and products relating to the district are listed in the Information Sources.

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Summary

This report provides an account of the geology of the Newtonmore-Ben Macdui district in the Grampian Highlands of Scotland, which extends from the Cairngorm massif in the north-east, west across to the Upper Spey valley and south into the upper parts of Glen Tilt and Glen Fearnach. The district is nearly all remote countryside with steep-sided glens between upland plateaus with relatively few distinct mountain peaks. The entire area lies within the Cairngorm National Park and much of the land is covered by large estates run for game conservation and recreational sports.

The bulk of the rocks are metasedimentary and most of these are assigned to the Neoproterozoic Dalradian Supergroup (Figure 1). In the north-west near Newtonmore, a ridge or 'palaeohigh' of older metasedimentary rocks, the Glen Banchor Subgroup, is considered to lie below the Dalradian. The Dalradian Supergroup forms a thick succession of originally clastic, carbonate and pelitic rocks. Much of the latter is graphitic and pelagic in origin. The metasedimentary rocks were intruded by relatively minor basic igneous and granitic bodies as the Rodinian palaeocontinent broke up.

At about 470 Ma the Laurentian continental margin collided with an island arc causing the Grampian Event of the Caledonian Orogeny. The orogeny is mainly manifest in four deformation phases which included early large nappe-like folds, ductile shear-zones and prograde Barrovian regional metamorphism. Most of the rocks in this district lie within the kyanite zone but, because most of the rocks are siliceous, this index mineral is scarce. Semipelitic rocks are locally migmatitic. The earlier Precambrian metamorphism in the Glen Banchor Subgroup is overprinted by the Grampian metamorphism.

In Siluro-Devonian time (Caledonian), the Cairngorm and Glen Tilt plutons were emplaced within the nappe pile together with other minor silicic to basic igneous intrusions of similar age. Where country rock composition was suitable, contact metamorphic aureoles are observed adjacent to the large intrusions. The region continued to be uplifted and cut by late-Caledonian to Carboniferous faulting. Several major faults, such as the Loch Tay Fault, cross the district on NE- to NNE trends and have overall sinistral displacements.

The geological record during the Tertiary (Palaeogene and Neogene periods) is largely one of slow landscape evolution by subaerial erosion, intermittent regional uplift and the development of deep weathering profiles. The Paleocene Epoch was marked by considerable volcanic activity along the western seaboard of Scotland. Uplift of as much as 1.5 km was associated with this event, causing an eastward tilting of peneplains formed during the Late Cretaceous and earlier. Some valleys in the district, such as the Dee-Geldie Water and Tarf Water, may have first become established on these tilted peneplains. A warm, humid climate prevailed until the late Miocene, during which time the effects of chemical weathering penetrated deeply below the land surface forming clayey saprolites, pockets of which remain in the district. Mechanical weathering became increasingly intense during the Pliocene and early Pleistocene epochs as the climate deteriorated and granular disintegration occurred.

During the Quaternary Period (i.e. the last 2.6 million years) the Scottish mainland has experienced numerous glacial episodes, but only the last widespread glaciation, the Main Late Devensian (MLD), has left an appreciable sedimentary record. Many geomorphological features, however, such as the Lairig Ghru, have clearly evolved during several glacial episodes. The MLD glaciation began between 32 and 28 ka before present day (BP), when the region became overwhelmed entirely by ice. There is growing evidence from north-west Europe that the Last Glacial Maximum (LGM) occurred relatively early in the Late Devensian, before 22 ka BP. A

period of glacial retreat followed before significant readvances occurred after 18.4 ka BP, particularly involving coastal ice streams and possibly including a readvance in the Cairngorms.

Deglaciation commenced in a cold, arid environment and parts of the Cairngorms probably witnessed several thousand years of ice-free, periglacial conditions before the onset of rapid warming at about 14.7 ka BP, the beginning of the Windermere (Lateglacial) Interstadial (WI). The abrupt amelioration in climate occurred when temperate waters of the Gulf Stream returned to the sea off the western coasts of the British Isles. River terraces and alluvial fans formed across the district by paraglacial processes, sweeping away loose glacial debris before soils became stabilized by vegetation. An oscillatory climatic deterioration occurred during the WI and it is likely that glaciers had already started to build up in the mountains before more sustained cooling began at about 12.9 ka BP, at the start of the Loch Lomond Stadial (LLS) (Younger Dryas). Glaciers undoubtedly existed in the district during the LLS, but controversy remains as to their extent and whether any remnants of the MLD ice sheet survived during the WI.

The Holocene began abruptly at about 11.7 ka BP when the warm Gulf Stream current became re-established, providing an ameliorating influence on the climate of the British Isles. Intense erosion would have occurred at first on the bare ground before vegetation became established and soils developed. At first braided rivers flowing across gravelly floodplains were common, but they later stabilised into the mainly single-thread and locally meandering streams of the present day.

1 Bedrock Geology

1.1 INTRODUCTION

The Newtonmore-Ben Macdui district (Figure 1) includes the southern parts of the Cairngorm and the Monadhliath mountains extending south across the Gaick plateau into the Forest of Atholl and upper Glen Tilt. It constitutes a rugged, sparsely populated terrain with rounded hills and ridges generally rising to 600 – 900 m OD. In the south-east of the district the quartzite ridges such as Beinn a' Ghlo and Carn an Righ rise above 1000 m. Mountains only rise above 1200 m within the granitic Cairngorm massif, where Ben Macdui forms the highest summit at 1309 m. Newtonmore and Kingussie are the main centres of population and lie in the upper Spey valley which forms the conduit for the main road and rail links to Inverness.

The bulk of the rocks in the district are Neoproterozoic metasedimentary strata, deformed and metamorphosed during the Grampian Event of the Caledonian Orogeny at about 470 Ma and cut by Siluro-Devonian intrusive rocks. The oldest rocks, in the north-west of the district (Figure 1), are the *Glen Banchor Subgroup* which was also affected by a tectonothermal event at about 800 Ma.. Formerly the Glen Banchor succession of Smith et al. (1999), these rocks are now formally assigned subgroup status in the Badenoch Group. Badenoch Group rocks are overlain by the Dalradian Supergroup and there appears to be an orogenic unconformity between the two; although it is largely obscured by ductile shearing. The Glen Banchor Subgroup, comprising gneissose psammites and semipelites, has uncertain Knoydartian or Moinian affinities and its base is not exposed. Isotopic studies indicate that the comparable Dava Subgroup to the north was affected by pre-Caledonian (c. 840-800 Ma) events (Noble et al., 1996; Highton et al., 1999).

The Dalradian Supergroup (Harris et al., 1994) is an extensive, mainly metasedimentary, succession ranging from Neoproterozoic to Arenig in age (Soper et al., 1999, Tanner and Sutherland, 2007). It was deposited on the Laurentian continental margin during and following the break-up of the supercontinent Rodinia. Only the lower parts, i.e. the Grampian, Appin and Argyll groups, crop out in the district. The basal Grampian Group comprises a thick succession of siliciclastic deposits that are mainly psammitic, but with subsidiary intervals of semipelite. Locally, the preservation of sedimentary structures allows a coherent lithostratigraphy to be established. This lithostratigraphy has been extended across postulated depositional rift basins (Banks, 2005; Leslie et al., 2006), so that the equivalents of the Corrieyairack and Glen Spean subgroups can be identified to the south-east of the major Ericht-Laidon Fault (Figure 1).

The extensive Gaick Psammite Formation is the predominant component of the Glen Spean Subgroup and was deposited in a shallow marine environment. It now lies in a stack of recumbent Caledonian folds facing sideways to the south. The broad expanse of Gaick Psammite becomes more steeply inclined south-eastwards and passes stratigraphically up into the basal beds of the Appin Group near the major NE-trending Loch Tay Fault (Figure 1). This distinct lithological change is obscured by a high strain zone, the Boundary Slide, related to the earlier recumbent folding. To the south-east of the slide and the Loch Tay Fault, all the subgroups of the Appin Group are represented although the basal Lochaber Subgroup appears to be condensed and/or attenuated (Figure 1). The latter subgroup has been recognised in the Atholl area as the Glen Banvie Formation and farther north, in the Dee catchment as the Tom Anthon Mica Schist Formation. The succeeding Ballachulish Subgroup includes a sequence ranging from prodelta graphitic pelite through turbiditic into coarse delta-top quartzitic beds capped by phyllites and metalimestones. Substantial thicknesses of quartzite, which are more resistant to erosion, form mountainous ridges such as Beinn a' Ghlo. The overlying Blair Atholl Subgroup (Figure 1) comprises graphitic pelites and metalimestones with cleaner semipelites, psammites and carbonates towards the top as deposition continued in more oxygenated waters. At the base of the Argyll Group in Glen Tilt, impersistent glacigenic boulder beds lie within the succeeding quartzitic Islay Subgroup. This subgroup includes the Schiehallion Quartzite as exposed in Glen

Tilt, and Creag Leacach Quartzite in Glen Fearnach, both of which are relatively thin developments of the subgroup compared to the Schiehallion district. The overlying Easdale Subgroup begins with graphitic pelites indicating a gradual deepening and a deeper water character to the basin. The overlying calcareous schists and psammites signal a gradual shallowing.

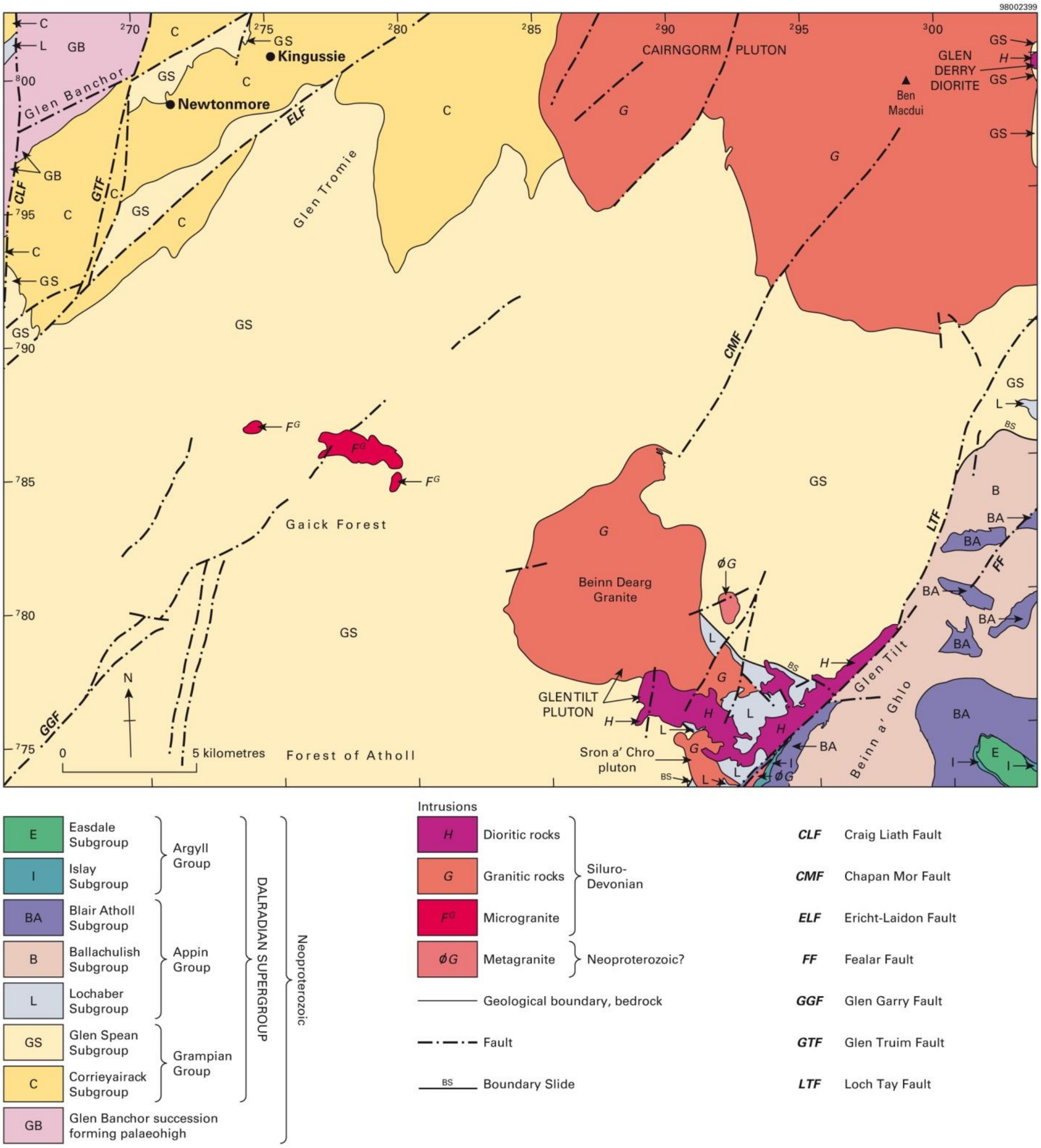

Figure 1: Outline Bedrock Geology of the Newtonmore – Ben Macdui district (Sheet 64W & E)

As the basin continued to expand during latest Neoproterozoic times, basic volcanic rocks erupted and minor basic sills/dykes and granitic sheets were intruded. These rocks were all deformed during the Caledonian Orogeny, dominated by the Grampian (Ordovician) deformation phase, which formed the Gaick Fold Complex and the Tay Nappe (Leslie et al., 2006). The frequent changes in lithology and competence in the Appin and Argyll groups gave rise to the numerous folds accompanied by attenuation and sliding/slicing of the lithostratigraphy. The orogeny resulted in Barrovian regional metamorphism of the nappe pile and the rocks presently exposed lie essentially within the kyanite zone but few lithologies have suitable mineral compositions to produce metamorphic index minerals. Locally semipelites are migmatitic. The Caledonian Orogeny terminated with extensive calc-alkaline plutonic magmatism that produced the Cairngorm and Glen Tilt plutons and numerous minor intrusions during late Silurian to early Devonian time.

The concluding period of rapid uplift and erosion in Devonian times was accompanied by brittle movements focussed on the major NE-trending Ericht-Laidon Fault and Loch Tay Fault systems.

1.2 PREVIOUS WORK

The area covered by this explanation includes classic areas for the study of geology ever since 1785 when 'the father of modern geology' James Hutton made an excursion up Glen Tilt, (Figure 1) searching for proof of his 'theory of the earth' (Hutton, 1788, 1794; Craig et al., 1978; Stephenson, 1999). He had been invited by the Duke of Atholl to accompany him in the shooting season into Glen Tilt (Playfair, 1805). To the north-east of Forest Lodge Hutton found metasedimentary rocks invaded, veined and recrystallised by granite, indicating that the latter intruded as a hot magma. These observations attracted other geologists such as Lord Webb Seymour (1815) to the glen and MacCulloch (1816) went so far as to report 'having blown up a considerable portion of the rock, I am enabled to say that it is of a laminated texture throughout'. These were already considered classic geological localities.

Nicol (1844; 1863) gave his overall opinion on Central Highland Geology. Later in the 19th century Murchison and Geikie (1861) traversed the Highlands and drew sections through Glen Tilt. They noted how the quartz-rocks would originally have been sandstones and granular limestones were once calcareous mudstones. Early in the 20th century the Geological Survey workers (Barrow et al., 1913) referred the bulk of the psammites (i.e. Grampian Group) to the 'Moine Series' and the quartzite, limestone and schist succession to a Perthshire or Central Highland Series, which was one thin sequence intensely interfolded. The 'Newer' granite masses of Glen Tilt and the Cairngorms were distinguished from 'Older', foliated biotite-granites or augen gneiss sheets.

Bailey (1925) recognised that the metasedimentary Banvie Burn succession is separate from the rest of the Perthshire succession. However, the quartzite (of the Perthshire succession) on Beinn a' Ghlo was miscorrelated with that at Schiehallion (Bailey, 1925; Pantin, 1961). Thomas (1965; 1979; 1980) described the Iltay Boundary Slide between the psammitic Atholl Nappe and the Tay Nappe. The Atholl Nappe was rooted to the north-west in a primary steep belt near Newtonmore and folded over the secondary Drumochter Dome to the south-east. The presence of the Ballachulish Subgroup east of Glen Tilt was recognised (Smith and Harris, 1976) and the geology around the Beinn a' Ghlo range was revised by Smith (1980).

The debate on the status of the gneissose rocks in the north-west of the area was started when Piasecki and van Breemen (1979) described an older Central Highland 'Division' basement and a younger cover (regarded an equivalent of the Grampian Group) separated by a ductile shear termed the Grampian Slide. Piasecki (1980) interpreted the slide as a deformed unconformity containing pegmatites dated at about 720 Ma (Knoydartian) and correlated part of the basement rocks with the Glenfinnan Group of the Moine Supergroup in the Northern Highlands. Subsequently the basement rocks were referred to as the Central Highland Migmatite Complex (Highton, 1992; Harris et al., 1994; Stephenson and Gould, 1995) but more recently they have been referred to the Glen Banchor (Figures 1 & 2) and Dava successions (Smith et al., 1999). The latter workers also described the Grampian Group successions in the Corrieyairack and Strathtummel basins either side of a Glen Banchor 'basement high'.

Studies of the Cairngorm Pluton (Figures 1 & 4) were made by Harry (1965) and Harrison (1986, 1987). Harry (1965) concluded that the pluton was a stock-like intrusion and distinguished 'Porphyritic Granite' on Carn Ban Mor and beside Loch Einich from the 'Main

Granite'. Harrison (1986, 1987) recognised three textural facies within the Main Granite and four other phases within the pluton. The relationships of the granites and diorites in the Glen Tilt Pluton (Figure 1) have been described (Deer, 1938, 1950, 1953; Mahmood, 1986; Beddoe-Stephens, 1999). Beddoe-Stephens (1999) concluded that the biotite granodiorite/granite was emplaced early in the intrusive sequence and that localised melt remobilisation and back veining accompanied diorite emplacement.

The foliated 'Older'granites, including the one east of upper Glen Tilt (Clachghlas), were considered to have been emplaced between D2 and D3 by Bradbury et al. (1976). More recent dating (Rodgers et al., 1989) and studies of the similar Ben Vuirich Granite (Tanner and Leslie, 1994: Tanner; 1996; Tanner et al., 2006) indicated that the analogous foliated granites are probably pre-tectonic intrusions.

Field and isotopic studies by Piasecki and van Breemen (1983) were carried out on pegmatites in shear zones within the Glen Banchor Subgroup (their Laggan Inlier of the Central Highland Division). They concluded that the quartz and pegmatite veins were segregations formed during ductile shearing under amphibolite-facies conditions. Muscovites from the veins in the Glen Banchor Subgroup yielded ages between about 750 and 700 Ma (Piasecki and van Breemen, 1983). The mineralogy and geochemistry of the shear zones associated with the Glen Banchor Subgroup were described by Hyslop and Piasecki (1999).

The recently published papers based on work by the geological survey have elucidated the basin architecture in the northern Grampian Highlands including the Glen Banchor Subgroup (Smith et al., 1999) and recognised that the Appin and Grampian groups onlap on to the Glen Banchor 'high' (Robertson and Smith, 1999). The timing and P-T conditions of the regional metamorphism have been discussed (Phillips et al., 1999). The lithostratigraphy and structure of the Gleann Fearnach area (Figure 3) has been described in a memoir on the adjacent Glen Shee district (Crane et al., 2002). They recognised that the Carn an Righ, Carn Dallaig, Glen Loch and Glen Lochsie slides were folded around the Meall Reamhar Synform (Figure 7). They also demonstrated that, as a result of regional metamorphism of the mafic rocks, garnet amphibolites in Gleann Mor and Gleann Bheag lay to the north of garnet-epidote amphibolites. Thermobarometry calculations on the garnet amphibolite indicated temperatures of 540-590°C at 8.6 Kbar.

In the Gaick area, the fold complex (Figures 5 & 6) in the Grampian Group psammites has been related to the Tay Nappe structure (Leslie et al., 2006). A sedimentological and provenance study of the Grampian Group in the northern Grampian Highlands (Banks, 2005) has described its depositional facies and established the links between the Corrieyairack and Strathtummel basins.

1.3 LITHOSTRATIGRAPHY

1.3.1 Glen Banchor Subgroup of the Badenoch Group

This metasedimentary succession, up to 1 km thick, including distinct gneissose and migmatitic lithologies (Smith et al., 1999), is exposed along Glen Banchor to the west of Newtonmore (Figure 2) and continues northwards on to the Tomatin Sheet 74W (British Geological Survey, 2004) and south-westwards on to the Dalwhinnie Sheet 63E (British Geological Survey, 2000a) as part of an antiformal structure. It was previously referred to the 'Central Highland Division' (Piasecki and van Breemen, 1979; 1983; Piasecki and Temperley, 1988) although its definition is not precisely the same. This is because the development of migmatitic and gneissose rocks depends largely on geochemical composition and cannot form the basis of discriminating basement-cover relationships. In Glen Banchor, Piasecki and Temperley (1988) proposed a tripartite division with a Lower Siliceous 'group', a Middle Pelitic 'group' and an Upper Psammitic 'group'. They considered that the succession is separated from the Grampian Group by the Grampian Slide which incorporates sheared pegmatites dated at c. 750 Ma (Piasecki and van Breemen, 1983). However, since the base of the succession is not exposed and because the succession is highly tectonised and metamorphosed, its internal stratigraphy and true relationship with the Grampian Group are not known. No sedimentary structures are preserved within it, but despite the sheared and faulted relationship with the Grampian Group, the rocks are considered to be part of an older Neoproterozoic shallow marine succession unconformably overlain by the Grampian Group (Robertson and Smith, 1999; Banks, 2005). It was probably deposited before c. 850 Ma and the youngest concordant detrital zircon from it has been dated at 900 +/- 17 Ma (Cawood et al., 2003).

The succession comprises interlayered semipelite and K-feldspar-bearing banded psammite, some of which is distinctly gneissose. Subordinate quartzites are commonly associated with a transition from psammitic to semipelitic units within the succession (Figure 2). Although there are no way-up indicators, there appears to be a sequence from, structurally lowest, interbedded psammite and semipelite into striped and gneissose semipelite and quartzite followed by a psammitic unit.

The striped semipelites and psammites are well exposed on the northern flank of Glen Banchor, on Creag Liath [NH 665 005] and on Creag an h-Iolaire [NH 675 015], where interlayered psammite and semipelite, quartzite and striped semipelite crop out around a large synform plunging north-north-east.

In places the sequence contains migmatitic or flaggy and micaceous intervals. The subordinate non-gneissose, predominantly psammitic, rocks are K-feldspar rich and petrographically similar to the feldspathic psammites that dominate the Grampian Group (Phillips et al., 1999). Massive garnet-muscovite semipelite or schist intervals locally contain prominent burgundy-coloured garnets and pass into semipelite with thin layers of micaceous psammite (Plate 1).

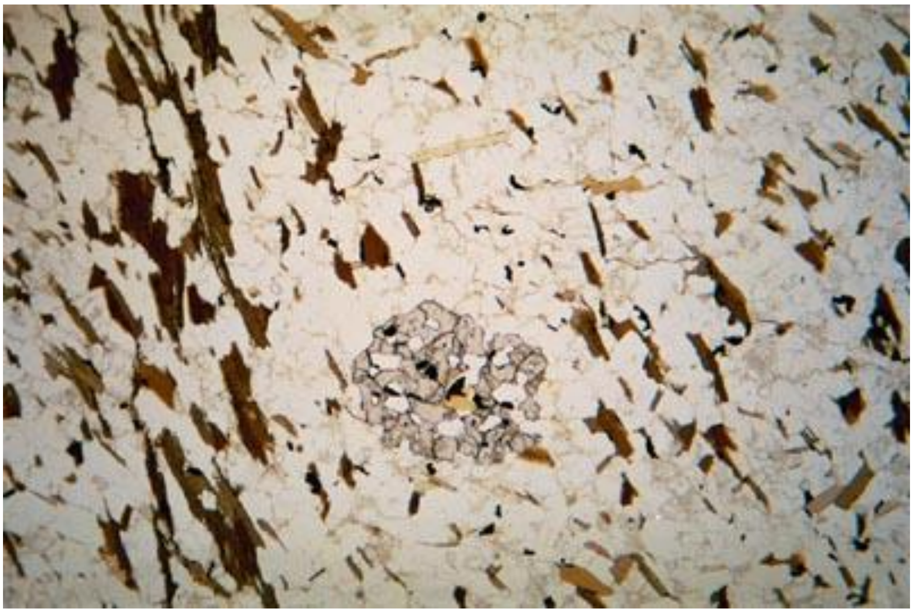

Plate 1: Photomicrograph of a micaceous psammite from Allt a' Chaorainn, Glen Banchor, two miles north-west of Newtonmore showing brown biotite mica flakes and a garnet (centre) within a pale quartzo-feldspathic groundmass. BGS Petrology sample no. S99651. BGS Imagebase No. P515219

Some semipelites contain coarse muscovite porphyroblasts and these have locally been found to contain relict kyanite. The principal foliation in the Glen Banchor Subgroup is generally a composite S0/S1 or, commonly in semipelitic lithologies, an S1/S2 foliation of biotite ± muscovite. In ductile shear-zones the earlier fabrics are transposed or replaced by a locally phyllonitic, muscovite-bearing, S2 shear-fabric. Sheared semipelites also contain fibrous sillimanite within foliae (Plate 2, Sample no. S99663 Creag an Loin NH 6997 0058).

Plate 2: Photomicrograph of a sheared semipelite from Creag an Loin, two miles north-west of Newtonmore containing grey fibrolite foliae parallel to aligned laths of brown biotite in a fine-grained quartzo-feldpathic matrix. BGS Petrology sample no. S99663. BGS Imagebase No. P515224

Trace amounts of fibrolite were also noted (S99692) in the highly foliated garnet-muscovite schistose semipelite from Allt Coire Shairaidh [NH 6698 9800].

In Coire an Eich [NN 6683 9980] massive white feldspathic quartzite with lenses of garnet-zoisite-tremolite-bearing calcsilicate rock as well as interbanded quartzite and siliceous psammite are exposed. Distinctive gneissose quartzites also contain K-feldspar and have a more massive appearance.

The Glen Banchor and Dava subgroups have been identified as basement to the Dalradian Supergroup (Smith et al., 1999) but the inferred unconformity is affected by ductile shearing. Deformation of the succession has been described in the structural section. Within these basement subgroups, blastomylonites developed along ductile shear-zones and are associated geochemically with deformed pegmatites (Hyslop and Piasecki, 1999). These pegmatites were thought to have formed during the ductile shearing at around 750 Ma (Rb-Sr muscovite ages, Piasecki and van Breemen, 1979) and are considered to have been formed during the Knoydartian Orogeny. Piasecki and van Breemen (1983) made a detailed study of tectonic schists with sheared pegmatite veins within the Glen Banchor Subgroup (their Central Highland Division) at a locality on Creag Shiaraidh [NN 663 978] in Glen Banchor (Figure 2) and another on Craig Blargie on Sheet 63W. At Creag Shiaraidh, muscovite books from deformed veins, quartz-feldspar aggregates and whole-rock tectonic schists were dated isotopically using Rb/Sr methods. The ages ranged from 739+/-8 Ma to 702+/-8 Ma with an overall regression age of 727+/-17 Ma. The micas from syn-D2 and late-D2 veins could not be separated isotopically and this was taken as support for the interpretation that the veins and the tectonic schists developed together due to interaction between the schists and fluids active in the slide zones (Piasecki and van Breemen, 1983). U-Pb analyses of monazites from large pegmatites in similar tectonic situations at A' Bhuideanaich and Lochindorb to the north yielded ages of about 800 Ma (Noble et al., 1996). U-Pb dating of single zircon grains within Dava Subgroup migmatites near Slochd yielded an age of 840 +/-11 Ma (Highton et al., 1999) and this has been interpreted as evidence of a Knoydartian tectonothermal event, which did not affect the Dalradian Supergroup. Although the Glen Banchor Subgroup is cut by a Caledonian pegmatitic sheet-complex there is no record of earlier migmatite in Glen Banchor rocks, which are overprinted by younger Caledonian fabrics.

Studies of U-Pb isotopes in detrital zircons from the Glen Banchor Subgroup have shown that the source rocks can be grouped into several age ranges; at about 1800, about 1650 and a smaller group about 1100 Ma (Cawood et al., 2003). The youngest concordant detrital grain yielded an age of 900+/-17Ma. This detrital age range is similar to that of the Dava Subgroup and the Moine Supergroup. The detrital zircon provenance record is also similar to that within the overlying Grampian Group (Cawood et al., 2003) and so the two units may have had similar Proterozoic sources.

In the Newtonmore district only one small amphibolite plug (Figure 2) is recorded [at NN 653 974] intruding the succession (*cf.* Robertson and Smith, 1999). Since a similar body occurs within the Grampian Group nearby, these intrusions may relate to the extensional magmatic event at about 590 Ma (see Section 2.3). However, other small amphibolite bodies within the Glen Banchor Subgroup (Figure 2) on Sheet 63E [for example, at NN 579 927] contain the assemblage garnet-hornblende-plagioclase-ilmenite-titanite-quartz. These rocks have textural similarities to eclogitic amphibolites (Baker, 1986) and the garnets have coronas of plagioclase-hornblende without quartz. Quartz is abundant but is always separated from garnet coronas by a reaction rim of hornblende, and Baker (1986) suggested that the rock once contained the assemblage garnet-omphacite-quartz, indicative of an early high-pressure metamorphic event. Preliminary observations (Cuthbert, 2008) indicate that the amphibolite shared the migmatisation of the country-rock, hence the eclogite-facies metamorphism predates the migmatisation (about 840 Ma) and is younger than the youngest reliable detrital zircon age in the Glen Banchor Subgroup (900±17 Ma).

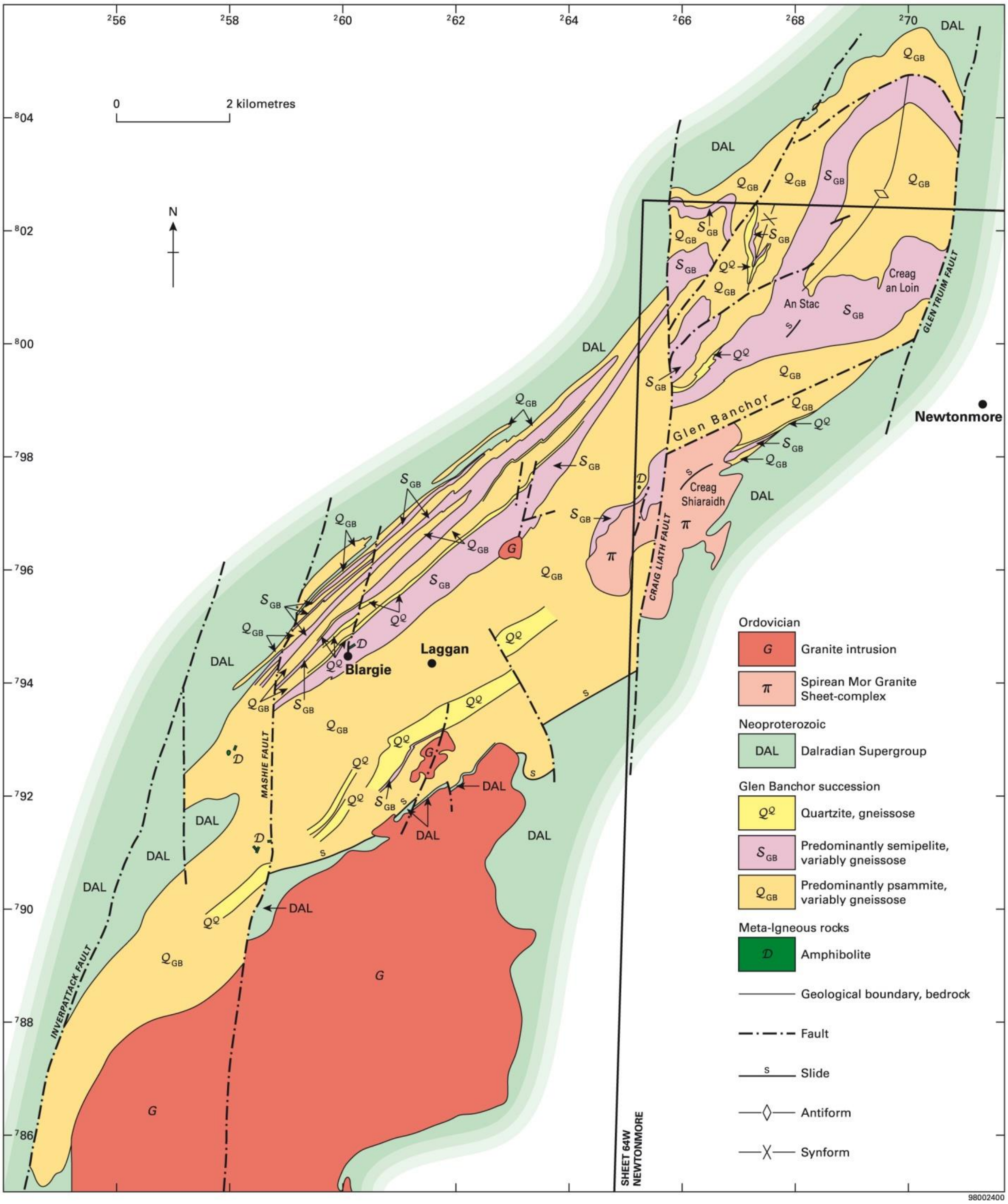

Figure 2: Simplified geological map of the Glen Banchor Subgroup outcrop

1.3.2 Dalradian Supergroup

This succession of metasedimentary rocks with subordinate metavolcanic rocks (Harris et al., 1994) occupies the majority of the Newtonmore-Ben Macdui district. Taking the Glen Banchor Subgroup in the north-west corner of the district (Figures 1 and 2) as basement to the supergroup (Smith et al., 1999), all the succeeding strata belong to the Dalradian Supergroup. The supergroup has an overall younging to the south-east, starting with the dominantly psammitic Grampian Group, passing through the shelfal limestones, quartzites and pelites of the Appin Group into the deeper water quartzites, pelites, calcareous semipelites and basic volcanic rock of the Argyll Group.

The supergroup represents part of a former extensive continental shelf succession which is thought to have started (Grampian Group) in a broad ensialic rift which opened north-eastwards to form a marine gulf. The Grampian Group is dominantly a deep-water turbiditic pile passing up into a mainly shallow marine shelf succession. The metasedimentary rocks belonging to the Appin and Argyll groups represent deposition on the north-west side of the widening gulf. The Appin Group can be subdivided into subgroups which have persistent character along the continental shelf; i.e. the Ballachulish, Blair Atholl and Islay subgroups. The Ballachulish Subgroup has a persistence of lithological type, which can be extended from the classic Dalradian succession in the Appin area north-east into Aberdeenshire and south-west to Donegal. The Blair Atholl Subgroup begins to show signs of instability in the depocentre and these become more emphatic in Islay Subgroup times. Deeper water deposits of the Easdale Subgroup (Argyll Group) are associated with extensional rifting.

The Dalradian Supergroup below the Ben Lawers Schist Formation in this district is thought to have been deposited in the Cryogenian Period and its boundary with the overlying Ediacaran is located within the Easdale Subgroup (at the base of the Cranford Limestone in Donegal, McCay et al., 2006).

The thickness of the Dalradian succession and the length of time that supposed continuous sedimentary deposition operated (pre-750 Ma to 470 Ma) have caused several authors to question whether there are not distinct stratigraphical unconformities (e.g. Prave, 1999) or even orogenic unconformities (e.g. Dempster et al., 2002) within the supergroup. This district continues to have potential for the study of these questions.

1.3.2.1 GRAMPIAN GROUP

The Grampian Group is a widespread conformable succession of psammites, feldspathic quartzites and semipelites. The group has been divided in this district into a lower Corrieyairack Subgroup and an upper Glen Spean Subgroup (Table 1) on the basis of a lithostratigraphy established in the western Grampian Highlands where the succession is more complete. The thick siliciclastic package was deposited in a series of intracratonic basins created during the attempted break-up of the supercontinent Rodinia (Banks, 2005). In the Newtonmore district, only a small part of the Grampian Group was deposited in the Corrieyairack depocentre, which lies to the north-west of the Glen Banchor palaeohigh. The bulk of the group was deposited in the Strathtummel Basin on the south-east side of the ‘high’.

Corrieairack Subgroup

The Corrieyairack Subgroup comprises psammitic and semipelitic formations deposited in deep water basins by turbiditic currents. It was defined in the Corrieyairack Basin and is a transgressive sequence of submarine fans that passes up gradually into cleaner psammites with minor semipelite and quartzite lenses. On the Newtonmore Sheet, the Creag Meagaidh Psammite, which crops out to the north of the Glen Banchor palaeohigh and west of the Craig Liath Fault (Figure 1), was deposited in the Corrieyairack Basin. The equivalent sedimentary formations to the south and east of the Glen Banchor ‘high’ were deposited in the Strathtummel Basin (Table 1).

West of the Craig Liath Fault

Creag Meagaidh Psammite Formation. In the Corrieyairack Basin to the north-west of the Glen Banchor palaeohigh, i.e. the north-west corner of Sheet 64W, this formation is the uppermost unit of the Corrieyairack Subgroup or the Corrieyairack ‘Turbidite Complex’ Deep Water Association of Glover et al. (1995). The formation comprises grey psammite and micaceous psammite with mica laminae and calcsilicate-rock lenses. It is dominated by monotonous sequences of grey, flaggy, fissile micaceous psammite in medium to thinly bedded (c. 10-15 cm thick) units that preserve normal grading into thin (c. 1 cm thick) schistose semipelite tops (Banks, 2005). Where observed, the grading is considered to reflect primary graded bedding. The formation is exposed on the slopes west of Allt Fionndrigh [NH 656 019] dipping steeply to the south-east. The total thickness of the formation is not exposed on Sheet 64W but it is estimated to be 750 m thick in the Dalwhinnie district.

The Fara Psammite Formation. Feldspathic psammites, correlated with the Fara Psammite Formation on Sheet 63E (Dalwhinnie), lie on the western margin of Sheet 64W, and west of the Creag Liath Fault. The Fara Psammite Formation comprises grey flaggy psammite and micaceous psammite in attenuated beds each now typically less than 10 cm thick as exposed on the adjacent Sheet 63E.

Mashie Semipelite Formation. This formation was established to the west of the Creag Liath Fault (on Sheet 63E), but is not exposed in this district. The semipelite is schistose to gneissose and in tectonic contact with the Glen Banchor Subgroup. It has a gradational boundary with the Fara Psammite Formation and is at least 100 m thick. It is of uncertain stratigraphical position but is probably part of the Corrieyairack Subgroup and considered to correlate with the Coire nan Laogh Semipelite Formation (Banks, 2005). It also could correlate with the Creag na Sanais Semipelite if part of the Fara Psammite belongs to the Glen Spean Subgroup.

Between the Craig Liath and Glen Truim/Ericht-Laidon faults

Torr na Truim Semipelite Formation. This formation is a dominantly schistose semipelite although locally gneissose and more massive (Leslie et al., 2003). It belongs to the Corrieyairack Subgroup but its base is cut out by faulting. It was considered by Banks (2005) to correlate with the Coire nan Laogh Semipelite Formation. It includes subordinate thin quartzite, psammite and micaceous psammite units, and intercalations of finer grained quartzose semipelites are common. Fine-grained psammite units 1-2 cm thick occur in several outcrops. Psammite units become thicker towards the top of the formation but the junction with the overlying Creag Dhubh Psammite Formation is poorly exposed. Where schistose semipelite is present, muscovite and biotite are common together with quartz and feldspar porphyroblasts. Small garnet porphyroblasts occur mainly in the more quartzose units.

The formation is well exposed in the type area around Torr na Truim [NN 681 954] where the schistose semipelite has an F3 crenulation-cleavage dipping 15°NE. In the forested area south and east of Mains of Glen Truim [NN 680 944], craggy outcrops of semipelite are commonly gneissose with small quartz and plagioclase segregations in a biotite-muscovite-quartz-feldspar ± garnet matrix. Thickness is estimated as ≥ 750 m. According to Banks (2005) this formation comprises mudstone facies M1 and M2. M1 comprises homogeneous mudstone units tens of metres thick suggestive of quiescent, low-energy sedimentation. M2 contains homogeneous mudstone units separated by quartzitic beds. No unequivocal sedimentary structures are preserved, although a fine, compositional banding may reflect original planar lamination. The inclusion of clean sands within the muddy facies indicates that either in-situ sediment was reworked by tidal/current activity or that reworked sands were washed in from adjacent environments. A nearshore shelf is a plausible depositional environment (Banks, 2005).

Creag Dhubh Psammite Formation. This formation belongs to the Corrieyairack Subgroup and typically comprises graded, thin-bedded to laminated psammite with micaceous psammite and semipelite interbeds. These mainly belong to a facies association (MS4 of Banks, 2005) in which sheet-like, massive muddy sandstones and graded muddy sandstones occur in laterally extensive homogeneous successions. The association includes small-scale thinning and thickening upwards cycles and is interpreted to form in depositional lobes of lower submarine fans. The sheet-like nature of the beds suggests a lack of significant sea-floor topography (Banks, 2005). Subordinate thinly bedded, graded, muddy sandstone-mudstone couplets (Facies association MS6 of Banks, 2005) are also laterally continuous. Their nature suggests deposition by weak/dilute turbidity currents in an interlobe or distal lobe-fringe setting.

In its type area near Creag Dhubh, the transitional junction with the stratigraphically underlying Torr na Truim Formation is observed [at NN 690 983], about 1.5 km to the north-east of Creag Dhubh cairn. In the north, the formation consists of a grey psammite with micaceous psammite layers showing grading to thin schistose semipelite tops. The overall thickness for the formation is estimated to be 700 – 1000 m. On Creag Dhubh there are massive amalgamated psammites, 5 m thick, and in the cliffs to the south [NN 671 958] are stacked, upward bed-thinning cycles with graded bedding and widespread calcsilicate lenses. North-east of Creag Dhubh summit and folded round it, is an interbanded interval [NN 685 980], up to 200 m thick, in which semipelite is more common than psammite towards the base of the predominantly psammite formation. Minor interbanded psammite and semipelite units are also mapped within the formation, e.g. at [NN 681 961].

The Creag Dhubh Psammite Formation crops out extensively between Cnocan na h-Oidche Uvie [NN 668 947] and Cruban Beag [NN 668 923]. South of Am Binnein [NN 667 910] the formation is displaced by the Ericht-Laidon Fault and west of Am Binnein the formation is structurally and stratigraphically overlain by the Creag na Sanais Semipelite Formation. North-east of Creag a' Chrubain [NN 676 931] the lowest exposed beds are grey flaggy fine-grained psammites, 1-5 cm thick, with thin micaceous psammitic to semipelitic partings. Where the preservation state is sufficient, these are interpreted locally as graded beds with semipelitic tops. The semipelitic fraction is generally less than 1 cm thick and only rarely are semipelite bands or lenses up to 10-20 cm thick present. Minor thin fine-grained calcsilicate lenses are also present. Farther west up-slope, psammites with individual beds 10-40 cm thick are common; exceptionally the beds reach 70 cm thick. Amalgamated psammites up to 6 m thick are inferred, probably indicating channelled deposits. Beds generally dip moderately westwards but changes in younging direction indicate that tight to isoclinal folds with wavelengths of 400-500 m are present. Apart from the grading, little else in the way of primary sedimentary structure can be seen due to lack of clean exposures and the effects of deformation.

North-west of the Ericht-Laidon Fault, on the south-eastern slopes of Creag Bheag, near Kingussie, medium-bedded grey psammitic units grade up into thin semipelitic tops. This sequence youngs into structurally overlying quartzitic psammites with thin garnetiferous semipelites at the top of the formation [at NH 742 012] lying below a predominantly semipelitic unit now correlated with the Falls of Phones Semipelite Formation. The **Pitmain Semipelite Member** is schistose to gneissose semipelite with thin beds of psammite bound by interlayered units of striped quartzose psammite, semipelite and garnetiferous calcsilicate rock. It occurs on the northern margin of sheet 64W [at NH 726 022] interbedded within the Creag Dhubh Psammite Formation. The semipelite [at NH 745 015] north of Pitmain farm, near Kingussie, which was termed the Pitmain Semipelite is now correlated with the Falls of Phones Semipelite Formation (see below). This makes the use of the name Pitmain Semipelite Member for the unit within the Creag Dhubh Psammite Formation confusing and a change to a name such as the 'Creag Mhor Semipelite Member' (see the Tomatin sheet 74W) would be more appropriate.

South-east of the Ericht-Laidon Fault, south of Etteridge, interbedded grey fine-grained psammites, micaceous psammites, semipelites and pelites dip south-east structurally below the Falls of Phones Semipelite Formation. The interbedded sequence was formerly termed the Etteridge Lodge Psammite and Pelite Formation (Leslie et al., 2003) but has since been correlated with the Creag Dhubh Psammite Formation (Leslie et al., 2006). The turbiditic psammites exposed at Feshiebridge [just north-east of Sheet 64W at NH 852 043], and on Creag Dhubh [NN 824 997] about 2 km west of Glen Feshie, are also now assigned to the Creag Dhubh Psammite (Leslie et al., 2006). A good section through the upward change from graded, turbiditic psammite through the Falls of Phones Semipelite and into the quartz-rich psammites at the base of the Gaick Psammite Formation is exposed on Creag na Sroine [NN 840 969].

Glen Spean Subgroup

The Neoproterozoic Glen Spean Subgroup comprises distinctive semipelites and clean feldspathic and siliceous psammites which have a widespread distribution in the district (Figure 1). In the Newtonmore area, the subgroup consists of a thin semipelite formation below a much thicker, more widespread psammite formation. The semipelite is termed the Falls of Phones Semipelite Formation to the east of the Glen Truim and Ericht-Laidon faults (Table 1). West of these faults the Creag na Sanais Semipelite Formation is probably equivalent to the Falls of Phones Semipelite (Leslie et al., 2003) with the overlying Allt nan Biorag Member equivalent to the lower part of the Gaick Psammite Formation (Table 2). This relationship is most probably similar to that of the Clachaig Semipelite below the Inverlair Psammite in the Corrieyairack depocentre (Banks, 2005).

The bulk of the psammites to the north-west of the Loch Tay Fault on Sheet 64E and W belong to the Gaick Psammite Formation. These quartzofeldspathic rocks have a distinct biotite-rich lamination, which in areas of low strain, can be shown to reflect original bedding. In places this includes cross-bedding and indications of shallow water deposition. This persists throughout the subgroup in the Strathtummel Basin that lies to the south-east of the Glen Banchor high and extends up to the Loch Tay Fault. Quartzofeldspathic psammites interpreted as shallow-water deposits to the south-east of the Loch Tay Fault have not been assigned to a particular formation as they are interbedded with impersistant limestones and quartzites. These are atypical of the Gaick Psammite Formation and may reflect a passage into the previously recognised but now obsolete Strathtummel Subgroup of Treagus (2000) which has been offset sinistrally by the Loch Tay Fault.

Creag na Sanais Semipelite Formation. The Creag na Sanais Semipelite Formation consists of dark grey or brownish grey, gneissose semipelite containing local thin fine-grained biotite-rich and quartzose psammite interbeds. Its base is marked by the incoming of a coherent gneissose semipelite above thinly interbedded psammites and semipelites at the top of the Creag Dhubh Psammite Formation. The semipelite is coarsely foliated in places, and elongate quartz grains and feldspar porphyroblasts are wrapped by the biotite-and-muscovite-dominated foliation. Thin fine-grained biotitic and quartzose psammite beds contain scattered garnets (Leslie et al., 2003). The formation is well exposed in the type area on the slopes south of Creag na Sanais [NN 655 921] and the crags to the south [at NN 657 917].

The facies association is mudstone with quartzite but sedimentary structures are very limited. The formation is considered to represent a prodeltaic mud in a transition from deep water turbiditic to shelfal lithofacies which occurs above the Creag Dhubh Psammite Formation. This means that the Creag na Sanais Semipelite Formation is the lowermost formation in the Glen Spean Subgroup and probably correlates with the Falls of Phones Semipelite (Table 1) on the south-east side of the Ericht-Laidon Fault (Banks, 2005). West of Creag na Sanais, the overlying Allt na Biorag Member forms part of the Gaick Psammite Formation. Full resolution of the lithostratigraphy in this area will require some re-investigation of the Fara Psammite Formation in Sheet 63E (Dalwhinnie).

Falls of Phones Semipelite Formation. This semipelite formation lies to the south-east of the Ericht –Laidon Fault and was established at the type locality at the Falls of Phones on Allt Phoineis [NN 707 933]. It is also exposed near the A9 road [at NN 6776 9105] and on the slopes south-east of Etteridge Farm [at NN 6945 9237], where it is interbedded with thin psammite beds. The semipelitic unit [at NH 745 015] near Pitmain Farm is also correlated with this formation. The semipelite is mainly gneissose, but locally schistose with local lenses of micaceous psammite. It contains mainly biotite, quartz and feldspar with subordinate muscovite and garnet. The exposures near Pitmain Farm include subsidiary quartzose psammites, quartzites and calcsilicate rocks.

The formation is about 100 m thick and passes down transitionally into the Creag Dubh Psammite Formation. At the type locality, local channels of cross-bedded biotite-rich psammite indicate younging to the south-east where it is structurally and stratigraphically overlain by the Gaick Psammite Formation (Table 1, Table 2). As with the Creag na Sanais Semipelite, the formation probably represents a prodeltaic mud.

Table 1: Relationships of the subgroups, formations and members of the Grampian Group present on Sheet 64

CORRIEYAIRACK BASIN	STRATHTUMMEL BASIN				
North of Glen Banchor High	*West of Craig Liath Fault*	*Between Craig Liath and Glen Truim faults*	*East of Glen Truim Fault*	*SE of the Ericht-Laidon Fault*	
		Allt nam Biorag Psammite Mbr of the Gaick Psammite Fm	Gaick Psammite Fm	Gaick Psammite Fm	GLEN SPEAN SUBGROUP
		Creag na Sanais Semipelite Fm	Falls of Phones Semipelite Fm	Falls of Phones Semipelite Fm	
Creag Meagaidh Psammite Fm	The Fara Psammite Fm	Creag Dhubh Psammite Fm	Creag Dhubh Psammite Fm (Meadowside Psammite of Banks, 2005) including Pitmain Semipelite Mbr	Creag Dhubh Psammite Fm (Feshiebridge Psammite Fm)	CORRIEYAIRACK SUBGROUP
	Mashie Semipelite Fm	Torr na Truim Semipelite Fm	(not seen)	(not seen)	

Gaick Psammite Formation. This monotonous succession of flaggy laminated biotite psammitic rocks is extensively exposed from Glen Truim to the Loch Tay Fault. It belongs to the Glen Spean Subgroup (Table 1) as correlated from the Corrieyairack Basin into the Strathtummel Basin. The formation is widespread and has had several names (Table 2).

The formation comprises mainly thin or medium-bedded psammite, subordinate quartz-rich psammite and micaceous psammite with minor amounts of quartzite and semipelite. Calcsilicate lenses are small and scattered. The base of the formation is marked locally by a c. 10-20 m-thick unit of quartzitic psammite or quartzite. Good exposures of this unit occur on Creag na Sroine [NN 840 969]. This transitional passage towards its base reflects the change from deeper water to overlying deltaic deposits forming the bulk of the formation.

The banding or layering within the psammites reflects variation on 10-30 cm scale between the pale grey and darker grey quartzo-feldspathic layers but internal pelitic to semipelitic laminae are also common on a mm scale. This reflects the occurrence of biotite as disseminated flakes or concentrated into laminae between granoblastic quartz-plagioclase +/- K-feldspar layers. Garnet is a minor component in some lithologies. Muscovite and chlorite are rare and commonly products of retrograde metamorphism. A few quartzose psammites occur within the formation and in places, such as near Glen Derry [NO 038 996], quartzite interbeds are mapped. Small scale cross-bedding and rare graded beds within weakly deformed psammites indicate way-up of the succession but only a few cases of reliable way-up are preserved (Plate 3). In some examples, psammites become less micaceous upwards, in the same direction of younging as indicated by ripples or cross-bedding. This suggests deposition in shallow water with some current-winnowing of the sediment.

Table 2: Stratigraphical jargon-buster for the Glen Spean Subgroup in the Strathtummel Basin (adapted from Banks et al., 2006; 2007)

Recommended formational nomenclature	**Ben Alder (Sheet 54)**	**Also known as:**
Gaick Psammite	Gaick Psammite	Allt nam Biorag Psammite Member, Atholl Subgroup, Bruar Psammite Formation, Ordan Shios Psammite Formation, The Fara Psammite Formation (part), Struan Flags
Falls of Phones Semipelite	Garbh Choire Semipelite	Ardair Semipelite Formation, Creag na Sanais Semipelite Formation, Ordan Shios Semipelite Formation, The Fara Psammite Formation (part), Tromie Semipelites, Pitmain Semipelite (near Pitmain)
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 (part)
Coire nan Laogh Semipelite	Lethois Semipelite	Kincraig Limestone Formation, Mashie Semipelite Formation, Ord Ban Subgroup, Torr na Truim Semipelite Formation

Plate 3 : Right-way-up cross-bedding in Gaick Psammite beside Allt Bhran [NN 7707 8971] BGS Imagebase No. P514826.

Well-exposed sections in the Gaick Psammite occur along the Allt Bhran [NN 767 900 and 770 897], where typical banded lithologies are exposed with examples of cross-bedded units. Also in Allt Bhran [NN 76559 90129], well-preserved sedimentary cross-lamination is folded by minor south-east-facing F2 structures (Leslie et al., 2006). In exposures around Loch an Duin [NN 729 803], flaggy psammites display rounded F2 fold hinges about subhorizontal axial planes. Other well-exposed sections lie in Allt a' Chama/Edendon Water [NN 71 79] and Allt Gharbh Ghaig (Plate 4).

Overall the succession youngs to the south-east in a stack of recumbent folds which are structurally overlain by the Lochaber and Ballachulish subgroups near the 'Boundary Slide' which lies close to the Loch Tay Fault. Near the Loch Tay Fault minor impersistent interbeds of semipelite occur. The Glen Spean Subgroup psammite to the south-east of the Loch Tay Fault has not been included in the Gaick Psammite Formation as it is also associated with quartzite and limestone units (c.f. the Strathtummel Subgroup of Treagus (2000)).

Allt nam Biorag Psammite Member. This member (Table 1, Table 2) lies to the east of the Craig Liath Fault where it forms the lower part of the Gaick Psammite Formation (Banks, 2005). It comprises quartzitic and quartzose psammites with minor calcsilicate lenses typical of the lower part of the Gaick Psammite Formation. Small lenses of gneissose semipelite have been mapped within the unit, which is cut out to the west by the Craig Liath Fault. The member is well exposed on Meall Ruigh nam Biorag [NN 655 905] south-east of Allt nam Biorag, in the type area. On this ridge, examples of cross-laminated units occur in quartzose psammites.

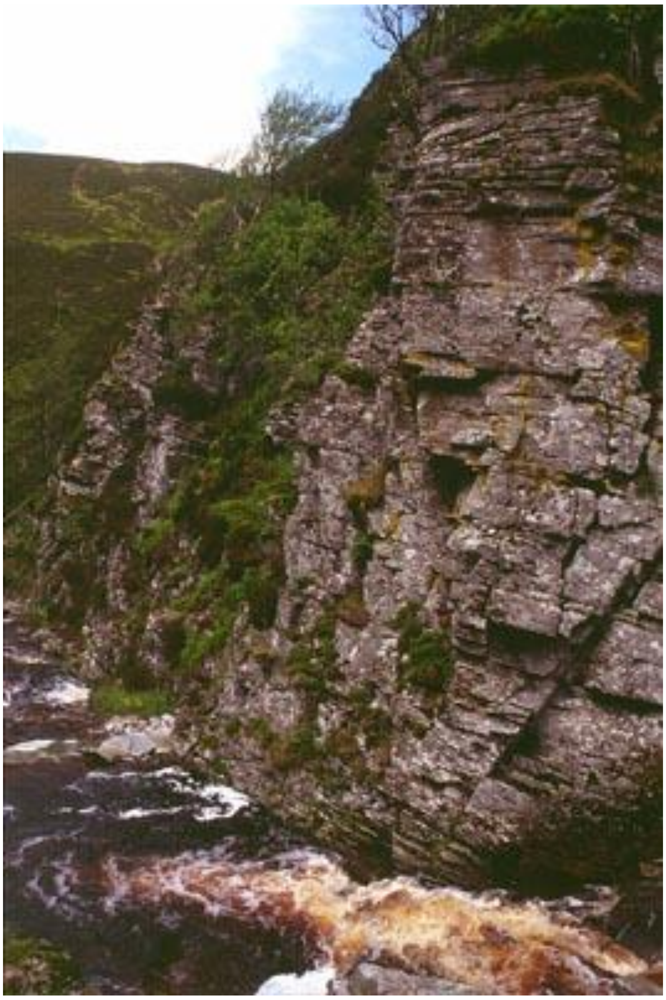

Plate 4 : Crags with dominant planar foliation in psammite and micaceous psammite, Gaick Psammite Formation in Allt Gharbh Ghaig, Gaick [NN 78847 81847] BGS Imagebase No. P521713.

1.3.2.2 Appin Group

This group heralds a distinct change to alternating units and coarsening upwards cycles of metalimestone, pelite, semipelite, psammite and quartzite in the Lochaber, Ballachulish and Blair Atholl subgroups (Table 3). Several of the pelitic and calcareous formations are graphitic. The thickness of the group varies as it is partly diachronous with the Grampian Group but also onlaps onto the Glen Banchor 'high'. In this district the majority of the group crops out to the south-east of the Loch Tay Fault (Figure 3).

Lochaber Subgroup

The Lochaber Subgroup is of variable facies and has been considered as a transition between the thick pile of psammites (Grampian Group) and the shelfal muds, carbonates and quartz sands of the Appin Group. The gross lithological contrast between the groups is most probably the reason for the development of the Boundary Slide in this district. The subgroup is mainly limited to the north-western side of the Loch Tay Fault on Sheet 64E where the *Glen Banvie Formation* has been established. It is affected by the Boundary Slide and invaded by the Glen Tilt Pluton so that its true lithological sequence is difficult to ascertain. Farther south-west, for instance near Crianlarich, the Lochaber Subgroup includes a basal quartzitic formation (Harris et al., 1994). Such a quartzite cannot be readily correlated in the Glen Tilt area and may not have been deposited or is strongly drawn out by the sliding (*cf.* Treagus, 2000). South-east of the Loch Tay Fault, the Tom Anthon Mica Schist Formation overlies the Grampian Group on the eastern margin of the sheet.

Glen Banvie Formation. The Glen Banvie Formation (Figure 3) is considered part of the Lochaber Subgroup established farther west (Treagus, 2000) and compares with the Loch Treig Schist and Quartzite or Leven Schist formations (Key et al., 1997). It comprises two members, the lower heterogeneous **Forest Lodge Member** and the structurally overlying, quartzitic **Carn a' Chlamain Member**. No convincing way-up structures have been found, but the latter is considered the younger member on the grounds that the Grampian Group is older and structurally underlies the Forest Lodge Member. Dips are commonly steep to vertical within the formation, partly affected by the intrusion of the Glen Tilt Pluton, which also overprinted contact metamorphism on these metasedimentary rocks. The rocks were originally laid down as tidal shelf deposits in shallow open seas.

The formation was formerly termed the 'Banvie Burn series' (Bailey, 1925) and structurally overlies the monotonous Gaick Psammite Formation in the Glen Tilt area. Their junction appears to be sheared but the amount of metasedimentary succession cut out is probably minor. The **Forest Lodge Member** comprises a varied, commonly banded, succession of semipelites and micaceous psammites, calcsilicate rocks, hornblende schists and thin impure metalimestones (Plate 5). These pass northwards into calcsilicate rocks and pelites that are commonly schistose and biotitic with local opaques, including possible graphite. Most of the lithologies have been affected by contact metamorphism resulting from the Glen Tilt Pluton; some pelitic rocks contain late andalusite porphyroblasts. The member is well exposed [at NN 936 744] in the River Tilt, in its type area 350 m north-east of Forest Lodge. Interbedded pale grey metalimestone and dark grey semipelite are exposed at the latter locality, whereas pelites and interbedded calcsilicate rocks are exposed along Allt Glac na Conlaich [NN 940 768 to 933 772]. Parallel laminated amphibole-rich schists, dominated by tremolite-actinolite, are probably para-amphibolites. The larger amphibolites and hornblende schist bodies (*D*), such as that exposed at [NN 942 755], are considered to be Neoproterozoic meta-igneous rocks.

Table 3 : Relationships of the formations in the Appin and Argyll groups of the Dalradian Supergroup on Sheet 64

Group	Subgroup	*Glen Tilt area*	*Gleann Fearnach – Glen Shee areas*	*North of Glen Banchor High*
ARGYLL GROUP (top not seen)	**Easdale Subgroup**		Ben Lawers Schist Fm	
			Ben Eagach Schist Fm	
	Islay Subgroup	Schiehallion Quartzite Fm	Creag Leacach Quartzite Fm	
APPIN GROUP	**Blair Atholl Subgroup**	Cnoc an Fhithich Banded Semipelite Fm	Gleann Beag Schist Fm	
		Blair Atholl Dark Limestone and Dark Schist Fm	Tulaichean Schist Fm	
			Sron nan Dias Pelite and Limestone Fm	
	Ballachulish Subgroup	Glen Loch Phyllite and Limestone Fm	Glen Loch Phyllite and Limestone Fm	
		An Socach Quartzite Fm	An Socach Quartzite Fm	
		Beinn a' Ghlo Transition Formation	Beinn a' Ghlo Transition Formation	
		Glen Clunie Graphitic Schist Formation		
	Lochaber Subgroup	Glen Banvie Formation	Tom Anthon Mica Schist Formation	*Fault/Slide*
				Aonach Beag Semipelite Formation
GRAMPIAN GROUP (for complete group see Table 1)	**Glen Spean Subgroup**	Gaick Psammite Fm/ Glen Spean Subgroup undivided		Inverlair Psammite Formation (not exposed)

Plate 5 : Folded metalimestone and semipelite in the Forest Lodge Member, Glen Banvie Formation above the ruined Dail-an-eas Bridge, Glen Tilt [NN 9387 7466]. BGS Imagebase No. P663222.

The **Carn a' Chlamain Member** includes mainly pure, pink or white quartzites that vary from massive to laminated. Some quartzite is described as almost glassy containing small grains of reddish feldspar (Barrow et al., 1913). This is likely to be the result of contact metamorphism by the Glen Tilt Pluton. The member is partly exposed in the type area between Carn a' Chlamain [NN 915 758] and Conlach Mhor [930 768]. Subordinate banded biotite-bearing micaceous psammites are also associated with this member.

Tom Anthon Mica Schist Formation. Farther north at [NO 033 865], the isolated outlier of schist is correlated with the Tom Anthon Mica Schist established in the Braemar district (Upton, 1986). It appears to directly overlie Glen Spean Subgroup psammites (Figure 3) and therefore lies at the base of the Lochaber Subgroup. Exposures are poor in this district and blocks of biotite-muscovite schist and semipelite are taken to be representative of the formation. A biotite pelitic schist has been collected (N1196).

Aonach Beag Semipelite Formation. Cropping out to the north-west of the Glen Banchor 'high' on Sheet 64W, this formation belongs to the Appin Group (Robertson and Smith, 1999) or more specifically the Lochaber Subgroup (British Geological Survey, 2000a). The formation structurally and unconformably overlies the Glen Banchor Subgroup in the area north of Glen Banchor [NH 654 010] and forms the basal part of the Appin Group in the Geal-Charn – Ossian Steep Belt. The formation varies along strike from its type section on Sheet 63E (British Geological Survey, 2000a) and in this district it comprises schistose semipelite and micaceous psammite, which locally contains kyanite. Quartzite interbeds increase in abundance towards the top of the formation. Calcsilicate rocks are sparsely developed and generally comprise tremolite-actinolite schists. The formation is poorly exposed in the district and its top is cut out by the Aonach Beag Slide against the Creag Meagaidh Psammite Formation lying to the north-west.

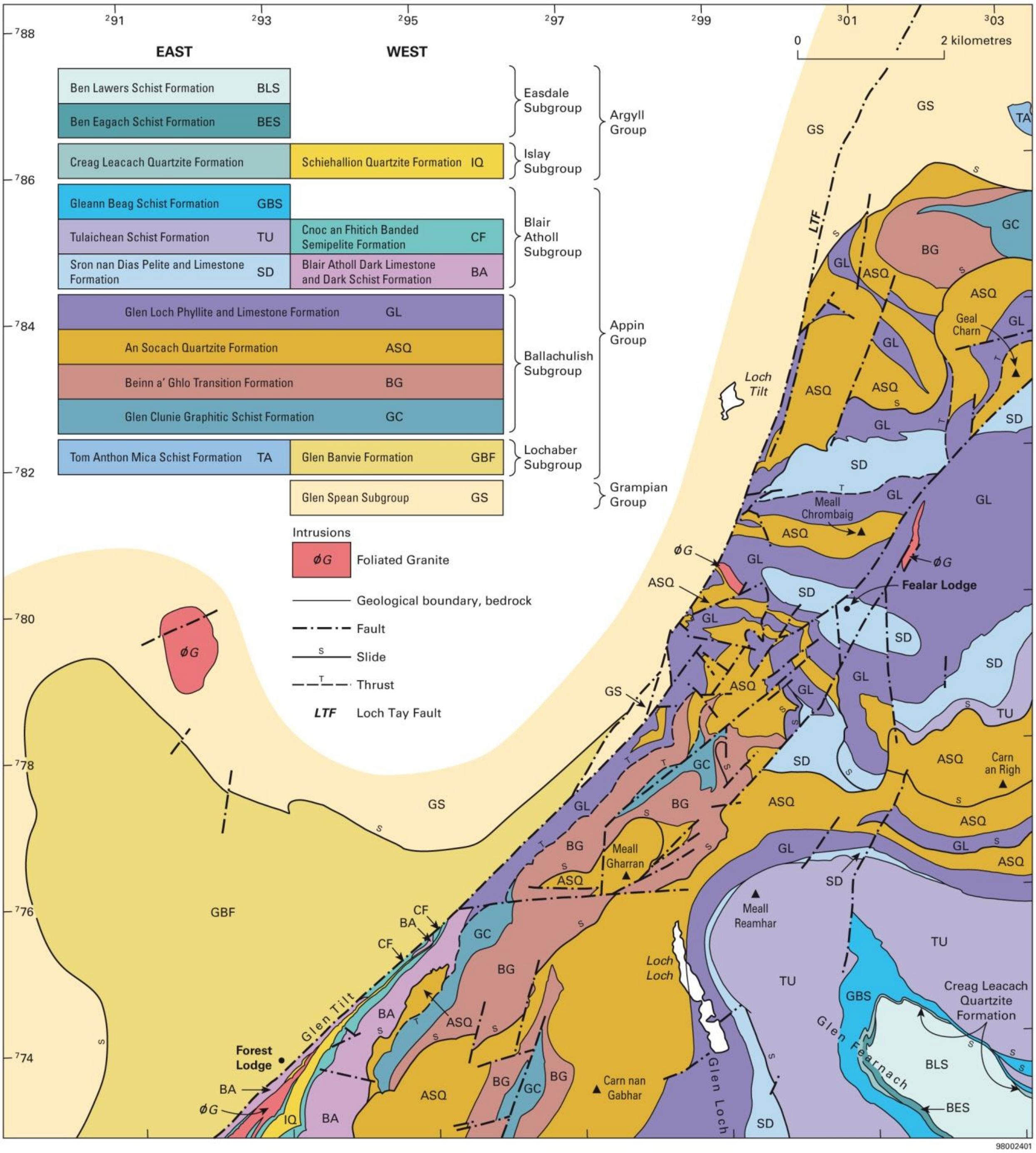

Figure 3 : Distribution of Appin and Argyll groups on Sheet 64E without the Siluro-Devonian intrusions and minor faults.

Ballachulish Subgroup

The succeeding Ballachulish Subgroup (Table 3) has a more widespread outcrop than the Lochaber Subgroup but it is restricted to the south-east of the Loch Tay Fault (Figure 3). The severe faulting and sliding focussed towards the base of the Appin Group along Glen Tilt has cut out the equivalent of the Ballachulish Limestone on Sheet 64E (Ben Macdui). The overlying Glen Clunie Graphitic Schist Formation, is partly exposed and is the equivalent of the Ballachulish Slate Formation. This is succeeded in turn by the Beinn a' Ghlo Transition, the An Socach Quartzite and the Glen Loch Phyllite and Limestone formations. The sequence represents euxinic carbonate, probably precipitates, and muds over which a deltaic sand body built out to become capped by carbonates, muds and sands, partly in cyclic siliciclastic/ clastic carbonate layers.

Glen Clunie Graphitic Schist Formation. This graphitic pelite formation (Figure 3) is partly exposed in the core of the antiform at Beinn a' Ghlo [NN 962 735], immediately above the Glen Tilt Thrust between Carn Torcaidh and Allt Fheannach and in inliers around An Lochain [NN 984 777] and the confluence of the Allt Feith Lair and the Allt a' Ghlinne Mhoir. The succession is locally laminated and becomes phyllitic where interbedded with siltstone or quartzite towards the top of the formation. Grey schists, that are locally only slightly graphitic, take on a spaced crenulation cleavage; elsewhere the rock has a fine-grained slaty appearance. Pyrite is common locally although disseminated, producing a rusty iron oxide coating on weathered surfaces. Towards the base of the section in Allt Fheannach [NN 9594 7590], local impure metalimestones contain green calcsilicate bands. The presence of metalimestones towards the base of the formation suggests a passage down into the equivalent of the Ballachulish Limestone (*cf.* Baddoch Burn Limestone of Upton, 1986) which is not exposed in this section due to faulting. Local beds of quartzite [at NN 9508 7476] indicate a clastic input into the muddy prodeltaic environment. The pelitic succession passes up into the Beinn a' Ghlo Transition Formation (Smith and Harris, 1976). The main constituents of the schist are muscovite, biotite and quartz. Garnets are poorly developed and commonly altered to chlorite. Rare kyanite porhyroblasts are present together with minor plagioclase and iron oxides. The calcsilicate beds contain fibrous tremolite with carbonate minerals or pale green actinolite with quartz and biotite.

Beinn a' Ghlo Transition Formation. This formation comprises interbedded psammites, quartzites, flaggy siltstones and graphitic pelites forming a passage up into the An Socach Quartzite Formation. Its type area is within the Beinn a' Ghlo range (Figure 3) whence it takes its name. The lower part of the formation is well exposed in the tributary to Glas Leathad [at NN 965 737], in Coire Mhuirich [NN 965 754] and in the valley of An Lochain [NN 984 775] (Plate 6).

Plate 6 : Interbanded graphitic semipelite and fine-grained quartzite typical of the Beinn a' Ghlo Transition Formation. Allt an Lochain at about NN 986 772. BGS Imagebase No. P922402.

The upper part of the formation is exposed in Allt Coire a' Chaisteil [NN 966 748], where there is a gradual increase upwards in the number of quartzite beds occurring within the formation. The quartzites tend to be massive, fine-grained and in places over 1 m thick. In Allt Fheannach [NN 960 752], where psammite and quartzite beds predominate over graphitic pelite, distinctively banded grey and orange-brown rocks consisting of 1-10 cm-thick interbeds of psammite and pelite are exposed. Many graded units are 15-20 m thick and have sharp bases yielding good younging information (Stephenson, 1990). Some of the fine-grained phyllitic intervals are laminated dark and pale grey on a mm scale. Cross-bedding, washouts, small-scale channels, slump structures and slump breccias have been recorded (Smith and Harris, 1976) which consistently young towards the An Socach Quartzite. Near the bottom of Allt Feith Ghuithsachain [NN 987 767], the formation youngs to the north-west and is separated from the An Socach Quartzite by the Carn an Righ Slide.

The depositional environment is considered to be one in which fine quartz sands were transported from an encroaching delta over the prodelta muds of the Glen Clunie Graphitic Schist Formation. In the semipelitic part of the formation, biotite and muscovite flakes are usually conspicuous together with small pyrite crystals. Some pelitic beds also contain small garnet and feldspar porpyroblasts.

An Socach Quartzite Formation. The An Socach Quartzite Formation (Figure 3) is equivalent to the Appin Quartzite of the south-west Grampian Highlands and continues north-eastwards to An Socach and The Cairnwell in the Braemar district (British Geological Survey, 1989). In the present district the quartzite forms the peaks and ridges of the Beinn a' Ghlo range, as it is a resistant rock-type but the hill slopes are generally covered in quartzite scree or regolith. Quartzite is particularly well exposed on Carn nan Gabhar [NN 972 734], Carn an Righ [NO 028 772] and Stac na h-Iolair [NO 018 772].

Plate 7 : Multiple cross-bed sets younging towards the top of the photograph in An Socach Quartzite Formation on Carn an Righ [NO 0219 7689]. BGS Imagebase No. P258111.

Fresh quartzite is commonly white or pink to yellow-brown, massive to thin bedded, and locally coarse-grained to pebbly. Fine- to medium-grained quartzite is typically pure with only a minor content of iron oxides, titanite and rutile which tend to be concentrated in heavy mineral layers. The coarse-grained feldspathic variety weathers to have a porous appearance as exposed around Coire a'Chaisteil [NN 973 749] (Stephenson, 1995). This rock-type was described by Barrow (Geological Survey of the United Kingdom, 1902) as 'porous quartzite'. Granular quartz and feldspar clasts are set in a pinkish quartzose matrix with a vitreous aspect. The pink and white feldspar clasts are generally from 2 to 4 mm in length. Feldspar grains comprise up to 15% of the volume of the quartzite and the commonest type is microcline, followed by plagioclase. A few small biotite and muscovite laths are scattered within the quartzite. Clear and milky quartz pebbles, 1 to 3 cm long, tend to be concentrated at the bases of some beds, although isolated pebbles are also scattered within quartzite beds. Sedimentary structures such as trough cross-bedding, grading and slumping are locally preserved e.g. on Carn nan Gabhar [NN 9704 7319].

Details of the formation around Carn an Righ [NO 029 773] were given by Crane et al. (2002, p.13-14). They described trough cross-bedding (Plate 7) and graded bedding south and west of

Stac na h-Iolair [NN 019 772]. However, 'pseudo cross-bedding' was also noted (Crane et al., 2002) in deformed quartzite near Carn an Righ, where tight to isoclinal minor folds of hematite partings have only one limb preserved, juxtaposed against S2. On Carn an Righ, the quartzite is commonly platy due the proximity of tectonic slides. However, about 200 m to the south-east, well-preserved cross-bedding is present in the quartzite which passes up into the Glen Loch Phyllite and Limestone Formation. A fairly energetic depositional environment is considered to be the setting for these deltaic to shelfal sand bodies.

Glen Loch Phyllite and Limestone Formation. This varied succession, well exposed in the type area around Glen Loch (Figure 3), comprises mainly interbedded grey biotite-bearing or calcareous phyllitic semipelites and psammites and pale grey to white metalimestones. The well-exposed type section was established by Stephenson (1991) from the Allt Ruigh na Cuile area in Glen Loch [NN 985 756 to NN 987 755] and detailed descriptions were given by Crane et al., (2002, p.14 -16).

Throughout the area, the base of the formation is marked consistently by a thin bed of pure white siliceous metalimestone that rests directly upon the underlying quartzite, incorporating sand grains presumably derived from that substratum. This bed seems to be preferentially exposed although it is rarely more than 1 metre in thickness. Several exposures occur in the hinge of the Meall Reamhar Synform [e.g. at NN 994 765]. Where it is not exposed, it is commonly marked by a line of small sink holes (e.g. NNE of Allt Ruigh na Cuile). It is arguably one of the most reliable stratigraphical markers in the sequence and, in areas of complex structure, is an invaluable indicator of the top of the An Socach Quartzite.

Plate 8 : Crag of layered metalimestone and semipelite ('tiger rock') on purer metalimestone within the Glen Loch Phyllite and Limestone Formation, looking north-east up Glen Tilt at about NN 977 779. BGS Imagebase No. P922403.

Throughout the formation in general, the metalimestones vary from thick white or pale grey medium-grained metalimestones to cream coloured dolomitic metalimestones. Fine-grained saccharoidal dolomitic metalimestones are exposed near Allt Ruigh na Diollaide [NN 985 730] and where the beds are slightly siliceous or marly [NN 9835 7300], tremolite laths develop in abundance. Distinctive thinly interbedded metalimestones and calcareous phyllitic semipelites were called ‘tiger rock’ by Bailey (1925), because dark ribs of semipelite alternate with orange- or yellow-weathered carbonate-rich bands (Plate 8). These sequences are commonly developed; for example, at [NN 9847 7353]. Locally psammites, quartzites and greenish calcsilicate rocks are present. Pelites become more common towards the top of the formation, which passes upwards stratigraphically into the Blair Atholl Subgroup. Exposures within the semipelites and psammites in Allt a’ Ghlinne Mhoir [NO 009 765] show textural and compositional grading that indicates younging to the south in near vertical beds.

The prominent banded pale- to medium-grey metalimestone present at the top, or near the top, of the formation is called the **Gleann Mor Limestone Member** (Crane et al., 2002) and is currently the only established member within the formation (Plate 9). Locally near the top of this member there are pelitic interbeds and at the base schistose graphitic pelite is present. The member varies from about 30 m thick south-west of Carn an Righ [NO 021 759] to 150 m on Creag an Loch [990 741], although this may be due to folding within the limestone. It is well exposed in a strike section along Allt a’ Ghlinne Mhoir [NO 010 765 to 015 762].

Plate 9 : Domino-style boudinage and extension structures in metacarbonate rocks of the Gleann Mor Limestone Member in Gleann Mor [NO 0137 7634]. BGS Imagebase No. P258112

In Allt Feith Guithsachain [at NN 9945 7655] a section through the formation starts with the basal 5 m-thick pure white, coarsely crystalline limestone resting directly on the An Socach Quartzite. Upstream, in a waterfall, banded grey, pink and white limestone or ‘tiger rock’ is exposed below grey and grey-green phyllitic psammite and semipelite with thin partings of garnet-biotite schist (Stephenson, 1990). A cream-coloured dolomitic metalimestone is mapped in this stream section below the Gleann Mor Limestone Member. Other examples of 'tiger rock' are exposed in Allt Coire Caseagallach [at NN 9841 7353] where biotitic phyllites are prominent, and north-east of Fealar Lodge, at the head of Allt Feith Lair [NO 0348 8305] and details are given in Stephenson (1990; 1991, 1995). The depositional environment, in which there was a sharp decrease in clastic input into areas of carbonate accumulation under oxidising conditions, is characteristic of a mixed clastic carbonate shoreline.

Blair Atholl Subgroup

In the Glen Tilt area, the Ballachulish Subgroup is conformably overlain by the Blair Atholl Subgroup, which comprises the graphitic Blair Atholl Dark Limestone and Dark Schist Formation succeeded by the non-graphitic Cnoc an Fhitich Semipelite Formation and Drumchastle Pale Limestone Formation. East of Glen Loch, adjacent to the Glen Shee district (Crane et al., 2002) lateral facies changes and interfingering of lithologies necessitates the establishment of different formations. The Sron nan Dias Pelite and Limestone Formation is approximately laterally equivalent to the Blair Atholl Dark Limestone and Dark Schist Formation and is succeeded by the Tulaichean Schist Formation. The overlying Gleann Beag Schist Formation can be correlated laterally with the Cnoc an Fhithich Banded Semipelite Formation (Table 3). The Gleann Beag Schist is divided into two members on Sheet 64E. The strata represent shelf and shoreline clastic carbonates and offshore muds and sands. The presence of graphite, locally towards the base of the subgroup, probably indicates some deposition as precipitates in euxinic conditions.

Blair Atholl Dark Limestone and Dark Schist Formation. This formation can be traced up Glen Tilt from its type area in Blair Atholl. A graphitic pelite or schistose semipelite usually lies at the base of the sequence followed by various units of mid-grey or blue-grey graphitic crystalline metalimestone with thin pelitic to semipelitic bands. The pelitic units tend to be more quartzose, more biotitic and less graphitic than the Glen Clunie Graphitic Schist and typically contain muscovite and some garnet as well as biotite.

South-west of Coire Rainich [at NN 952 753], the graphitic pelite contains local beds of quartzite. By way of contrast, in Coire Thorcaidh [NN 938 735], the graphitic, biotitic pelite includes grey metalimestone interbeds tens of metres thick, but the base of the formation is cut out by the Carn an Righ Slide. Towards the top of the formation in Allt Torcaidh, a thick unit of dark grey metalimestone contains some pelitic and psammitic interbeds and passes up into the Cnoc an Fhithich Banded Semipelite Formation. In the Blair Atholl area, a 'Dark Schist' unit can generally be distinguished lying stratigraphically below 'Dark Limestone'; this distinction does not persist into the Ben Macdui district where the formation appears to be condensed.

Cnoc an Fhithich Banded Semipelite Formation. This succession is generally non-graphitic, interbedded quartzose semipelite and psammite, mainly banded, with local metalimestones. Towards the top, pale banded metalimestones include schistose biotite semipelite and green calcsilicate rocks. These correlate with the Drumchastle Pale Limestone Formation around Schiehallion (see Treagus, 2000). It appears that the Cnoc an Fhithich Banded Semipelite and Drumchastle Pale Limestone formations are combined in this district because the limestone sequence is intercalated with the semipelites and psammites. This may be due to facies changes in a condensed sequence as indicated by the thin Islay Subgroup succession which lies stratigraphically above in the south-eastern flank of Glen Tilt opposite Forest Lodge (Figure 3).

The quartzose psammites and semipelites are commonly interbedded on the scale of 1-10 cm, as exposed in Allt Coire Fhiann [NN 931 729] and Allt Torcaidh [NN 933 736]. Some of the semipelites are rich in muscovite and biotite. Some fine-grained pale grey-green calcareous schists occur in the transition into the metalimestone beds. Pale banded metalimestone with schistose biotite semipelite and green calcsilicate rock, occurs in two impersistent lenses [at NN 935 739 and NN 939 745]. The most common calcsilicate mineral in the metacarbonate rocks is tremolite with minor white mica (?talc) and phlogopite. The depositional environment is considered to be a warm shallow coastal one in which silts and marls were deposited in lagoons, the sands on bars or spits and the carbonate, clastic or possibly stromatolitic, on banks or shoals.

Sron nan Dias Pelite and Limestone Formation. This formation comprises a varied succession of graphitic pelite and grey graphitic limestone which crops out in the area east of Glen Loch on Sheet 64E (Figure 3). The pelites are variably graphitic, commonly schistose and biotitic with local intercalations of semipelite. Towards the top, quartzite interbeds are present. The metalimestones are locally thinly interbedded or flaggy but usually the thicker units of dark to mid-grey medium-grained metalimestone, about 10 to 15 m thick, contain only thin ribs of pelite or semipelite (Plate 10). The metalimestones have characteristics in common with the Gleann Mor Limestone Member but are interbedded with pelites typical of the Blair Atholl Subgroup.

Plate 10 : Boudinaged, folded grey pelitic layers in metalimestone. Sron an Dias Pelite and Limestone Formation on Sron an Dias [NN 9935 7295]. BGS Imagebase No. P922404.

Two interbedded metalimestone units are recognised (Crane et al., 2002); exposed in Allt Choire na Moine [NO 018 785] and on the western slopes of Beinn Iutharn Mhor [NO 030 792]. The formation includes garnet and biotite-bearing graphitic pelites and semipelites with some calcsilicate rocks and the brown-weathering metacarbonate rocks on Sron nan Dias [NN 994 730] lie within schistose biotite pelite and semipelite. Boudinaged lenses of semipelite and pelite occur throughout the metacarbonate rock. On the slopes immediately east of Sron an Dias, conspicuous beds of brown-weathering metacarbonate rock occur within garnet-mica schists.

In thin section, the semipelites contain muscovite and biotite with some local hornblende, orientated in a good foliation within a matrix of fine-grained recrystallised quartz and plagioclase. Garnets are inclusion free and wrapped by the schistosity (Crane et al., 2002).

Tulaichean Schist Formation. Most of this formation consists of medium-bedded, schistose biotite-muscovite semipelite; subordinate laminated phyllitic semipelite and psammites include some graded beds and laminated metasiltstone. The schistose semipelites are mostly well foliated and abundantly garnetiferous. Minor garnet amphibolite, quartzite, calcite-bearing semipelite and calcsilicate rock are present. The main outcrop (Figure 3) lies in the Carn an t-Sionnaich [NO 01 75] area and a significant quartzite intercalation is mapped to the west [at NO 006 755], near the centre of the Meall Reamhar Synform. On the ridge [NO 246 751] about 1 km to the west of Carn an t-Sionnaich, a belt of laminated semipelitic to psammitic schist is sparsely garnetiferous (Plate 11). Calcsilicate rocks, such as those at NN 9973 7473, tend to be associated with amphibolites and may be skarns. Such amphibolites are relatively common in the Tulaichean Schist Formation and are considered to be mafic metaigneous rocks, possibly intrusive or volcanic (see section 2.3). At a structurally lower level, [at NO 02 78], garnet-mica schist of the formation lies between the Sron nan Dias Pelite and Limestone Formation and the Carn an Righ Slide.

Plate 11 : Laminated garnet-poor metasiltstones of the Tulaichean Schist Formation, near the watershed on the Carn an t-Sionnaich - Faire a' Ghlinne Mhoir ridge [NO 0246 7513]. BGS Imagebase No. P258113.

Structurally above the Glen Loch Slide on Meall Reamhar [NN 993 759], very large garnet porphyroblasts (Plate 12) occur within muscovite-biotite-amphibole schist associated with amphibolitic intrusive units in the hinge of the Meall Reamhar Synform.

Micaceous psammite and massive quartzite forms a significant part of the formation on the south-west limb of the Meall Reamhar Synform and is exposed west of Creag Leacagach [NO 000 728]. The micaceous psammite is typically fine-grained, grey and flaggy. It has a granoblastic texture composed mainly of quartz with some feldspar and scattered biotite. Biotite-rich foliae, heavy mineral concentrations and hematitic partings define compositional layering, which at one locality [NN 9997 7290] has preserved centimetre-scale trough cross-bedding

(Crane et al., 2002) younging towards the centre of the Meall Reamhar Synform. A crude schistosity of probable S1 age is developed subparallel to the compositional layering in the thin biotitic layers. Bedding and S1 foliation are overprinted by the main S2 schistosity (Crane et al., 2002). The western margin of the quartzitic unit is marked by a broad zone of high D2 strain. The resulting finely laminated, blastomylonitic quartzites with down-dip rodding are part of the Glen Loch Slide-zone which lies within the Blair Atholl Subgroup (Crane et al., 2002).

Plate 12 : Very large pink garnet porphyroblasts weathering out of muscovite-biotite-amphibole schist within the Tulaichean Schist Formation near the top of Meall Reamhar [NN 993 759]. BGS Imagebase No. P922405.

The quartzitic unit at the base of the formation was included within the Killiecrankie Schist Formation on Sheet 55E (Institute of Geological Sciences, 1981) but it passes up into thin schistose semipelites typical of the Tulaichean Schist Formation and so is assigned to the Blair Atholl Subgroup (Goodman et al., 1997). The establishment of the Tulaichean Schist Formation above the Sron nan Dias Pelite and Limestone Formation, within the Blair Atholl Subgroup, highlights the problem of correlation with the adjacent Pitlochry district, where the equivalent formation was mapped as part of the Killiecrankie Schist in the Easdale Subgroup. An alternative solution is that the lower part of the Killiecrankie Schist on Sheet 55E is the upper part of the Blair Atholl Subgroup on Sheet 64E, and if the Schiehallion Quartzite was missing along strike, the upper Blair Atholl Subgroup would then be succeeded by Lower Easdale Subgroup (Stephenson, 1995). Another model in which the Tulaichean Schist equates to the Killiecrankie Schist in the lower Easdale Subgroup bounded by slides (*cf.* Bailey, 1925) has also been postulated (Stephenson, 1995).

Gleann Beag Schist Formation. This is the uppermost formation of the Blair Atholl Subgroup in the Glen Fearnach area (Table 3). The formation equates to the upper part of the Blair Atholl Subgroup (Crane et al., 2002). It `comprises a lower, **Glen Lochsie Calcareous Schist Member** and an upper, **Glen Taitneach Schist Member**.

The lower, calcareous member consists of dark graphitic calcareous schists and calcsilicate rocks interbedded with metacarbonate rock, psammite, graphitic pelite and garnetiferous semipelite. The brown-weathering metacarbonate layers are commonly dolomitic. The member crops out round the Meall Reamhar Synform near the head of Gleann Fearnach [NO 01 74] and is of the order of 250 m thick where least deformed. It is severely attenuated along the north-east side of the Meall Reamhar Synform against the Carn Dallaig Slide.

The upper, Glen Taitneach Schist Member is predominantly a black to silver-grey, and locally garnetiferous, graphitic pelite. Minor semipelite, metacarbonate rock and psammite interbeds are present. The siliciclastic component increases west of the Glen Shee district and at Gleann Fearnach [NO 010 747] the member grades into laminated micaceous psammites and pelites with some non-graphitic schistose semipelite. Metacarbonate-rock layers are common throughout the member, particularly near the base. In the centre of the Meall Reamhar Synform [NO 009 747], the member contains thin metacarbonate rock (marble) lenticles within graphitic schist and carbonate breccia with sulphides. As the graphite content of the member decreases westwards in Gleann Fearnach [NO 0091 7480] the metacarbonate layers are creamy white with only a few graphitic laminae. One of these dolomitic metacarbonate rocks contains grossular garnet in graphitic pelite laminae.

This member is commonly intensely folded and attenuated, probably due to its enhanced ductility as a result of its graphitic nature. Changes in thickness over short distances make it difficult to determine the depositional thickness of the member, but 200 to 300 m is considered to be a reasonable estimate (Crane et al., 2002).

1.3.2.3 Argyll Group

Islay Subgroup

In many areas, such as the type area at Schiehallion (Sheet 55W), this subgroup comprises a thick quartzite formation which can be mapped separately from an underlying glacigenic boulder bed formation. On the Ben Macdui sheet, where the subgroup is poorly developed, the boulder beds are impersistent and are included within the Schiehallion Quartzite Formation as an informal member. The stratigraphically equivalent quartzite adjacent to Sheet 56W (Glen Shee), where it is also associated with glacigenic boulder beds, has been assigned to the Creag Leacach Quartzite Formation (Crane et al., 2002). These fairly clean quartzites are considered to have been deposited on a tidal shelf. This means that in the sequences across Sheet 64W the Islay Subgroup contains only one formation (Table 3).

The glacigenic horizon is an important marker horizon along the strike of the Argyll Group, distinguishing the Islay Subgroup quartzites from those in the Ballachulish and Lochaber subgroups. In this district critical evidence for the glacial origin of the boulder beds is lacking due to poor exposure and the degree of tectonism. However, because the boulder beds are interbedded in waterlain deposits and not associated with a glaciated ‘basal pavement’ (Spencer, 1971), they were probably deposited under water. Because the glacigenic horizon (boulder bed or tillite) is widespread in the Islay Subgroup and is associated with dolomitic beds (cap carbonates) it is considered to be the product of a widespread Neoproterozoic glaciation. This was formerly considered to have occurred during the latest Precambrian to Cambrian (Spencer, 1971). Later geochronological data indicated that this could be correlated with the Varangerian/Marinoan glaciation which lasted from about 590 to 564 Ma but since the Tayvallich Volcanic rocks are dated at about 600 Ma, this correlation is unlikely (Prave, 1999). Prave (1999) argued that the glaciation at the base of the Argyll Group (Port Askaig Tillite) is the Sturtian glacial episode at around 750-700 Ma and that the Varangerian episode is represented by the Loch na Cille Boulder Bed in the Southern Highland Group.). U-Pb Shrimp ages from Idaho (Fanning and Link, 2004) indicate that the Sturtian glacial epoch may have lasted until 670 Ma. The $\delta^{13}C$ of the carbonates associated with the Port Askaig tillites were correlated with the Sturtian glaciation elsewhere (Brasier and Shields, 2000). No equivalent carbonates are recorded in this district.

The subsequent correlation of the glaciation at the base of the Argyll Group with the Marinoan event c. 635 Ma (Leslie at al. 2008) was based on correlations with strata in East Greenland and Northern Namibia (Gaucher et al. 2005). However, new isotopic evidence from carbonate beds associated with glacigenic strata indicates that the Argyll Group covered both the Sturtian and Marinoan events. The isotopic evidence for Marinoan-equivalent events within the Easdale Subgroup comes from the Stralinchy-Reelan-Cranford sequence in Donegal (McCay et al., 2006) and the Whiteness Limestone in Shetland (Prave et al., 2009).

Schiehallion Quartzite Formation. This formation forms the bulk of the Islay Subgroup in this district and contains glacigenic boulder beds near its base which are considered to be the equivalent of the Schiehallion Boulder Bed Formation (Treagus, 2000) in the Schiehallion area. Most of the quartzite formation consists of white to yellow-brown-weathering fine- to medium-grained metaquartzite. The rock is commonly flaggy, particularly near shear-zones and slides. The boulder beds contain pebbles to boulders of granite and quartzite in a finer grained matrix. There are also thin interbeds of pale grey metacarbonate and calcsilicate rock locally near the base of the formation. In this district the quartzite occurs in a narrow NE-trending outcrop on the south-east flank of Glen Tilt (Figure 3) and the most continuous section through the formation occurs in Allt Coire Fhiann [NN 930 730] although this sequence is tightly folded and no boulder beds were recorded.

In Allt Torcaidh [NN 9322 7374] a representative of the Schiehallion Boulder Bed appears to be repeated by the folding within the quartzite. The boulder bed contains rounded pebble-sized clasts of pink granite and quartzite set in a psammitic to semipelitic matrix. The matrix is up to 70% quartz with scattered grains of plagioclase and K-feldspar and laths of biotite and muscovite. The strata on either side of the quartzite are assigned to the Blair Atholl Subgroup. Hence the formation here is interpreted to lie in a sliced isoclinal synform closing to the north-east (Stephenson, 1995), affected by slides within and structurally below the quartzite.

Creag Leacach Quartzite Formation. In the Gleann Fearnach area [NO 009 740], cream quartzite and micaceous psammite is assigned to the **Bad an Loin Quartzite Member** of this formation (Crane et al., 2002). The member acts as a marker between the Blair Atholl and Easdale subgroups and forms the upper immature facies of the formation (Crane et al., 2002). It is highly attenuated around the head of Gleann Fearnach (Figure 3) and is no more than a few tens of metres thick. As a consequence, the full Islay Subgroup succession is not seen, and no associated boulder beds are known, in the south-east of Sheet 64E (Ben Macdui). The rock generally weathers white, but has a buff or beige colour on a fresh surface. The member is thinly bedded with little internal structure although rare pebbly horizons were recorded along with other details by Crane et al., (2002).

Easdale Subgroup

This subgroup contains several laterally variable and impersistent formations due to increasing instability in a deepening basin as continued extension led to rifting and volcanic activity. A rapid shift in seawater $^{87}Sr/^{86}Sr$ in Dalradian limestones between the Islay and Easdale subgroups recorded by Thomas et al. (2004) is consistent with a significant change in basin dynamics. Currently there is no correlation with the Marinoan-equivalent glacial and associated cap carbonate sequence recognised within this subgroup in Donegal (McCay et al., 2006).

In the Gleann Fearnach area (south-east corner of the Ben Macdui sheet), the Islay Subgroup is succeeded, through a thin transitional passage, by the Ben Eagach Schist Formation followed by the Ben Lawers Schist Formation (Table 2).

Ben Eagach Schist Formation. This formation is stratigraphically the lowest formation in this subgroup. It is a schistose pelitic unit that is typically black to dark grey due to disseminated graphite and sulphides. The schist is relatively soft and weathers to a rusty brown colour due to the sulphide content, but no significant mineralisation has been noted that could compare with the baryte deposit in the same formation near Aberfeldy. Thin fine-grained, micaceous psammites and semipelites are interbedded and these fine-grained and graphitic lithologies are taken to indicate a renewed period of rapid basin deepening. Because the schists are relatively incompetent, they act as a locus for deformation with significant thickening in fold hinges and attenuation on limbs [e.g. at NO 009 739]. Even allowing for the deformation the unit is relatively thin in west Gleann Fearnach (Figure 3) and hardly more than 100 m thick. The formation is cut out to the south by the Creag Uisge Slide.

Within the schist, quartz comprises about 50% of the rock and plagioclase, less than 10%, in a granoblastic matrix containing graphite and lepidoblastic muscovite and biotite. Garnet and retrogressive chlorite occurs locally. Pyrite is the dominant sulphide; pyrrhotite has been recorded and some magnetite (Crane et al., 2002). The predominantly pelitic deposition together with carbonaceous material suggests a euxinic environment with a restricted clastic input.

Ben Lawers Schist Formation. This formation consists of mainly schistose carbonate-bearing to calcsilicate rocks with thin beds of psammite. Its maximum thickness is about 700 m (Crane et al., 2002) but its full thickness is not seen on the Ben Macdui sheet. It extends south-east into the Glen Shee district where it is succeeded lithostratigraphically by the Farragon Volcanic Formation. Its main outcrop in this district is in the east of Upper Gleann Fearnach [NO 02 73] but it is poorly exposed on grassy slopes. The calcareous schists tend to be pitted where the calcite grains have been dissolved. Local interbeds of cream-white metalimestone occur up to 15 m thick.

The rocks are commonly greenish due to their content of chlorite and amphibole. The amphiboles are typically developed as grabenschiefer textures on the schistose surfaces and amphibolite-rich rocks grade into schistose amphibolites. At deposition, the background siliceous detritus may have mixed with a basic volcanic source. In the upper part of Gleann Fearnach [NO 01 73] a distinctive fine-grained hornblende schist contains thin psammitic beds. This unit is considered to have a volcanic protolith and has been referred to informally as the 'Laoigh metabasites' (Crane et al., 2002). On Creag Beag [NO 0113 7368], these basic meta-igneous rocks contain a cream metacarbonate layer, similar to that seen elsewhere within the calcareous schists. Geochemical analysis of the hornblende schists has shown that they are comparable to the overlying Farragon Volcanic Formation in the Glen Shee area (Goodman and Winchester, 1993) and they probably represent an early stage in the volcanic activity that culminated in the more widespread eruption of the Farragon 'Beds' from Glen Shee to the Loch Tay area. Stable isotope studies (Scott et al., 1991) confirmed the importance of a magmatic and volcanoclastic input into the Ben Lawers Schist Formation.

Thin section details are given by Crane et al. (2002). Typically fine-grained quartz and plagioclase mosaics are interspersed with laths of muscovite, green-brown biotite and chlorite as well as local aggregates of calcite. Large amphiboles are poikiloblastic, epidote occurs in small grains and garnet is rare.

1.4 IGNEOUS INTRUSIONS

1.4.1 Neoproterozoic to Ordovician: pre- and syntectonic intrusions

Metamafic Rocks

Amphibolite bodies (with relict ophitic texture in places) probably had intrusive basalt or microgabbro protoliths produced during rifting of the extensive Dalradian basin at about 600-590 Ma (as they lie below the Tayvallich Subgroup). As far as is known, the amphibolites on Sheet 64 all pre-date D2 and therefore belong to the 'older suite' of metamafic rocks described by Crane et al. (2002).

A minor plug-like body of garnet amphibolite is recorded from the Glen Banchor Subgroup [NN 653 974] and within the Torr na Truim Semipelite Formation nearby, two small lenses of metagabbroic amphibolite [at NN 693 995 and NN 6695 9787] occur. The latter locality is associated with the Spirean Mor Granite Sheet-complex and is too small to be shown at the 1:50k scale. It is not certain if the amphibolites in the Glen Banchor Subgroup are the same age (or suite) as those in the Grampian Group as they have slightly different mineral compositions. The amphibolites within the Glen Banchor Subgroup of the Dalwhinnie district are probably older since there is evidence that they experienced earlier eclogite-facies conditions (Baker, 1986).

Several concordant to semi-concordant metamafic sheets and lenses occur within the Blair Atholl to Easdale subgroups, being particularly common in the Tulaichean Schist Formation e.g. around Meall Reamhar, [NN 995 759]. These sheets are generally a few metres to tens of metres thick and can be traced laterally for a few hundred metres. They are clearly porphyritic in places and are interpreted as pre-metamorphic basic sills and dykes. The amphibolites range from fine- to coarse-grained and commonly contain biotite and garnet. In places the bodies are discordant to bedding, but tend to have a foliation at their margins parallel to S2 in the country rocks. In the thick amphibolite outcrop west of Cnapan Liath [at NO 003 763] the foliation appears to have been folded prior to being folded round the Meall Reamhar Synform (see below).

Clachghlas and Fealar metagranites and associated granite intrusions

These foliated pinkish coarse-grained biotite-granites are similar in character to the larger Ben Vuirich granite (Pitlochry Sheet 55E) and may have a similar Neoproterozoic age, about 590 +/- 2 Ma (Rogers et al., 1989). The Ben Vuirich Granite is described as exhibiting a mildly A-type character and is considered to be a pre-orogenic rift-related intrusion (Tanner et al., 2006). The foliated granites and mafic igneous rocks about 600 Ma in age are now formalised as the Vuirich Suite (c.f. Tanner et al., 2006). No geochemical data are known from the foliated granites in the Newtonmore-Ben Macdui district, but a range of bulk compositions is likely within the Vuirich Suite as the small metagranites in this district appear to lack the metamorphic garnet present in the Ben Vuirich Granite (although they lie well within the Barrovian garnet zone).

On the south-eastern side of Glen Tilt a lenticular body of pink and grey spotted coarse-grained biotite-granite, known as the Clachghlas Granite, extends south-west from opposite Forest Lodge [NN 933 740] for about 2 km on to Sheet 55E. The margins and foliation of the granite dip at 25° to 54° to the south-east. This body consists of a series of granite sheets, up to 250 m thick in total, intruded concordantly into metasedimentary rocks. The body includes screens of the latter which are metamorphosed and/or metasomatised so that the junctions are indistinct and commonly biotite-rich. The granite lies close to or at the lower margin of the Schiehallion

Quartzite Formation in Glen Tilt which has been subjected to strong shearing, and the latter may have affected the body or controlled its intrusion (Stephenson, 1995).

Farther north-east, a smaller foliated granite is exposed on the south-east slopes above Allt Garbh Buidhe and extends south-east to Tulach Breac [NN 993 801]. This fractured and shattered red granite/microgranite has a foliation dipping 60°-65° to the north-east.

Highly sheared granite is also exposed in Allt Feith Lair [NO 016 805], about 800 m north-east of Fealar Lodge. It is a fine- to medium-grained, grey microcline-biotite granite with a strong foliation wrapping feldspar augen and a stronger stretching lineation plunging east-south-east. The microclines are well rounded and set in a fine-grained groundmass of quartz and other minerals, probably as a result of shearing.

Lying to the north-west of the Loch Tay Fault, the foliated granitic body on the western side of Meall Dubh-chlais [NN 920 795] lies within, and contains xenoliths of, the Gaick Psammite Formation. It contains thin dykes of foliated aplite and is associated with a foliated dioritic dyke. It appears to be older than the Glen Tilt Pluton but it is uncertain if the body is of similar age to the Ben Vuirich Granite or is an early Caledonian intrusion (see below).

1.4.2 Caledonian Igneous Supersuite

1.4.2.1 LATE-TECTONIC (ORDOVICIAN TO SILURIAN) IGNEOUS ROCKS (LATE D3)

These rocks include the veins and larger intrusive bodies related to the Strathspey vein system i.e. the Spirean Mor Granite Sheet-complex and scattered small bodies of granite, pegmatitic granite and aplitic microgranite.

Pegmatitic granites

Numerous but scattered coarse-grained to pegmatitic veins occur within the metasedimentary rocks of the district. Most individual pegmatitic veins have been omitted from the 1:50k maps for clarity. The limit of pegmatitic/granitic veins as shown in the north-western area of the Newtonmore sheet includes veins within the Glen Banchor Subgroup as well as those intruding the adjacent Grampian Group. A few foliated pegmatitic veins, with radiometric ages of around 800 Ma, have been identified within the Glen Banchor Subgroup of this district (Piasecki and van Breemen, 1983; and *cf.* the Tomatin district) but the undeformed veins are considered to be Ordovician in age. Many undeformed pegmatitic veins in the Glen Banchor area are probably related to the Spirean Mor Granite Sheet-complex (see below).

The pegmatitic veins are predominantly composed of pale or pinkish potash feldspar, mainly microcline, with quartz, some plagioclase, and commonly large plates of muscovite. Pegmatitic rock locally grades into coarse granite and in places contains garnet and biotite. Associated aplitic microgranite is also garnet-bearing. The pegmatitic rocks occur in veins or lenses up to 2 m thick, but are generally 0.1-1 m thick, roughly concordant with the main foliation. However, most pegmatitic rocks in the district are not foliated and are considered to be later than the foliation (i.e. post-D2 in age). Some pegmatitic rocks are foliated locally, but this could reflect D3 or late local deformation as some Silurian dykes are also foliated.

Additional areas of complex granitic/pegmatitic veining are delimited on the map in the Loch Cuaich area and on Meall an Dubh-chadha [NN 790 908]. Scattered pegmatitic granites within the Gaick Psammite Formation are shown on the map to the north and west of Carn na Cairn [NN 675 820] as well as farther to the east in Allt Gharbh Ghaig [NN 796 817]. However, the pegmatitic granite suite appears to be lacking from the eastern margin of the Newtonmore Sheet.

Pegmatitic rocks also have a limited distribution on the Ben Macdui Sheet where pegmatitic granites, which generally have an easterly trend, occur around the Chest of Dee [NO 013 886]. The veins are between 0.4 and 2 m thick and can be traced for up to 200 m along their length.

They may be related to an early phase of the Cairngorm Pluton but are described by Barrow et al. (1913 p.59) as ‘regionally metamorphosed, foliated muscovite-pegmatites’ and may be related to the foliated granites (see above).

Farther south on the Ben Macdui sheet, veins of sheared pegmatitic rock (**σπ**) are exposed within the Gaick Psammite Formation in the Bynack Burn area, for example at [NN 995 848]. They are rarely over 0.5 m thick and may be Neoproterozoic in age; related to the foliated granites (see above).

Spirean Mor Granite Sheet-complex

This complex of porphyritic coarse granite and pegmatitic sheets includes numerous screens and xenoliths of country rock. The limits of predominantly granitic sheet-complex are shown on the Newtonmore Sheet (Figure 2) but the complex continues westwards onto the Dalwhinnie Sheet 63E (British Geological Survey, 2000). The sheet-complex is garnet- and muscovite-bearing and locally foliated. Passive intrusion of the complex is indicated by the preservation of the rock-type and strike of the xenoliths concordant with the surrounding country rocks. The trace of a ductile shear-zone between the Glen Banchor Subgroup and the Grampian Group can also be followed through the complex on account of the numerous xenoliths of sheared rock. The complex is considered to be Ordovician in age (British Geological Survey, 2000) as post-tectonic (Silurian) dyke intrusions of microgranodiorite cut the complex.

1.4.2.2 POST-TECTONIC (LATE SILURIAN TO MID DEVONIAN) IGNEOUS ROCKS

The major plutons in the district (the ‘Newer Granites’ of Read, 1961) are the products of widespread uplift and granitic plutonic activity towards the end of the Caledonian Orogeny. Intrusive activity occurred towards the end of the Silurian and into the Early Devonian (about 427 – 395 Ma), contemporaneous with the final oblique closure of the Iapetus Ocean (Hutton, 1987) in which sinistral transpression was involved (Soper, 1986). Formerly the Glen Tilt granite was classified with the late-orogenic Caledonian granites (main phase) and the Cairngorm granite with post-orogenic granites (Watson, 1984). The Caledonian plutons are essentially calc-alkaline in character. Using petrochemical and isotopic criteria, Stephens and Halliday (1984) divided the post-tectonic granites of the Grampian Highlands into Argyll, South of Scotland and Cairngorm suites. These three suites are presumed to reflect the different nature of the lower crust under the areas occupied by the suites. The Cairngorm granite is probably interconnected at depth with the nearby Glen Cairn, Lochnagar, Ballater and Mount Battock granites (Rollin, 1984).

The Cairngorm Suite, which intrudes the Aberdeenshire-Buchan area, includes the Cairngorm Pluton and was considered to extend eastwards on a structural lineament, the Deeside Lineament (Fettes et al., 1986). Trewin and Rollin (2002) found no geophysical evidence for the Deeside Lineament, but they considered an ESE East Grampian Lineament to be the main control on the Cairngorm Suite of granites. The suite consists of evolved, largely I-type, high heat-producing granitic plutons (Webb and Brown, 1984). The Cairngorm Pluton is dated at around 408-404 Ma (see below) and as the suite clearly post dates the Iapetus Suture, Harrison (1987) concluded it could not be subduction related. Halliday and Stephens (1984) argued for a predominantly lower crustal origin on the basis of geochemical and isotopic evidence. Evidence for an underlying ‘Knoydartian’ granitic protolith (c. 845 Ma) below this suite was produced by Oliver et al. (2000). Studies of zircons from I-type granites, such as Lochnagar, in the Grampian Highlands (Appleby et al., 2006; 2007) showed contrasting whole-rock isotope and geochemical characteristics pointing to sources of significantly different age and/or composition compared to the Argyll Suite (Etive Pluton). The studies also indicated that formation of these 430-400 Ma Caledonian granites is dominated by crustal recycling rather than crustal growth.

The Glen Tilt Pluton is part of the South of Scotland Suite (Stephens and Halliday, 1984), which contains more granodioritic and dioritic intrusions than the Cairngorm Suite, with pyroxene-mica diorite and appinitic components. Stephenson and Gould (1995 included it more specifically in their South Grampians Suite and this has been defined formally in recent BGS publications as the South Grampian Subsuite (Gillespie et al. 2011). Recent work on U-Pb zircon dating (Oliver et al., 2008) of the Glen Tilt granite has produced one of the youngest ages among the Scottish granitoids at 390±5 Ma. In fact, they attribute the Mid Devonian intrusion to a far-field effect of the Acadian Event.

Cairngorm Suite

Cairngorm Pluton

The Cairngorm Pluton is the largest exposed component body of a distinct Cairngorm Suite forming the inferred East Grampian Batholith (Plant et al., 1980) and covers a total area of 365 km^2. Over 140 km^2 of the south-west of the pluton is exposed on the Ben Macdui Sheet 64E (Figure 4) which includes three of the six component granitic phases recognised by Harrison (1986; 1987a, b). The exposed phases are shown on the 1:50 000 map and are mainly textural varieties of biotite monzogranite with approximately equal proportions of quartz, plagioclase (oligoclase) and K-feldspar. The phenocrysts of K-feldspar are commonly large twinned orthoclase and quartz has a brown colour. Biotite is the only mafic silicate present, although it is locally altered to secondary muscovite. Common accessory minerals are apatite, Fe-Ti oxides, zircon and monazite (Harrison, 1988). Late hydrothermal alteration has caused widespread reddening of feldspars, due to exsolution of hematite from plagioclase. The presence of numerous aplitic and pegmatitic rocks with vuggy cavities suggests emplacement at a relatively high structural level, less than 12 km (Harrison, 1986); possibly 5-8 km below the surface (Harrison and Hutchison, 1987). Harry (1965) concluded that the pluton had a stock-like form and distinguished the Porphyritic or Carn Ban Mor phase in the western lobe of the pluton (Figure 4). The part of the pluton, including phases 2, 4 and 5, lying on the Aviemore Sheet (74E) has been described by Highton (1999). Phases 1 (Glen Avon Granite) and 3 (Beinn Bhreac Granite) are exposed in the eastern lobe of the pluton in the adjacent Braemar and Glenlivet districts (Figure 4).

Harrison (1987) found the Cairngorm Granite almost structureless internally, its external contacts vertical, discordant and unchilled, and large country rock xenoliths are rare. Hornfelsing is absent or localised and the foliation in the Grampian Group country rocks is undisturbed. Harrison therefore concluded that it had reached its present level of exposure by stoping large blocks of country rock and found no evidence of diapiric emplacement. A whole-rock Rb/Sr age of emplacement is recorded as 408±3 Ma (Pankhurst and Sutherland, 1982). A U-Pb zircon study (Oliver et al., 2008) dated the Main Phase on the Aviemore Sheet [at NH 986 072] at 404±18 Ma. The pluton comprises I-type granites with an $^{87}Sr/^{86}Sr$ initial ratio of about 0.706.

The Cairngorm granite has a high SiO_2 content (72-77%) and is moderately peraluminous (Harrison, 1988). The chemistry of all the phases is typical of minimum melt granites with a low MgO, CaO and P_2O_5 content. No systematic differences in chemistry between the porphyritic and non-porphyritic types were found and compositions plot close to the thermal minimum in the granite system (Harrison, 1988). Chemical analyses of the granite, including some samples containing small Mn-rich garnets, indicate that the pluton is transitional between I-type and A-type granites since it is very restricted in its major element composition, enriched in incompatible elements such as Y, Nb, Th, U, Sn, Be, and F, yet is part of a broadly calc-alkaline suite (Harrison, 1988). The garnets occur locally near the margins of the pluton and are all considered to be the products of magmatic crystallisation from a Mn-enriched, volatile granite ponded against the walls of the body (Harrison, 1988). The Cairngorm Pluton (Brown et al., 1981) is relatively depleted in Ba and Sr and enriched in radio-active elements such as U and Rb, also tin and beryllium. They are considered to be primary constituents of the intrusion and the incompatible behaviour of REEs (e.g. high Y content) in the Cairngorm intrusion coupled with a strong negative europium anomaly suggests cumulate feldspar at depth (Brown et al., 1981).

Exposures vary from jointed surfaces of solid rock to masses of slightly displaced blocks and a deeply weathered quartz and feldspar sand. The best exposures of the Main Phase (Phase 2) are in the corrie walls around Ben Macdui, Cairn Toul, Braeriach and Derry Cairngorm. Farther west exposures are common around Loch Einich. Areas of tors and sheet jointing in Glen Geusachan (Glasser, 1997) occur in the coarse-grained porphyritic subphase of the Main Granite.

Lower Devonian conglomeratic outliers overlie adjacent granitic intrusions and it is likely that parts of the Cairngorm granite were first exposed as high mountains around that time (Glasser, 1997) and that post-Devonian depths of erosion have been modest, since the Cairngorm granite retains near-surface (< 1.5 km) hydrothermal effects (Hall, 1991). The Cairngorm Mountains have formed the main Grampian watershed since the Early Devonian (Trewin and Thirlwall, 2002), suggesting that erosion over the mountains has been limited since that time. The current elevation of the Cairngorm massif is a result of Palaeogene uplift and subsequent minor phases of tectonic and isostatic vertical movement (Hall, 1991). Pre-glacial landform elements of the Cairngorms have been discussed by Gordon (1993).

Main Phase Granite (Phase 2). This is the main component of the pluton at outcrop (Figure 4) and comprises a largely coarse-grained biotite monzogranite with three textural varieties (Harrison 1986). The predominant variety is pink to red non-porphyritic medium to coarse biotite granite ($\boldsymbol{G^{G}}_{\mathbf{c2a}}$) with a grainsize between 4 and 7 mm. This variety forms the main exposures, for example, south-east of Ben Macdui [NN 998 980] (Plate 13) and around Cairn Toul [NN 961 972].

Plate 13 : Weathered boulders of Main Phase Granite, part of the Cairngorm Pluton as exposed on Derry Cairngorm [NO 0173 9803] looking west to Lochan Uaine and Ben Macdui in the background. BGS Imagebase No. P51430

North-east of Ben Macdui [NJ 022 002] there is a coarser grained (7-12 mm) non-porphyritic granite ($\boldsymbol{G^{c}}_{\mathbf{2c}}$) in which pegmatitic patches are common. Porphyritic granite ($\mathbf{G^{c}}_{\mathbf{2b}}$), with megacrysts of K-feldspar 1-3 cm long, lies mainly in a belt south of Ben Macdui, around the

Devil's Point [at NN 976 951]. The contacts between the two facies are gradational over several hundreds of metres (Harrison, 1987). The Main Granite intrudes the earlier white porphyritic Glen Avon Granite (Phase 1) and is intruded by the finer grained leucocratic Beinn Bhreac Granite (Phase 3) in the Glenlivet district (British Geological Survey 1996).

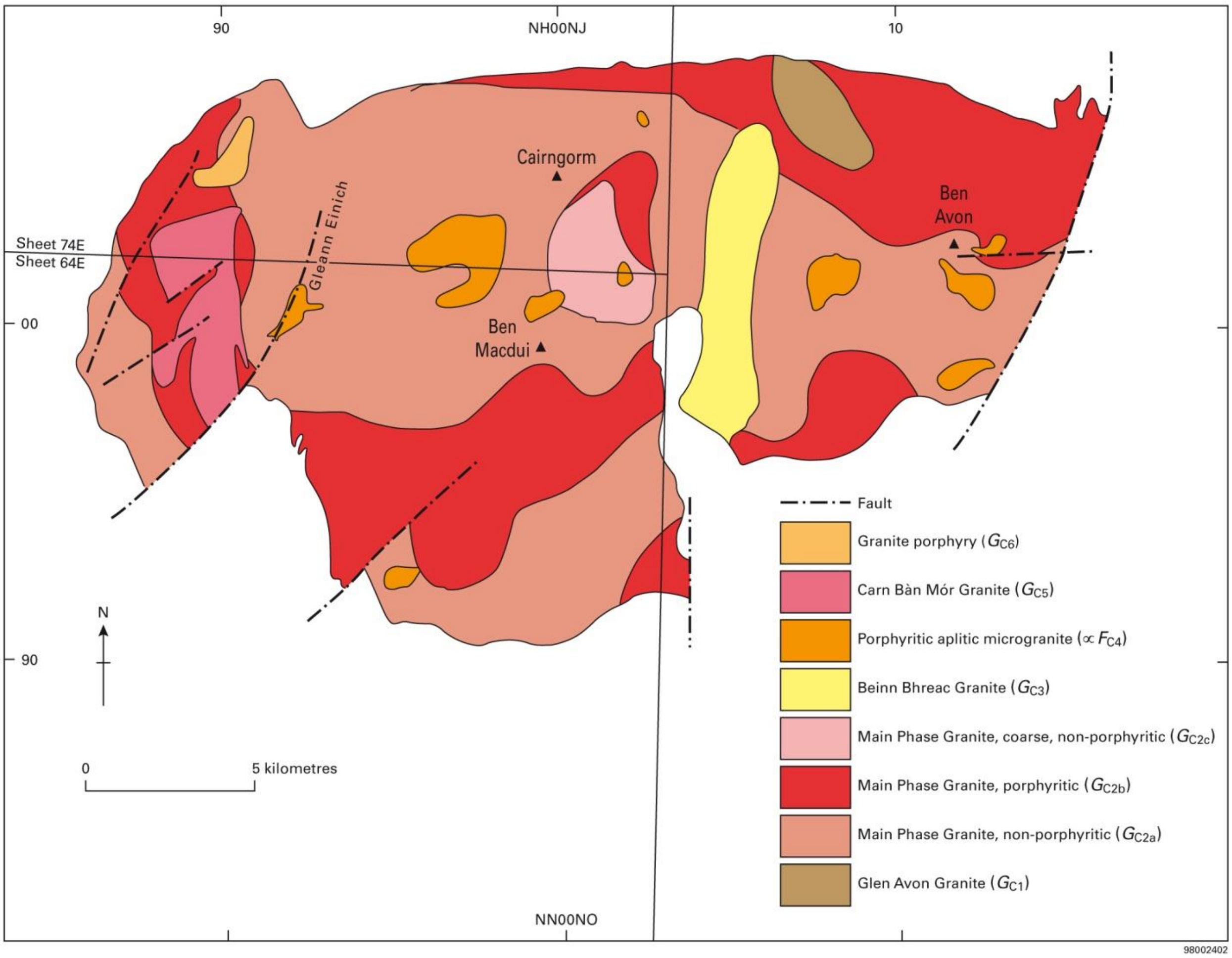

Figure 4: Distribution of internal components within the Cairngorm Pluton (Modified after Harrison, 1986).

Porphyritic Aplitic Microgranite (Phase 4). This grey-pink, medium granite (**αF_{C4}**) is weakly porphyritic and forms relatively small lenses or sheets within, or at the margin of the Main Phase Granite. It contains oligoclase and biotite with interstitial microcline and quartz. On its south-west margin the sheets [at NN 923 970 and NN 932 930] are peripheral to the pluton. Here the porphyritic aplogranite does not appear to grade into the Main Granite and may indicate a localised concentration of volatiles at the contact (Harrison, 1987). Another belt within the Main Phase Granite has been traced across Gleann Einich [NN 915 990].

Carn Ban Mor Granite (Phase 5). In the western lobe of the pluton [NN 890 990], this porphyritic microgranite (**F^{G}_{C5}**) lacks aplitic and pegmatitic patches and was mapped as a separate late phase (Harrison 1986; 1987). Its contact with the Main Phase Granite (Figure 4) is sharp and subvertical and it is the last major intrusive phase in the pluton. Although there is no evidence of a chilled margin, this phase becomes less porphyritic within a few metres of the contact with the Main Phase Granite.

Aplitic microgranite dykes **αF** [e.g. at NN 910 906] are associated with the Cairngorm Suite and dykes filled with hydrothermally altered intrusion breccia and accompanying quartz veins appear to be late-stage components.

Hydrothermally altered intrusion breccias. These minor late phase intrusions (***htX)*** generally form dyke-like bodies trending north-east to north-north-east and are associated with similarly trending, late (?Siluro-Devonian) quartz veins in the vicinity of the Cairngorm Pluton. The hydrothermal alteration generally results in kaolinisation of feldspars, chloritisation of biotite and oxidation of iron oxides to produce hematite.

Contact metamorphic aureole. The metamorphic aureole around the Cairngorm Pluton in this district is difficult to determine as it lies within the psammitic lithologies of the Grampian Group. The aureole extends for at least 1 km south of the pluton on to Cairn Geldie [NN 995 885] in Gaick Psammite Formation where assemblages of biotite-plagioclase-quartz-K-feldspar occur. These minerals have been recrystallised into a harder fine-grained hornfels. The foliation is barely discernable in this zone but way-up structures have locally been preserved e.g. at [NO 007 897]. To the north of the pluton in the Aviemore district (Highton, 1999), semipelitic interbeds contain biotite+plagioclase+quartz+K-feldspar assemblages, including cordierite and andalusite. No new garnet or sillimanite has been recorded from the aureole of the Cairngorm Pluton. This assemblage is consistent with the P-T estimate of 650°C and 4.6 kb for another semipelitic assemblage recorded north of the pluton (Wells, 1979). However, P-T estimates recorded by Harrison (1988) for calcareous and pelitic assemblages in the Cairngorm aureole lie in the range 550±30°C and 1.2-2.0 kbar.

South of Scotland Suite (South Grampian Subsuite)

Glen Derry Diorite $\boldsymbol{H}_\mathbf{C}$

A small portion of the Glen Derry Diorite (Figure 1) lies on the north-eastern margin of the Ben Macdui sheet [NO 037 997]. The bulk of the intrusion lies on Sheet 65W (Braemar). The coarse diorite consists mainly of labradorite, augite and hornblende (mostly secondary). The diorite intrudes the Gaick Psammite Formation but the western contact of the body against the main phase of the Cairngorm granite includes a zone of intermediate composition as a result of fusion by the granite (Barrow et al., 1912; 1913). The fused rock contains biotite, interstitial quartz and a less calcic plagioclase than the hornblende-bearing diorite. The diorite is one of a number of small dominantly intermediate plutonic intrusions including the Glen Doll Diorite (Smith et al., 2002) considered part of the South of Scotland Granitic Suite. It is considered to be Silurian in age and certainly older than the Cairngorm Pluton dated at 404-408 Ma.

Glen Tilt Pluton

The Glen Tilt Pluton lies just to the north-west of the Loch Tay Fault (Figure 1) and covers an area of nearly 77 km^2. It intrudes Grampian and Appin group metasedimentary rocks (Plate 14) juxtaposed by the Boundary Slide. The pluton comprises a main intrusion of pink granite together with marginal granodioritic to dioritic rocks on its south-east side (Deer, 1938; 1950; 1953; Mahmood, 1986; Beddoe-Stephens 1993; 1994; 1997; 1999). South-east of the main Beinn Dearg granite (Figure 1), a smaller satellite body is centred on Sron a' Chro. This satellite and an extensive area of the south-eastern part of the main pluton is granodioritic (*sensu stricto*). The granodioritic rocks typically have 64-72% SiO_2; the more basic variants representing hybridisation between granodiorite and diorite magma. The contacts between the main phases are gradational and show evidence of hybridisation. The Beinn Dearg granite is pink and coarse-grained with little biotite. High-silica granite varieties become more abundant towards the centre of the Beinn Dearg intrusion.

Plate 14: Pink granite veins of the Glen Tilt Pluton intruding Glen Banvie Formation below the ruined Dail-an-eas Bridge, River Tilt [NN 9385 7465]. BGS Imagebase No. P663227

The diorite is mainly a massive, coarse-grained non-porphyritic intrusion containing abundant hornblende and variable proportions of biotite, plagioclase, quartz, K-feldspar, iron oxides and titanite. The diorite includes varieties of quartz-diorite, some of which contain chlorite as an alteration product of the mafic minerals (Mahmood, 1986).

Appinitic variants, containing large zoned hornblendes preserving clinopyroxene cores, occur locally grading into the main body (Beddoe-Stephens, 1993). Compositionally the diorite ranges from 48-58% SiO_2 and the appinitic lithologies are significantly richer in MgO, Ni and Cr. Inhomogeneous crystallisation led to initial localised accumulation of clinopyroxene to form the appinitic rocks. A later increase in the water content of the melt caused the alteration of the pyroxene to hornblende (Beddoe-Stephens, 1997). The non-appinitic diorites record variable cumulus enrichment of plagioclase or Fe-Ti oxide with movement and variable entrapment of residual intergranular melt in the form of quartz-K-feldspar crystallisation. In more-evolved diorites, the biotite content dominates over hornblende which it replaces. Mineral chemistry and analyses were given by Mahmood (1986) and Beddoe-Stephens (1999). Consideration of mineral chemistry and experimental phase relations led Beddoe-Stephens to conclude that the diorite crystallised from hydrous basic magma at 2-4 kbar and over the temperature range 1000-700°C. The pressure estimates are consistent with phase assemblages developed in the contact metamorphosed pelitic rocks. Mahmood (1986) noted that plagioclase and clinopyroxene were early crystallising phases and that biotite, alkali feldspar and quartz were late interstitial phases. The quartz-diorites, granodiorites and biotite granites show trends of enrichments in Th, Zr, K and Rb and depletion in Nb, P, Ti and La. A parental diorite composition appears to be incompatible with fractionation to quartz-diorite (Mahmood, 1986) and the quartz-diorite could not be modelled to form the biotite granite. She concluded that separate pulses of magma formed the Glen Tilt Pluton. The quartz-diorites and granodiorites could be linked by fractionation of a magma derived by melting of continental crust, whereas the earlier dioritic parental magma may have been derived from the upper mantle, as indicated by the high Ni and Cr values in the diorites and appinitic diorites (Mahmood, 1986).

The earlier workers (e.g. Deer 1938; Mahmood, 1986) stated that the diorite was intruded earlier than the granite as supported by the evidence of granitic veins and feldspar porphyroblasts within the diorite. Subsequently Beddoe-Stephens (1999) concluded that biotite granodiorite/granite was intruded before the diorite but the intrusions were close enough in time that local melt remobilisation and back-veining accompanied the diorite emplacement. A comagmatic suite of microdiorite porphyry dykes intrudes the granitic rocks and more rarely the diorite in the pluton. They contain zoned plagioclase microphenocrysts 1-2 mm long in a fine-grained matrix including primary brown hornblende and biotite and are locally quartz-phyric. These slightly fractionated melts were expelled during crystallisation of the diorite (Beddoe-Stephens, 1999).

The complex shape of the diorite is partly controlled by the late NW-trending fold of the junction between the Grampian Group and the Glen Banvie Formation. On the south-east side of the diorite, major movements on the Loch Tay Fault post-date the main intrusions of the pluton as they are truncated and do not appear on the south-east side of the fault (Stephenson, 1999). Despite later brittle movements on the Loch Tay Fault, which brecciate some minor micrgranitic and microdioritic intrusions in the fault zone, this fault or a precursor, appears to have controlled the southeasterly extent of the pluton. A similar conclusion was arrived at by Oliver et al. (2008) in their study which dated the Sron a’ Chro body at 390±5 Ma using ion microprobe U/Pb zircon methods. They concluded that these I-type granites were intruded along the active, sinistrally transpressive Loch Tay Fault as an effect of far-field Acadian (Mid-Devonian) events. Oliver et al. (2008) also recorded local east-west-striking subvertical foliation and parallel ellipsoidal enclaves of (unfoliated) diorite and (foliated) psammite within the granite as evidence of deformation related to these events.

Later small leucogranite bodies, such as that on the south-east side of Conlach Mor [NN 932 766] intrude both the granite and the diorite. They are more evolved and contain muscovite (+/- biotite) and microcline. The body near Conlach Mor is a fine- to medium-grained, elongate stock-like intrusion (Beddoe-Stephens, 1993). The muscovite occurs as squat crystals up to 2.5 mm long, which appear to be primary (magmatitic in origin), rather than a replacement phase. The decrease in biotite content corresponds with an increase in SiO_2 and there is a silica gap between evolved granite (>75% SiO_2) and granite/granodiorite (<71-72% SiO_2). The commonly associated Siluro-Devonian dykes of quartz porphyry, felsite and lamprophyre do not appear to have intruded the Glen Tilt Pluton, but in the west minor microgranite and granodiorite, micromonzodiorite and quartz-diorite dykes occur both within and outside the Beinn Dhearg granite. The Sron a’ Chro intrusion is cut by microdiorite dykes typical of the late-stage activity within the pluton.

Contact metamorphic aureole. Because of the unreactive nature of the lithologies in the bulk of the Gaick Psammite Formation on the north-west side, and truncation by the Loch Tay Fault on the south-east side of the pluton, its metamorphic aureole has not been mapped. Barrow (1893; 1904) found evidence for an extensive ‘sillimanite aureole’ extending between the Glen Tilt Pluton and the Chest of Dee, based on the presence of small sillimanite needles in the psammites above Loch Tilt (Barrow et al., 1913 p.37).

Pelitic schists of the Glen Banvie Formation occur within enclaves of country rock north-west of the Loch Tay Fault and include contact metamorphic aluminosilicates, cordierite, spinel and corundum while associated calcsilicate rocks include garnet (grossular-andradite?)- diopsidic pyroxene skarns and tremolite/actinolite-diopside rock (Beddoe-Stephens, 1997). Sillimanite-bearing assemblages (S95369) occur in Appin Group strata 50 m south-east of the Loch Tay Fault (Beddoe-Stephens, 1997) indicating that the intrusion affected these rocks and limiting the displacement on the fault

An early attempt to calculate the contact temperatures and pressures of the aureole of the Glen Tilt Pluton was made by Wells and Richardson (1979). Based on the assemblages cordierite-biotite-sillimanite-K-feldspar-plagioclase-quartz and cordierite-biotite-hypersthene-anthophyllite -plagioclase-K-feldspar-quartz, they calculated that the intrusion induced temperatures of 770°±40°C at 5.5 ±1.2 kb (total pressure with P_{H2O} close to P_{solid}) within the aureole.

As a result of the mapping by the Geological Survey, around the Glen Tilt Pluton near Beinn Mheadhonach [NN 880 756] contact metamorphic mineral assemblages were recorded in local semipelitic beds within the Gaick Psammite Formation. These include garnet-cordierite (biotite-quartz-plagioclase-K-feldspar) rocks with a granoblastic texture (Beddoe-Stephens, 1997). The diagnostic assemblage of cordierite, sillimanite (locally after andalusite) and K-feldspar (S96542), and also minor amounts of spinel and corundum were recorded (Beddoe-Stephens, 1999) from pelites and semipelites in the Glen Banvie Formation. After consideration of mineral assemblages and inferred reactions in the contact rocks, Beddoe-Stephens (1999) concluded that a best estimate of pressure was in the range 2-3 kbar (consistent with other evidence that the pluton crystallised at 2-4 kbar under hydrous conditions). The evidence for partial melting is limited to small areas of granophyric quartz-feldspar intergrowth and these features are compatible with a relatively low pressure of contact metamorphism and peak temperature around 650-700°C. Locally (e.g. S95384) muscovite has been consumed to form aluminosilicate or cordierite assemblages. In places andalusite is partially replaced by sillimanite, probably as temperature increased. The locally observed breakdown of sillimanite (with biotite) could have occurred at higher PT to produce the cordierite+K-feldspar+/-corundum assemblages (Beddoe-Stephens, 1997).

1.4.2.3 Siluro-Devonian Calc-alkaline Minor Intrusion Suite

The numerous minor intrusions of Caledonian (Siluro-Devonian) age include intrusion breccia, and silicic and intermediate to basic minor intrusions. Some of them can be related to the plutonic suites in the area (Beddoe-Stephens, 1997).

Intrusion breccia

Intrusion breccia forms an oval body intruding the Gaick Psammite 4 km south of the Cairngorm Pluton [at NN 996 840] and may be related to an explosive late stage of the pluton's emplacement. The rock is a densely packed breccia with psammite fragments in a sparse fine-grained micrograniti matrix.

Silicic minor intrusions

Several minor granite, biotite granite, granodiorite, biotite granodiorite and granitic rock bodies are present although many cannot be directly related to the major plutonic suites. However, they all appear to be post-orogenic and probably late-Silurian to Mid-Devonian in age.

There is a distinct swarm of microgranitic or felsite (fine- to medium-grained felsic rock, unclassed) rocks, which are locally quartz- and/or feldspar-phyric. This swarm intrudes the Main Phase Cairngorm granite so is relatively late (i.e. post 404±18 Ma). The sheets and dykes also intrude some of the pre-existing shear-zones and north-north-east-trending faults, as well as along minor mainly east-north-east-trending faults, e.g. on Meall na Spionaig [NO 005 774]. On the south-east side of Glen Tilt they commonly occur in groups of three or four sheets, each up to 3 m thick. The rock typically has a pale grey-green, very fine-grained groundmass containing prominent white feldspar and less common clear quartz phenocrysts. A large sheet of quartz-feldspar porphyry with a granodioritic groundmass trends north-north-easterly from Gleann Mor, across Carn Dearg [NO 022 799] and on to Sheet 65W (Braemar). This rock consists of abundant euhedral phenocrysts of plagioclase feldspar and rounded quartz up to 4 mm in diameter. Additionally, numerous smaller biotite and a few amphibole phenocrysts are set in a fine- to medium-grained, granular, quartzofeldspathic matrix (Stephenson, 1990). It was emplaced into a major dislocation that significantly affects the Dalradian outcrop (see below).

Porphyritic microgranitic bodies, commonly in the form of sills, are relatively abundant intrusions in the Gaick Psammite Formation around the Gaick Forest [e.g. at NN 739 849]. Microgranodiorite is less common and locally granophyric /porphyritic.

Intermediate to basic minor intrusions

These are on the whole less common volumetrically than silicic minor intrusions. They include:- microdiorite, porphyritic microdiorite, quartz-microdiorite, micromonzodiorite, diorite and quartz-diorite, occurring mainly in the form of dykes, sills or plugs. Small dioritic bodies with a wide variety of grain-size, texture and colour index occur in the Loch Tay Fault-zone and probably relate to the Glen Tilt Pluton. A fine grained grey-green microdioritic rock is exposed in Allt na h-Easg' Leathain [NN 9972 8165]. Locally it has a texture like a microdiorite but is pale and siliceous and may be more felsitic (Stephenson, 1995).

Minor appinitic diorite occurs in very small plugs north-east of Creag Dhubh [NN 6926 9915 and 6936 9895]. The rock is coarse grained, mafic rich and contains titanian amphibole, biotite and clinopyroxene set in a matrix of plagioclase, K-feldspar and quartz.

Lamprophyric dykes include spessartites, which are the hornblende-plagioclase-rich variety. They are fine to medium grained with locally titanian amphibole macrophenocrysts.

1.4.2.4 Late (?Siluro-Devonian) quartz veins and sheets, and Late-Carboniferous dykes

A swarm of quartz veins and sheets of probable Siluro-Devonian age cuts the Gaick Psammite Formation between A' Bhuidheanach Bheag [NN 660 775] and Carn na Caim [NN 670 820] in the south-west of Sheet 64W. The veins commonly trend north-east or NNE and may relate to the brittle faulting of similar trend in the area.

Minor undeformed doleritic dykes of probable Late Carboniferous age (about 300 Ma) crop out [at NO 090 748 and NO 090 749] within the Gleann Beag Schist Formation in the core of the Meall Reamhar Synform.

1.5 STRUCTURE AND METAMORPHISM

1.5.1 Ductile Deformation

The district is predominantly affected by the Grampian orogenic event, which occurred in the mid Ordovician at about 470 Ma. Any earlier Precambrian tectonothermal metamorphism (see below) is considered to be limited to the Glen Banchor Subgroup (*cf.* Dempster et al., 2002). The Grampian Event deformed the Dalradian Supergroup into a complex regional fold pattern of tight to isoclinal folds with amplitudes of up to tens of kilometres. In the 'root zone – mushroom model' of Thomas (1979) the Grampian Group was folded into the Atholl Nappe and the younger part of the Dalradian Supergroup into the Tay Nappe during D1. The early folds, mainly developed during intense D1 and D2 deformation (Lindsay et al., 1989), and their associated axial planar cleavage were considered to 'fan' across the region from upright structures in the north-west to south-east facing fold-nappes in the south-east where they pass into the overturned limb of the Tay Nappe (see Stephenson and Gould, 1995). There has been a debate as to whether the upright folds were part of a root zone to the recumbent folds or later refolding (Thomas, 1979; Bradbury et al., 1979; Treagus, 1987; Krabbendam et al., 1997). The recent British Geological Survey mapping (Leslie et al., 2006) has identified large-scale recumbent F2 folds, which face consistently south or SSE. The Gaick area is essentially a flat belt which gradually steepens to face downwards to the south below the Appin Group rocks and the Boundary Slide structure.

1.5.1.1 Deformation in the Glen Banchor Subgroup

The main phase of deformation to affect these rocks is characterised by large-scale, gently inclined to recumbent folds with axes trending east-west. These were affected by widespread north- to north-north-westerly-directed shearing along major high-strain zones such as the Blargie-Glen Banchor shear zone (Phillips et al., 1999). The high-strain zones include the Grampian Shear-zone (Piasecki, 1980).

The S2 fabric seen in the Glen Banchor pelites is a composite, coarse schistose to gneissose foliation. At a later stage in the D2 phase, much of the deformation became focussed along the major ductile shear-zones characterised by schistose to blastomylonitic rocks. Some of the shear-zones in the Glen Banchor basement, including one on An Stac [NH 680 003], were studied by Temperley (1991), Hyslop and Piasecki (1999), and the latter authors concluded that transport during the Knoydartian was approximately to the north-north-east. Sheared pegmatitic veins and pods are included in these zones and though it is debatable whether these are syn-tectonic, they have yielded Rb-Sr muscovite ages of 750-700 Ma (Piasecki and van Breemen, 1979; Piasecki and van Breemen, 1983). Within the Grampian Shear-zone farther north, neocrystalline monazite from both the associated pegmatitic rocks and the blastomylonite have yielded U-Pb isotope ages of about 806 Ma (Noble et al., 1996) and a U-Pb zircon age of 840+/-11 Ma was obtained from leucosome in a migmatitic psammite near Slochd Summit (Highton et al., 1999). This forms the evidence that at least part of the metasedimentary sequence south-east of the Great Glen Fault experienced a Neoproterozoic tectonometamorphic event (Highton et al., 1999). The fabric in the shear-zones is a composite S0-S2 fabric and is broadly coplanar with S2 outside the shear-zones.

The D2 structures are reworked by later upright north-east-trending F3 folds, which control the outcrop pattern of the main lithostratigraphical units. A large-scale upright antiform, cored by interlayered psammite with subordinate semipelite (Q_{GB}), has an axial trace trending north-east to the north of An Stac (Figure 2). About 2 km to the west, a complementary upright synform plunges to the north-north-east.

The later stages of this D3 phase were contemporaneous with the emplacement of pegmatitic and granitic intrusions at about 450 Ma (van Breemen and Piasecki, 1983). Since this would appear to be the same D3 as that which affects the Grampian Group, it begs the question as to whether the D1/D2 that affects the Dalradian rocks has also affected or overprinted the early deformation recognised in the Glen Banchor Subgroup. Lindsay et al. (1989) concluded that none of the migmatised rocks in the Glen Banchor Subgroup carried earlier (pre-Grampian Event) deformation or metamorphic fabrics but only the D1-D3 recognised in the Grampian Group and they could not confirm the existence of the Grampian Slide.

1.5.1.2 Ductile deformation north-west of the Loch Tay Fault

The nature of the ductile fabrics and fold architecture developed in much of the Grampian Group north-west of the Loch Tay Fault is relatively simple, in part due to the dominantly psammitic nature of the succession. Three phases, D1-D3, have been recognised. Planar S fabrics (Plate 15) dominate; with the exception of intersection lineations (S2 on S0 or vice versa) and/or F2 fold hinges, there are no widely developed L fabrics, e.g. conspicuous mineral or rodding lineations, apparent on S0 or S2.

Plate 15 : A transecting S2 fabric on S0 bedding in the Gaick Psammite Formation, An Dun, Gaick [NN 71895 80823]. BGS Imagebase No. P521694

The degree of co-axial flattening strain may have been considerable, the best preserved cross-bedding occurs in hinge-zones, elsewhere on folds limbs original bedding features have not been readily identified. Only hints of convergence of compositional laminae are seen in places. Regional facing is typically gently down to the south. The D2 structure only appears significantly modified (by D3 folding and fabrics) in the north-west part of Sheet 64W towards the Glen Banchor 'high', and suggests that buttressing against this basement feature (Robertson and Smith, 1999) is a significant factor south-east of Glen Truim.

D1 Deformation

The earliest phase, D1 has only been recognised in a few well-exposed sections such as on the A9 road cutting (Thomas, 1988) east of Crubenmore Lodge [NN 678 916]. Here isoclinal minor F1 folds with weak axial planar fabrics are refolded by the main recumbent F2 folds (Figures 5, 6) carrying the main regional foliation, S2. One recumbent refolded metre-scale F1 fold has a horizontal hinge trending N103° but interference patterns show that the F1 folds have curvilinear axes. No large scale or regional F1 folds or shear-zones have been identified in the Gaick area. In some semipelitic lithologies, the S1 fabric can be seen crenulated by S2, particularly in F2 fold hinges and it appears to be tectonic in nature (Leslie et al., 2006). Elsewhere the 'bedding parallel' fabric is defined by a preferred parallel orientation of small prismatic biotite crystals, which is rarely oblique to S0.

D2 Deformation

In the north-west of the district, in Glen Truim, both south-east- and north-west-verging folds are present and the overall geometry of the minor structures is consistent with the steep common limb of a F2 syncline-anticline pair, now displaced by faulting (see the cross-section on the Newtonmore sheet).

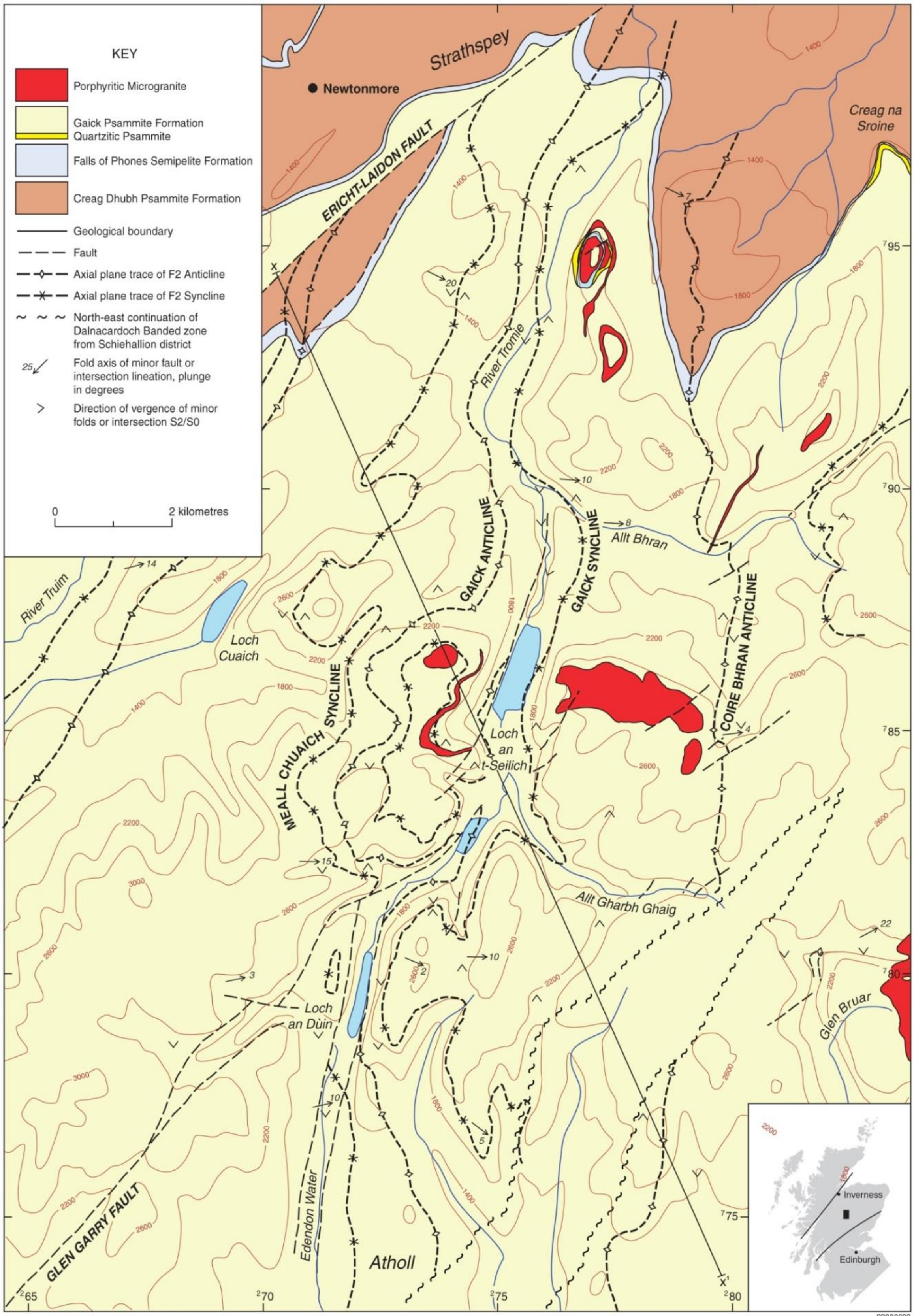

Figure 5 : Simplified geological map of Gaick region (Sheet 64W) showing the system of north-south trending F2 fold axial traces detected. The section line X-X' is the line of section on Figure 6. The inset map shows the general location as a black rectangle (taken from Leslie et al. 2006).

In the Gaick area, D2 produced the dominant regional planar foliation accompanying kilometre-scale recumbent folds and minor parasitic folds. In psammites S2 is the main penetrative foliation, defined by a stubby biotite alignment. In more pelitic intercalations S2 is a tight crenulation cleavage (Leslie et al., 2006). Systematic observation of the transection of the biotite foliation with bedding (S0) is commonly possible and together with identification of discrete hinge-zones (e.g. Allt Bhran NN 765 903), has been used to constrain a stack of kilometre-scale tight to isoclinal recumbent F2 folds (Figures 5, 6 and the cross-section on the 1:50k Bedrock geology Sheet 64W Newtonmore). A section through the Creag an Lochan Duin recumbent F2 syncline is exposed above Loch an Duin (Plate 16).

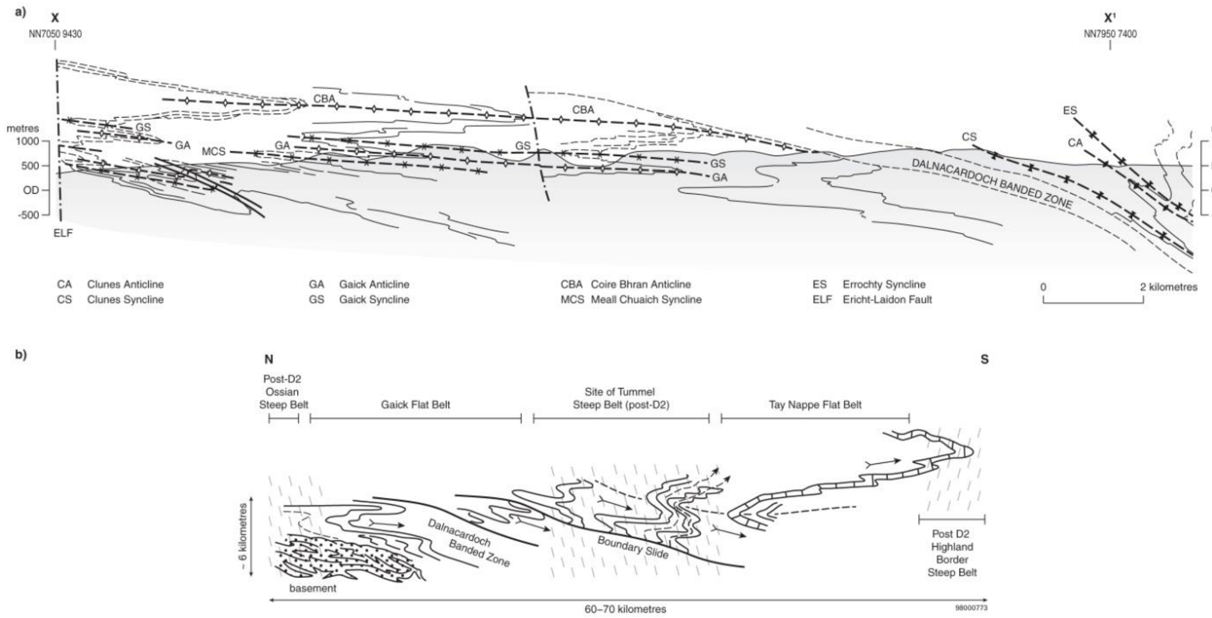

Figure 6 : (a): Transect of the Gaick Fold Complex for the section line X-X' on Figure 5. (b): Schematic cross-section from the Geal Charn-Ossian Steep Belt in the north to the Tay Nappe Flat Belt in the south (taken from Leslie et al., 2006).

Plate 16: The Creag an Lochan Duin fold. Photomontage of fold profile in Gaick Psammite Formation at An Dun/Creag an Loch, Gaick [NN 72007 81311]. BGS Imagebase No. P5217000.

F2 fold traces extend broadly north-south across the Gaick plateau and represent typically gently east-dipping fold axial surfaces with gently east-plunging fold axes. The regional F2 hinge-zones are marked by stacks of close to tight F2 folds each with wavelengths of 0.5 m or less and commonly with a good axial planar fabric. Such hinge-zones can be several tens of metres thick and can have quite rounded profiles in a subvertical fold envelope as on Creag an Loch [NN 7292 8030] and along Allt Bhran [NN 770 897], which both lie on the trace of the Gaick Syncline (Figure 5). The limbs of the regional F2 folds are characterised by zones of moderately high strain, with very straight laminations in psammite, subparallel to S0.

The best examples of stratigraphical younging evidence and hence facing are seen along Allt Bhran [NN 772 896 – 764 902]. This section contains many F2 folds in mm-scale laminated psammites, clearly preserving cross-bedding and indicating southerly facing (Plate 17).

Plate 17 : South-east-facing (to the right) in a F2 minor fold hinge affecting sedimentary cross-lamination in Gaick Psammite Formation. Cross-lamination oversteepened in the hinge-zone above the compass. Allt Bhran [NN 76559 90129]. BGS Imagebase No. P514833.

Southerly facing is also demonstrated in right-way-up graded (turbiditic) psammites at Feshie Bridge [NH 852 043], Creag Dhubh [NN 824 996] and Creag an Sroine [NN 838 970]. However, in an exceptional high-strain zone (depicted in the south-east of Figure 5 with sheared rock symbols) S0, S1 and S2 are absolutely parallel. This zone is up to 1 km thick and is apparently a north-eastward continuation of the Dalnacardoch Banded Zone as defined in the Schiehallion area (Treagus, 2000) and section B in Figure 6. The boundaries of the zone are transitional and it appears to die out north-eastwards on the Newtonmore Sheet. To the south-west in the Schiehallion district this increasingly flaggy zone is considered the product of strong deformation associated with the Boundary Slide and the tight Errochty Synform (Treagus, 2000). This deformation effectively prevents the subdivision of the Grampian Group into formations (British Geological Survey, 2000b). The Dalnacardoch Banded Zone had formerly been considered as a likely product of D3 sliding creating a composite S1, S2 and S3 (Thomas, 1980). The lack of a conspicuous linear fabric in this high-strain zone suggests intense flattening rather than highly non-coaxial strain.

South-east of the Dalnacardoch Banded Zone, south-facing F2 folds can again be traced due to systematic changes in vergence (Leslie et al., 2006). These are part of the Meall Reamhar/Clunes system of F2 folds recognized by Treagus (2000). The extension of the Coire Bhran Anticline (Clunes Syncline on Figure 6), the Clunes Anticline, and the Errochty Syncline have been traced (Figure 6). Although the trace of the Coire Bhran Anticline is aligned with the Bohespic Antiform (part of the post D2-preD3 Errochty phase of Treagus, 2000) on the current edition of the Schiehallion sheet (British Geological Survey, 2000b), this is unlikely to mark a single continuous fold trace. The relationships of the Bohespic Antiform were re-examined in critical sections of the Schiehallion district (Leslie et al., 2006) and it was concluded that the fold is a composite structure consistent with a F2 antiformal syncline closure that is overprinted by co-axial crenulations folding and co-planar cleavage development.

D3 Deformation

Evidence for D3 deformation is found in the north-western part of the Newtonmore Sheet as the Glen Banchor 'high' is approached. Open to close folds with overturned axial planes assigned to D3 are common in the Glen Truim area but vary in abundance and tightness. The major F3 synform passing through Creag Dhubh [NN 677 975] can be traced south-west for over 3 km and a complementary anticline may be located in the poorly exposed ground east of the Glen Truim Fault [NN 687 944]. On the south-east limb of the Creag Dhubh synformal structure, numerous minor F3 folds with an associated crenulation cleavage are seen in interbedded psammite and pelite lithologies. The axes generally trend north-east – south-west (in contrast to the south-easterly orientation of F3 'crossfolds' in the Glen Tilt and Gleann Fearnach areas). In the north of this area the axes of minor F3 folds plunge ≤ 20° to the north-east, but to the south they plunge ≤ 30° to the south or south-west. The folds generally have steep long limbs and shallowly dipping short limbs; axial surfaces dip moderately to steeply south-east in contrast to the gently ESE-inclined S0/S1 in the Gaick region. In semipelitic bands the axial planar, commonly widely-spaced, crenulation cleavage dips about 60° to 80° to the south-east. The crenulation cleavage is well seen in the Creag na Sanais semipelite east of Meall Ruigh nam Biorag. However, locally there appears to be fanning of the crenulation cleavage to dip up to 40°NW. Near the summit of Am Binnein a large scale F3 culmination appears to be upright and plunging south-west.

In the south-east of the Ben Macdui area (Figure 7), north-west-trending axial traces of folds of the S2 fabric indicate the later development of 'F3 crossfolds'. These later structures have a similar relationship to the local earlier fabrics as that of the Trinafour phase folds in the Schiehallion area (Treagus, 2000).

The open north-west-trending synform (Conlach Mhor Synform) within the Glen Banvie Formation to the north-west of the Loch Tay Fault appears to fold the Boundary Slide (see below) and has its axial trace passing south of Conlach Mhor. A complementary dome-like antiform (An Sligearnach Antiform) has a NW-trending trace lying about 2.5 km north and passing through An Sligearnach [NN 952 782]. Close to the Loch Tay Fault, in the north-western bank of the River Tilt between NN 935 743 and NN 938 745, minor upright close to tight folds of Glen Banvie Formation strata plunge at 10 - 20^{o} to the north. The axes, some with related mullions, are fairly consistent in orientation but might reflect their proximity to the fault. The major fold axes probably plunge to the south. However, in close proximity to the Glen Tilt Pluton the foliation in the country rock is variable suggesting intrusion-related deformation.

Boundary Slide north-west of the Loch Tay Fault

On the north-west side of the Loch Tay Fault, the Boundary Slide (Figure 7) is considered to be a D2 high-strain zone separating the Glen Banvie Formation from the Gaick Psammite. It is largely obscured by the intrusion of the Glen Tilt Pluton but Beddoe-Stephens (1997) found slight evidence of higher degrees of strain-related recrystallisation in the flaggy rocks at Allt Mheann [NN 973 781] and Allt a' Chrochaidh [NN 956 768].

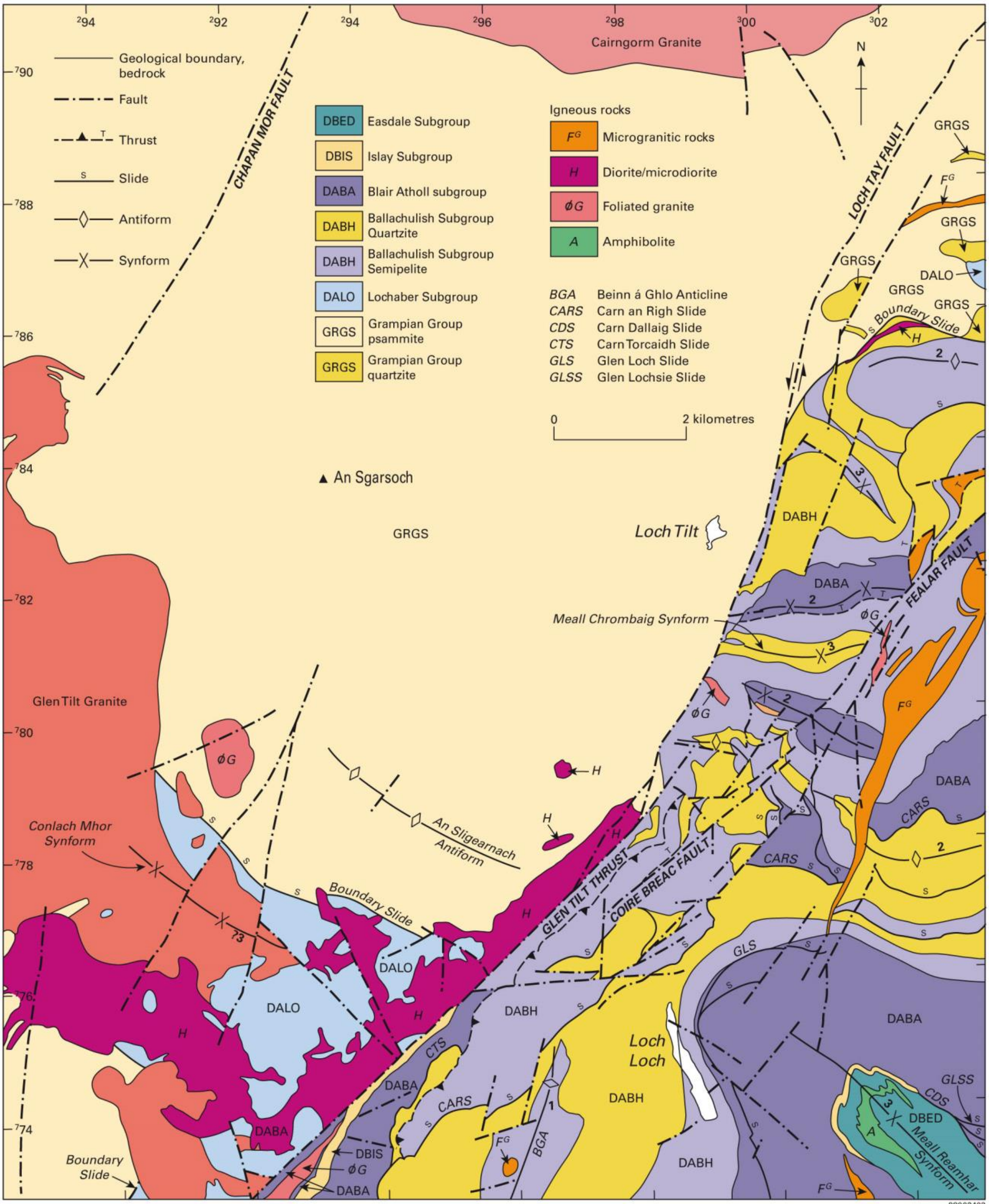

Figure 7 : Major structures in the southern part of Sheet 64E (Ben Macdui), with emphasis on the Appin and Argyll Group Dalradian.

1.5.1.3 DUCTILE DEFORMATION SOUTH-EAST OF THE LOCH TAY FAULT

Early Folds (F1/F2)

Early folds are tight to isoclinal and, west of Glen Loch, axes trending NE-SW are common (due to refolding?) whereas east of Glen Loch, axes trend nearly E-W. In common with other regional interpretations (e.g. Treagus, 2000), isoclinal F1 folds in the Glen Tilt area are interpreted as being refolded by near-coaxial, tight to isoclinal F2 folds. Therefore F1 folds either face upwards to the north-west or downwards to the south-east.

The major F1 fold in the south of the Ben Macdui 64E sheet is the Beinn a' Ghlo Anticline which has a north-north-east-trending axial trace (Figure 7) and lies above the Carn an Righ Slide (see below). Older rocks of the Glen Clunie Graphitic Schist are exposed in its core where the axial plane dips steeply to the east-south-east. The fold axis appears to be curvilinear and the fold is upward facing according to Bradbury et al. (1979).

In the Bedrock cross-section 1 on the accompanying 1:50k edition of Sheet 64E the Beinn a'Ghlo Anticline is interpreted as an F1 fold lying on the short limb of a larger north-west-verging F2 fold whereas Bradbury et al. (1979) considered it to be F3.

One major fold which has been clearly assigned to F1 is the downward south-east-facing anticline in the Beinn a' Ghlo Transition exposed in northern Glen Loch between the Coire Breac and Fealar faults [NN 988 777] near Creag Dhearg (Stephenson, 1991). It is downward facing due to refolding by D2 and is also refolded by smaller-scale upright F4 folds. The core of this anticline, occupied by the Glen Clunie Graphitic Schist Formation, is exposed west of Creag Dhearg, on the immediate south-east side of the Coire Breac Fault around [NN 988 779].

Throughout the area south-east of the Loch Tay Fault minor tight to isoclinal folds with axes trending approximately NE-SW are assumed to be early (F1 or F2). Both north-easterly and south-westerly plunging folds are observed but the majority plunge north-east at gentle angles (< 20°) and most have north-westerly vergence. Good examples are exposed in Allt Fheannach, just below the junction with Allt Coire a' Chaisteil [NN 967 747], Plate 18. A range of folds are well seen in metalimestones below the Glen Tilt Thrust where they have attenuated limbs and resemble the shear folds attributed to D2 elsewhere (Stephenson, 1995).

North-east of Glen Loch, a stack of recumbent F2 folds facing north, has been identified within the Ballachulish and Blair Atholl subgroup strata below the Carn an Righ Slide (see cross-section 2 on 1:50k Bedrock Sheet 64E). One downward-facing closure is marked by a limestone within the Glen Loch Phyllite and Limestone Formation at [NO 007 786]. To the north [NO 007 797] the axial trace of a northward-facing F2 recumbent fold is repeated about the open F3 Meall Chrombaig Synform. To the north of the loch, below the slide on Sron a Bhoididh at [NO 001 830], An Socach Quartzite is folded by a tight F2 fold repeated about a NW-SE trending F3 fold cored by Glen Loch Phyllite and Limestone Formation. South of the Boundary Slide, near Buachaille Breige, at [NO 022 852] a downward-facing F2 antiform is cored by Glen Clunie Graphitic Schist Formation.

Plate 18 : Major fold hinge (?F2), plunging towards the viewer in crag on the right, within metalimestones of the Glen Loch Phyllite and Limestone Formation, looking east up a small burn north of Creag an Duibh, taken from Glen Tilt at about NN 983 791. BGS Imagebase No. P922763.

F3 folds

The major fold of this 'D3 crossfold' phase is the Meall Reamhar Synform (Figure 7). This broad synform (see cross-section 2 on 1:50k Bedrock Sheet 64E) has a south-easterly trending trace [NO 013 740]. It is an upright to inclined fold with an axial plane that dips steeply to the north-east in places and subsidiary minor folds that plunge 25° to 40° ESE. The S2 fabric and Glen Loch Slide are folded around this syncline (Stephenson, 1995). It has a complex D1 to D3 history according to Crane et al. (2002) as it refolds the F1 Gleann Fearnach Syncline. The synform has an open closure at the head of Gleann Fearnach and the Ben Lawers Schist Formation crops out in the fold core. On the south-west limb of the synform, minor F3 folds consistently verge to the north-west across the earlier Beinn a' Ghlo Anticline.

The Meall Chrombaig Synform (Figure 7) is another large-scale open F3 fold centred on the ridge of An Socach Quartzite Formation at Meall Chrombaig [NO 008 807] where exposure is poor but the fold appears to have an easterly trending fold trace. Farther north a large F3 fold with a roughly E-W axial trace [at NO 019 850] occurs south of Buachaille Breige.

Elsewhere in the area many of the F3 intermediate and minor scale folds are close to tight, or locally isoclinal, with axes that plunge east to south-east. A large cylindrical F3 fold in quartzite [NN 9516 7509] appears to deform the Carn Torcaidh Slide.

East of Glen Loch, D3 affects the rocks in the Gleann Mor section below the Carn an Righ Slide, where a prominent late, spaced or crenulation cleavage in pelites has a regular dip of 40° to 60° to the south-east. This is axial planar to NW-verging folds. Close F3 folds exposed in the Sron nan Dias Pelite and Limestone Formation in Crom Allt [NO 026 788] plunge 42° NE, verge north-west and have an axial planar cleavage dipping to the south-east.

Late folds (F4)

NW- to NNW-verging F4 monoclines and close folds with a wavelength of up to a few tens of metres are prominent locally, and are particularly well exposed in the Beinn a' Ghlo Transition Formation in the An Lochain stream section [NN 984 776] (Stephenson, 1991). Here, between the Carn an Righ Slide and the Glen Tilt Thrust, is a NE-SW-trending synform of F4 age with associated near-horizontal minor fold hinges. The F4 fold is complicated by the effect of the Coire Breac Fault which lies close to or coincident with the F4 hinge for most of its length (Stephenson, 1995).

An associated spaced or crenulation cleavage, dipping steeply to the south-east or SSE, is widespread throughout the area in suitable lithologies. This deformation is considered to relate to the D4 Highland Border Downbend (Crane et al., 2002), which mainly affects the Tay Nappe farther south-east.

Shear-zones/Slides/Thrusts south-east of the Loch Tay Fault

The differing competencies of the lithological units within the Appin Group, and that between the Grampian Group and the Appin Group as a whole, have caused several thrusts and slides to develop in the area south-east of the Gaick Psammite Formation (Figure 7). The more major ductile breaks in the succession divide the pile into fold packages. Most of the ductile dislocations are considered to relate to the D2 deformation phase.

The Boundary Slide is the term given to the D2 high-strain zone between the more competent Gaick Psammite and the overlying heterogeneous Appin Group succession in the Glen Tilt area (Figure 7). The Boundary Slide crops out on the south-east side of the Loch Tay Fault north of Buachaille Breige [NO 022 854] and continues striking east onto Sheet 65W (Braemar). Farther south it is inferred to lie below the current level of erosion. North of Buachaille Breige the slide is a steep discordant structure (see Cross-section 2 on the 1: 50 000 map) which appears to have been reactivated in D3. Just to the south of the slide here, the Lochaber Subgroup is excised and Ballachulish Subgroup strata are tentatively interpreted as being disposed in a downwards-facing F1/F2 fold refolded by D3.

In Glen Tilt south-west of Creag an Duibh [NN 983 788] a dislocation, possibly indicating the Boundary Slide, trends N046°, dips 36°SE and separates metalimestones above from shattered green-grey banded psammites below (Stephenson, 1991; 1995). The sinistral offset of the slide either side of the Loch Tay Fault system as observed in the Glen Tilt area is therefore estimated to be about 6 km (see discussion on the Loch Tay Fault).

On the south-east side of Glen Tilt, the *Carn Torcaidh Slide* superimposes the An Socach Quartzite above tightly folded metalimestones of the Blair Atholl Dark Limestone. It extends for about 2.5 km from just east of the Allt a' Choire Bhuide Mhoir at [NN 9515 7492], where it is over-ridden by the Glen Tilt Thrust, to [NN 940 732] where it is over-ridden by the Carn an Righ Slide. Where the dislocation follows Allt air Chul, a strong planar fabric occurs in the quartzite at [NN 9435 7417] and the underlying metalimestone is very reddened with hematite (Stephenson, 1995). At a waterfall [NN 9494 7501] in Allt air Chul, a tight fold in the quartzite over-riding schist suggests movement of the quartzite to the NW. The Carn Torcaidh Slide appears to be an early structure as it has been folded around a SE-plunging tight F3 fold.

The *Glen Tilt Thrust* lies 100-300 m to the south-east of the Carn Torcaidh Slide, dipping 35° to 50°SE. This dislocation thrusts a right-way-up succession of lower Ballachulish Subgroup rocks over a tightly folded package of upper Ballachulish Subgroup and Blair Atholl Subgroup rocks, all dipping regionally to the south-east. The structure is most noticeable where it superimposes the orange-brown-weathering Beinn a'Ghlo Transition Formation above grey Glen Loch Phyllite and Limestone rocks. It crops out for about 7 km from Allt Ruigh na Cuile in the north-east at [NN 9866 7873] to Allt Coire Riabhaich in the south-west [NN 942 734]. At its north-eastern end it is cut off by late brittle faults and at its south-western end it is over-ridden by the Carn an

Righ/Glen Fender Slide. Details of the thrust and minor parallel dislocations were given by Stephenson (1995).

The *Carn an Righ Slide* is a major dislocation (Figure 7) which along most of its strike length juxtaposes An Socach Quartzite, much of which lies on an inverted fold limb, over a range of older and younger rocks. It crops out on the northern side of Carn an Righ [NO 026 782]. The slide has been traced for about 24 km south-west into the Glen Fender Slide on Sheet 55E. North of the Beinn a' Ghlo range, it passes to the north-west of Meall a' Mhuririch at [NN 970 755], then can be traced north of Meall na Spionaig, across the north of Carn an Righ and on to Sheet 65W. Locally it is associated with a wide zone of shearing and stretching lineation developed in the strong planar fabric. The position of the slide is commonly marked by later brittle deformation, which caused growth of coarse-grained muscovite and pyrite.

The Carn an Righ Slide is associated with two subsidiary slides; one on the south side of the Carn an Righ summit and the other, farther south, repeats the An Socach Quartzite and the Glen Loch Phyllite and Limestone formations on a southward younging fold limb. Details of the slide, related dislocations and folds were given by Stephenson (1995) and Crane et al. (2002). About 500 m north-west of the main slide, the slides mapped encircling Meall Gharran at [NN 980 770] and crossing Creag Dhearg at [NN 989 779] may be related to, or down-faulted sections of the Carn an Righ Slide (Stephenson, 1995).

The *Glen Loch Slide* is folded around the F3 Meall Reamhar Synform to the east of Glen Loch. It juxtaposes the Tulaichean Schist above the Glen Loch Phyllite and Limestone Formation and, farther south, the Sron nan Dias Pelite and Limestone Formation as it cuts up slightly through the underlying succession (see Cross-section 2 on the 1:50K Bedrock Sheet 64E). It is exposed in Allt Glen Loch near [NO 001 718], where metalimestones and pelites are overlain by very flaggy grey psammite/quartzite (Stephenson, 1995). Adjacent to the slide the rocks carry a persistent stretching and/or intersection lineation plunging ESE at about 40°.

Extended south onto Sheet 55E (Pitlochry) this slide equates to the Killiecrankie Slide (Bradbury et al., 1976), but the section north of the Ben Vuirich Granite was renamed the Glen Loch Slide (Crane et al., 2002) as the slide has been interpreted to act within the Blair Atholl Subgroup (and not between the latter and the Killiecrankie Schist of the Easdale Subgroup; see section on the Tulaichean Schist Formation)

The *Carn Dallaig Slide* zone is marked by the attenuation of the Glen Lochsie Calcareous Schist Member between the Tulaichean Schist and Ben Lawers Schist formations in upper Gleann Fearnach [NO 02 73]. This D2 slide extends on to Sheet 65W/56W (Crane et al., 2002) and links with the Glen Lochsie and other slides at higher structural levels. At lower structural levels, a high-strain zone, marked by attenuated Blair Atholl to Easdale Subgroup formations in west Gleann Fearnach [NO 00 74] links with the Carn Dallaig Slide. The slide and the S2 fabric in its vicinity have a north-westerly strike and dip steeply to the north-east.

1.5.2 Regional Metamorphism

The regional metamorphic zones were first described in the Grampian Highlands in terms of zones defined by a set of index minerals developed in pelitic rocks (Barrow, 1893; 1912). These prograde Barrovian Zones (chlorite-biotite-garnet-staurolite-kyanite-sillimanite) were slightly modified by Tilley (1925) and extended across the Scottish Highlands. The Barrovian metamorphic facies series proved to be distinct from the Buchan facies series in the north-east Grampian Highlands as the difference between an intermediate to high pressure series and a low pressure series was established (Fettes et al., 1976). The metamorphic zones were extended into areas to the north-west which generally lacked pelites by Winchester (1974) working mainly on comparisons with calcsilicate assemblages. According to the widespread definitions of metamorphic facies the Newtonmore and Ben Macdui sheets lie within the medium pressure lower amphibolite metamorphic facies (Harte, 1988) developed during a single, but polyphasal, Grampian Event.

Wells (1979) used calcsilicate assemblages (commonly hornblende-plagioclase-garnet-epidote-quartz-titanite) within the Grampian Group to calculate P-T which varied from 560°C and 7 kbar near Loch Laggan to 650°C and 9.5 kbar in the centre of the Spey Valley. The uncertainties in the P-T estimates correspond to a minimum pressure for the central Spey Valley near Kingussie of 8 kbar at 600-650°C. The pressure conditions correspond to 30-35 km of tectonic cover, increasing to 35-40 km in the direction of Glen Tilt, at metamorphic temperature maxima. These P-T estimates place the Grampian Group of the district, including Glen Tromie, within the kyanite zone (Wells, 1979).

However, the P-T conditions estimated over the district are not likely to be coeval and the Glen Banchor Subgroup might have been metamorphosed prior to the Grampian Event so that the facies pattern there is likely to be composite and polymetamorphic due to the Grampian overprint. Semipelites within the Glen Banchor Subgroup have assemblages:- quartz, biotite, plagioclase, muscovite +/- garnet, kyanite, K-feldspar and rare staurolite. In the Glen Banchor Subgroup within this district two garnet-bearing semipelite samples [at NH 700 008 and NN668 983] have been calculated to have mean P-T estimates of 638° and 4.6-5.4 kbar and 575° and 4.0-4.3 kbar (Phillips et al., 1999).

In the coarse schistose to gneissose Glen Banchor lithologies the S1 foliation is defined by lenticular, anastomosing mica folia wrapping quartz-plagioclase lenticles; K-feldspar is rare. In these rocks the local development of migmatites suggests that incipient anatexsis occurred (at high pressures indicated by kyanite assemblages).

Within the ductile late-D2 shear-zones, the assemblage quartz-biotite-muscovite-garnet-plagioclase (An_{20-33}) +/- fibrolite and rare prismatic sillimanite is found (Phillips et al., 1999). The fibrolite appears to form from the breakdown of biotite, not necessarily from breakdown of kyanite. The fibrolite foliae are deformed by tight crenulations and S-C-like fabrics and so appear to be contemporaneous with the late-D2 shearing. Fibrolite development may be strain induced (Vernon, 1987), but the P-T estimates for the Glen Banchor Subgroup within the district lie within the sillimanite stability field (Phillips et al., 1999) which followed a decompression event (i.e. after the eclogite facies). The same sillimanite-grade conditions however, affected to varying degrees the Glen Banchor succession, the Grampian Group, and the Appin Group in the Blargie-Glen Banchor area (Phillips et al., 1999 Figure 4). Phillips et al. (1999) concluded that there is no evidence for more than one orogenic event in the area, and according to available geochronological data for the Central Grampian Highlands, this could be entirely Precambrian (840-800Ma).

Across much of the Grampian Group there are few lithologies which give the true regional metamorphic index minerals. This makes any distinction between the metamorphism of the Glen Banchor Subgroup and the Dalradian Supergroup difficult. However, it is known that during the Grampian Event, peak metamorphic conditions were attained broadly synchronous with the main deformation phase (D2) (Phillips et al. 1994; 1999). Petrological textural studies show that most of the mineral growth was post D2. Biotite, and local garnet, assemblages are recorded from these rocks. Phillips et al. (1999) reported a coherent metamorphic history in all the stratigraphical groups with development of biotite during D1 and kyanite early in D2. The general conditions for this kyanite growth as calculated by Phillips et al. (1999) are 7-8 kbar and 500-600°C.

During the later part of D2, significant decompression resulted from movements on the shear-zones in the north-west of the Newtonmore area and consequently P-T conditions of 5-6 kbar and 585-695°C prevailed (Phillips et al. 1999). The rocks were therefore moved out of the stability field of kyanite into that of sillimanite. However, in the south of the district no similar pressure decrease occurred and the rock remained in the kyanite field.

Within the Gaick Psammite Formation north of the Glen Tilt Pluton, assemblages in psammitic and semipelitic schists include quartz-plagioclase-biotite+/-garnet+/-K-feldspar (+/-chlorite). Garnet is a minor phase found in some lithologies, occurring as small inclusion-free anhedral porphyroblasts in the quartz-feldspar-biotite matrix. The biotite is usually green-brown, weakly to moderately aligned parallel to compositional layering or the laminar fabric of the rock (Beddoe-Stephens, 1997). One psammitic schist (S99219) contains the assemblage quartz-plagioclase-biotite–hornblende-?K-feldspar and appears to be a calcsilicate assemblage. These rocks appear to be essentially muscovite-free; except in one case (S95398) where ragged laths are probably retrogressively replacing biotite and K-feldspar. Chlorite has locally replaced biotite. Small areas of granophyric quartz-feldspar intergrowth are evident suggesting incipient melting in suitable lithologies (Beddoe-Stephens, 1997). Cordierite-bearing assemblages are considered to lie within the metamorphic aureole of the Glen Tilt Pluton.

The Glen Banvie Formation contains a wider variety of lithologies, including amphibolites with assemblages of quartz-plagioclase-K-feldspar-hornblende+/-biotite; metacarbonate rocks typically with calcite+/-plagioclase+/- secondary chlorite; calcsilicate rocks with quartz-muscovite-chlorite-actinolite/tremolite+/-biotite+/-plagioclase; quartzites containing quartz-plagioclase+/-muscovite+/-biotite+/-chlorite as well as pelites and semipelites containing quartz-plagioclase-muscovite-biotite-garnet+/-calcite. These assemblages have commonly been overprinted in the contact metamorphic aureole of the Glen Tilt Pluton and as a result these pelites contain cordierite and /or sillimanite/andalusite. The overprinted calcsilicate rocks contain diopside together with the above assemblages (Beddoe-Stephens, 1997). Prior to the overprinting, all these assemblages are presumed to have formed within the medium pressure kyanite zone. Pelitic assemblages from the formation containing kyanite were recorded in the adjacent Pitlochry district to the south (Smith, 1980). The chlorite and some white mica are products of retrogression.

The Dalradian Supergroup to the south-east of the Loch Tay Fault in this district is indicated to be within the kyanite zone (Baker, 1985). This agrees with the Appin Group assemblage quartz-plagioclase-garnet-biotite recorded in the area (Beddoe-Stephens, 1997) and the records of garnet (Stephenson, 1995) and kyanite (Pantin, 1961) found within the Glen Clunie Graphitic Schist Formation.

Within the Appin Group in Glen Tilt [at NN 928 737 and NN 937 736] two pelitic samples indicated temperatures of 630-635°C from garnet-biotite exchange thermometer data (Baker, 1985). This is at the upper end of the range calculated earlier by Wells and Richardson (1979). However, regional metamorphic pressures calculated by Baker (1985) tend to be lower (6-10 kbar) than those calculated for the eastern Dalradian (9-12 kbar) by Wells and Richardson (1979). Also within the kyanite zone east of Glen Tilt, Chinner (1980) traced an isograd $Ky_{50,}$ based on the coexistence with kyanite and staurolite of biotite M/FM=50, which delineates a recumbent thermal anticline. However, the wide crop of kyanite zone regional metamorphism across the district suggests that the metamorphic gradient is low and hardly affected by post-peak of metamorphism (Grampian deformation).

The kyanite zone extends to the south-east corner of the Ben Macdui district (Crane et al., 2002), although pelitic assemblages containing kyanite are rare due to lack of rocks with suitable composition. In this area, at this grade, semipelites (and psammites) in the Tulaichean Schist Formation contain the assemblage quartz-biotite-muscovite-plagioclase-K-feldspar-garnet. The garnets are wrapped by the S2 foliation and grew syn to late D2 based on inclusion trail evidence, and before the development of S3 crenulation cleavage (Crane et al., 2002).

The basic meta-igneous rocks (pre-D2), within the Ben Lawers Schist Formation contain assemblages: hornblende-plagioclase-quartz-epidote+/-garnet+/-calcite. These indicate that a lower grade epidote-bearing zone can be tentatively drawn in the south-east corner of the district (Crane et al., 2002; Figure 22), since farther north-west, in Gleann Mor, amphibolites contain garnet but no epidote. The typical assemblage in the latter amphibolites is: hornblende-plagioclase-quartz-garnet with accessory opaque minerals and titanite; biotite is probably retrogressive. As epidote is trapped in syn-D2 garnet inclusion trails but absent outside the porphyroblasts, the garnet amphibolites probably indicate a north-westwards increase in metamorphic grade from the epidote-garnet amphibolites.

Within the Appin and Argyll groups there are also numerous metacarbonate and calcsilicate rock assemblages and potentially any systematic change in their metamorphic assemblages should be recognisable across the area from Glen Tilt to Gleann Fearnach. However, the variation in composition, with impurities such as feldspar, phlogopite and epidote group minerals, together with the dependence on fluid composition, make it difficult to distinguish any zonation (*cf.* Crane et al., 2002). This means, for instance, the range of metacarbonate rocks to calcareous schists in the Glen Loch Phyllite and Limestone typically contain assemblages: calcite+/-quartz+/-muscovite+/-biotite or phlogopite+/-plagioclase+/-K-feldspar+/-garnet. Calcareous assemblages in the Blair Atholl Subgroup are similar but locally with abundant graphite.

The calcareous schists in the Ben Lawers Schist, Gleann Beag and Tulaichean Schist formations typically contain assemblages: quartz-muscovite-biotite-chlorite-amphibole-feldspar-epidote and the amphibole is commonly hornblende and/or tremolite in large porphyroblasts arranged in a random garbenschiefer texture on the schistosity surface (Crane et al., 2002).

Calcsilicate rock layers, for example, forming subordinate poorly foliated layers in the Tulaichean Schist Formation and the Glen Lochsie Calcareous Schist Member typically contain assemblages: quartz-plagioclase-biotite-epidote/zoisite/clinozoisite-garnet-amphibole. The amphibole may be tremolite/actinolite or hornblende.

1.5.2.1 Age of Metamorphism

The exact age of the initial progressive tectonothermal event affecting the Central Grampian Highlands is uncertain. Within the equivalents to the Glen Banchor Subgroup, ages from partial melt migmatitic psammites (Highton et al., 1999) give a potential age constraint on the Central Grampian Highland D1-D2 of 840 Ma, while the shear-zone fabrics suggest that late-D2 decompression occurred about 800 Ma (Noble et al., 1996). If this D2 is the same as that in the overlying Dalradian Supergroup, it places much of the tectonic history of the district in the Precambrian, as opposed to the Ordovician as it would be if the early deformation was due to the Grampian Event. This interpretation requires a major unconformity or tectonic discontinuity at a higher level in the Dalradian Supergroup for which there is no current support. While it may be argued that the older ages were obtained from tectonically emplaced older basement, Phillips et al. (1999) noted that this does not explain the c. 800 Ma U-Pb monazite ages obtained from the blastomylonitic schists derived from late-D2 shear-zones associated with muscovite and fibrolite growth. The timing of the D3 phase is constrained by granites, such as the Strathspey Granite and associated pegmatitic rocks which give U-Pb monazite ages of c. 447 Ma (Noble in Phillips et al., 1999).

Metamorphic garnet from the Southern Highland Group in the Pitlochry area has been dated using Sm-Nd isotopes (Oliver et al., 2000) at between 476.6+/- 2.5 Ma and 472+/-2 Ma. These are the times at which the garnet stopped growing, as the rocks were metamorphosed below the c. 700°C Nd diffusion blocking temperature. Dalradian metamorphic K-Ar and Rb-Sr muscovite and biotite ages tend to be younger, as they are dependent on cooling/blocking temperatures, but they are generally the same age, within error, or younger than the age (467+/-8 Ma) of the Ballantrae Ophiolite metamorphic sole (Oliver, 2001). Oliver (2001) interpreted the latter to be the age of contemporaneous island-arc collision and obduction in Scotland and the cause of the Grampian Event of the Caledonian Orogeny. Sm-Nd age determinations from garnet in the sillimanite zone of Glen Clova confirmed that the peak metamorphic temperatures in Barrow's zones occurred penecontemporaneously (Baxter et al., 2002) at 472.9+/-2.9 Ma (early stage) and 464.8+/-2.7 Ma (late stage). Baxter et al. suggested that local igneous intrusions provided additional heat beyond relaxation of over-thickened crust.

1.6 FAULTING

1.6.1.1 LINEAMENTS/EARLY DEDUCED FAULTS

The north-easterly trend of the Glen Banchor 'high' is a persistent feature in the architecture of the north-west of the district associated with slides and unconformity and it appears to control the Grampian D3 deformation and some of the brittle faulting.

The Deeside Lineament has no surface expression but is believed to have controlled the intrusion of the inferred East Grampian Batholith (Stephenson and Gould, 1995).

1.6.1.2 BRITTLE FAULTS

Major faults

The Newtonmore area is cut by the north-easterly-trending *Ericht–Laidon Fault.* This major late-Caledonian fracture is traceable for about 170 km north-eastwards from Tayvallich, through Loch Ericht and across Glen Truim towards Grantown-on-Spey.

In the Dalmally district, south-west of the Etive Pluton, Treagus (1991) recorded an early dip-slip component of about 1.3 km down to the north-west followed by sinistral strike-slip of 4-5.5 km. The fault movement largely pre-dates the eruption of Siluro-Devonian (Gradstein et al., 2004) Lorn lavas (424-415 Ma). About 25 km south-west of the Newtonmore district the sinistral offset on the fault as it affects the Moor of Rannoch Granite is 6-7 km and dip-slip is apparently absent there (Hinxman et al., 1923; Treagus, 1991).

Nearly 4 km south-west of Newtonmore, the Falls of Phones Semipelite Formation is repeated across the Ericht–Laidon Fault and there appears to be a component of dip-slip down to the north-west of up to 3 km (see Cross-section on Newtonmore Bedrock sheet). This throw is probably less to the south-west of the junction with the Glen Truim Fault as it downthrows to the east. The amount of sinistral displacement on the fault cannot be quantified in this district as the stacking of flat-lying folds makes matching of the semipelite units difficult in three dimensions. To the north-east, in the Tomatin and Aviemore districts it is estimated that up to 8 km of sinistral displacement occurred on the fault, although it appears to have decreased to approximately 1 km around Grantown-on-Spey (Highton, 1999) and it has not been recognised on the Knockando Sheet (85W) to the north-east.

The Ericht–Laidon Fault is not directly exposed in the district but exposures along the Allt a' Bhinnein [NN 6694 9100] show numerous minor faults and crush zones, which are associated with brittle-fractured red granite veins. The main fault is inferred to lie partly along the line of Allt a' Bhinnein and, to the east of the A9 road, along the length of Loch Etteridge. A subordinate synthetic fault with a similar north-easterly trend lies just to the west of Meall Odharaich [NN 6865 9039]. To the north-west, in Coire Mhoraich [NN 658 913] and south of Creag na Sanais [NN 656 920], minor north-easterly trending faults offset the Creag na Sanais Semipelite Formation sinistrally.

The *Glen Banchor Fault,* trending north-east along Glen Banchor, is probably part of the fault-set subparallel to the Ericht–Laidon Fault (*cf.* Treagus, 1991). It intersects the Craig Liath Fault to the south-west, but appears to continue north-eastwards through Loch Gynack with only a minor offset on the Glen Truim Fault. Since younger rocks lie on its south-east side, a component of downthrow to the south-east has occurred.

The north-north-easterly-trending *Glen Truim Fault* is a complex splay of the Ericht–Laidon Fault, on its north-western side, controlling the orientation of Glen Truim. It is similar to the Riedel shears trending N010°-015° related to other major northeast-trending faults with sinistral displacement. Faulting and brecciation is exposed near the Falls of Truim [NN 6807 9230], and along the Glen Truim gorge east of Crubenbeg [NN 6833 9273] and east of Poll Uaigh. The downthrow on the fault is considered to be to the south-east.

The northerly-trending *Craig Liath Fault* is inferred from mapping to fault out the Glen Banchor Subgroup in the north-west corner of the Newtonmore Sheet. It may also be a splay of the Ericht–Laidon Fault.

Farther south, the *Glen Garry Fault* system trends north-east cutting the Gaick Psammite on the Gaick plateau (Leslie et al., 2006; Leslie et al., 2003). This fault system is one of a set of the prominent north-east-trending faults crossing the Grampian Highlands. The system is a complex of related fractures that extends across the region from the south-west corner of Sheet 64W (Newtonmore) into Cama Choire [NN 688 785], passing just south of Gaick Lodge, across Mullach Coire nan Dearcag [NN 779 862], towards Glen Feshie. It intersects the Cairngorm Pluton just south of Loch Einich on Sheet 64E (Ben Macdui). The north-eastern end of the fault system may constrain the granite contact locally but no significant post-emplacement faulting occurs along this north-east – south-west-trending segment of the granite contact (pers. comm. M. Gillespie, 2002). A north-north-east-trending fault occurs south of Loch Einich. The complex of Reidel shears and normal faults is produced by sinistral strike-slip. To the south-west on Sheet 54E (Loch Rannoch) the fault system passes along Loch Garry to link with the Bridge of Balgie Fault (Johnstone and Smith, 1965; referred to as the Killin Fault by Treagus, 1991). South-east of the Glen Garry Fault N010°-trending faults are mapped along the steep slopes confining Loch an Duin, and to the north-west a similar fault is located along the west side of Loch an t-Seilich with the aid of aerial photography. Normal faulting with a N010° trend is exposed in the River Tromie [at NN 76456 88997] and throws down to the east. Easterly downthrow would be consistent with the general down-to-the-east component of displacement associated with the major north-east-trending strike-slip faults (Treagus, 1991). Granite sheets and dykes east of Gaick Lodge [at NN 7695 8522] exploit a N010°-trending pre-existing set of faults. Brecciation on a N010° trend at Sronphadruig Lodge [NN 7149 7831] clearly post-dates the emplacement of granite sheets and later fine-grained lamprophyre sheets. This argues for an extended fault history, as well as localisation of the igneous intrusions along this fault system (Leslie et al., 2003).

In the south-east quadrant of the Ben Macdui district, the orientation of Glen Tilt (Plate 19, Figure 7) is largely controlled by the major north-east-trending *Loch Tay Fault system* which, when traced north-east of Bedford Bridge, swings north-north-eastwards, although several splay faults with subparallel north-east-trends extend for over 3 km south-east of the main fault. This sinistral strike-slip fault system has been estimated to have a net sinistral wrench component of 6-10 km and evidence of an episode of dextral movement (Treagus, 1991). It continues south-west to join the Highland Boundary Fault (Anderson, 1942). The fault system comprises a series of anastomosing near vertical planes with local near horizontal slickensides and brecciated zones. The fault system lies close to the Boundary Slide between the Grampian Group and the younger Dalradian rocks, indicating that the difference in competence may also have been a factor in its development. The fault system also appears to ‘control’ the south-east margin of the Glen Tilt Pluton, particularly the diorite intrusion which projects about 4 km to the north-east along the main fault line.

Plate 19 : Major linear gully along the line of the Loch Tay Fault exploited by the River Tilt with the Beinn a' Ghlo range in the background. Looking south-west down Glen Tilt from Creag an Duibh [NN 986 791]. BGS Imagebase P601615.

Shattered minor intrusions and slickensided fractures in diorite and granite belonging to the Glen Tilt Pluton indicate that at least some movement on the Loch Tay Fault post-dated their intrusion. Within the Sron a' Chro granite/granodiorite close to the fault, much carbonate alteration is apparent as veinlets and patchy granular aggregates and the rock is distinctly sheared, with relict grains of K-feldspar and quartz surrounded by swathes of carbonate and chlorite. The Sron a' Chro granite/granodiorite [at NN 918 728] was sampled and dated, using the high-resolution ion-microprobe method (Oliver et al., 2008), at 390±5 Ma. This Mid Devonian granite shows weak east-west-striking, subvertical foliation and parallel ellipsoidal enclaves of unfoliated diorite and foliated psammite. This evidence for deformation and the elongate outcrop pattern of the diorite suggested to Oliver et al. (2008) that the intrusion was controlled by the sinistral Loch Tay Fault active at 390±5 Ma. They attributed the sinistral movement (reactivation?) on the Loch Tay Fault to a far-field effect of the Mid Devonian Acadian Event caused by the effects of flat-slab subduction of Rheic Ocean lithosphere (Woodcock et al., 2007). Other minor intrusions show little or no deformation and appear to post-date the main movement on the fault. An element of downthrow, possibly of only a few hundred metres, on the south-east side of the fault was postulated by Treagus (1991) as the pluton is not obviously offset laterally. This is supported by the fact that evidence for a metamorphic aureole on the south-east side of the fault is limited and also that the Glen Banvie Formation is not represented on the south-east side.

One of the best exposed sections of the Loch Tay Fault and the associated fault intrusions is that near Forest Lodge, extending for 1.2 km from the junction of Allt Torcaidh with the River Tilt [NN 9304 7386] to Hutton's classical locality at the ruins of Dail-an-eas Bridge [NN 9386 7465]. At the junction of Allt Torcaidh, brecciated quartzite is intruded by coarse-grained red granite which contains large xenoliths of psammite and/or quartzite and is much fractured. In the south-east bank of River Tilt opposite Forest Lodge, highly brecciated quartzite includes yellow-brown weathering bands which may be silicified carbonate rock (?dolomitic) in the fault zone. Here, minor buckle folds almost at right angles to the fault plane are probably related to movements on the fault. Just below the waterfall about 250 m north-east of Forest Lodge a fault breccia consisting of fragments of quartzite, psammite and/or silicified limestone is exposed on the south-east bank of the river. Adjacent to this breccia, the fault plane is seen in the river bed, trending N045°, where brecciated sedimentary rock is in contact with brick-red granite. At the bend in the River Tilt just below the waterfall at Dail-an-eas, there are two fault parallel planes. The south-eastern plane is marked by a thin dyke of brecciated granite, to the north-west of which are banded quartzite/psammites dipping 26° to the south-south-west. The second fault plane lies 20 m to the north-west and on its north-western side, red coarse granite extends to the top of the waterfalls at Hutton's locality (Stephenson, 1999). Here the granite encloses and veins large screens of grey, banded limestone and calcareous phyllites dipping 66° to the south-south-west and belonging to the Glen Banvie Formation.

Details of the exposures adjacent to the Loch Tay Fault and the associated fault intrusions to the north-east of Dail-an-eas were given by Stephenson (1991; 1995; 1999). Between the junction of the River Tilt and An Lochain north to Bedford Bridge over the Tarf Water the trace of the main fault branch trends N020° but farther north it trends N030°, following the steeply incised valley of Allt Garbh Buidhe. This stream generally follows a marked lithological change from greenish grey quartzites and psammites (Gaick Psammite Formation) on the west-north-west bank, to a variety of quartzites, semipelites and limestones (Appin Group) on the east-south-east bank separated by fault breccia. Exposures of intensely brecciated brown quartzitic rock on the west-north-west bank at the junction with the Caochan Dubh Mor [NN 9966 8201] and 300 m north-north-east at [NN 9979 8233] are considered to be on the fault plane (Stephenson, 1995).

Minor north-east-trending faults

The Coire Breac Fault [NN 990 782; Figure 7] has a well-marked topographical expression in places, such as in Coire Breac at [NN 981 775]. It probably throws down to the north-west as indicated by the outcrop pattern of the Glen Clunie Graphitic Schist. It appears to follow, and is possibly controlled by, the axial trace of a major F4 synform.

The Fealar Fault system farther to the south-east [NO 010 796] extends to the south-east of Meall Gharran where it appears partly responsible for the apparent downthrow to the north-west of the An Socach Quartzite. This north-easterly system appears to be offset by later, near east-west-trending faults (see below).

About 9 km north-west of the Loch Tay Fault, and roughly parallel to it, the Chapan Mor Fault (Figure 7) cuts through Gaick Psammites [at NN 930 900] and offsets the margin of the Cairngorm Pluton by nearly 800 m in a sinistral direction.

Within the Glen Tilt Pluton, the fault pattern (Beddoe-Stephens, 1997) consists of a set trending just east of north; a set parallel to the Loch Tay Fault and a set approximately perpendicular to it. Since these faults cut the intrusions and are subvertical, late block faulting is probably related to post-orogenic (Acadian) uplift (see Oliver et al., 2008).

Some post-tectonic Siluro-Devonian porphyritic felsites (e.g. at NO 007 764) occupy north-north-east-trending faults (Stephenson, 1990). Both the felsites and the north-north-east-trending faults are cut by a later set of minor north-east-trending faults.

North-north-east-trending faults

North-north-east-trending faults result in considerable displacement of outcrops locally. Some are probably related to the major north-east-trending fault-set, such as the Loch Tay Fault which has segments and associated splays with this orientation. In the east of the area, the quartz-feldspar-phyric microgranodiorite of Carn Dearg [NO 023 799] was emplaced into a large-scale north-north-east-trending discontinuity and brecciated quartzite occurs in places against its margin [NO 0084 7693]. The discontinuity coincides with a major change in regional strike and dip direction (the general dip is to the north-east on the west side and to the south-east on the east side) Displacement of the Carn an Righ Slide and An Socach Quartzite indicates a significant downthrow to the east. Other marked examples lie along the valley of Glas Leathad [NN 960 731] and cut the Glen Tilt Pluton in Gleann Mhairc [NN 887 760] as well as to the east of Meall Tionail [NN 920 775], and so are later than the intrusion age of 390±5 Ma.

A less prominent fault-set strikes nearly north-south.

Near east-west faults

A smaller set of near east-west-, east-north-east-, or west north-west-trending faults appear to be relatively late brittle structures, producing minor offsets on north-east-trending faults and minor Siluro-Devonian intrusions. The intrusion of the quartz-feldspar-phyric microgranitic dyke on Meall na Spionaig [NO 002 775] may have followed one of these east-north-east-trending faults.

The Fealar Fault system is cut by an easterly-trending fault set, for example at [NN 990 771]. These later faults and a northerly set cause notable displacements in the Appin Group south-east of the Loch Tay Fault.

A near east-west-trending fault crops out in Allt a' Chama Choire [NN 7050 7962]. This fault has a 30 m-wide zone of cataclasis within the Gaick Psammite Formation (Plate 20) and may have some reverse movement (Leslie et al., 2003).

Plate 20 : A 30 m-wide cataclastic zone in Gaick Psammite exposed in Allt a' Chama Choire at [NN 7050 7962]. BGS Imagebase No. P514843.

Farther up this glen [at NN 7002 7938], a microgranitic dyke trending N160° has a strongly sheared margin, effectively turning the dyke margin into a gneiss. The fabric in this sheared margin contains epidote and chlorite, suggesting that both fluid influx and deformation occurred at elevated temperatures (c. 300°C?).

1.7 GEOPHYSICS

The Bouger gravity anomaly in this district is generally negative, partly as a result of the prevalence of the thick low-density siliciclastic Grampian Group.

The Cairngorm Pluton has a strong negative Bouger gravity anomaly indicating significant mass deficiency within the upper 10 km of crust. It also has an annular magnetic anomaly which is implied to reflect zoning within the intrusion (Trewin and Rollin, 2002). Over the Cairngorm Pluton maximum aeromagnetic anomalies are around 180 nT, generally within the granite outcrop (Rollin 1993). The Bouger gravity anomalies over the Cairngorm Pluton are less than -65 mGal and lineations picked up from the regional gravity data trend N040° and N120° (Rollin, 1993). 2.5D integrated gravity and magnetic modelling has explained the gravity anomaly across the Cairngorm Pluton in terms of granite to a depth of 6-8 km below OD within Grampian Group rocks to depths of about 12 km. Magnetic anomalies have largely been explained by magnetic phases of the granite (Rollin, 1993). Gravity modelling indicates the Cairngorm Pluton is connected at depth with the nearby Glen Cairn, Lochnagar, Ballater and Mount Battock plutons (Rollin, 1984).

The Cairngorm Pluton is considered to extend eastwards on a structural lineament, the east-west Deeside Lineament (Fettes et al., 1986). This lineament is well defined in the gravity and magnetic anomaly data (B. Chacksfield, pers. comm.) and is coincident with the northern limit of the pluton. It is not necessarily a deep-seated lineament and may relate to east-west structures affecting the North East Grampian Basic Suite. Trewin and Rollin (2002 p.21) found no geophysical evidence for the Deeside Lineament, but they considered an east-south-east-trending East Grampian Lineament to be the main control on the Cairngorm Suite of granites.

Brown (1979) noted the coincidence of the negative gravity and positive aeromagnetic anomalies over the Cairngorm Pluton. This suggested a deep rooted magnetic anomaly source comparable in size to the outcropping intrusion since the rocks at surface have too low a remanent magnetisation. Possible sources considered were either mafic crystal cumulates at depth or metamorphic effects in the basement around the granite root zone. Brown and Locke (1979) favoured the latter explanation as there is no gravity evidence for high-density crystal cumulates and because some British Caledonian granites farther south lack the aeromagnetic anomaly and penetrated a different type of lower crust. Locke (1980) modelled the Cairngorm Pluton and its neighbouring intrusions down to at least 12 km below surface and with outward sloping margins. Substantial volumes of low-density rock in the crust are also indicated by the prominent gravity low extending from the Cairngorm Pluton eastward forming part of the inferred Eastern Grampian Batholith.

The Glen Tilt Pluton does not show up at all in the gravity anomaly data but has a very distinct residual magnetic anomaly (B. Chacksfield, pers. comm.). Trewin and Rollin (2002) suggested that the Mid-Grampian line, separating the Cairngorm Suite of granites from the southern suite, might be related to a deeper basement boundary separating the Grampian Highland and Midland Valley terranes at depth. The Allt Bhran granodioritic intrusion lacks a clear geophysical signature and therefore does not seem to be voluminous at depth.

An elongate lobe with a positive anomaly of about 30 nT on the aeromagnetic plot extends south-south-east from Loch an't-Seilach. Although there is nothing specific in the surface geology to explain this, it may relate to a concealed intrusion, perhaps a smaller diorite related to the Glen Tilt Pluton. However, there is a similar shaped anomaly in the geochemical data in this area and the anomaly is approximately strike parallel so it may be that the local psammites are slightly more magnetic than normal (B. Chacksfield, pers. comm.).

2 The physiography, Cainozoic landscape evolution and Quaternary geology of the district

2.1 PHYSIOGRAPHY

The district embraces the south-western sector of the Cairngorms, which include some of the highest mountains in Britain, notably Ben Macdui (1309 m), Braeriach (1296 m) and Cairn Toul (1213 m) (Figure 8).

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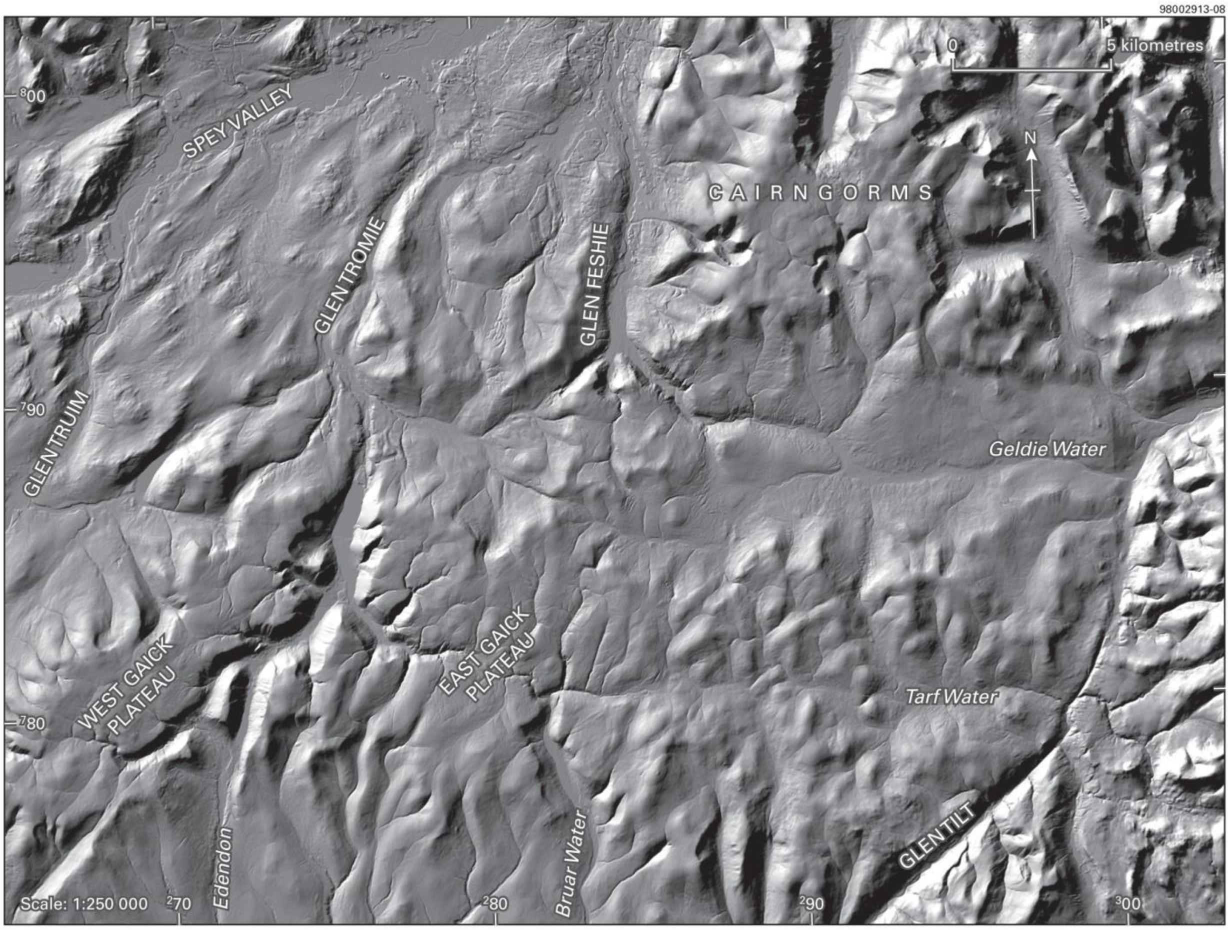

(NEXTMap Britain™ elevation data from Intermap Technologies. For further information on this and other images contact the Remote Sensing Manager, BGS Keyworth)

This image shows an elevation model from the NEXTMap Britain™ dataset of England, Wales and Scotland. The data were collected between 2002 and 2003 using an advanced airborne RADAR mounted on a fixed-wing aircraft. Elevations were measured at night, at 5 m spacing and from an altitude of up to 8.5 km. The model is illuminated from the north-west and has been shaded to illustrate topographic relief.

Figure 8 : Hillshaded Digital Elevation Model of the district. The huge corries and troughs of the Cairngorms contrast with the relatively less glacially modified ground to the south. Networks of subparallel, glacial drainage channels are prominent on the west-facing slopes of the Cairngorms and Glen Tromie where the margin of the last ice sheet retreated towards the western Highlands. The broad valley of the Geldie Water once contained the headwaters of the River Dee, but the catchment has been captured by the northward flowing River Feshie. Likewise, the valley of the Tarf Water to the south now flows into Glen Tilt rather than the Dee. The southern half of the district is dominated by the Gaick Plateau, which is dissected by small corries and a major glacial breach that links Glen Tromie, in the north, with the valley of the Edendon Water in the south. The limited glacial erosion here contrasts starkly with that to the north-west, where powerful, topographically-constrained ice streams following Glen Truim and the Spey Valley have deeply etched and scoured the landscape, forming several prominent roche moutonée**.**

These mountaintops represent high points on the extensive, deeply dissected Cairngorm Plateau (Hall, 1986; Hall and Sugden, 1987). Running approximately north–south through the plateau is the Lairig Ghru (Figure 9), a deep glacial breach that connects Speyside in the north to Deeside in the south-east. Another near-parallel breach lies to the east linking Strathnethy with Glen Derry to the south.

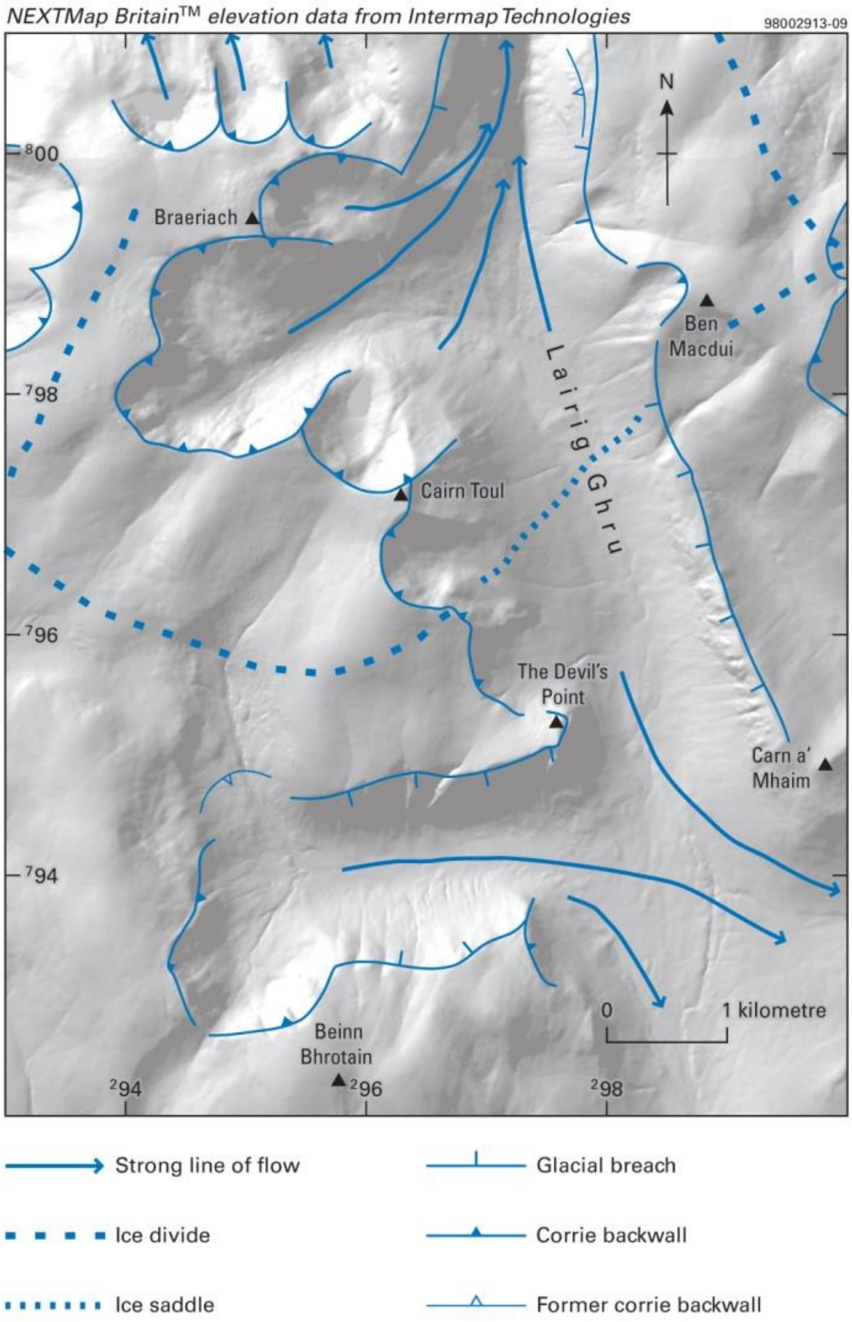

Figure 9 : Hillshaded Digital Elevation Model of the southern end of the Lairig Ghru in the Cairngorms showing glacial features and a reconstruction of ice flow at the Late Glacial Maximum (LGM).

The Cairngorms are an area of outstanding geomorphological interest (Shaw and Thompson, 2006), comprising an exceptional assemblage of pre-glacial, glacial, glaciofluvial and periglacial landforms and deposits (Gordon, 1993; Glasser and Bennett, 1996). These include planation surfaces, tors and pockets of deeply weathered bedrock that have survived several periods of glaciation, illustrating aspects of longer-term landscape development. It contains a striking assemblage of landforms created by 'selective glacial erosion', including vast corries, arêtes and breaches, together with those related to the retreat and decay of glacier ice, including moraines, deep drainage channels and deposits formed in temporary ice-dammed lakes. In addition, the Cairngorms include a wide range of periglacial phenomena, both active and relict, that result from repeated freezing and thawing of rocks and soil under the influence of gravity.

The north-west of the district extends almost to the rim of the extensive Monadhliath Plateau. Between this massif and the Cairngorms lies the heavily glaciated Spey Valley, through which relatively fast-flowing corridors of ice (ice streams) have flowed during several glaciations, scouring away most weathered rocks and laying down extensive blankets of till on the valleysides. The south-facing slopes of the Monadhliath Plateau are characterized by knobbly, mammillated, heavily ice-plucked rock surfaces whereas several large, highly elongate, streamlined roche moutonée features lie in the centre of the vale (Figure 10).

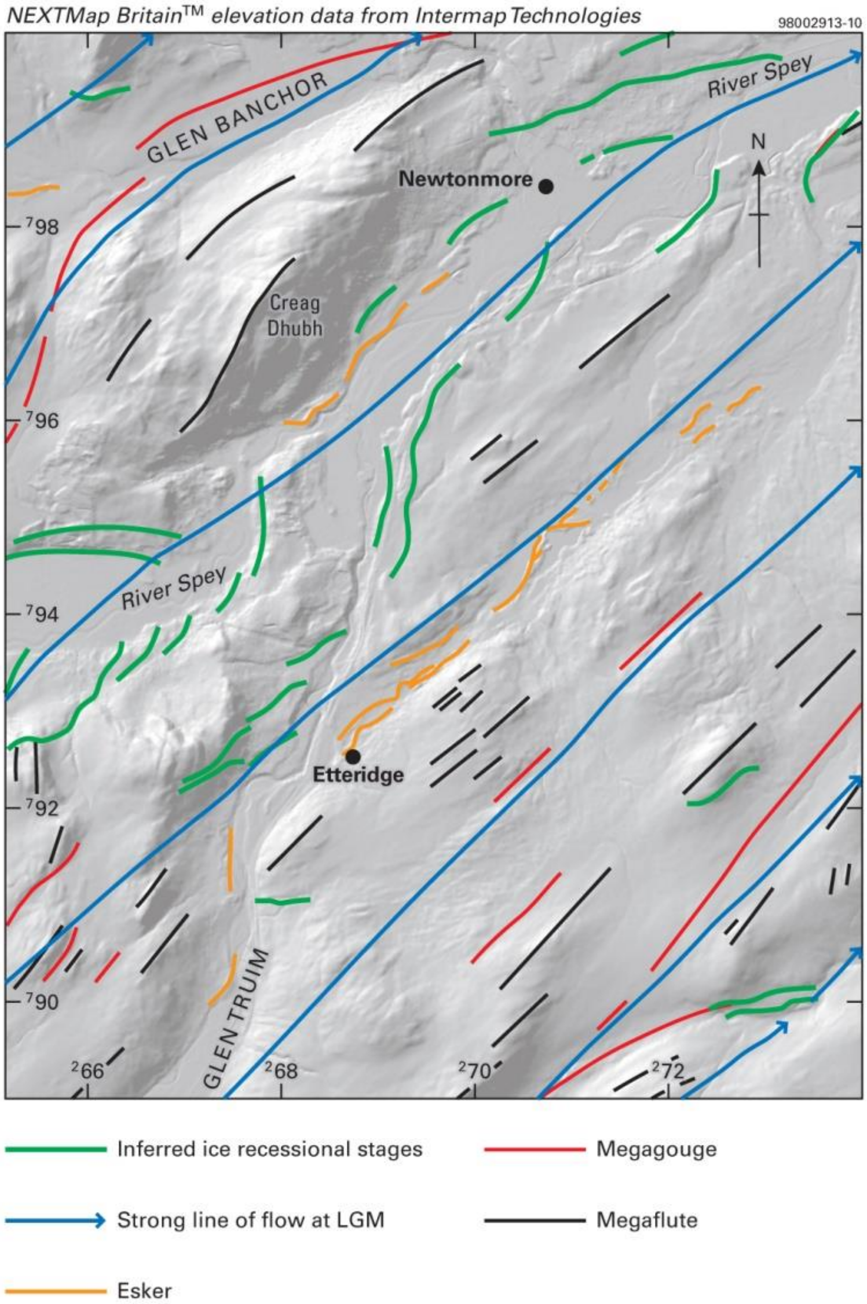

Figure 10 : Hillshaded Digital Elevation Model of Glen Truim and Strathspey showing glacial features, a reconstruction of ice flow at the LGM and inferred recessional stages.

The high ground in the south of the district takes the form of another extensive, gently undulating plateau with isolated higher mountaintops, the altitudes of which range from 800 m to the highest point, Carn na Caim, at 941 m OD. This area includes the Gaick Forest and northern parts of the Forest of Atholl, but is generally referred to as the Gaick plateau or the 'Gaick' (Sissons 1974; Hall and Mellor, 1988). The plateau is dissected by a major north-south glacial breach that links Glen Tromie, in the north, with the valley of the Edendon Water, to the south, and is referred to generally as the 'Gaick Pass'. Though slightly lower (400 m) than the Pass of Drumochter to the west, and a more direct route, the valley was apparently too narrow and tortuous for the railway and main road to follow with the result that it now is a splendid wild, rugged and relatively unspoilt glen. The Gaick Pass contains three lochs, Loch an t-Seilich, in the north, Loch Bhrodainn, in the centre, and Loch an Dùin in the south (Plate 21).

Plate 21 : The central breach through the Gaick plateau looking NNE through the Loch an Dùin Gap. Valley of the Edendon Water in the foreground. Cairngorms in the distance to the left. BGS Imagebase No. P239928.

The plateau is best developed between the Gaick and Drumochter passes where it is bounded by steep grassy slopes with 200 to 450 m drops to lower ground. The plateau surface is largely peat covered (Plate 22), but there are also extensive areas of short, grassy turf grazed by deer in the summer months, that have developed on the relatively free-draining regolith.

Plate 22 : The peat-covered Gaick plateau looking west towards A' Bhuidheanach Bheag. BGS Imagebase No. P543641.

The plateau is generally lower to the east of the Gaick Pass, where it is bounded to the north by the valleys of the 'Upper Feshie' and the Geldie Burn, and to the south by the steeply incised Glen Tilt. The highest point is Beinn Dearg (1008 m), which is capped by a magnificent blockfield formed of granite belonging to the Glen Tilt Pluton (see section 2.6.6.3).

Glen Tilt is a long, straight, fault-guided valley that is unlike most in the region. It is a classical v-shaped valley that displays very little evidence of glacial modification. The steep-sided slopes of the valley are underlain by extensive deposits of talus, but little till. The absence of glacial erosion is partly the result of the area having been protected within a local centre of ice dispersion, and partly because ice flowed across the valley, not through it (Sutherland, 1984). The headwaters of the River Tilt have become deeply incised to form almost impenetrable gorges. Glen Tilt is overshadowed by the towering northern flanks of the Beinn a' Ghlo massif, which are truncated to the east by Glen Loch, an impressive glacial breach. The steep slopes in this part of the district have foundered extensively.

2.2 LANDSCAPE EVOLUTION DURING THE CAINOZOIC ERA

The geological record during the Tertiary is largely one of slow landscape evolution by subaerial erosion, intermittent regional uplift and the development of deep weathering profiles (see Hall and Sugden, 1987; Hall, 2004 for summary). The Paleocene Epoch was marked by considerable volcanic activity along the western seaboard of Scotland. Uplift of as much as 1.5 km was associated with this event, causing an eastward tilting of peneplains formed during the Upper Cretaceous and earlier. Some valleys in the district, such as the Dee-Geldie Water and Tarf Water, may have become first established on these tilted peneplains. A warm, humid climate prevailed until the late Miocene, during which time the effects of chemical weathering penetrated deeply below the land surface forming clayey saprolites, pockets of which remain in the district. Mechanical weathering became increasingly intense during the Pliocene and early Pleistocene epochs as the climate deteriorated and granular disintegration occurred, particularly of coarse-grained igneous rocks, to form granular saprolites. Subsequent glacial erosion has failed to remove these ancient regoliths over the plateaux of the district, where they locally extend to depths of 10 m or more (Hall, 2004).

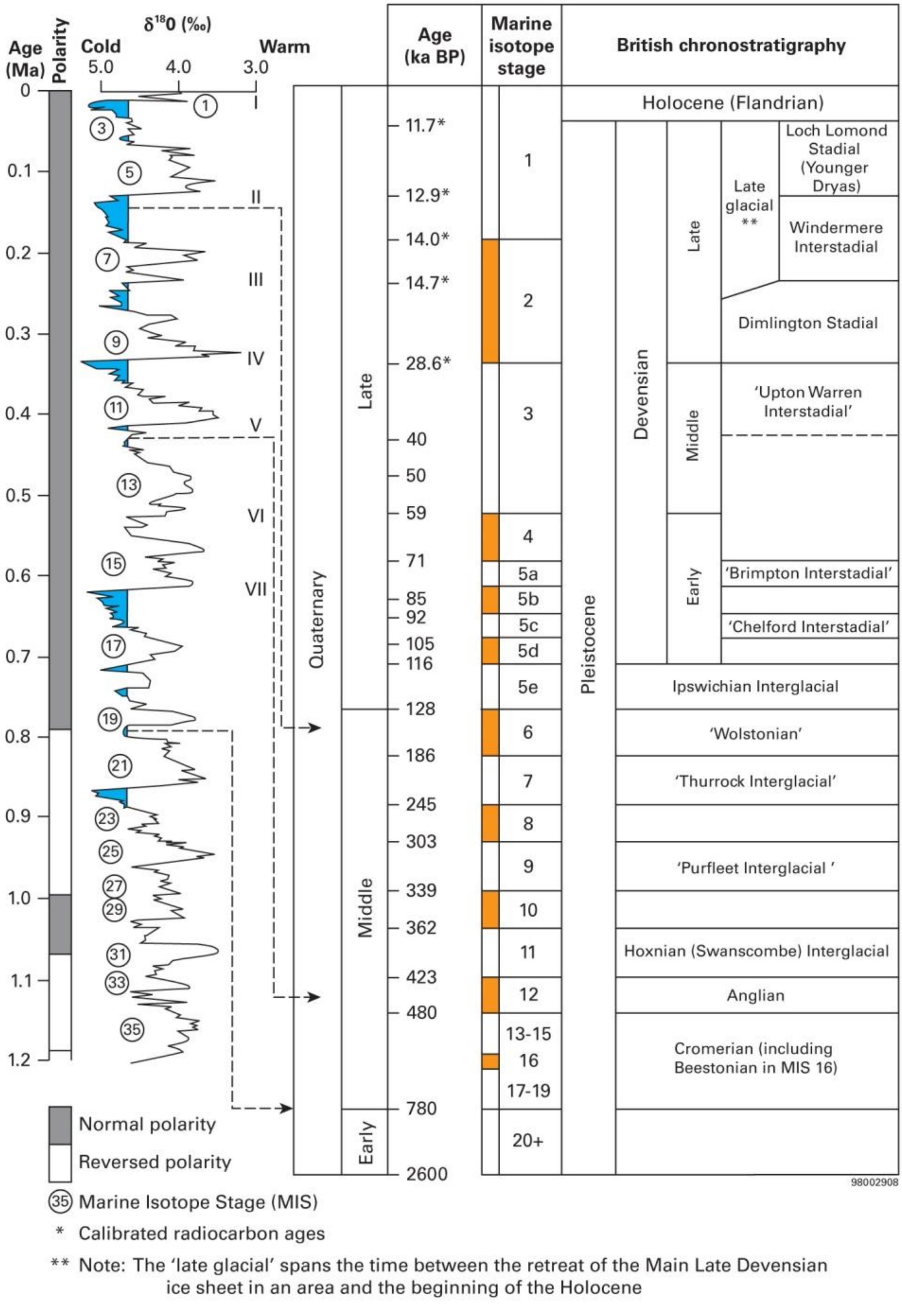

Figure 11 : British Quaternary chronostratigraphy (after Gordon, 1997; Bowen et al., 1999) and a representative oxygen isotope and geomagnetic polarity record (ODP 677) (after Shackleton et al., 1990; Bowen et al., 1999). Note the tie lines from the isotope and polarity records to the chronostratigraphy.

Many valleys in the district are long-established elements of the drainage system (Bremner, 1942; Hall, 1991, 2004; Linton, 1951). For example, eastward directed valleys such as the upper reaches of the Spey and the Geldie Water/Dee appear discordant to regional structures, implying superimposition. The River Feshie has captured the former upper reaches of the Geldie Burn where it changes abruptly in direction at a point close to the watershed (and county boundary) separating the principal catchments of the rivers Spey and Dee (Linton, 1949). The eastern part of the plateau is drained by the Tarf Water, which was also a former tributary of the River Dee, but has been captured by the River Tilt at the Falls of Tarf, and now forms part of the catchment of the River Tay.

The repeated glaciations of the Quaternary have considerably modified the pre-glacial topography of the district by widening, straightening and deepening pre-existing river valleys, breaching watersheds and carving out corries (Hall and Jarman, 2004). The imprint of the last major glaciation (Main Late Devensian, MLD) (Figure 11) is the strongest, but many features of glacial erosion must partially owe their existence to earlier events and to the 'average' glacial conditions that pertained for most of the Quaternary Period (Porter, 1989; Sutherland and Gordon, 1993). Despite considerable Pleistocene erosion, large expanses of high, gently undulating, pre-Pleistocene erosion surfaces remain relatively intact, both on the Gaick and the Cairngorm plateaux (Hall, 1986; Hall and Sugden, 1987). During the major glaciations relatively fast-flowing, warm-based ice streams flowed around the Cairngorm and Gaick plateaux causing considerable subglacial erosion in Strathspey, Glen Truim and Glen Garry, whereas sluggish cold-based ice on the adjoining plateaux had little erosive power (Sugden, 1968).

2.3 THE QUATERNARY RECORD

2.3.1 Pre-Late Devensian events

Some fourteen climato-stratigraphical stages of alternating glacial (cold) and interglacial (temperate) conditions are recognised in the British Isles (Gibbard et al., 2005) (Figure 11), but no deposits of the last (Ipswichian) interglacial or older periods have been positively identified in the district, although weathered remnants of a formerly more extensive till sheet that has been largely eroded away during the MLD glaciation have been found (Pattack Till Formation; Ailleag Diamicton Member). When compared to the longer sequences found in the Inverness area, where intervening interglacial and interstadial deposits have been located (Fletcher *et al*., 1996), the colour, iron staining and weathered condition of many clasts in these remnants suggests that they have been exposed to full interglacial conditions and are pre-Devensian in age. No Early or Mid-Devensian deposits have been identified in the district, which might indicate that the last ice sheet built up relatively early.

2.3.2 Late Devensian

Most of the glacigenic deposits in the district were laid down during the Main Late Devensian (MLD) glaciation which began between 32 and 28 ka BP. There is growing evidence from north-west Europe that the Last Glacial Maximum (LGM) occurred relatively early in this glaciation, before 22 ka BP (Bowen et al., 2002: Bradwell et al., 2008), when the region was overwhelmed entirely by ice (Sutherland and Gordon, 1993; Boulton et al., 2002). A period of glacial retreat followed before significant readvances occurred after 18.4 ka BP, particularly involving coastal ice streams. In north-eastern Ireland, high-precision radiocarbon dating on foraminiferids contained within glaciomarine muds indicates that a period of ice retreat between 16.7 and 14.7 ka BP preceded another significant readvance at c.14 ka BP (McCabe et al., 1998). The latter event was possibly accompanied by significant readvances in the district (Everest and Kubik, 2006).

The MLD glaciation probably first witnessed the expansion of ice fields and glaciers in the mountains of the Western Highlands. As the ice advanced eastwards, it blocked some suitably orientated valleys causing ponding, such as in the upper reaches of the rivers Pattack and Mashie (Merritt, 1999). Eventually the deltaic and glaciolacustrine sediments (Ceardaich Sand and Gravel and Linn of Pattack Silt formations respectively) deposited in these lakes were overridden and largely reworked into diamictons of the Ardverikie Till Formation beneath the advancing ice. A similar passage of events occurred to the south of the Gaick plateau, where ice first blocked the lower reaches of southward draining valleys causing ponding before it overrode the deposits and impinged against the plateau (Merritt, 2004d). The absence of far-travelled erratics within the Cairngorms and eastern Gaick indicates that local ice caps had developed there, at least, before the district became overwhelmed by ice sourced from the west (Bremner, 1929; Sissons, 1976). Strathspey ice carried erratics of psammite to elevations of up to 800 m on the flanks of the northern Cairngorms (Sugden, 1970).

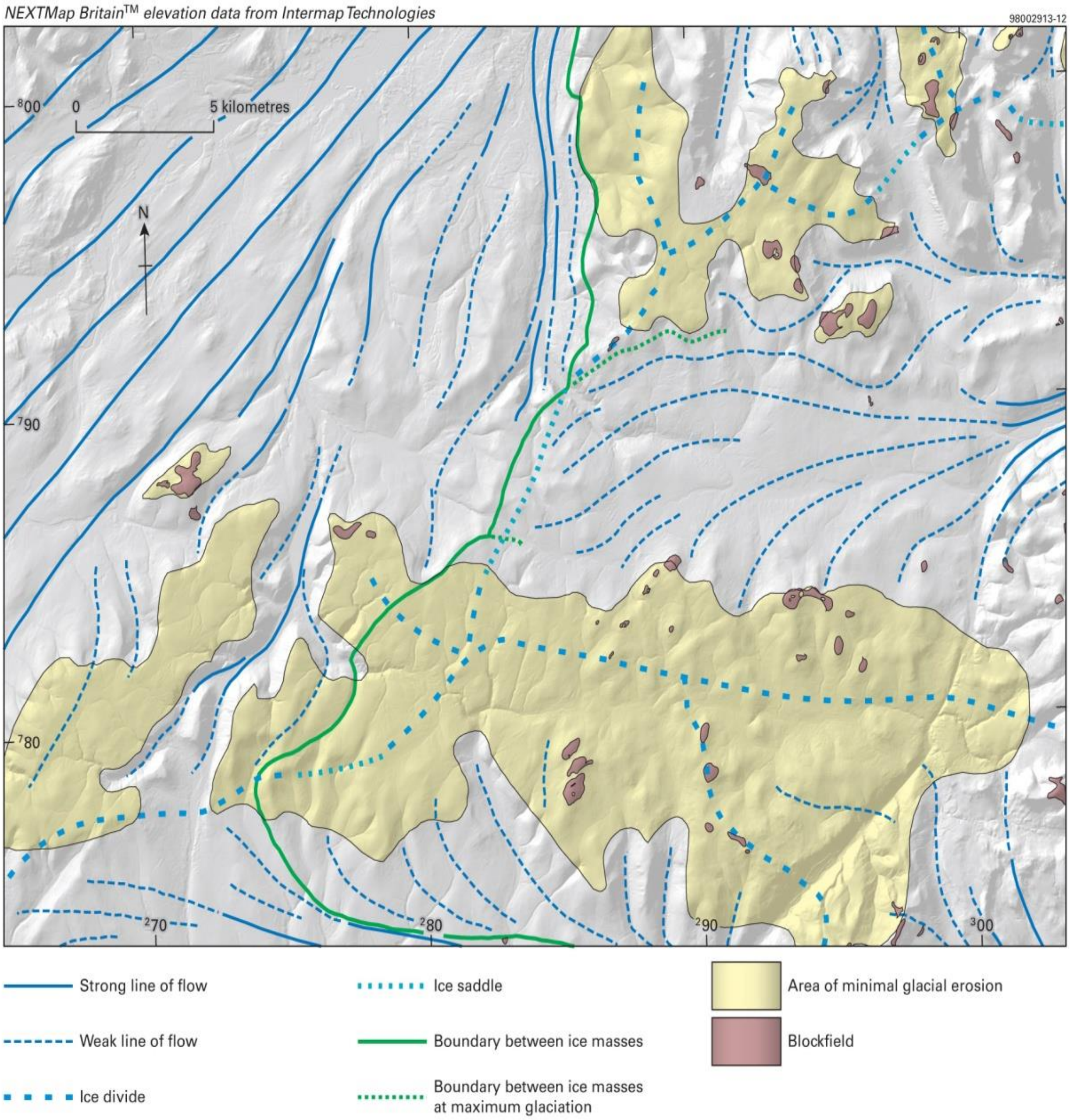

Figure 12 : Reconstruction of flowlines and ice divides within the Main Late Devensian ice sheet following the Last Glacial Maximum (LGM). Some West Grampian-Strathspey ice probably flowed eastwards into the valley of the Geldie Water at the maximum build-up of ice.

The entire district was probably overtopped by ice by the LGM (Figure 12), judging from the evidence of lee-side joint-block removal, glacially transported tor blocks and stripping of blockfields at elevations of up to 1200 m on Ben Macdui, Beinn Mheadhoin and Derry Cairngorm (Hall and Glasser, 2003). A powerful topographically controlled ice stream was centred on the Spey Valley, as evidenced by severely ice plucked and mammillated rocks on the western valley sides overlooking Newtonmore and Kingussie, and the mega-roche moutonnée features of Creagan a' Choin and Ordan Shios, south of Newtonmore (Plate 23), which have tails of drift stretching in the former up-ice direction. Strathspey ice extended eastwards against the Cairngorm massif and probably penetrated into the catchment of the River Dee via the valley of the Geldie. The Strathspey ice stream was mainly sourced to the west of the district with a feeder draining ice from the Loch Ericht depression via the valley of the River Truim. Ice flowing through the Loch Garry depression impinged on the southern slopes of the Gaick plateau.

Plate 23 : Creagan a' Choin [NN 703 957], a large roche moutonnée feature in the Spey Valley south of Newtonmore. Ice flowed from right to left, north-eastwards. BGS Imagebase No. P543686.

The contrast in intensity of glacial erosion between deeply incised troughs and undulating high plateau is exemplified in the Cairngorms (Figure 9), which represent a classic example of such 'selective linear erosion' (Sugden, 1968; Rea, 1968; Hall and Glasser, 2003). Ice on the plateaux is believed to have been relatively thin, dry, cold-based and to have flowed predominantly by internal deformation. In contrast, convergent flow within valleys and across cols was wet based, promoting basal sliding and enhancing rates of glacial erosion (Sugden, 1968; Gordon, 1993). Similar contrasts in erosion occur in the Gaick, for example, the deep 'U-shaped' glaciated valley of Chama Choire that cuts into the plateau to the west of the Gaick Pass. The mouth of the valley of the Allt Gharbh Ghaig, east of Gaick Lodge, is also 'U-shaped', similar to the main glacial breach forming the Gaick Pass. However, it soon becomes 'V-shaped' eastwards with interlocking spurs, suggesting that these upper 'canyons of adjustment' have experienced minimal glacial erosion (Hall, 2004). This observation is supported by the particularly widespread development of deep weathering profiles hereabout.

2.3.3 The pattern of deglaciation

The general pattern of deglaciation across the district has been established from the distribution and cross-cutting relationships of ice-marginal glacial drainage channels and associated low, sub-parallel moraine ridges, together with lee-side and humped-profile channels on cols, and eskers. The reconstruction shown in Figure 13 also takes into account sedimentological evidence, clast provenance and the distribution of ice-marginal outwash fans. There is, however, very little chronological control and, despite many years of research, the timing and extent of glacial readvances in the district causes controversy.

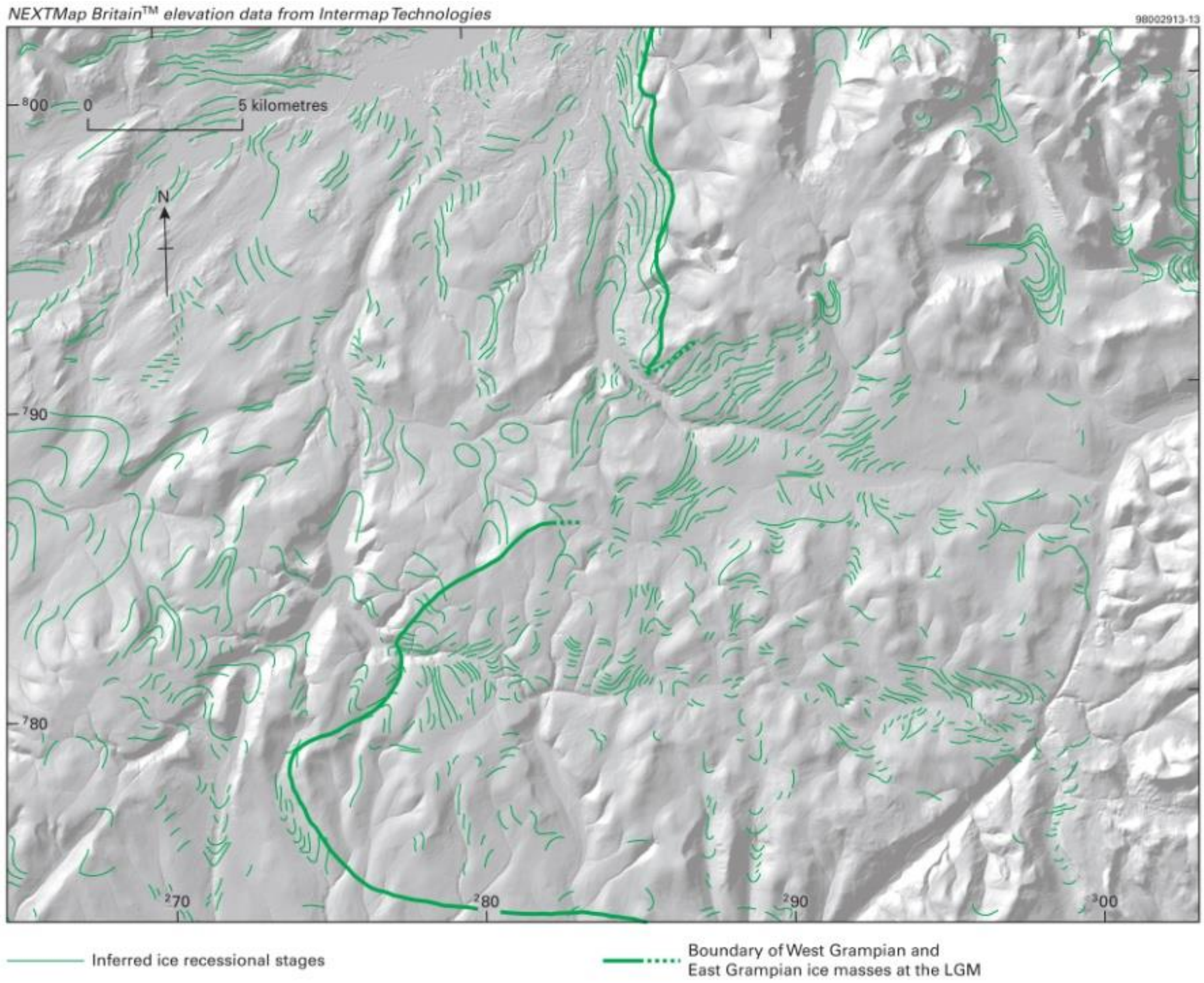

Figure 13 : Reconstruction of the pattern of ice recession. Thick line denotes approximate boundary between West Grampian-Strathspey ice and ice sourced over the Cairngorms and Gaick at the LGM.

There is converging evidence from the Cairngorms that locally sourced ice began to decouple from ice flowing from the main Western Highlands divide via the Strathspey outlet glacier following the LGM, but before the sudden climatic amelioration at the beginning of the Windermere Interstadial (Everest and Golledge, 2004; Everest and Kubik, 2005). An independent plateau ice cap supporting a radial pattern of outlet glaciers developed on the western Cairngorms for at least one millennium. These glaciers retreated actively to form 'classical' hummocky moraine, such as in Glen Geusachan. Sissons (1979a), however, had attributed these landforms to the LLR (Figure 14). If Everest and Kubik are correct the Cairngorms may have contained relatively little glacier ice during the LLS, as concluded by Sugden (1970, 1980).

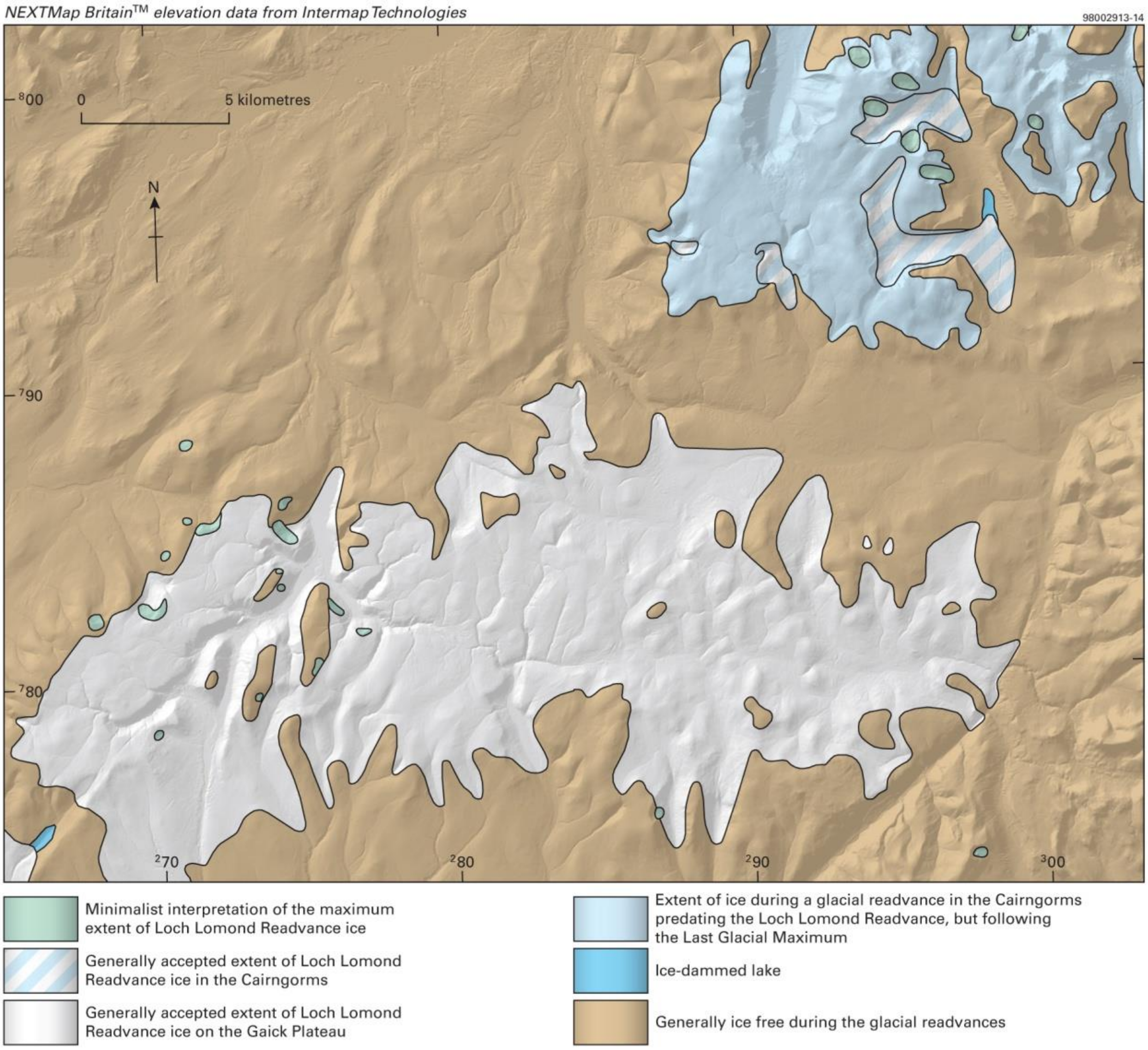

Figure 14 : Limits of glacial readvances following the LGM and including the Loch Lomond Readvance.

There is abundant evidence in the north-western part of the district for the sequential retreat of the Strathspey outlet glacier, following its evacuation of Rothiemurchus. For example, there is a series of ice-marginal drainage channels, benches, kame terraces and associated lateral moraines that stretch along the northern side of the Spey Valley between Kincraig and Glen Banchor. The features occurring in the vicinity of Loch Gynack, north of Kingussie, are particularly fine examples. The channels descend eastwards at successively lower elevations and were clearly formed at the margin of the retreating glacier. Short-lived ice-marginal lakes formed locally into which meltwater streams laid down deltas; these deposits of sand and gravel now form flat-topped mounds with former ice-contact slopes facing down the valleyside. Evidence from Raitts Burn, 4 km north-east of Kingussie (Phillips and Auton, 2000; Phillips et al., 2007), indicate that the glacier remained active during its retreat westwards.

Following its retreat from Glen Banchor, the snout of the Strathspey glacier appears to have stabilised for a while in the vicinity of the Woods of Glentruim, 6 km east of Laggan, where an assemblage of moraines, kame terraces, eskers and other ice-contact features are preserved. The presence of Strathspey ice hereabout caused meltwaters emanating from a contemporaneous outlet glacier occupying Glen Truim to be diverted via the site of Loch Etteridge. Once the Strathspey glacier had retreated westwards towards Laggan, the Truim was able to take its present course, abandoning the Etteridge route, and in doing so saving the remarkable set of glaciofluvial features preserved there from subsequent fluvial erosion (Walker, 1993).

There is also abundant evidence in the form of ice-marginal drainage channels, benches, kame terraces and associated lateral moraines for the retreat of the south-eastern margin of Strathspey ice, firstly along the eastern slopes of the valley of the River Feshie downstream of Glenfeshie Lodge (Werrity and McEwen, 1993), then subsequently along the eastern slopes of Gleann Chomhraig and the valley of the Allt an Dubh-chadha (Golledge, 2000), to the west of the lodge.

The presence of suites of ice-marginal meltwater channels along the south-facing slopes of the Cairngorms in Glenfeshie Forest suggests that ice sourced from an ice divide over the Gaick had held Cairngorm ice at bay. Ice from both centres had funnelled into the valley of the River Dee in the vicinity of White Bridge. A series of ice-marginal channels that cross the southern slopes of Glen Luibeg most probably mark lateral positions of the combined Dee/Luibeg outlet glacier following its separation from an entirely Cairngorm-sourced glacier in Glen Derry during ice-sheet deglaciation (Golledge, 2003).

It is clear that the Gaick was affected by three discrete masses of ice (Merritt (2004a). The eastern part was covered by a local ice cap that extended south-eastwards into Glen Loch and eastwards towards Glen Shee. North-eastern parts of the Gaick were affected by ice sourced in the Cairngorms, whereas the remainder was over-ridden by ice sourced to the west. A boundary along the north-western margin of the Gaick separated ice flowing from Drumochter and the Loch Ericht basin around the northern rim of the plateau ('Strathspey' ice), from ice flowing directly from the West Drumochter Hills and the Loch Garry basin around the south of the plateau ('Perthshire' ice). The configuration at the Last Glacial Maximum (LGM) (Figure 12) has been extrapolated taking into account the position and orientation of prominent glaciated valleys, valley-side prisms of till and large-scale glacial gouges.

The eastern Gaick was occupied by a locally sourced ice cap that was centred on some of the lowest ground and extended to the south-west. Locally sourced ice converged with ice flowing from afar, especially through the deep valleys to the west and south-west. As suggested by Sutherland (1984), ice flowed across Glen Tilt, not through it, which explains why this classical 'V-shaped' valley shows little evidence of glaciation. Glen Loch and valleys to the south-west of the area were major outlets. There is no evidence that the eastern Gaick was ever over-ridden by ice sourced from outwith the area.

The initial retreat of ice over the eastern Gaick was probably restricted to outlet glaciers within Glen Loch and Gleann Mhor, where there are excellent retreat moraines and associated features. It is speculated that once ice sourced from outwith the eastern Gaick began to retreat to the north, west and south, local ice was able to expand. It funnelled down the main valleys around the periphery and then retreated actively to form the suites of moraines and ice-marginal channels. No distinct terminal moraines have been identified suggesting that these outlet glaciers were short lived. The distribution of ice-marginal drainage channels and associated low moraine ridges of the Gaick plateau Moraine Formation (Plate 24) indicate that the ice continued to retreat concentrically inwards towards the lowest ground in the valleys of the Tarf Water and Bruar, where it finally decayed. It is unlikely that the shrinking mass of ice remained 'active', suggesting that the concentric features formed by seasonal ice melt and paraglacial processes around the periphery of cold-based ice, rather than seasonal ice advance. The features are best developed where bedrock is thoroughly decomposed and hence prone to glaciofluvial erosion and slope processes (Merritt, 2004e).

Plate 24 : Recessional moraine ridges and associated ice-marginal glacial meltwater channels in the valley of the Tarf Water looking north-east towards the head-covered slopes of Sron na Macranaich [NN 937 818]. BGS Imagebase No. P536161.

The rest of the Gaick was over-ridden by ice sourced from the west-south-west of the district. It flowed across the western plateau into all the valleys draining into the Gaick Pass, including the lower valley of the Allt Garbh Gaig. Strath Spey ice shrank away from the northern rim of the plateau leaving behind the extensive sets of low benches and shallow ice-marginal drainage channels that are particular apparent in the spring when snow melts on these slopes (Merritt, 2004e, 2004f). As the two ice masses ‘unzipped’, ice flowed from the plateau into the vacated northern corries, firstly into Coire Bhran [NN 805 855], then into the mouth of the central breach. Here an outwash fan was laid down at the northern end of Loch an t-Seilich [NN 762 875] (Merritt, 2004b). Subsequently, ice flowed into Coire Chuaich [NN 717 864] and finally into Choire Chais [NN 695 825]. A continuous series of recessional features tracks the retreat of ice from the Loch an t-Seilich basin south-westwards through the Gaick Pass, along the valley of the Allt na Craoibhe and into Cama Choire (Figure 13).

At a relatively early stage in the deglaciation, Perthshire ice began to retreat from Glen Tilt and the southern slopes of the eastern Gaick lying to the east of the Bruar Valley. This allowed ice to funnel down the deep, parallel valleys of Gleann Diridh and Gleann Mhairc from the eastern Gaick ice cap. However, the absence of clearly defined terminal moraines and associated outwash fans in the Gaick Forest suggests that the readvances were short lived. As Perthshire ice continued to withdraw it allowed ice from the western Gaick to advance into the valley of the Edendon Water and neighbouring valleys where it subsequently retreated to form splendid sets of ice-marginal moraine ridges and associated drainage channels (Merritt, 2004c).

Strathspey ice retreated westwards from the valley of the Allt Bhran at an early stage allowing ice sourced from the south to flow into Coire Bhran. A massive outwash fan [NN 7675 8825] (Bruach Dhubh Fan) was formed at the mouth of the central breach by meltwaters flowing from the south (Merritt, 2004b), whilst Strathspey ice retreated westwards towards Meall Chuaich. The latter ice subsequently pulled back from the breaches on either side of Meall Chuaich and retreated down the valley of the Allt Cuaich towards Dalwhinnie. There is evidence of both ponding and minor readvances within the valley of the Allt Cuaich (Merritt, 2004f).

The final stage in the deglaciation of the Gaick witnessed the retreat of ice from Coire Mhic-sith, in the south-west corner of the district. This was accompanied by the formation of an ice-dammed lake in the valley, which drained initially via spillways and later along the ice margin (Lukas and Merritt, 2004; Lukas, 2004).

2.3.4 The Windermere (Lateglacial) Interstadial

Deglaciation commenced in a cold, arid environment and parts of the Cairngorms at least probably witnessed several thousand years of ice-free, periglacial conditions before the onset of rapid warming at 14 692 BP, the beginning of the Windermere Interstadial (WI) (Lowe et al., 2008). The abrupt amelioration in climate occurred when temperate waters of the Gulf Stream returned to the sea off the western coasts of the British Isles. River terraces and alluvial fans formed across the district by paraglacial processes, sweeping away loose glacial debris before soils became stabilized by vegetation (Ballantyne, 2002). Reported evidence of the WI is restricted to one site in the district, Loch Etteridge, where buried organic deposits have been cored (Walker, 1993; Lowe et al., 2008). An oscillatory climatic deterioration occurred during the WI and it is likely that glaciers had already started to build up in the mountains before more sustained cooling began at 12 896 BP, the start of the Loch Lomond Stadial (LLS).

2.3.5 The Loch Lomond Stadial

Glaciers undoubtedly existed in the district during the LLS, but controversy remains as to their extent (Figure 14) and whether any remnants of the MLD ice sheet survived during the WI (Merritt et al., 2004a). Many periglacial deposits and features formed during this very cold period.

There are four possibilities for when the high ground in the southern half of the district was last glaciated (Merritt et al., 2004b). The generally accepted paradigm is that renewed glaciation occurred in the Loch Lomond Stadial (LLS) following the complete decay of the Main Late Devensian ice sheet (Sissons, 1979b; Sutherland and Gordon, 1993). The second option is that most of the glacial landforms and deposits on and around the Gaick plateau formed during the progressive and substantially uninterrupted retreat of the MLD ice sheet: any LLS ice was restricted to a few small corrie and niche glaciers. The third option is that the Cairngorm model provides a paradigm for the Gaick in that at least some of the evidence previously linked with the LLR relates to independent plateau ice sheets that developed during ice sheet deglaciation prior to the Windermere Interstadial. A fourth option is that deglaciation of the MLD ice sheet had not been complete before cooling associated with a regional readvance of ice masses occurred during latter stages of the Windermere Interstadial and through the LLS.

The glacial reconstruction of a single, independent, late-glacial ice cap over the Gaick plateau is clearly at odds with the account of deglaciation given above, which suggests that as the underlying relief was uncovered topography gained an increasing control on the ice margin. Ice funnelled into valleys and corries locally to form hummocky moraines and related features diachronously, not contemporaneously as proposed by Sissons. Besides the absence of direct dating control, the main problem is the lack of coherent, identifiably younger sets of terminal or lateral moraines in the area.

Benn and Ballantyne (2005) offered an alternative reconstruction to Sissons of an independent LLS ice cap sourced in the West Drumochter Hills and it is possible that a similar, highly asymmetrical ice cap formed over the western part of the Gaick plateau with outlet glaciers flowing eastwards into the central breach and the Edendon valley. The eastern Gaick possibly supported a contemporaneous ice cap not too dissimilar to that modelled by Sissons (1974), but with an outlet glacier flowing westwards into the central breach. The best terminal moraine in the area occurs within the corrie situated to the east of Carn nan Gabhar in the Beinn a' Ghlo massif; its LLS age is not disputed.

Benn and Ballantyne (2005) used well-practised and reported procedures to support the conclusion that the West Drumochter Hills and Pass of Drumochter were last glaciated during the LLS following the complete decay of the MLD ice sheet. However, they were unable to rule out the possibility that remnants of the MLD ice sheet remained in the area throughout the Windermere Interstadial as has been debated forcefully, for example, regarding the Cairngorm Mountains, some 25 km to the north-east of Drumochter (Sugden, 1980). Indeed, Ballantyne *et al*. (1987) and Stone and Ballantyne (2006) concluded that there is a distinct possibility that ice survived the Interstadial on high ground elsewhere in Scotland, and Clapperton (1997) argued that the MLD ice sheet was too large to have melted completely before the end of the interstadial. The survival of ice-sheet remnants would explain why no deposits of Lateglacial Interstadial age have been found hitherto within the Drumochter-Gaick area, why no coherent set of laterally extensive end moraines or stratigraphical evidence has been found that supports a separate LLS glaciation of the extent reconstructed by Sissons (1974; 1980) or Benn and Ballantyne (2005), and why the last ice to cover the eastern Gaick was centred over the lowest ground in the valley of the River Tarf (Merritt, 2004).

Ballantyne (2002) concluded that hummocky moraine is likely to have formed in particular climatic and glaciological settings following the LLR when there was a large reservoir of paraglacial material available for reworking, but it has yet to be demonstrated beyond doubt that these conditions only occurred towards the end of the LLS. For example, recent cosmogenic isotope ages obtained from boulders on 'classical hummocky moraine' in Glen Geusachan (Everest & Kubik, 2006) indicate that this particular example formed during the retreat of a local ice cap during an earlier readvance (c.16 ka BP).

The most recent sophisticated thermomechanical ice sheet modelling of the glacial configuration during the Loch Lomond Stadial by Golledge et al. (2008) suggests that mostly thin, cold-based plateau ice fields developed on the Cairngorm, Monadhliath and Gaick plateaux relatively early in the stadial (12.7 ka) (Figure 15). If correct, much of the evidence illustrated in Figure 13 for deglaciation across the Gaick is palimpsest and is indeed unrelated to LLS ice.

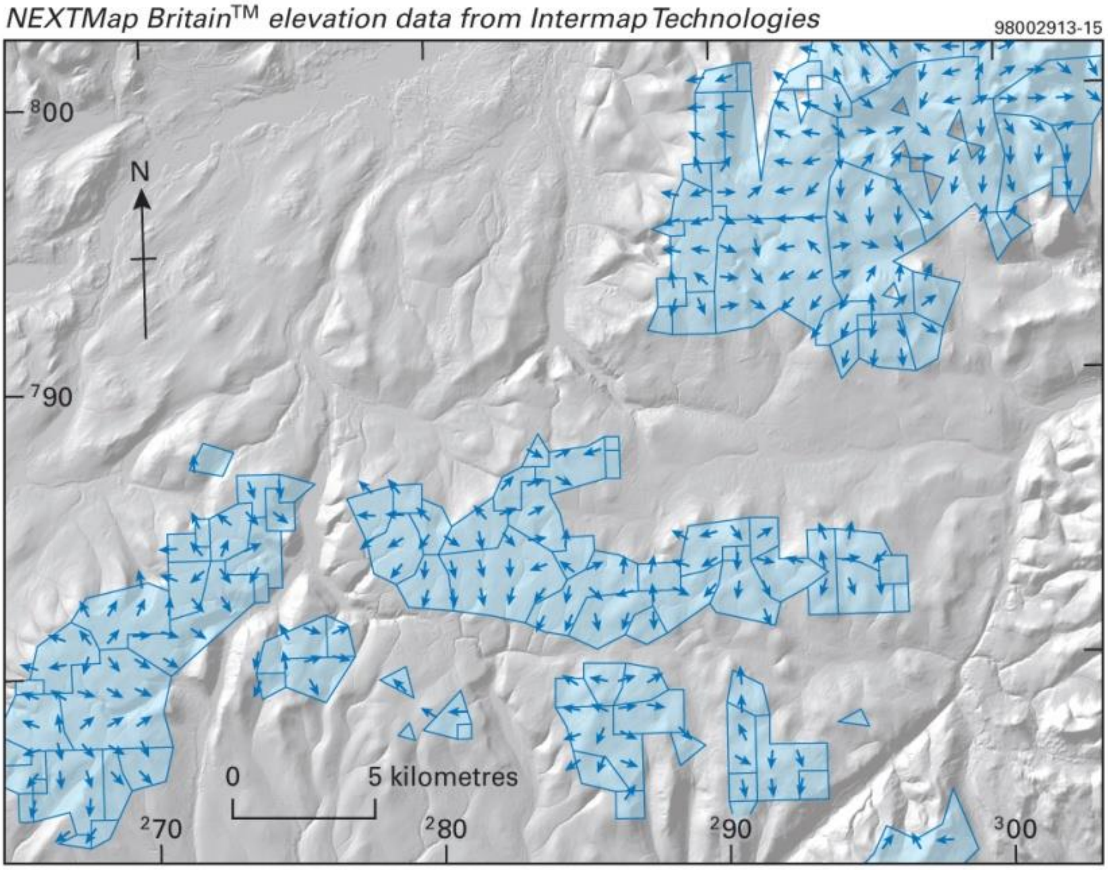

Figure 15 : Thermomechanical ice sheet model for the Loch Lomond Readvance (after Golledge et al., 2008).

2.3.6 Holocene

The Holocene began abruptly at 11 703 BP when the warm Gulf Stream current became re-established, providing an ameliorating influence on the climate of the British Isles (Lowe et al., 2008a). At first the widespread occurrence of bare, unstable soils must have led to a period of intense fluvial erosion and deposition with enhanced debris-flow activity on mountainsides and land slipping (Ballantyne, 2002). Soils gradually became more stable following the establishment of vegetation, firstly of shrubs and scrub communities, as during the early part of the Windermere Interstadial, and later by woodland (see Sutherland, 1993; Gordon, 1993; Bennett, 1996 for summary of research in the district). Sites at low altitude indicate that, following a distinct phase of juniper dominance, forests of birch and hazel with subsidiary oak and elm had developed early in the Holocene. Pine spread into the district at about 8800 yrs BP and was the dominant forest for the next four millenia (Bennett, 1989; 1996). Alder appears to have arrived after the arrival of pine, but was never abundant. Humans had begun to have an impact on the landscape around Loch Garten by 3,900 yrs BP, as reflected in the decrease in the number of trees, especially pine, and the concomitant increase in abundance of heather.

Climatic deterioration appears to have begun soon after the beginning of the Holocene. Distinct layers of pine and birch stumps preserved quite widely in blanket peat deposits indicate that the forest locally succumbed to the spread of *Sphagnum* moss when colder and wetter conditions pertained. The inception of blanket bog has been dated to between about 8,000 and 4,400 BP in the Cairngorms (Pears, 1970, 1988), where the treeline has fallen from about 790 m OD (recorded from the highest stumps of birch), to its present natural level of about 680 m OD (Pears, 1988).

Although the imprint of glaciation remains dominant, post-glacial processes have superimposed subtle, but distinctive, modifications on the landscape. Steep mountain sides have been modified by rockfalls, soil creep and debris flows, whereas valley floors have been affected by rivers forming spreads of alluvium and river-terrace deposits and by the accumulation of alluvial fans at the mouths of tributary streams. It is apparent that accelerated erosion, land slippage and debris flow have occurred within the past few centuries, but whether the increase is related to the destabilisation of mountain soils by overgrazing, or by a change to a more stormy climate, is debatable.

2.4 QUATERNARY GEOLOGY OF THE EASTERN GRAMPIAN HIGHLANDS

The history of Quaternary research in the Eastern Grampian Highlands has been summarised by Sutherland (1993). The primary survey of the region supported the prevailing opinion that deglaciation followed an orderly sequence of events comprising ‘ice cap’, ‘confluent glacier’, ‘valley glacier’ and ‘corrie glacier’ stages (Barrow et al., 1913; Hinxman and Anderson, 1915; Hinxman, et al., 1923). Former flow directions of ice at the ‘maximum glaciation’ were determined from the distribution of erratics, particularly granites and granodiorites from the south-west of the district, and the Cairngorms. This evidence suggested that regional ice accumulation areas were centred over the Ben Alder/ Rannoch Moor area and the Cairngorm massif. NNW-trending striae on the bedrock exposed at the head of Gleann Einich are cited as evidence for this western-sourced ice overtopping the Cairngorm Plateau. On the contrary, the absence of erratics of metamorphic rock in the core area of the mountains suggests that this ice was diverted around the Cairngorms, down Strathspey and through the valley of the Geldie Water towards Glen Dee (Brazier et al., 1996b). Barrow et al. (1913) concluded that deposits of the ‘maximum glaciation’ were chiefly restricted to the higher ground and cols, because till deposited in the valleys had been removed during the subsequent ‘valley glaciation’, when hummocky morainic deposits were laid down.

Granodiorites from the Rannoch area were found only on the western margins of the Gaick plateau and no Cairngorm granite was found within the Gaick. This indicated that the Gaick lay beneath an ice divide (‘ice shed’) and that ice sourced locally had been sufficiently strong to fend off ice flowing from afar. Barrow et al. (1913) concluded that the local ice later became dominant in parts of the Gaick when the exotic ice became less powerful. Ice flowing from the south-west via the Loch Garry basin split at about the Pass of Drumochter, some flowing north-eastwards toward the valley of the River Spey, the rest flowing south-eastwards toward Strathmore, encroaching only on the southernmost part of the district (Hinxman, et al., 1923).

The pattern of ice flow thus deduced at the ‘maximum glaciation’ has been accepted generally (Charlesworth, 1955, 1957; Sissons, 1967; Sutherland, 1984; Sutherland and Gordon, 1993). Charlesworth (1955, 1957) concluded that a distinct ‘Highland Readvance’ had affected the district, but his reconstructed ice margins were largely unsupported by detailed field evidence. Sissons (1967, 1974, 1979, 1981) subsequently used limits of ‘hummocky moraines’ and other evidence largely derived from air photographs to delineate areas affected by his more restricted ‘Loch Lomond Readvance (LLR)’. He reconstructed 17 glaciers in the Cairngorms, most of them in corries, but including larger valley glaciers in Glen Eidart, Garbh Choire and Glen Geusachan. Sugden (1970, 1980) interpreted many of the moraines in the Cairngorms as sub-glacial, glaciofluvial landforms, and, like Sissons, proposed that deglaciation took place by *in-situ* ice stagnation. This concept was endorsed by Young (1975, 1976, 1978) in his detailed geomorphological mapping from air photos of Glen Feshie, Rothiemurchus and adjoining areas. Sissons (1974) reconstructed an ice cap over the Gaick plateau with outlet glaciers radiating into the surrounding valleys, including the Pass of Drumochter, but could locate no terminal or lateral moraine ridges.

The LLR limits established by Sissons have been dated indirectly on pollen-stratigraphical evidence by comparing cores taken from organic sediment filling kettleholes both within and outwith those limits. For example, cores taken from Loch Etteridge [NN 688 929], some 19 km to the NNE of the Pass of Drumochter, reveal a classic ‘tripartite sequence’ including sediment deposited during the Loch Lomond Stadial and Windermere Interstadial (Sissons & Walker, 1974; Walker, 1975a, Walker 1993). The base of the organic sequence at Etteridge has yielded a new AMS uncalibrated radiocarbon date of 12 930 ±40 BP, indicating that the area around the loch has not been glaciated during the Loch Lomond Stadial (Everest and Golledge, 2004). This is corroborated by the recent identification towards the base of the sequence of microtephra correlated with the main Borrobol event at 14,400 cal BP (Lowe et al., 2008). In contrast, the basal pollen assemblage in cores taken from a kettlehole located on the col of the pass [NN 629 762] has been correlated with a similar assemblage at Etteridge that yielded an early Holocene radiocarbon date of 9405 BP (Sissons & Walker, 1974; Walker, 1975a, b; Walker, 2008). Furthermore, a series of radiocarbon dates from basal sediment in high corries on Braeriach were found to be no older than about 7 ka BP (Rapsom, 1985).

Both the general pattern of ice flow across the district and the series of events has been accepted generally (Jamieson, 1908; Hinxman and Anderson, 1915; Charlesworth, 1956; Sugden, 1970, 1974; Young, 1974; Sutherland, 1984, 1993; Hall and Mellor, 1988; Brazier et al., 1996a, 1996b, 1998), although modern three-dimensional thermomechanical ice-sheet modelling suggests that the ice sheets that covered the Central Highlands were more dynamic than thought hitherto (Boulton and Hagdorn, 2006). During deglaciation, ice sourced in the western Highlands (Strathspey ice) retreated in a general westerly direction exposing peaks and valleys in the east before those in the west. There were complex interactions with ice sourced locally in the Cairngorms and Gaick. Retreat was punctuated by at least one major stillstand involving Strathspey ice, evidenced by extensive lateral moraines in Glen More and at the mouths of Gleann Einich and the Lairig Ghru, just to the north of the district. Ice-marginal lakes were ponded up at this time within Gleann Einich and the Lairig Ghru, between active Strathspey ice occupying Rothiemurchus, and local glaciers (Brazier et al.,1998; Golledge, 2002).

Some of Sissons' (1979) LLR limits in the Cairngorms and his interpretation of the style of deglaciation have been challenged, especially in Glen Geusachan and Garbh Coire (Bennett and Glasser 1991; Bennett, 1996; Brazier et al., 1996b), also around the Gaick plateau and in the Pass of Drumochter (Lukas et al., 2004). Contrary to earlier views of widespread ice stagnation, deglaciation generally involved 'active retreat' of topographically controlled glaciers that produced hummocky moraine together with series of lateral moraines and associated drainage channels (Bennett and Boulton, 1993). Furthermore, it now appears from the cosmogenic dating of boulders that in the western Cairngorms the larger valley glaciers reconstructed by Sissons, such as Glen Geusachan and Garbh Coire, were outlet glaciers of a plateau glacier centred on Moine Mhor that became established during a prolonged stillstand in deglaciation between 16 and 14 kyr BP, prior to the Loch Lomond Stadial (Everest and Kubik, 2006) (Figure 14). These dates have been questioned by Ballantyne et al. (2009), but independent evidence from laminated sediments in Gleann Einich also suggest that the stillstand lasted at least 1000 years (Brazier et al.,1998).

On present evidence the stillstand cannot be correlated with a specific northern hemispheric cooling event. It occurred shortly after Heinrich Event 1 and before the LLS, probably mainly as a result of a local glacial reorganization brought about as topography increasingly affected local glacidynamic conditions during ice-sheet thinning and retreat. Recent, minimal cosmogenic ^{10}Be ages of 16.2 and 15.4 kyr BP on rock glacier deposits in Strath Nethy and the Lairig Ghru respectively confirm that these parts of the Cairngorms escaped glaciation during the Loch Lomond Stadial (Ballantyne et al, 2009) and luminescence ages of glaciolacustrine sediments within Gleann Einich and the Lairig Ghru suggest that Cairngorm ice may have retreated from these glens as early as between 23 and 17 ka BP (Golledge et al., 2002). This supports the conclusion of Sutherland (1982) that precipitation starvation, rather than climatic warming resulted in negative mass balance of eastern parts of the last ice sheet, particularly where accumulation areas were small, such as in Glen Luibeg. The margin of the Strath More ice lobe at the mouth of Gleann Einich was dynamic (Golledge, 2002) and other evidence of oscillatory of ice-lobe margins disturbing sediments deposited in temporary ice dammed lakes during deglaciation has also been reported in Glen Luibeg (Golledge, 2003), between the Lairig Ghru and Glen Derry, and at Raitts Burn in the Spey Valley north-east of Kingussie (Phillips and Auton, 2000; Phillips et al., 2007).

2.5 LITHOSTRATIGRAPHY OF THE NEWTONMORE – BEN MACDUI DISTRICT

The lithostratigraphical framework adopted for classifying the Quaternary deposits on sheets 64E and 64W is based on the 'top-down' scheme outlined by McMillan et al. (2004, 2011). Most litho-morphogenetic and formally defined units established for the glacigenic deposits (glacial, glaciofluvial, glaciolacustrine) are thought to be the product of Devensian stage glaciations. They are assigned to two geographically defined sub-groups of the Caledonia Glacigenic Group, namely the Central Highland Glacigenic Subgroup and the Cairngorm-East Grampian Glacigenic Subgroup. The boundary between the subgroups divides those areas affected by ice flowing from the main ice divide of the MLD ice sheet, to the west of the district, from areas affected mainly by locally sourced ice, namely the Cairngorms and eastern Gaick (Figure 16). Pre-Devensian units are assigned to similar subgroups of the Albion Glacigenic Group. Late-glacial and Holocene fluvial and lacustrine deposits together with peat, head and regolith are assigned informally to the Grampian Catchments Subgroup of the Britannia Catchments Group.

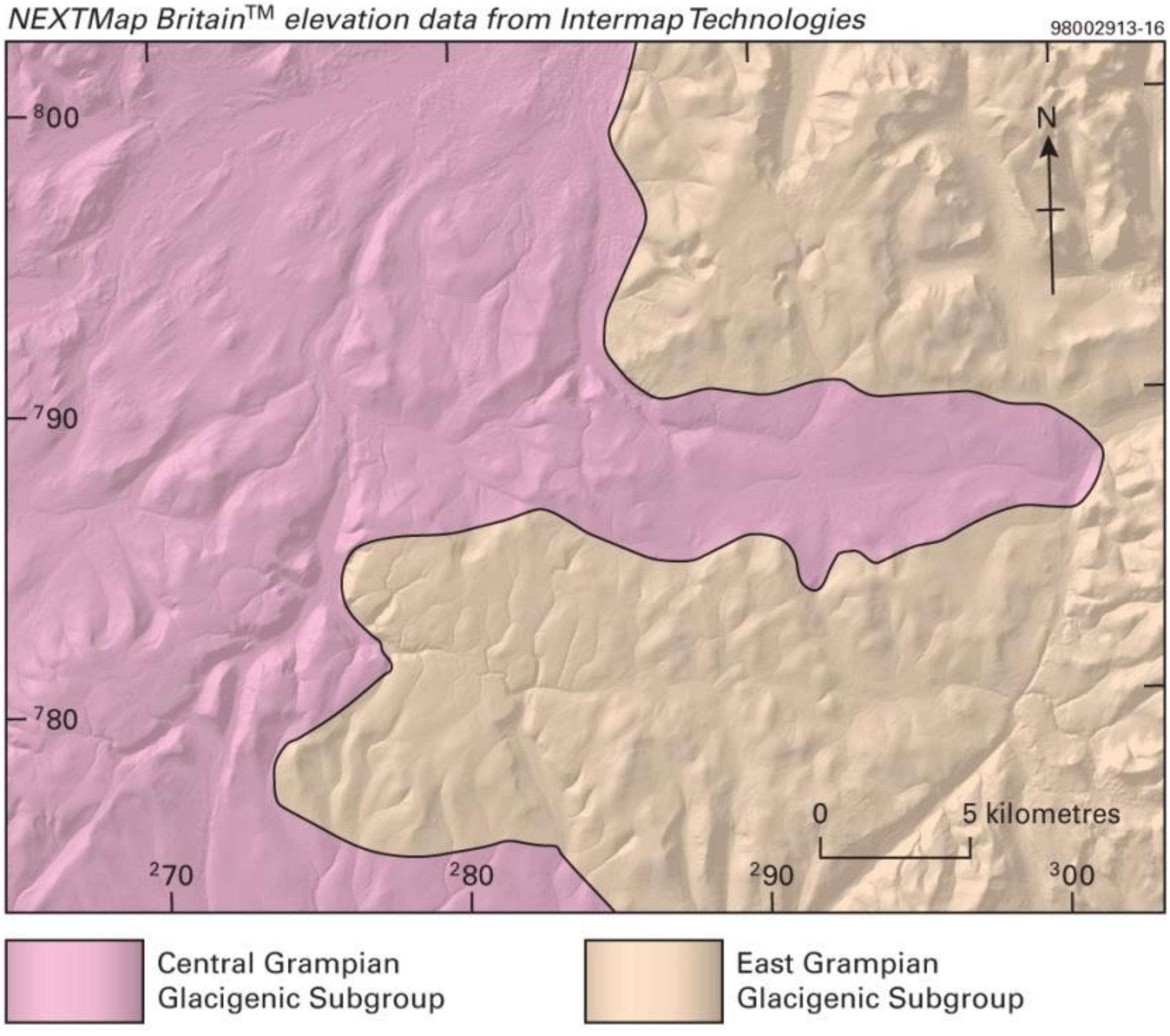

Figure 16 : Distribution of subgroups of the Caledonian Glacigenic Group.

Few formal lithostratigraphical units have been identified in the district apart from within the older glacigenic sequence (Table 4), for which the lithostratigraphy established on Sheet 63E (Dalwhinnie) is adopted (Merritt, 1999). These older units have been found mainly to the south of the Gaick plateau in the valleys of the Allt Shuas Chulaibh, Edendon Water, Allt Glas Choire, Allt a’ Mhuilinn, Allt a’ Chireachain, Allt a’ Choire Bhig and Allt a’ Choire Mhor (Merritt, 2004d).

Central Grampian Glacigenic Subgroup	East Grampian Glacigenic Subgroup
Gaick Moraine Formation	
Ardverikie Till Formation	Banchory Till Formation
Ceardaich Sand and Gravel Formation	
Linn of Pattack Silt Formation	
Pattack Till Formation	
Ailleag Diamicton Member	

Table 4 : Lithostratigraphy of some glacigenic deposits in the district.

The lowest unit in the succession, the **Pattack Till Formation** is a pale to moderate yellowish brown or light olive-brown, very compact, stony, very sandy, clayey diamicton with wisps of fine-grained sand. It contains angular to subrounded clasts of micaceous psammite, quartzitic psammite, reddish brown porphyritic felsite and sparse rounded to well-rounded cobbles and boulders of grey porphyritic granodiorite probably sourced from the Rannoch Moor area to the south-west. Many clasts are unsound and iron-stained suggesting moderate weathering. The till is at least 3.5 m thick locally and is mainly of ‘lodgement’ type (*cf.* Benn and Evans, 1998).

The **Ailleag Diamicton Member** of the Pattack Till Formation is a very compact, ferruginous, clast-supported diamicton resembling regolith that crops out from beneath till within the deeply incised valley of the Fèith Gorm Ailleag [NN 8029 7984], to the south of the Gaick plateau. This unit is probably a head deposit that predates the last regional glaciation of the area.

The Pattack Till is overlain locally by heavily iron-stained, poorly sorted gravely deposits that were probably laid down as moraines and ice-proximal fans during the retreat of the pre-Devensian ice sheet. More commonly the till is overlain by up to at least 12 m of sand and gravel assigned to the **Ceardaich Sand and Gravel Formation**. This unit generally coarsens upwards and its base is a sharp, uneven erosion surface. The subangular to well rounded gravel is similar in composition to the underlying till, although less weathered. The unit is either trough cross stratified (Plate 25), in which case it was laid down as glaciofluvial outwash, or displays larger scale planar cross stratification indicative of deltaic deposition (Plate 26). The deltaic sequences include ripple-drift cross-laminated sand overlying pale yellowish brown, laminated clay and silt (bottom sets) or thinly interlaminated, very fine-grained sand, silt and clay with sparse pebbles (dropstones). The basal, fine-grained part of this composite unit, up to at least 5 m thick, is assigned to the **Linn of Pattack Silt Formation**.

Plate 25 : Cross bedded gravel within the Ceardaich Sand and Gravel Formation at river cliff section ME 226 [NN 7937 7362] in the valley of the Allt a' Chireachain. BGS Imagebase No. P543664.

Plate 26 : Fine-grained, cross-stratified sand of the Ceardaich Sand and Gravel Formation overlain by diamicton of the Ardverikie Till Formation at section ME 225 [NN7960 7374] in the valley of the Allt a' Chireachain. The uppermost 0.5 m of the sand unit is pervasively sheared parallel to the planar base of the overlying till. Beds dip toward the SW. BGS Imagebase No. P543665.

The full sequence is rarely found as it pinches out laterally as a result of subglacial erosion and glacitectonism. The sand and laminated silt and clay has commonly been sliced-up, intercalated tectonically with beds of sand and gravel, or severely compacted, sheared, boudinaged and deformed into a glacitectonite (*sensu* Benn and Evans, 1998). The shearing and deformation increases upwards, with prominent slickensiding.

The deformed sediments are commonly bounded by sharp, subhorizontal, planar contacts at the base of overlying units of diamicton assigned to the **Ardverikie Till Formation**. The latter is generally a pale yellowish brown to light olive-grey, extremely compact, stony, silty, sandy diamicton containing angular to subrounded clasts mainly of micaceous and quartzitic psammite, with some reddish brown porphyritic felsite, mica-schist, and sparse pink granitic vein rock. Significantly, it also contains sparse rounded to well-rounded boulders of grey, porphyritic granodiorite (Rannoch?). The till locally contains wispy, subhorizontal laminae of fine-grained sand, some of which pass laterally into augen-shaped lenses (up to 30 cm thick) within which bedding is folded, microfaulted and sheared. These features are typical of deformation tills (Benn and Evans, 1998). Elsewhere the unit is generally of 'lodgement' type, being massive apart for subhorizontal fissures and concavo-convex discontinuities. A good fabric is commonly developed from which palaeoflow may be deduced.

2.6 SUPERFICIAL DEPOSITS AND QUATERNARY LANDFORMS

2.6.1 Till

Till underlies much of the lower-lying, relatively featureless and poorly-drained parts of the district, commonly concealed beneath younger superficial deposits such as peat. It generally comprises extremely compact, pale yellowish brown, silty, clayey, sandy, stony diamicton. The uppermost metre or so is generally less compact, crudely stratified and sandy. The colour and clast composition of till varies locally, governed by the type of underlying bedrock. However, those assigned to the Ardverikie Till Formation of the Central Grampian Glacigenic Subgroup are dominated by clasts of micaceous psammite and schistose semipelite with subordinate porphyry, granodiorite, and granite. Those assigned to the East Grampian Glacigenic Subgroup (Banchory Till Formation) are dominated by granite in the Cairngorms, micaceous psammite and porphyry in the Gaick and by calcsilicate rocks in Gleann Mòr and Glen Loch. Prisms of till tens of metres thick have been plastered on hillsides in the north-west of the district and to the south of the Gaick plateau; elsewhere it is generally thin (<5 m) and patchy.

Till mainly consists of ice-transported material laid down subglacially, but it also includes deposits formed as cohesive debris flows at the margins of retreating ice sheets and shortly after the ground was laid bare by paraglacial processes. Deposits formed in the last two environments commonly occur towards the surface, and comprise a metre or so of heterogeneous, very poorly sorted, crudely stratified, gravelly diamicton intercalated with gravel, silty sand, silt and clay. Sediments that accumulated at the ice front have been modified and partially redeposited by ephemeral meltwater streams and sheet-wash; they are generally permeable and include large boulders, locally up to several metres in diameter (Plate 27).

Plate 27 : Trackside section ME 293 [NN 6824 9887] in extremely poorly sorted, stratified, matrix-supported diamicton with laterally discontinuous beds of laminated sand and silt. Deposit was probably formed at the receding ice margin by debris flow and sheet wash processes. BGS Imagebase No. P543683.

In contrast, tills formed in the subglacial environment are generally more homogeneous, much more compact, clayey, fissile and are relatively impermeable. In general, it is not practical to map the different types of till separately, even though the boundary between them is commonly unconformable. Locally, however, the supraglacial deposits are several metres or more thick, form constructional mounds and have been mapped out as 'morainic deposits' (see below).

The subglacially formed diamictons generally take the form of 'lodgement' till (Plate 28). This type was deposited beneath actively moving glaciers as a result of frictional retardation of debris particles and debris-rich ice masses against the glacier bed. Such tills have also undergone intense subglacial deformation and are typically very stiff, stony, sandy, clayey diamictons with matrix support and little stratification. Boulders are generally not as large as those occurring in associated ice-marginal deposits, but they typically have bevelled and striated surfaces. Subhorizontal fissures resulting from shearing and subsequent pressure release are common towards the upper surface of lodgement tills, imparting a platy structure. Concavo-convex discontinuities formed by subglacial erosion and shearing are common throughout. All types of discontinuity may be lined with silt, clay and silty fine-grained sand, the latter commonly indurated and ferruginous.

Plate 28 : Subglacial till with a matrix of silty fine-grained sand exposed in a deep gully of the Ruighe Bad an Fheidh, southern Gaick. BGS Imagebase No. P543675.

Some units of till formed within the deforming bed of the ice as it overrode unconsolidated deposits or decomposed bedrock. These ‘deformation’ tills (*sensu* Benn and Evans, 1998) commonly comprise extremely compact, sandy, silty, clayey diamictons with a prominent, gently undulating subhorizontal fissility. Gravel clasts are relatively well dispersed in the matrix compared to lodgement tills, but boulder pavements and clusters of cobbles also occur. They exhibit considerable lateral and vertical variation in lithology and commonly include sheared lenses of sand, gravel, silt and clay (Plate 29).

Plate 29 : River cliff section ME 275b [NN 6844 8711] on the northern bank of the Allt Cuaich, revealing a boudinaged lens of sand within diamicton interpreted as deformation till with shearing towards the NE. BGS Imagebase No. P543708.

The latter have locally been severely compacted, sheared, boudinaged and deformed into planar to gently undulating, subhorizontal beds of 'glacitectonite' (*sensu* Benn and Evans, 1998). Excellent sections in deformation till and glacitectonite may be found in the catchment of the Allt Cuaich (Merritt, 2004f) and in valleys south of the Gaick plateau (Merritt, 2004d).

2.6.2 Morainic Deposits

Morainic deposits are typically hummocky and form several distinctive suites of sediment-landform assemblages. They are typically very poorly sorted and consolidated accumulations of boulders, gravel, sand and sandy diamicton, forming mounds up to 20 m high. Some particularly gravelly or bouldery deposits are prefixed SG or B respectively on the maps.

The deposits are highly variable lithologically and include complex interdigitations of matrix- and clast-supported diamicton, stratified and unstratified silty boulder gravel, and beds of sand, silt and clay. Most of the deposits in the district are 'constructional' moraines that formed at ice margins during 'active' glacial retreat (Plate 30). They were deposited by several processes, including dumping of debris from the glacier surface, 'bulldozing' of loose debris at the ice front during forward movement of the ice, squeezing of soft till from under the glacier margin and by the proglacial thrusting and stacking of slabs of frozen proglacial outwash sediment, debris-rich ice and weak rock at the ice front (*cf.* Benn and Evans, 1998; Bennett et al., 1998).

Plate 30 : Recessional moraine ridges and associated ice-marginal glacial meltwater channels in the valley of the Bruar Water [NN 8283 7700], looking north-north-east. Ice retreated towards the left. BGS Imagebase No. P543857.

The ice marginal moraines are generally intimately associated with meltwater channels that were eroded parallel to the ice margin, either subaerially at the margin or a short distance beneath the glacier. Taken together, the features provide a record of glacial recession across the district. They are generally most pronounced on ground that sloped towards the receding ice margin, notably along the eastern slopes of the valley of the River Feshie downstream of Glenfeshie Lodge (Werritty and McEwen, 1993) (Figure 17), the eastern slopes of Gleann Chomhraig and the valley of the Allt an Dubh-chadha (Golledge, 2000), to the west of the lodge, and on the north-western flanks of the Gaick plateau (Merritt, 2004f).

In some areas, notably within the Pass of Drumochter, Cairngorms and the Gaick, the moraines are apparently not so clearly related to the former positions of ice margins and have a more jumbled and chaotic distribution. Such 'hummocky moraines' were thought to result from the 'downthrusting' of stagnant ice, particularly at the end of the Loch Lomond Stadial (Sissons, 1967), but most of them are now believed to be closely-spaced push and dump moraines, deposited during repeated minor, perhaps annual, readvances by dynamically active glaciers (Lukas, 2003, 2005). Although appearing to be chaotic on the ground, linear patterns are generally apparent from air photographs and Digital Elevation Models and the mounds commonly form chains arranged *en echelon* across valley sides. Excellent examples of such moraines have been described in Glen Geusachan (Bennett and Glasser, 1991), Glen Eidart (Golledge, 2000), Glen Luibeg (Golledge, 2003) and the valley of the Edendon Water (Merritt, 2004c).

Good examples of morainic deposits formed mainly of sand and gravel may be examined in road cuttings along the A9 road within the valley of the River Truim and in the lower reaches of the Cuaich catchment (Merritt, 2004f). Here the moraine ridges range up to 20 m in height and their cross-sectional asymmetry, orientation and disposition clearly indicate that they formed periodically at the margin of an ice sheet that retreated towards the west-south-west (Plate 31).

Plate 31 : Roadside section ME 291 [NN 6982 9659] in loose, very poorly sorted, silty sand and gravel forming moundy morainic deposits to the south of Newtonmore. BGS Imagebase No. P543687.

They are typically composed of pale yellowish-brown, poorly compacted, coarse, extremely poorly sorted, yet relatively well-rounded, gravel with a ‘floury’ silty, sandy matrix. The deposits commonly pass laterally and vertically into heterogeneous stratified diamictons containing many boulders and blocks. Here, as elsewhere, it is commonly difficult to distinguish morainic and moundy glaciofluvial deposits, as both contain many rounded clasts.

A distinct suite of morainic deposits occurs on the Gaick plateau, particularly within the eastern Gaick. Assigned to the **Gaick plateau Moraine Formation**, these deposits are typically composed of yellowish brown, poorly consolidated, mainly clast-supported, gravelly, sandy, silty diamicton, and matrix-rich gravel (Merritt, 2004e). The gravel fraction is dominated by fragments of weathered psammite and porphyry. The suite takes the form of low, arcuate, recessional moraine ridges and parallel, shallow glacial drainage channels that record the decay of the ice concentrically toward the upper reaches of the valleys of the Tarf Water and Bruar Water (Plate 24).

A distinctive set of sharp-crested moraine ridges occur in Glen Loch, in the south-eastern corner of the district, where some of them allow passage across Loch Loch at low water levels (Plate 32).

Plate 32 : Recessional moraines in Glen Loch , looking north-north-east. BGS Imagebase No. P772049.

These features are probably De Geer moraines that formed at the margin of ice that retreated northwards towards an ice divide situated across the eastern Gaick. Features such as these formed at ice fronts that terminated in water (Golledge and Phillips, 2008).

2.6.3 Glaciofluvial Deposits

Where possible, moundy *glaciofluvial ‘ice-contact’ deposits* have been distinguished from terraced *glaciofluvial sheet deposits* and assigned to one or other of the glacigenic subgroups represented within the district. The ‘ice-contact’ deposits are generally a little older than ‘sheet’ deposits occurring at a particular locality, the former having been largely destroyed and redeposited by outwash streams to form terraced spreads (sandar). However, moundy and terraced spreads commonly merge together in which case boundaries drawn between them are somewhat arbitrary. Glaciofluvial terraces are generally distinguished from alluvial terraces occurring at lower levels in the valleys by the presence of ‘kettleholes’ that were formed by the melting of blocks of ice trapped within the sediment. However, many alluvial terraces were probably created only a short time after the glaciofluvial ones. Some large outwash fans have been distinguished separately as *glaciofluvial fan deposits*.

Ice-contact deposits mostly comprise sand and gravel, but include subsidiary beds of diamicton, silt and clay. The deposits were laid down on, under, or against glacier ice. Hummocky topography is characteristic and includes steep-sided ridges of gravel (eskers), flat-topped kame plateaux (often former deltas) and rounded hillocks of sand and gravel (kames), which were often deposited within ice-walled, water-filled chasms and enclaves. All ice-contact deposits are typically studded with kettleholes, and steep former ice-contact slopes are commonly recognisable. The kames and kame-plateaux are typically composed of coarsening-upward sandy deposits that formed as fan-deltas in ephemeral ice-marginal lakes. Most glaciofluvial deposits were laid down in an ice-marginal setting, but some esker deposits may have accumulated in tunnels beneath the ice some distance from the contemporary ice margin.

Glaciofluvial sheet deposits include sands and gravels underlying terraces and flat valley-floor spreads, together with some outwash fans and the more extensive kame terraces. The deposits were laid down by outwash streams proglacially and they generally become better-sorted and sandier away from the former ice front. The ‘sheet’ deposits are typically more gravelly and densely-packed than ice-contact deposits, also more uniform in composition and thickness (Plate 33). However, some spreads contain so many kettleholes locally that they are hummocky in appearance.

Plate 33 : Roadside section ME 292 [NN 6903 9503] in dense, very poorly sorted, clast-supported cobble gravel forming a glaciofluvial terrace in the valley of the River Truim. BGS Imagebase No. P543685.

Glaciofluvial fan deposits typically fine upwards and consist of very dense, very poorly sorted, silty, matrix-rich cobble-gravel, with subordinate lenses of sand and sandy gravelly diamicton. Branching distributary channels are commonly preserved on the surface of the features.

2.6.3.1 THE SPEY VALLEY AND GLEN TRUIM

The most widespread glaciofluvial deposits occur within the Spey Valley, where some deposits may be several tens of metres thick. Deposits lying on the north-western side of the valley around Newtonmore and Kingussie, and to the west of Loch Gynack, form kame terraces and benches that merge into moundy deposits. Deep kettleholes abound locally, as within Newtonmore. An esker extends south-westwards from Newtonmore, beside the A 86 road, towards thick, moundy deposits in the vicinity of Creagdhubh Lodge [NN 673 954]. Thick deposits occur on the southern side of the valley too, as around Nuide [NN 730 987] and Ralia Lodge [NN 713 976].

The valley of the River Truim was also a major route taken by glacial meltwater, as evidenced from a fragmentary esker on its western flank. The valley also contains fragmentary terraces that broaden out towards the confluence of the Truim and Spey. It is clear that meltwaters were at first diverted north-eastwards in the vicinity of the Falls of Truim, possibly when a large outlet glacier still occupied the upper Spey valley terminating in the vicinity of Ralia. These diverted meltwaters laid down a complex of eskers, mounds and terraces within the misfit valley that stretches from Etteridge towards Inverton [NN 745 993]. These moderately well-sorted deposits of glaciofluvial sand and gravel fan out and thicken towards the Spey Valley, between Milton of Nuide [NN 735 981] and the Ruthven Barracks, near Kingussie. The deposits are flanked by a spread of more poorly sorted, ice-marginal gravels that stretches to the north-east of Lùibleathann [NN 737 971]. Core taken through lacustrine deposits and kettlehole infillings in the vicinity of Loch Etteridge have provided an important record of late-glacial to Holocene vegetational, environmental and climatic change (Walker, 1993).

At an earlier stage in the deglaciation, meltwaters flowed through the valley occupied by Loch Cuaich [NN 695 878], where eskers are preserved to the north-east of the loch. Deposits lying within the Cuaich catchment have been described by Merritt (2004f).

2.6.3.2 GLEN TROMIE

Meltwaters also became concentrated within the valley of the River Tromie during ice-sheet deglaciation, laying down terraced spreads of cobble gravel, particularly in the vicinity of Bhran Cottage [NN 753 913]. Meltwater flowed from the south-west for a time, via cols to the north and south of Meall Chuaich, whilst western-sourced ice still occupied the Cuaich catchment. However, ice capping the Gaick plateau to the south was a more enduring source of meltwater. A very large outwash fan indeed was laid down at the mouth of the central breach, mostly on the eastern flank of Glen Tromie. The feature stands over 100 m above the valley floor and is apparently formed mainly of poorly-sorted, matrix-rich cobble gravel capped locally by boulders, blocks and slabs of micaceous psammite up to 0.4 m across. The gravel contains a relatively large proportion of pink granite, porphyry and felsite in addition to the ubiquitous micaceous psammite. The matrix of the deposit is yellowish brown, silty fine-grained sand with poorly developed lamination. The surface of the feature reaches about 545 m OD in the vicinity of Bruach Dhubh [NN 7675 8825], from which the fan has been named, and has been dissected by several distributary channels than fan out northwards from the apex of the feature at Glac nam Meirleach [NN 7650 8765]. The origin of the fan is probably quite complex, having been built up against the margin of Strathspey ice as it retreated westwards and parted from ice occupying the central Gaick (Merritt, 2004b).

A much smaller, lower-elevation outwash fan formed mostly of cobble gravel lies adjacent to the northern shore of Loch an t-Seilich. It is likely that the fan formed whilst a glacier of Loch

Lomond Stadial age occupied the loch basin and that the present cliffline is approximately situated at the former ice contact (Merritt, 2004b).

A large glaciofluvial outwash fan with branching distributary channels on its surface lies at the mouth of Glen Tromie. It apparently merges northwards into a moundy spread of glaciofluvial deposits on the southern flank of the Spey Valley, suggesting that they formed roughly contemporaneously when ice still occupied the latter valley. The large alluvial fan at the mouth of the Glen Tromie probably began to accumulate soon after ice retreated from the Spey Valley and meltwaters had dissected the higher, older fan.

2.6.3.3 GLEN FESHIE

Glaciofluvial terraces abound within the lower reaches of the valley of the River Feshie and Allt Fearnasdail, where they are associated with alluvial terraces at lower elevations, alluvial fans and debris cones. The valley is one of the most important sites in Britain for the study, interpretation and dating of such geomorphological features and of the processes of valley-floor development (see Werritty and McEwen, 1993 for summary). At least five periods of incision have occurred since ice-sheet deglaciation. Many of the terraces preserve distributary palaeochannels.

2.6.3.4 WHITE BRIDGE AND SOUTHERN GAICK

A large glaciofluvial fan lies at Chest of Dee [NO 015 884]. It was mostly laid down by meltwater emanating from Glen Dee, to the north-west, and partly from the valley of the Geldie Burn, to the west. Like most fans the feature is composed mainly of very dense, very poorly sorted, silty, sandy boulder gravel. Terraced spreads of glaciofluvial gravel of cobble to boulder grade occur upstream within Glen Dee, and downstream of White Bridge, commonly concealed beneath peat. Peat-covered terraces also floor the misfit valley of the Allt an-t Seilich, to the south.

A deposit of dense cobble-gravel containing pebbles of pink granite and psammite crops out from beneath till in the southern bank of the River Dee, 270 m downstream of White Bridge. This particular deposit has not been named, but elsewhere more-extensive units of sand and gravel underlying till to the south of the Gaick plateau have been assigned to the *Ceardaich Sand and Gravel Formation* (see lithostratigraphy above).

2.6.4 Glacioclacustrine Deposits

Fine-grained sand, silt and clay laid down in standing water form part of many coarsening upward, glaciofluvial (deltaic) sequences in the district, but it is generally impractical to map out these fine-grained deposits unless they are particularly widespread or form discrete units within glacigenic sequences. They may also occur as lenses within morainic deposits and till, for example, in upper Glen Feshie (Golledge, 2004, fig. 52). Mapped units are typically composed of stiff, pale yellowish brown clay interlaminated with silt and very fine-grained sand. Many deposits are varved (with annually-formed laminae) and contain dropstones.

Most deposits were laid down in ice-marginal, proglacial lakes that formed in the upper reaches of valleys whilst the lower reaches remained blocked by ice during ice-sheet deglaciation. For example, in the catchment of the Allt Cuaich there is a flat-lying area [NN 6767 8665], presumably a former lake basin, that is underlain by over 1.2 m of thinly interlaminated, silty fine-grained sand, silt and clay resting on stony diamicton. The basin is bounded by former shorelines to the east (Merritt, 2004f). Evidence of a temporary ice-dammed lake dammed by an ice lobe during deglaciation in Glen Luibeg, between the Lairig Ghru and Glen Derry, has been described by Golledge (2003). North-trending reverse faults and other glacitectonic structures evident in the laminated silt and sand accumulation reflect deformation resulting from oscillations of an ice margin to the south of the lake (Phillips et al., 2007). This glacier also appears to have supplied the majority of sediment that formed the northward-sloping deltaic feature in upper Glen Luibeg, (Golledge 2003).

An excellent section revealing >3.1 m of rhythmically laminated, fine-grained deposits was discovered beneath till during the recent survey in Coire Mhic-sith [NN 658 745] (Lukas and Merritt, 2004; Phillips et al., 2007). The glaciolacustrine unit (Plate 34) becomes increasingly compact, sheared and disturbed upwards, displaying overturned folds, some detached along thrusts towards the east (Plate 35). The sense of thrusting is towards the east, indicating that the ice that dammed the lake advanced from the Loch Garry basin to the west, probably during the Loch Lomond Readvance (Benn and Ballantyne, 2004).

The deposit in Coire Mhic-sith has not been named formally, but elsewhere more extensive, laminated, fine-grained units underlying till to the south of the Gaick plateau have been assigned to the *Linn of Pattack Silt Formation* (see lithostratigraphy above).

Plate 34 : Glacitectonised laminated silts and clays underlying till at the top of section ME 207 in Coire Mhic-sith [NN 658 745]. BGS Imagebase No. P551775.

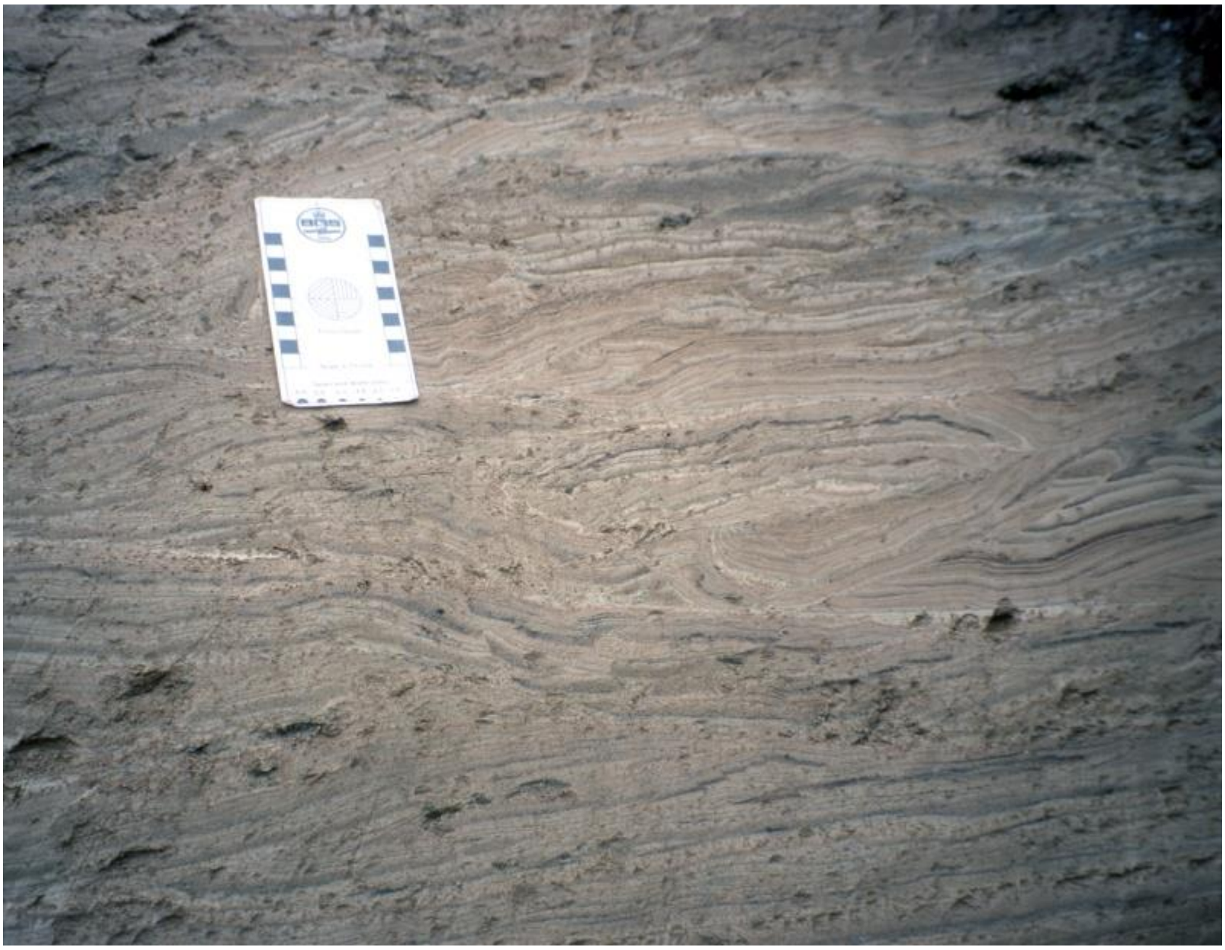

Plate 35 : Close-up of folded and faulted laminated silts and clays towards the top of the unit shown in previous figure. The sense of thrusting is toward the east (right) in this image. BGS Imagebase No. P551773.

2.6.5 Alluvial and Organic Deposits

The alluvial deposits in the district are of five types; (1) fluvial deposits underlying the floodplains and low-lying terraces of rivers, (2) lacustrine alluvium, (3) alluvial fans and (4) river terrace deposits. Organic deposits include peat and organic mud.

2.6.5.1 Alluvium

Gravelly alluvium underlies the floodplains and low-lying terraces of most rivers in the district, which are commonly bordered by steep, unstable bluffs up to 25 m high. Most streams are fast flowing and braided, with beds of cobble and boulder gravel, bifurcating channels and shifting linear bars of shingle. The river gravel is generally less than about 5 m thick, water-saturated, with subangular to well rounded, variably sorted clasts. Thicker deposits probably underlie stretches of some of the larger rivers, such as the Truim, Feshie and Dee. Tabular boulders exhibit a pronounced upstream-dipping imbrication. Unless streams have become engorged into bedrock they are prone to alter course periodically following flood events. Abandoned braid-bars soon become rough, boulder-strewn scrubland whilst abandoned channels become filled with sand and silt. Slower flowing stretches are associated with more sandy beds, wider floodplains and meander belts. Here riverbank sections commonly reveal clast-supported gravel (shingle) capped by ‘overbank’ deposits that accumulated during the waning stages of periodic flood events. The latter deposits consist of one or two metres of laminated, humic, micaceous, silty sand (loam), locally intercalated with peat.

The River Feshie is generally taken to be a textbook example of an upland stream and is one of the most studied in Scotland (see Werritty and McEwen, 1993 for summary of research).

The most extensive deposits of alluvium in the district are associated with the River Spey, the floodplain of which is about 1 km wide in the vicinity of Kingussie. The river bed is formed mainly of sand or subrounded to rounded gravel, but the floodplain is generally underlain by compressible, fine-grained 'overbank deposits' that are between 0.5 and 2.5 m thick. These deposits consist of yellowish brown, coarsely laminated, humic, micaceous, silty, sand (loam), locally intercalated and/or capped with organic mud and peat. Former meander channels and ox-bow lakes are filled with organic mud and peat, although the more modern features may have provided repositories for farm waste and other materials locally. Artificial levées have been constructed to help constrain flooding, which occurs regularly. The overbank deposits of the Spey are underlain by many metres of water-saturated sand and gravel commonly grading down into fine-grained sand and silt (see transect on Sheet 64W Superficial and Simplied Bedrock).

2.6.5.2 LACUSTRINE ALLUVIUM

Flat spreads of interbedded humic sand, silt and clay have been mapped adjacently to some bodies of water, such as Loch Gynack, but it has generally been impractical to distinguish between lacustrine alluvium and the alluvial 'overbank' deposits of streams flowing into lochs, such as on the southern side of Loch an t-Seilich, in the Gaick. Some lacustrine alluvium began to accumulate during late-glacial times, as for example, that associated with Loch Etteridge, where organic sediments preserve records of vegetational and climatic change that has occurred in the district since deglaciation (Walker, 1993). Gravelly lacustrine beach deposits have been mapped around Loch Einich.

2.6.5.3 RIVER TERRACE DEPOSITS

Dissected remnants of former floodplains flank the alluvium of many of rivers in the district. These form terraces that slope gently down-valley and are typically underlain by several metres of poorly stratified, clast-supported cobble gravel; many are capped by peat. Terrace aggradation occurred mainly during late-glacial and early Holocene times, associated with braided streams. The gravel is locally overlain by spreads of sand and silt up to about 2 m thick, laid down as 'overbank' deposits during the waning stages of periodic flood events. These fine-grained deposits are most widespread on the broad terraces of the major rivers, including the Spey, Truim and Feshie, where they produce well-drained, light sandy soils. The terraces of the River Feshie have been described by Werritty and McEwen (1993).

Most river terraces in the district are judged to have formed during ice-sheet deglaciation and consequently have been mapped as 'glaciofluvial sheet deposits'. These terraces contain kettleholes and commonly merge into spreads of moundy, ice-contact glaciofluvial deposits.

2.6.5.4 ALLUVIAL FAN DEPOSITS

Fans composed of very poorly sorted, matrix-rich gravel, silty sand and gravelly diamicton are common throughout the district where tributary streams with relatively steep gradients debouch onto flatter ground. The deposits were laid down by braided distributaries that migrated slowly across the fan surface, and during sheet flood events. Many of the features are now relatively inactive and have been partially dissected by drainage. General speaking, the rate of fan accumulation was greatest immediately following deglaciation from when it diminished exponentially for several thousand years 'paraglacially' (Ballantyne, 2002).

Many excellent examples of high-angle alluvial fans occur within the central breach of the Gaick (Merritt, 2004b) in and around the Cairngorms and in Glen Loch. There are few natural sections allowing fan deposits to be studied in detail, but exceptionally one occurs in the valley of the Edendon Water [NN 715 776], 1.3 km south of Stronphadruig Lodge, where a tributary stream has formed a small fan that has been dissected by the main river (Ballantyne and Whittington, 1999; Ballantyne, 2004a). Together with studies of several large fans and debris cones on the eastern flanks of the Feshie Valley (Werrity and McEwen, 1993), and within the Pass of

Drumochter (Ballantyne, 2004b), immediately to the east of the district, radiocarbon dating of organic layers indicates that the accumulation reflects a small number of extreme rainstorm-generated flood events rather than anthropogenic influences or long-term climate change.

Several large, relatively low-angle alluvial fans occur within the Spey Valley, including those at the mouths of the Truim and Tromie, and at Newtonmore and Kingussie. Another occurs at Cuaich, where the Allt Cuaich joins the valley of the River Truim. These features are likely to be formed of less coarse, better sorted sand and gravel than the steeper fans formed on mountainsides.

2.6.5.5 Peat

Most deposits of peat in the district comprise blanket upland accumulations of wet, acidic, partially decomposed vegetation, generally less than 2 m thick, but locally over 5 m. They are most widespread within topographical depressions, over the more poorly drained, gently undulating parts of the Gaick plateau, in the upper catchment of the River Feshie, and on the more extensive spreads of till. The hill peat is locally undergoing severe erosion, especially on the Gaick plateau to the west of the central breach (Morrocco, 2004).

2.6.6 Periglacial Deposits

A wide range of periglacial features and deposits occur across the district, but it is not possible to depict many of them on the maps. For example, ‘stone lobes’ are a characteristic feature of many slopes above about 750 m OD (Plate 36). These are lobe-shaped accumulations of boulders are typically up to a few tens of metres wide and up to 5 m or so high. Piedmont lobes commonly occur where several lobes have coalesced. The lobes are the washed-out, wind-deflated remnants of large gelifluction lobes that formed in the harsh periglacial conditions that prevailed in the district during ice-sheet deglaciation and during the Loch Lomond Stadial (Ballantyne and Harris, 1994; Ballantyne et al., 2009). The boulders were transported to the front of the lobes where they are now piled up following the subsequent removal of the original finer-grained matrix. The Cairngorms and the Gaick plateau are internationally important areas for the study of such phenomena, which include a gamut of ‘fossil’ late-glacial features together with smaller scale, active periglacial forms (Ballantyne, 1984, 1987). The particularly good range of phenomena occur within the Lairig Ghru, including fossil rock glaciers and protalus ramparts (see Gordon, 1993 for summary of research; Glasser and Bennett, 1996; Brazier et al., 1996)

Plate 36 : A stone lobe on the southern flank of Sròn na Faiceachan [NN 8182 7635]. BGS Imagebase No. P543657.

2.6.6.1 HEAD

Head deposits are poorly sorted and poorly stratified sediments that have mainly formed as a result of the slow, viscous, downslope flow of waterlogged soils (solifluction and gelifluction), soil creep and hillwash. Solifluction was most active whilst periglacial conditions pertained in the district during the latter part of the main Late Devensian glaciation and the Loch Lomond Stadial. It occurred during the summer months when the uppermost 0.5 to 1 m of the soil, the so-called 'active layer', thawed, whilst the ground below remained permanently frozen. The thickness and potential mobility of active layers depends very much upon the cohesiveness of the sediments affected, hence the thickest head deposits tend to occur where thoroughly decomposed rocks and clayey tills have been remobilised.

Most mapped deposits in the district are accumulations of angular, clast- or matrix-supported fragments of weathered rock with a matrix of silty sand. Much of the material is derived from frost-shattered rocks and mountaintop regolith. Most deposits are thinner than they appear to be, but thicken substantially on lower slopes. Deposits of head of this type are particularly widespread on the steep slopes of Glen Tilt, the Lairig Ghru and around the Gaick plateau, where they have been substantially reworked by debris flow processes. The widespread head deposits mapped in the Cairngorms are mostly composed of granite boulders and 'corestones' in a matrix of gritty, quartzo-feldspathic sand.

Some particular bouldery deposits (blockslopes) have been identified, for example, around Meall Chuaich and Beinn Dearg.

2.6.6.2 BLANKET HEAD (REGOLITH)

The category has been applied to sheets of *in-situ* or nearly *in-situ* weathering products lying on mountaintops, including disintegrated rock, rock fragments and mineral grains. It is commonly a compact, yellowish brown to orange, matrix- to clast-supported diamicton, formed of angular fragments of weathered rock in a silty sand matrix. Granular, non-cohesive, non-frost-susceptible deposits tend to accumulate over coarse-grained igneous rocks such as granite and psammite whereas mica-rich, clayey, cohesive, frost-susceptible deposits form on schistose rocks. The more massive psammites, quartzites and granites commonly break down into blockfields (see below). The granular regoliths are generally well drained and are typically covered by smooth, mossy turf, such as on the Gaick plateau (Morrocco, 2004).

A feature of regoliths is that gravel-sized clasts and larger fragments generally form a wind-deflated pavement at the surface, below which the material is finer grained. This vertical sorting is the result of frost churning, a process that is particularly effective in the more clayey regoliths (Ballantyne and Harris, 1994). Some frost churning takes place on mountaintops at the present day, but it was far more rigorous in past periglacial climates. Horizontal sorting has also occurred in favourable circumstances to produce 'patterned ground'. This generally takes the form of polygonal networks of erect stones with turf developed on finer materials at the centre of each polygon. The polygons commonly become elongated downslope and merge into 'stone stripes'.

Granular regolith derived from psammite and felsite is widespread across the Gaick plateau (Merritt, 2004f), where it forms a blanket 1 to 5 m thick. This gravelly deposit is relatively well drained and produces the grassy turf that provides important summer grazing on the plateau for red deer (Plate 22). More rubbly deposits (gelifractates) mantle some summits where the underlying rock is less decomposed. In general, thin deposits of till on the lower flanks of the plateau give way upslope to rubbly, frost-shattered rock at about the 575 m contour, where the mountainside steepens. The slopes become steeper about 100 m higher, where they are underlain by thin deposits of head on deeply weathered and broken psammite. Blanket head has been mapped above about 800 m where low solifluction lobes and turf-backed terracettes are commonly developed.

A unit of very compact, ferruginous, clast-supported diamicton resembling regolith crops out from beneath till within the deeply incised valley of the Fèith Gorm Ailleag [NN 8029 7984], to the south of the Gaick plateau. This unit (Ailleag Diamicton Member of the Pattack Till Formation) is probably a head deposit that predates the last regional glaciation of the area. The till, about 2 m thick, is overlain by orange-brown sandy gravel that contains sparse cobbles of grey granodiorite in addition to angular to subrounded clasts of local psammite and pink granitic vein rock. The gravel is about 20 m thick locally and quite widespread over the plateau surfaces of the eastern Gaick, where it thins away from the valleys towards the surrounding interfluves. It was probably formed as a result of sheet wash and debris flow processes redistributing weathered and decomposed psammitic bedrock, but is not delineated from blanket head.

2.6.6.3 BLOCKFIELDS AND BLOCKSLOPES

Blockfields are *in-situ* or nearly *in-situ* mountaintop accumulations of blocks produced by the frost shattering of underlying rocks. They are generally clast-supported, open-work and are rarely covered by soil. Blockfields have developed on many mountaintops in the Cairngorms, notably on Ben Macdui and Derry Cairngorm (Plate 13), in the eastern Gaick, such as on An Scarsoch, on Meall Chuaich (Merritt, 2004f) and on Carn an Righ (Figure 12).

The summit of Beinn Dearg is capped by a particularly extensive boulder-field (Merritt, 2004e) (Plate 37). It mainly occurs above about 900 m OD and rises to the main summit at 1008 m by way of several high, concentric ramparts. The rounded boulders constituting the feature are up to 3 m across and composed entirely of local pink, biotite-granite. The blockfield is divided into three segments by two narrow, shallow, WSW-ENE-trending depressions that may have been created originally as subglacial gouges. If so, the blockfield largely predates the last regional glaciation and invites comparison with the partially eroded blockfields and tors that occur on the Cairngorms (Hall and Glasser, 2003).

Plate 37 : Blockfield developed on pink biotite-granite on the main summit of Beinn Dearg [NN 853 778]. BGS Imagebase No. P543669.

2.6.6.4 SCREE

Scree, or talus, is typically a clast-supported accumulation of angular rock fragments derived from cliffs or steep rock slopes above by mechanical weathering. Scree deposits may be referred to as gelifractates, because most of the fragments have been dislodged by freeze-thaw processes. Actively accumulating screes are not common within the district, but there are many that are being reworked by debris flow processes during heavy rainfall and by snow avalanches, notably within the Lairig Ghru and Glen Tilt. The rate of scree accumulation was greatest immediately following deglaciation and during the Loch Lomond Stadial (Ballantyne, 2002). Particularly coarse screes occur on both sides of the valley of the River Tromie upstream of Glentromie Lodge, and overlooking Loch Cuaich. Other notable examples occur within the central breach of the Gaick plateau overlooking Loch an t-Seillich, Loch Bhrodain and Loch an Dùin (Merritt, 2004b).

2.6.6.5 TALUS CONE DEPOSITS

These deposits consist of steep, matrix-rich, cone-shaped accumulations of rock fragments at the foot of gullies or chutes that are steeper than those identified as alluvial fans. They are commonly associated with the reworking of screes and head deposits on very steep slopes across the district, but only the larger ones have been delineated. Debris cones are mainly formed catastrophically during heavy rainfall as a result of landslides that develop quickly downslope into debris flows; many cones are bounded by levées up to 2.5 m high (Ballantyne and Harris, 1994). Talus cones are particularly common on the steep slopes of Gleann Einich, the Lairig Ghru (Plate 38) and in the central breach of the Gaick plateau. Some cones in the Lairig Ghru are demonstrably the result of snow avalanches (Ballantyne, 1996).

Plate 38 : Talus cones in the Lairig Ghru in the vicinity of the Pools of Dee. BGS Imagebase No. P536315.

2.6.6.6 Rock glacier and protalus rampart deposits

These enigmatic deposits are very uncommon, but both are reported to occur within the district. Rock glacier deposits are thick, lobate or bench-like masses of interlocking, predominantly angular rock fragments on valley floors at the foot of, but separated from precipitous slopes by up to several hundred metres. They typically have steep bouldery margins with transverse ridges and deep, enclosed depressions akin to kettleholes. The origin of rock glaciers is controversial; some may result from the downslope creep and deformation of ice-rich talus in a periglacial environment, whereas others may result from rockfall onto glacier ice (Ballantyne and Harris, 1994). The former type of rock-glacier deposit has been identified in Coire Beanaidh [NH 956 007] (Ballantyne, 1996), in the Cairngorms, and possibly in Coire Cas-eagallach [NN 976 737] during the recent survey. Ballantyne et al. (2009), however, cast doubt on the identification of all rock glaciers in the region, concluding that most, if not all of them result from catastrophic rock falls that occurred shortly after deglaciation locally.

Protalus ramparts are ridges or ramps of predominantly coarse debris that accumulated at the foot of steep, talus covered slopes covered by perennial firn snow in a periglacial environment. They are commonly up to about 12 m high and 15 m broad, lying parallel to, but separated from the slope by about 12 m, and with accumulations of boulders on their proximal (upslope) sides (Ballantyne and Harris, 1994). Protalus ramparts have been identified at 650 m OD on Devil's Point [NN 978 947] and 940 m OD on Sròn na Lairige [NH 970 010] (Ballantyne, 1996), in the Cairngorms, and at 450-480 m OD on the slopes below Sron na h-lolaire (Golledge, 2004).

2.6.7 Landslide Deposits

Landslides are common within the central breach of the Gaick plateau and in the southern corner of the district around the Beinn a' Ghlo massif and adjoining mountains. As elsewhere in the Highlands, rock slope failure is principally a paraglacial response to glaciation and deglaciation involving stress relief and re-equilibration (Ballantyne, 2002; Jarman, 2007). Landslides are probably under-represented on the maps, because many are poorly developed and difficult to identify unambiguously. For example, antiscarps can be misidentified as ice-marginal glacial drainage channels. Furthermore, some landslides undoubtedly failed before the last glaciation and have been subsequently modified and masked by glacial deposits. Landslides have influenced the long-term landscape evolution of the region and they tend to cluster within relatively recently formed glacial breaches (Hall and Jarman, 2004; Jarman, 2007).

The landslides that occur within the Gaick have been described by Jarman (2004). A cluster of them occur around the remarkable hill of An Dún, west of Loch an Dúin. Other notable examples occur on buttresses to the west of Gaick Lodge and within the valley of the Allt Gharbh Ghaig, east of the lodge, where at [NN 776 820] there is a jumbled array of steep-sided, boulder-strewn, conical mounds (Merritt, 2004b). Tension cracks have been identified from air photographs on the flanks of Srón Bhuirich [NN 751 827] and A' Chaoirnich, to the south-west. These features rise and branch diagonally up the mountainside and are associated locally with 4 to 7 m wide benches and antiscarps (Plate 39), but with no evidence of sliding or bulging (Jarman, 2004). They are indicative of weak slope deformation and compression. Similar tension cracks have been identified to the east [NN 773 804], near Carn na Moine.

Plate 39 : Tension cracks and antiscarp benches on the steep slopes of A' Chaoirnich in the Gaick Pass. (Reproduced with the kind permission of D. Jarman)

Another cluster of landslides is associated with the Beinn a' Ghlo massif, especially within the steep sided valley of the Allt Fheannach; some may be more extensive than mapped by BGS (D. Jarman, written communication). A relatively recently formed tension crack [NN 9575 7450] was observed behind the main backscarp of one of these landslides. Yet another cluster occurs at the head of the valley of the Allt Fearnach, to the east of Glen Loch. A potentially major landslide was identified on air photos encompassing Dubh Chlais [NN 975 755], on the western flank of Glen Loch, but insufficient corroborating evidence has been found. The feature may instead represent a remnant of a knickpoint in a Cainozoic erosion surface that can be traced around the northern and eastern flanks of Beinn a' Ghlo at this general elevation (D. Jarman, written communication; Hall, 2004). It possibly represents an incipient corrie that was occupied by a niche glacier like several others that have been identified in the Gaick (Merritt, 2004a).

2.6.8 Features of Glacial Erosion

Evidence of glacial erosion on a large scale is ubiquitous in the district (Figure 8 and 9), including huge corries in the Cairngorms epitomised by Choire Etchachan (Gordon, 1993, 2001), deep glacial breaches such as the Lairig Ghru, the Gaick Pass and one occupied by Loch Cuaich, and enormous 'U-shaped' valleys, including Glen Dee, in the Cairngorms, and Cama' Choire, to the west of the Gaick Pass. Massive glaciated rock walls are a feature of Gleann Einich, Stob Coire Etchachan and The Devil's Point, providing some of the toughest rock climbing in Scotland. Other large-scale evidence includes severely ice smoothed, plucked and mamillated rocks on the western side of the Spey Valley overlooking Newtonmore and Kingussie, and the mega- roche moutonnée features of Creagan a' Choin (Plate 23) and Ordan Shios, south of Newtonmore, which have tails of drift stretching in the former up-ice direction. Evidence on a small scale takes the form of ice-scratched rock surfaces (glacial striae) and glacially-smoothed, whaleback-shaped crags, some with ice-plucked ends facing in the former direction of ice movement (roches moutonées). The most commonly observed indicator erratics are large boulders of white porphyritic granodiorite from the Strath Ossian Granodiorite Pluton lying to the west of the district.

2.6.9 Features of Glaciofluvial Erosion

2.6.9.1 GLACIAL MELTWATER CHANNELS

Channels cut by glacial meltwaters are very common throughout the district. Three broad genetic types of channel have been recognised: subglacial channels, ice-marginal channels and proglacial spillways. Although the best examples of each type are distinctive, most channel systems formed time-transgressively, causing distinctions between them to become blurred. Furthermore, many of the larger ones probably have a long and complicated history spanning more than one glaciation.

Subglacial, ice-directed channels

Channels of this type formed whilst most of the district remained buried beneath ice. Subglacial meltwaters were constrained by the regional hydraulic gradient to flow parallel to the regional direction of ice movement, irrespective of the local subglacial topography. Meltwaters flowed uphill in places (as in a syphon) within subglacial channels, giving them their characteristic 'up and down' long profiles. They are most commonly preserved in cols cutting across topographic barriers lying at an oblique angle to the former direction of ice movement. The channels commonly begin at the crests of such barriers and spurs where the hydraulic gradient and discharge was greatest. Many ice-directed channels are to be found on the north-eastern sides of major protuberances in the north-western of the district.

Ice-marginal channel systems

Complex networks of shallow, 1-5 m deep, arcuate channels are encountered across most of the district. They are interpreted here to have been eroded by meltwater at, or closely within the margins of receding, typically cold-based, subpolar ice sheets or outlet glaciers (Benn and Evans, 1998). They are characteristically curved or crescentic in plan view, asymmetric in cross profile, and commonly occur in anastomosing flights across hillsides, where higher channels truncate, or feed into, lower ones, indicating that they formed progressively as the ice margin retreated. Some shallow gradient channels pass into steeper submarginal 'chutes' and *vice versa*. Many occur as benches on steeper slopes (one-sided channels) or as isolated flights of short channels that loop into the hillside ('in-out-channels').

The channels are commonly intimately associated with ice-marginal moraine ridges. Taken together, these arcuate features provide a record of glacial recession across the district. They are generally most pronounced on ground that sloped towards the receding ice margin, notably along the eastern slopes of the valley of the River Feshie downstream of Glenfeshie Lodge (Werritty and McEwen, 1993), the eastern slopes of Gleann Chomhraig and the valley of the Allt an Dubh-chadha (Golledge, 2000) (Figure 17), to the west of Glenfeshie Lodge, and on the north-western flanks of the Gaick plateau (Merritt, 2004f). An excellent suite of meltwater channels incised into bedrock occurs on the southern slopes of Glen Luibeg, most probably marking a stillstand position of the Luibeg glacier following its separation from the Derry Glacier during ice-sheet deglaciation.

Ice-marginal channels are intimately associated with the distinct suite of morainic deposits that are assigned to the Gaick plateau Moraine Formation. These occur on the Gaick plateau, particularly within the eastern Gaick, where they record the decay of the ice concentrically toward the upper reaches of the valleys of the Tarf Water and Bruar Water (Merritt, 2004e) (Plate 24).

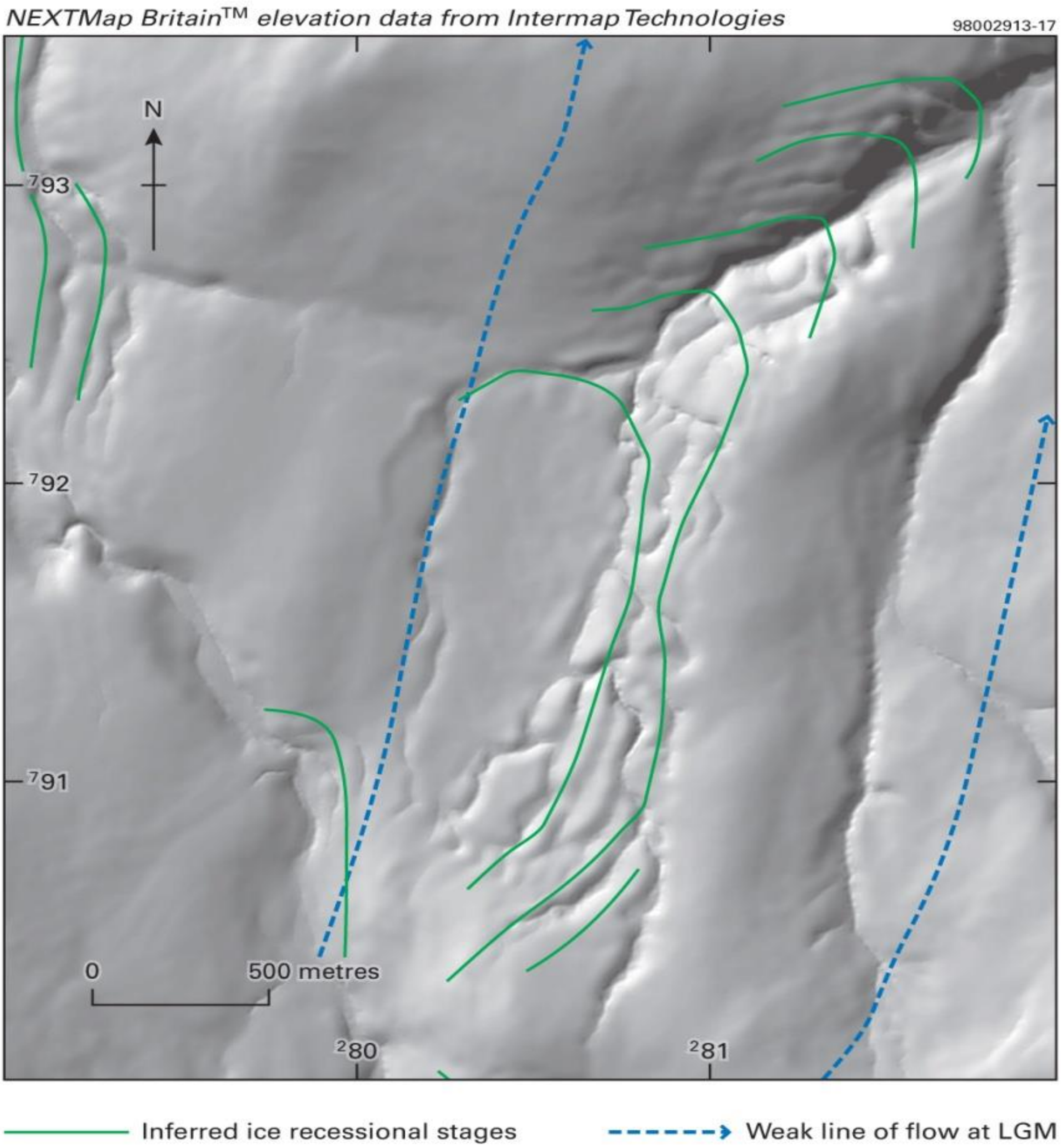

Figure 17 : Hillshaded Digital Elevation Model of ice-marginal channels in the valley of the Allt an Dubh-chadha showing inferred ice recessional stages and reconstruction of ice flow at the LGM.

Proglacial spillways and glacial lake shorelines

In contrast to the subglacial and ice-marginal drainage channels described above, proglacial spillways generally have regular longitudinal profiles. When cut into bedrock, they also typically have a pronounced V-shaped cross-section, and interlocking spurs. Many formed as 'overflow' channels when major drainage routes became blocked by ice and the resulting ice-dammed lakes drained across cols. This situation occurred in Coire Mhic-sith, in the south-west corner of the district, where a set of such features (Glas Mheall Spillways) cut across the col [NN 676 764] at 787 m OD lying between Coire Mhic-sith and the valley to the south-east (Lukas and Merritt, 2004). The spillways connect with a well-defined lake shoreline. Other possible shorelines occur in flights on the south-eastern side of Coire Mhic-sith [NN 669 760], below Glas Mheall Beag, and on the opposite spur of Meall Uaine [NN 664 763]. The benches are between 1 and 3 m wide and cut mostly into bedrock. The near-horizontal bedding would have favoured the formation of lake shorelines, particularly by the process of ice riving (*cf.* Dawson, 1980), and it has probably contributed to their conservation. Bench features that may also represent former shorelines occur on the eastern side of the valley of the Allt Dearg [NN 758 775], south of the Gaick plateau, but no associated spillway was identified.

Concealed channels

Concealed channels are likely to be common in the district, but they are generally only discovered from site investigations, as for example, in upper Glen Tromie. Tunnelling operations revealed concealed channels on either side of the present river at its outlet from Loch an t-Seilich. The base of the channel to the west lies beneath 76 m of glacigenic sediment, the channel to the east beneath 46 m. The tunnelling encountered cavities within the glacigenic deposits up to 27 m from the surface that possibly formed after the slow melting of blocks of ice originally buried within the sediment (Anderson, 1951).

3 Applied Geology

3.1 MINERAL RESOURCES, QUARRYING AND MINING

3.1.1 Mineralisation

Presently the Newtonmore–Ben Macdui district has not produced any significant economic minerals and no indications of economic metalliferous mineral deposits were found during the latest survey. The following description summarises the results of geochemical sampling and mineral collecting in this area.

The Cairngorm granite has primary magmatic characteristics similar to Sn-U granites (Plant et al., 1980: Plant et al., 1990) however, its emplacement into essentially dry crystalline basement rocks has inhibited the generation of water-rock interaction necessary to induce extensive metalliferous mineralisation. Late-stage pegmatitic and hydrothermal fluids produced veins of quartz and mineralised pegmatites with miarolitic vugs including the semiprecious smoky 'Cairngorm' quartz, beryl, K-feldspar, muscovite (p. 65 of Barrow et al., 1913, p 85 of Highton, 1999). In the past a thick vein of high-quality quartz has been quarried to the south-west of Carn na Caim, near [NN 659 803], and several other, similar quartz veins are known in the vicinity.

Minor accessory minerals such as garnet, topaz and uraninite are reported from the Cairngorm Granite (Harrison, 1988) as well as the rare minerals, bertrandite, genthelvite (Highton, 1999) and phenakite (Livingstone, 2002). Elsewhere in the Dalradian outcrop, the Argyll Group and particularly the Ben Eagach Schist Formation has been found to host sedimentary exhalative mineralisation in the form of stratabound Zn-Pb-Ba sulphates, silicates and sulphides (Colman and Cooper, 2000). Equivalent lithostratigraphical units crop out in the south-east part of the Ben Macdui area but no mineral potential has been identified to date.

Geochemical anomalies over the Cairngorm Pluton are evident in the regional geochemical atlas of the East Grampians (British Geological Survey, 1991) with Be, Li, and Sn anomalies over the Cairngorm Pluton and locally Mo. Radio-active elements such as U and Rb are also high over the pluton. The granite is enriched in Yttrium and heavy rare-earth elements.

Minor Zn, Pb and Cu anomalies occur along Glen Tilt. Stream sediments over the Glen Tilt and Glen Derry diorites have local Cr values over 500 ppm and lesser Ni anomalies (British Geological Survey, 1991). They also have high Sr anomalies particularly compared to the Cairngorm granite, which correlates well with the whole-rock values (British Geological Survey, 1991). Stream sediments around the Glen Tilt Pluton have local silver anomalies (British Geological Survey, 1991). North-east of the Glen Tilt Pluton a local stream-sediment anomaly of >2 % Mn associated with high Zn values is attributed to secondary enrichment.

3.1.2 Road stone, building stone, sand and gravel, clay

Greenish grey and white mottled marble was in the past exploited from the Glen Banvie Formation along Glen Tilt (near Marble Lodge on Sheet 55E) and attractive examples can be seen in nearby Blair Castle. Thin marbles occur in the same formation near Forest Lodge but quantities are limited and imperfections, such as minor sulphides in the rock, together with difficulties in transport make it an uneconomic prospect.

3.1.3 Peat

Peat deposits cover much of the Gaick plateau but few deposits are more than 1 m in thickness. Extraction has occurred in the past for fuel in domestic consumption (Barrow et al., 1913). The most accessible peat mosses are south of the Spey near Newtonmore and along Glen Banchor at Dalballoch, and between Insh and Killiehuntly at the foot of Glen Tromie. Smaller areas occur near Loch Etteridge and west of Crubenmore. In some valley bottoms such as Glen Feshie, there are 2-3 metres of peat, but generally over the hills and forests of Gaick and Atholl, peat is less accessible and locally eroded into hags. Commercial exploitation is unlikely and much of the area is under conservation.

3.2 GROUNDWATER/AQUIFERS

Supplies of good quality, potable water can be found in many parts of the district from surface sources. Water analyses carried out during a regional stream sediment sampling programme (British Geological Survey, 1991) of the East Grampians, found high acidity waters over the Cairngorm and Glen Tilt granites, extending westwards onto the Gaick Psammite Formation. This is probably the effect of blanket peat on the Gaick plateau as areas of similar bedrock have low acidity to the north and south at lower altitudes. The stream waters also have very low conductivity (up to 15 microsiemens) over the Cairngorm granite and low values (15-31 microsiemens) extend south across the Gaick to the Glen Tilt Pluton. The association of high acidity and low conductivity waters is characteristic of upland, peat-bog environments. Levels of bicarbonate in stream waters are also low over the Cairngorm-Glen Tilt area and fluoride is low over the Glen Tilt and Gaick areas rising towards the Cairngorm granite. In this case the increase in fluoride may relate to the enrichment in the element accompanying the magmatism of the Cairngorm Pluton.

Groundwater occurs in most rock formations but the amount of water available depends largely on the rock type and the frequency of fissures and joints within 100 m of rockhead. This is because much of the groundwater movement occurs within cracks and joints in the near-surface weathered zone. Faulted zones in metamorphic bedrock, such as along the Glen Truim Fault, are potential targets.

There is good potential for abstracting groundwater from the gravelly alluvium in the Spey valley for local consumption. A few farms have developed wells in the alluvium of the Spey and Tromie valleys. Currently much of the water used in the area (c. 6 million litres per day) is taken from Loch Einich. This supply cannot satisfy public water demand at certain times and lies within an environmental sensitive area where augmentation schemes are not acceptable. Scottish Water is in the process of developing the aquifer in the gravels below the Spey valley. Water will be abstracted from a network of 60 boreholes penetrating to an average depth of 50 m but the aquifer may extend to depths of 85 to 100 m before reaching bedrock. This network could provide an average of 9 million litres per day to the area stretching from Cromdale in the north to Newtonmore in the south. Alternative schemes involving direct abstraction from the River Spey or an infiltration gallery on the river bank are also being considered.

There may be potential for more supplies of water from surface reservoirs either for public use or hydro-electric schemes. At present the Cuaich hydro-electric scheme in Glen Truim, which feeds into the larger Loch Tummel Scheme, takes water westwards from Loch an t-Seilach via a tunnel to Loch Cuaich and then from the 2.5 MW Cuaich Power Station along an aqueduct to Loch Ericht. This scheme was developed in the 1940s/1950s and there may be scope to upgrade the scheme in the search for additional sustainable supplies of energy. Other sites which might be considered include Loch Gynack, Loch an Duin and tributaries to Glen Tilt.

3.3 GEOLOGY, PLANNING, HAZARDS AND HERITAGE

Geological assessments play an important role in planning land-use development. With the increasing demand to manage developments and their visual impact, knowledge of the geological environment is required in planning. Other factors to be considered are the potential mineral resources available and the types of geological hazards likely to be encountered in the area. There is a growing awareness of the value of geological heritage and geodiversity in the rock outcrops and landscape, not only in the geological community but in the fields of education, recreation and tourism. These interests need to be balanced against the continuing need for the provision of land for housing, commercial, industrial, waste disposal and mineral extraction.

No minerals are currently being exploited in the Ben Macdui and Newtonmore districts, although there may be potential for hardrock quarrying. Rock, till and sand and gravel generally provide sound foundation conditions below the weathered zone. Poor foundation conditions can be caused by surface deposits such as peat, clay and silt, alluvial deposits, slipped ground, scree and landfill. Where peat and soft clay are buried they can give rise to variably compressible ground and waterlogged silt and fine sand may become liquefied so all these deposits require careful site investigation.

Potential for landslip and rockfalls should be considered in future developments. The stability of superficial deposits on steep slopes may be affected by loading, saturation, natural undermining by meandering rivers and/or excavation. These processes make them susceptible to minor landslip and debris flow. The stability of bedrock in cliffs and steep-sided excavations may depend on its resistance to weathering and the presence of joints, faults and inclined foliations Movement on such planar features may give rise to rockfalls as well as landslips.

Former quarries and sand and gravel workings may have affected the local water drainage and this factor should be considered if the sites are used for landfill. Landraise, in which natural hollows and valleys are infilled, would also be possible in these districts.

Man-made (or artificial) ground includes tips of waste rock near former quarries, landfill, and both railway and road embankments. Worked ground is mapped where excavations have been made in the original ground surface; this category includes quarries and cuttings for road and rail. Where excavations have been backfilled, the ground is designated as ‘infilled ground’.

3.3.1 Geological Heritage and Geodiversity

Areas such as the Cairngorms and Glen Tilt include classic Geological Conservation Review sites (GCRs) of which the most celebrated is Hutton’s locality near Forest Lodge (Stephenson, 1999). This historical site is known worldwide as a locality where Hutton (1794) demonstrated that granitic magma intruded metasedimentary strata. A full geodiversity audit of the Cairngorm National Park as a whole has been made recently (Barron et al., 2012a) together with a landscape assessment (Barron et al., 2012b).

There are several Quaternary GCRs in the Cairngorms (Gordon, 1993; Werrity and McEwen, 1993). Within the Cairngorms, the range of pre-glacial, glacial, glacio-fluvial and periglacial features makes it an outstanding area for geomorphological and environmental study (Shaw and Thompson, 2006; Kirkbride and Gordon, 2010). Loch Etteridge (Walker, 1993), south of Newtonmore, lies in an ice hollow that has preserved organic lake sediment important in dating late Quaternary history. Glen Feshie contains an outstanding assemblage of valley-floor and valley-slope landforms and deposits formed during late Glacial to Holocene times.

All GCR sites have been notified as Sites of Special Scientific Interest (SSSI), which are the responsibility of Scottish Natural Heritage, Battleby Redgorton, Perth, PH1 3EW.

Hill walking and climbing are common activities in the Cairngorms. Harveys have recently produced a Cairngorms map at 1:40 000 in their British Mountain Map series, which includes a geological map and description of the geology. However, the potential for geotourism has hardly been tapped.

4 Information Sources

Further geological information held by the British Geological Survey relevant to the Newtonmore and Ben Macdui districts is listed below. Searches of indexes to some of the collections can be made on the Geoscience Data Index in BGS libraries and on the BGS website at http://www.bgs.ac.uk.

4.1 BGS MAPS

1:625 000

Bedrock geology of the UK: North Map, 2007; Quaternary geology: North sheet 1977

1:250 000

57N 06W Great Glen, Solid Geology 1989; 57N 04W Moray Buchan, Solid Geology 1977;

56N 04W Tay Forth, Solid Geology 1986; 56N 06W Argyll, Solid Geology 1987

1:63 360

Original Geological Survey: Geological Survey of Great Britain (Scotland) 1" to 1 mile Sheet 64 (Kingussie) Solid and Drift, 1913

Adjacent 1"sheets (facsimile only) 73, 74, 75, 63, 65, 54, 55, 56

1:50 000

64W Newtonmore 2008 Bedrock; Bedrock and Superficial Deposits

64E Ben Macdui 2008 Bedrock; Bedrock and Superficial Deposits

ADJACENT SHEETS

54E Loch Rannoch, Solid & Drift, 1974; 55E Pitlochry Solid, 1981; 55W Schiehallion, Solid, 2001; 56W Glen Shee, Solid, 2000; 63E Dalwhinnie, Solid, 2000; Solid & Drift, 2002; 73E Foyers, Solid, 1996; 74W Tomatin, Bedrock; Bedrock and Superficial, 2004; 74E Aviemore, Solid, 1993; Superficial, 2012; 75W Glenlivet, Solid, 1996; 65W Braemar, Solid, 1989

Details of the original geological surveys are listed on editions of the 1:63 360 and 1:50 000 Series geological sheets. Copies of the fair-drawn maps of these earlier surveys may be consulted at the BGS Library, Edinburgh.

MAPS ON 64E BEN MACDUI SHEET

Original (Old Series) 1:10 560 maps

Perthshire 5, 6, 7, 12, 13, 14

Aberdeenshire 76, 77, 87, 88, 96, 97, 104

Inverness-shire 88, 89, 103, 104, 118, 119, 133

Banffshire 47

The most recent bedrock maps at 1:10 000 and 1:25 000 scale covering the 1:50 000 Series Sheet 64E are listed below, together with the map name, surveyor's initials and dates of the survey. The surveyors were B Beddoe-Stephens, A J Highton, S Robertson, C G Smith, M Smith, R A Smith, D Stephenson, M Krabbendam, A G Leslie, A Crane, and S Goodman. The maps are published for sale or are available for consultation at BGS libraries in Keyworth and Edinburgh and the BGS London Information Office.

1:10 000

NN97NW Carn a' Chlamain BB-S, DS 1992-96

NN97NE Upper Glen Tilt DS, BB-S 1990-96

NN97SW Forest Lodge DS, BB-S, RAS 1974-95

NN97SE part Glen Loch DS, RAS, AGL 1974-96

NO07NW Carn an Righ DS, AGL, AC, SG, MK 1990-96

NO07SW Daldhu DS, SG, AGL, AC 1990-92

NO08NW part, Chest of Dee DS, CGS, AJH 1993-99

NO08SW part, Carn Bhac DS 1990-96

1:25 000

Other relevant data including that on 1:10k sheets (bedrock) have been compiled on the following 1:25 000 scale clean copies:-

Part of NH80/90 and NJ00/10 on northern Cairngorm Leisure map

Part of NN89/99 and NO09/19 on southern Cairngorm Leisure map

Part of NN88/98 Upper Glen Feshie

Part of NN87/97 Upper Glen Tilt

MAPS ON 64W NEWTONMORE SHEET

The most recent bedrock maps at the 1:10 000 and 1:25 000 scale covering the 1:50 000 Series Sheet 64W are listed below together with the sheet name, surveyor's initials and dates of the survey. The surveyors were J E Cavill, T P Fletcher, A J Highton, M Krabbendam, A G Leslie, S Robertson, M Smith, R A Smith.

1:10 000

NH60SE A'Chaileach JEC, MS 1992-97

NH70SW Loch Gynack MS, RAS 1995-97

NH70SE Kingussie MS, RAS 1997-2004

NH80SW Loch Insch MS 1995-96

NN69NE Glen Banchor JEC, AJH, SR 1992-97

NN69SE Crubenmore SR, RAS 1997-2002

1:25 000

NN79 Glen Tromie MK, AGL 2002, with 1:10k parts TPF, AJH 1990-97

NN89 (part) Glen Feshie MK, AGL 2002

NN68 (part) Allt Cuaich MK, AGL 2002

NN78 Gaick Forest MK, AGL 2002

NN88 (part) An Eilrig MK, AGL 2002

NN67 (part) Dalnacardoch Forest MK, AGL 2002

NN77 (part) Dalnamein Forest MK, AGL 2002

NN87 (part) Bruar Water MK, AGL 2002

Digital geological map data

In addition to the printed publications noted above, many BGS maps are available in digital form, which allows the geological information to be used in GIS applications. These data must be licensed for use. Details are available from the Intellectual Property Rights Manager at BGS Keyworth. The main data sets are: DiGMapGB-625; DiGMapGB-250; DiGMapGB-50 and DiGMapGB-10

The current availability of theses can be checked on the BGS website at http://www.bgs.ac.uk/products/digitalmaps/digmap.html

Geophysical maps

1:1 500 000

Colour shaded relief gravity anomaly map of Britain, Ireland and adjacent areas, 1997.

Colour shaded relief magnetic anomaly map of Britain, Ireland and adjacent areas, 1998.

1:250 000

Gravity and Magnetic maps corresponding to the 1:250 000 UK and Continental Shelf Areas (UTM Series) are available.

CD-Rom packages and plot-on-demand maps are also held which summarise graphically the publicly available geophysical information held by BGS for the sheets.

Regional geochemical atlases

1:250 000

East Grampian area 1991; Argyll 1990; Great Glen 1987

Hydrogeological maps

1:625 000

Sheet 18 (Scotland) 1988

Groundwater vulnerablity map of Scotland. 1995

4.2 BGS BOOKS

Memoirs and other books or reports relevant to the Newtonmore-Ben Macdui district are arranged by topic. Most are not widely available, but may be consulted at BGS and other libraries.

British regional geology

Stephenson, D and Gould, D. 1995. *British regional geology: the Grampian Highlands* (4th edition). London: HMSO for the British Geological Survey.)

Memoirs and sheet explanations (out of print)

Explanation of Sheet 64. The geology of Upper Strathspey, Gaick and the Forest of Atholl. 1913.

Explanation of Sheet 74. The geology of mid-Strathspey and Strathdearn. 1915.

Explanation of Sheet 75. The geology of West Aberdeenshire, Banffshire, parts of Elgin and Inverness. 1896.

Explanation of Sheet 65. The geology of the districts of Braemar, Ballater and Glen Clova. 1912.

Explanation of Sheet 55. The geology of the country round Blair Atholl, Pitlochry and Aberfeldy. 1905.

Explanation of Sheet 54. The geology of Corrour and the Moor of Rannoch. 1923.

Solid geology of the Schiehallion district (Sheet 55W), 2000

Geology of the Glen Shee district (Sheet 56W), 2002

Geology of the Glen Roy district (Sheet 63W), 1997

Geology of the Ballater district (Sheet 65E), 2002

Solid geology of the Aviemore district (Sheet 74E), 1999

4.3 BGS DOCUMENTARY COLLECTIONS

Borehole record collection

BGS holds records of boreholes which can be consulted at BGS, Edinburgh, where copies of some records may be purchased. For the Newtonmore-Ben Macdui district the collection consists mainly of sites and logs close to the A9 road. Index information, which includes site references, for these boreholes has been digitised. The logs are either hand-written or typed and many of the older records are drillers logs.

Site exploration reports

This collection consists of records of site explorations carried out to investigate foundation conditions prior to construction. There is a digested index and the reports themselves have been digitally scanned or are on microfiche. For the Newtonmore-Ben Macdui district most investigations are in the vicinity of the A9.

Hydrogeological data

Records of a few water bores in the Spey and Tromie valleys are held at BGS, Edinburgh.

Geochemical data

Records of stream-sediment and other analyses are held at BGS, Keyworth.

Gravity and magnetic data

Records are held at BGS, Keyworth

Seismic data

Records of British earthquakes are held at BGS, Edinburgh.

4.4 BGS MATERIAL COLLECTIONS

BGS Photographs

Some 491 photographs illustrating aspects of the geology of the Newtonmore and Ben Macdui districts are deposited for reference at BGS libraries in Keyworth and Edinburgh, and in the BGS Information Office, London. They are also held digitally in a BGS Geoscience Imagebase. The photographs were taken at various times since the 1890s and depict mainly the geomorphology and Quaternary deposits. A list of titles can be supplied on request. Images can be supplied in a number of formats at various prices from the Photographic Department, BGS, Edinburgh.

Petrological collections

The petrological collections for the Newtonmore and Ben Macdui districts consist of hand specimens and thin sections. Many of the samples and thin sections are of the igneous rocks, but the metasedimentary rocks are also well represented. Information on databases of rock samples, thin sections and geochemical analyses can be obtained from the Mineralogy and Petrology Section, BGS, Edinburgh. Currently there are 537 samples in the BGS Britrocks database for Sheet 64 (excluding samples from the original survey).

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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