British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The Borrowdale Volcanic Group and related geology on 1:10 000 sheets NY31NE and NY41NW

Part of the 1:50,000 Sheet 29 (Keswick) and Sheet 30 (Appleby)

Lands and Resources

Internal Report IR/02/175

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/175

The Borrowdale Volcanic Group and related geology on 1:10 000 sheets NY31NE and NY41NW

Part of the 1:50,000 Sheets 29 (Keswick) and 30 (Appleby)

S C Loughlin

Key words

Cumbria, Greenside Mine, Ordovician, Borrowdale Volcanic Group

Bibliographical reference

LOUGHLIN, S. C. .2002..The Borrowdale Volcanic Group and related geology on 1:10,000 sheets NY31NE and NY41NW. *British Geological Survey Internal Report*,. IR/02/175, 29pp.

Keyworth, Nottingham British Geological Survey 2002

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham and Edinburgh; see contact details below or shop online at www.thebgs.co.uk

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

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

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

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

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.thebgs.co.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

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

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

☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

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

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS

☎ 028-9066 6595 Fax 028-9066 2835

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

☎ 01491-838800 Fax 01491-692345

Parent Body

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

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

Foreword

This report is the published product of a study by the British Geological Survey (BGS) carried out in the summer of 1996 as part of the Lake District Regional Geological Survey. This work benefited from discussion in the field with Derek Woodhall and Dave Millward.

Acknowledgements

Discussions with Derek Woodhall, Dave Millward and Phil Stone were helpful in the production of map sheet NY31NE and this report.

Notes

All grid references are within 100km square NY.

The term 'district' refers to the area mapped and described in this report.

Contents

FIGURES

Summary

This report describes the Borrowdale Volcanic Group, the Skiddaw Group, intrusive rocks and Quaternary deposits that crop out on 1:10,000 Sheet NY31NE (Glenridding) and part of Sheet NY41NW (Martindale). In addition, the structure of the area and mineralisation are also discussed.

An inlier of Skiddaw Group rocks crops out around Glencoyne Farm and Glencoyne Park. The Skiddaw Group exposures comprise dark grey, parallel-laminated mudstones, siltstones and fine-grained sandstones. They are crystal-rich with abundant muscovite and altered ferromagnesian minerals which may represent a volcanogenic component. The high degree of sorting and thin laminae have been interpreted as indicative of reworking and redeposition by turbidity currents.

The Birker Fell Formation is in contact with the Skiddaw Group in the northern part of the area, but the contact is not exposed. Though previously considered to be a thrust contact, more recent evidence suggests that the contact is interpreted better as a set of subvertical normal faults.

The Birker Fell Formation crops out in the northern part of the area and is also exposed to the east of Ullswater. It reaches a maximum thickness of about 1200m in the central part of the sheet (Glencoyne Head/Sheffield Pike) and also to the east on Patterdale Common. The northern area comprises a substantial thickness of autobrecciated basaltic andesite, andesite and dacite sheets with thin interbedded volcaniclastic sandstones or tuffs sparsely present. Most of these sheets are thought to be lavas but it is quite possible that some are intrusive and have gone unrecognised. In the eastern part of the area a succession of basaltic andesite, andesite and dacite sheets are overlain by a considerable thickness of volcaniclastic sandstone and andesitic to dacitic tuff and lapilli-tuff.

The Lincomb Tarns Formation comprises eutaxitic to parataxitic dacitic tuff with local accumulations of garnet. This formation is steeply faulted against the Birker Fell Formation along the major, roughly E–W trending Birkhouse Moor Fault. To the north of the fault there are small fault-bound blocks of Lincomb Tarns Formation within the Birker Fell Formation.

A successsion of volcaniclastic sedimentary rocks including bedded sandstones and siltstones, massive coarse sandstones and massive conglomeratic sandstones overlies the Lincomb Tarns Formation. These are assigned to the Esk Pike Formation.

A thick and laterally extensive flow-banded dacite lava, thought to be coeval with the Middle Dodd Dacite, overlies the Esk Pike Formation. The lava varies slightly in thickness and is locally autobrecciated. It contains sparse feldspar crystals and is locally overlain by a feldspar crystal-rich dacitic lava.

A substantial thickness of andesitic lapilli-tuff and lithic lapilli-tuff known as the Helvellyn Formation overlies the dacite. This formation is dominated by thin units of lapilli-rich tuff and lithic-rich tuff. Locally, especially in the lower part of the formation, large feldspar-phyric andesitic fiamme are present.

The Deepdale Formation is a further successsion of volcaniclastic sedimentary rocks which overlies the Helvellyn Formation and has a similar appearance to the Esk Pike and Seathwaite Fell formations. Bedded volcaniclastic sandstone, massive sandstone and conglomeratic sandstone are intercalated with andesitic/dacitic tuff and lapilli-tuff. Penecontemporaneous shallow-level intrusive andesite sheets typically follow the fine-grained dacitic tuff units, although they are locally transgressive.

A distinctive quartz-phyric microgranitic dyke thought to belong to the Armboth-Helvellyn Suite crops out in the northern part of the area. The dyke has a dog-leg shape following both E–W and N–S faults. The presence of this dyke was critical to the development of past economic ore shoots exploited and developed at the Greenside Mine.

The area is dominated by major E–W normal and/or strike-slip faults. The Birkhouse Moor Fault downthrows the upper parts of the Borrowdale Volcanic Group succession against the Birker Fell Formation to the north. This major fault is the northern margin of a substantial fault-bound depositional basin. South of the Birkhouse Moor Fault, the basin succession is displaced by major NNE-trending faults. Thickness and facies variations across these faults implies that they were syn-depositional. A syn-volcanic fault on Catstye Cam marks the abrupt western limit of the dacite lava. The Birker Fell Formation in the northern part of the area is transected by a major E-W trending fault zone which truncates several N–S trending faults. The Greenside lead vein occurs along one of these N–S structures and ore shoots developed mainly along the steeper parts of the vein. The vein contains an assemblage of galena, sphalerite and minor chalcopyrite and silver and is considered to belong to the Early Carboniferous Suite of the Lake District.
This area is extensively glaciated with abundant glacial and alluvial deposits. Hummocky deposits of the Loch Lomond interstadial are ubiquitous in the upper corries. Peat cover is also extensive on some higher slopes. The Greenside Mine has generated large volumes of mine waste that are piled up in a series of platforms in Glenridding valley.

1. Introduction

This report describes the geology of the 1:10,000 sheet NY31NE (Glenridding) and part of sheet NY41NW (Martindale) in the north-eastern Lake District and should be read in conjunction with these sheets. The area was mapped as part of the Lake District Regional Geological Survey in 1996 and forms part of the Keswick District 1:50,000 sheet (British Geological Survey, 1999) and part of the Appleby District 1:50,000 sheet (British Geological Survey, in press).

The survey area consists almost entirely of Ordovician (Caradoc) rocks belonging to the Borrowdale Volcanic Group (BVG); rocks belonging to the older Skiddaw Group (Tremadoc-Llanvirn) crop out in a small area in the northern part of the area (Figures 1 and 2). The Borrowdale Volcanic Group can be divided up into the Birker Fell Formation which covers almost half of the survey area and the younger Lincomb Tarns, Esk Pike, Middle Dodd Dacite, Helvellyn and Deepdale formations.

The southern end of Ullswater dominates the eastern part of the survey area. From its southern tip at Patterdale the lake trends northwards for 2 km at which point there is a sharp bend and the remainder is orientated south-west to north-east. Glenridding is situated alongside the western shores of Ullswater and Patterdale is just 1 km away to the south. Both villages lie on the road which runs along the western lake shore. East of the lake, the western slopes of Birk Fell and Place Fell lie on the eastern margin of this sheet.

The topography west of the lake is dominated by three U-shaped, drift-filled valleys with poor rock exposure, and the craggy ridges between them. The drainage in each valley is eastwards into Ullswater. The northernmost valley, Glencoynedale, trends eastwards and is a hanging valley. This is separated from Glenridding, the next valley to the south, by Sheffield Pike (~670 m). Glenridding is in turn separated from Grisedale, a north-east trending valley, by a ridge which includes Birkhouse Moor (~700 m) and part of Striding Edge. South of Grisedale the northern slopes of Patterdale Common and Deepdale Common lie on the southern margin of the survey area. Catstye Cam (~850 m) dominates the topography on the western margin of the survey area. The northern margin runs across the rather featureless peat-covered Watermillock Common and then down to the east through Glencoyne Park to the shores of Ullswater.

Glenridding is the site of Greenside Mine [362 178]. This was the largest working lead mine in the UK until its closure in the nineteen sixties. The mine lies along a north-south orientated vein set transected by several east-west orientated faults. There are two adits, one in Glenridding and one at the head of Glencoynedale.

Quaternary deposits are well developed in the survey area and include extensive till deposits and hummocky moraine deposits on the floors of high altitude valleys. The latter are locally associated with lacustrine deposits or present day lakes. Peat hags are well developed on high ground, and in the valleys fluvial deposits dominate, in particular alluvium and alluvial fans. Head, debris cones and scree are also locally abundant.

1.1 AIM OF THE PROJECT

This report provides descriptions and preliminary interpretations of the formations of the Borrowdale Volcanic Group mentioned above. The structure of the area, mineralisation and Quaternary deposits are also discussed.

2. History of previous research

This area has attracted much attention from geologists over the years, mainly due to the presence of the Greenside Lead Mine. A map of the area on the 1-inch scale was published in 1875 by the Geological Survey and was followed by two memoirs, providing general accounts of the geology of the northern Lake District (Ward, 1876; Dakyns et al., 1897). Eastwood (1921) briefly described the history and geology of the Greenside Mine. The Edinburgh office of the British Geological Survey contains unpublished reports and descriptions of the Greenside Mine including geological notes by W C C Rose with regard to the future development of the mine and descriptions of Rose's thin sections by Dunham. A comprehensive report detailing the structure of the Greenside lead vein and a generalised map covering much of the NY31NE Sheet was produced by Gough (1965).

The western part of Sheet NY31NE was mapped by Hartley (1941) during a study of the Helvellyn and Thirlmere region. He recognised the occurrence of highly evolved rocks that he named the 'Thirlmere Rhyolite'. Most of these rocks are now assigned to the Lincomb Tarns Formation, although geochemical work is required to prove that isolated outcrops of the 'Thirlmere Member' properly can be assigned to this formation.

Moseley (1960) mapped and described in detail the area to the south-east of Ullswater, which includes the easternmost part of sheet NY31NE (Patterdale Common). He then went on to map and describe the area to the north-west of Ullswater (Moseley, 1964); this includes the north-eastern part of sheet NY31NE (Glencoyne Park). He discussed the nature of the contact between the Skiddaw Group and the Borrowdale Volcanic Group in these areas. At Glencoyne Park the contact is not exposed, but a strong topographic feature gives the impression of a gently southward-dipping surface between the Skiddaw Group and the overlying Borrowdale Volcanic Group. Green (1915) published an account of the structure of the eastern Lake District in which he considered the contact to be conformable. Moseley (1964) considered the contact to be a moderately southward-sloping fault surface, which he termed the 'Ullswater Thrust'. However, both Campbell (1995) and Hughes (1995) pointed out that thrusting alone cannot explain a faulted relationship where younger rocks overlie older rocks. Moseley (1964) also described outcrops of andesite occurring within the Skiddaw Group inlier with cleavage at right angles to the regional trend. He cited this as evidence for rotation of a thrust slice of Borrowdale Volcanic Group material within the Skiddaw Group. However, Hughes (1995) reinterpreted the fabric as an S-C tectonite indicating a steeply inclined ductile displacement down to the south-west. He considered that the common andesite outcrops exposed within the Skiddaw Group of this area represent minor intrusions. Both Campbell (1995) and Hughes (1995) considered that in this area the contact comprises steeply dipping normal faults and this would appear to be supported by evidence from Greenside Mine (W C C Rose, in discussion of Moseley, 1960).

The southern margin of sheet NY31NE was mapped by Woodhall (1998). Areas adjacent to the study area have been mapped and described by Campbell (1995), Woodhall (1998) and Millward (1998).

3 Lithostratigraphy

The district is dominated by rocks of the Borrowdale Volcanic Group (Borrowdale Volcanic Group). The volcanic rocks include andesites of the lowest parts of the Borrowdale Volcanic Group succession and also more evolved rocks from the uppermost parts of the succession (Figure 1). An inlier of older Skiddaw Group rocks is present in the northern part of the mapping area. The geological succession is given in Figure 2.

3.1 SKIDDAW GROUP

The Skiddaw Group is a thick succession of mudstone, siltstone and greywacke of Early Ordovician age (Cooper et al., 1995). In the survey area, the Skiddaw Group is exposed within the 'Ullswater inlier' in the northern part of sheet NY31NE (Figure 1). The rocks belong to the Tarn Moor Formation which is Llanvirn in age and typically dominated by mudstones and siltstones with subordinate tuffaceous sandstones and reworked bentonites (Cooper et al., 1995; Hughes, 1995).

Hughes (1995) provided a detailed description of the lithologies cropping out in the survey area. Outcrops in Glencoyne Beck [380 180] are dominantly dark grey, parallel-laminated mudstones, siltstones and fine-grained sandstones. He described the mudstones as well-sorted, crystal-rich, with abundant muscovite and altered ferromagnesian minerals, and therefore suggested that the mudstones have a volcanogenic component. He interpreted the high degree of sorting together with the concentration of tuffaceous material in laminae and thin beds as indicative of reworking and redeposition by turbidity currents.

Fine to coarse-grained sandstone interbedded with siltstone and mudstone are exposed in the Glencoyne Park area, and along a strong topographic feature from Bell Knott towards Glencoyne Farm [383 193]. Some of these sandstones lack a volcanogenic component, containing sedimentary lithic clasts, quartz grains and no significant crystalline material (Hughes, 1995).

Hughes (1995) also described further outcrops south-west of Near Swan Beck [3847 1943]. These comprise about 8m of pale grey-green, laminated silty mudstone, siltstone and fine-grained sandstone with thin dark grey mudstone laminae. Thin sections reveal crystal-rich laminae and disharmonic and discontinuity folding of laminae suggesting soft-sediment deformation. There is also evidence of slight hornfelsing. Nearby outcrops at [3838 1933] show similar evidence of soft-sediment deformation and associated brecciation.

Graptolites were collected from Glencoyne Beck and from underground trial borings in Greenside Mine, Glenridding. The poorly preserved specimens from Glencoyne Beck were *Didymograptus* sp of Llanvirn age. Diverse species were collected in the mine and are probably latest Arenig or Llanvirn age (Hughes, 1995).

3.2 BORROWDALE VOLCANIC GROUP

A system of approximately east–west faults, including the Birkhouse Moor Fault, transect Sheet NY31NE, separating rocks of the Birker Fell Formation to the north from younger Borrowdale Volcanic Group rocks to the south. The Birker Fell Formation comprises an extensive plateau-like succession dominated by tabular andesite, basaltic andesite and basalt lavas intercalated with sporadic volcaniclastic units (Petterson et al., 1992). The post-Birker Fell Formation strata are mostly volcaniclastic and include the Lincomb Tarns, Esk Pike and Deepdale formations. The Middle Dodd Dacite is a distinctive effusive lava body.

The term 'sheet' is used in this report to include both intrusions and lava flows. The emplacement mechanism of these sheets can be very difficult to ascertain, particularly in areas of poor exposure.

3.2.1 Birker Fell Formation (BFA)

BASAL CONTACT

Throughout this area the basal contact of the Birker Fell Formation with the Skiddaw Group is not exposed but is believed to be faulted (Figure 1). This contact is described more fully in section 5.

THICKNESS AND DISTRIBUTION

The thickness of the Birker Fell Formation west of Ullswater is difficult to assess due to limitations imposed by variable exposure and faulting. Around Sheffield Pike [370 180], good exposure reveals a succession with a faulted base which is up to ~700m thick. An upper contact is not exposed and unidentified intrusive sheets may make up a small proportion of this thickness. Workings at the Greenside Mine were mostly confined within the Birker Fell Formation, but reports indicate that the lowest workings reached the underlying Skiddaw Group, which is steeply faulted against the Borrowdale Volcanic Group, at a depth of approximately 30 m below sea level. Assuming a stratal dip of 30-60°, the minimum thickness of the Birker Fell Formation in the mine area (Glencoyne Head [361 189]) is therefore between 400 and 700m. The top of this succession is not seen and again intrusive sheets may comprise a proportion of the total thickness. Tentative correlations drawn between the successions at Glencoyne Wood, Sheffield Pike and Glencoyne Head suggest a maximum thickness (including any intrusive sheets) in the order of 1100m.

East of Ullswater the Birker Fell Formation is well exposed. The succession is about 1200m thick but this includes up to 200m of intrusive sheets and neither the base nor the top of the succession were observed during this survey.

LITHOLOGY

Basalts and basaltic andesites

Basalts and basaltic andesite sheets are relatively common in the district, but sheets that have been interpreted as lavas tend to be restricted to certain sites where several flows occur together. Localities of particular note include:

a) the northern slopes of Birkhouse Moor [361 167]
b) Glenridding Beck and Glenridding Common [352 166], and
c) Stang End [360 175].

Isolated basaltic andesite and basalt sheets occur elsewhere, but their emplacement mechanism is unclear and several may be intrusive. According to plans of Greenside Mine, basic rocks occur in the lower parts of the mine suggesting that the lowest part of the Birker Fell Formation succession in this district is represented in between the Birkhouse Moor and Glenridding faults.

Basaltic andesite and basalt lavas vary in thickness from 3 to 4 m (Birkhouse Moor [3635 1685]) to over 50 m (Stang End [3620 1760]). Lavas are typically massive with irregular blocky jointing, though thin lavas may have closely spaced discontinuous fractures parallel to the basal contact. Many of the lavas have reddened scoriaceous and rubbly tops, and some flows are composed almost entirely of scoria, for example at. [3637 1716]. Basalts and basaltic andesites have distinctive white-grey to grey-green or buff-weathered surfaces which are often pitted due to the weathering of plagioclase feldspar phenocrysts and/or amygdales. Fresh surfaces are typically dark blue-grey or green-grey.

Most basalt and basaltic andesite lavas are porphyritic, the proportion of phenocrysts typically varying from <2% to ~15%, although individual flows north of Birkhouse Moor contain <50% phenocrysts locally (e.g. [3637 1716], E71154 and [3661 1695], E71158). Phenocrysts of pyroxene and plagioclase feldspar are typically set in a glassy groundmass or a microcrystalline groundmass of feldspar, iron oxide and secondary chlorite and carbonate.

The basalts and basaltic andesites of Stang End, Glenridding Common and Glenridding Beck are distinctive due to the relative abundance (up to 5%) of large (up to 5 mm) sub-rounded pyroxene phenocrysts. Plagioclase feldspar phenocrysts are subordinate in number and size and in some flows form glomerophyric clusters with the pyroxene phenocrysts. The subhedral to anhedral pyroxene phenocrysts of the Stang End basalt (E71469) form clusters, commonly with individual twinned phenocrysts that are zoned towards the outer margins. Some pyroxenes are fresh, but most are pseudomorphs of chlorite and iron oxide. Plagioclase phenocrysts are usually completely replaced by sericite and carbonate.

Andesite

Most andesites occur in the northern part of the area, north of the Glenridding and Birkhouse Moor Faults. They can be crudely divided into two groups based on field appearance. Silica-rich, garnetiferous andesites with pale green/grey fresh surfaces and cream-buff weathering seem to predominate in the upper parts of the succession, and darker blue-grey, locally scoriaceous, feldspar-phyric andesites with abundant mafic phenocrysts and orange-brown weathering are more abundant in the middle parts of the succession. The andesites containing more mafic phenocrysts form well featured craggy terrain e.g. Black Crag [374 183], Sheffield Pike [369 182], Glenridding Dodd [381 175], but elsewhere exposure is poor. Most of the andesites are autobrecciated, usually towards the top of a flow but some are brecciated throughout. Laminated, fine-grained sandstone and siltstone are present between the clasts. The laminae roughly follow the dip of the lava sheets suggesting that these are lava flows.

A succession of garnetiferous acid andesites is present at the head of Glencoynedale. Just east of Hart Side they are overlain by dacites [365 190]. The distinction between the two is subtle and garnets occur as isolated rounded crystals up tp 3 mm in diameter. Garnetiferous andesites form the top of Birketts Fell [364 198] and [358 198], and to the west, on Great Dodd (the adjoining sheet) garnetiferous andesites are overlain by eutaxitic dacitic tuffs of the Lincomb Tarns Formation.

Dacite

Dacite and andesite of the Birker Fell Formation may look very similar in the field. In this report and on the map, rocks described as dacite are typically white to cream weathered and pale green-grey on fresher surfaces. Dacite is commonly feldspar-phyric with few mafic phenocrysts.

The dacitic rocks on sheet NY31NE are commonly garnetiferous, the garnets occur as individual rounded crystals. The rocks are fine-grained, massive to autobrecciated and were glassy. They comprise both coherent lava-like lithologies and tuffs and lapilli tuffs.These are interpreted as the upper part of the Birker Fell Formation although they do have similarities with the Lincomb Tarns Formation.

Volcaniclastic rocks

On the northern flanks of Birkhouse Moor [365 175] lavas form a well featured succession with thin discontinuous interbeds of tuff, lapilli-tuff and volcaniclastic sandstone. Bedded successions vary from finely laminated to massive and, locally, bedding is disrupted and chaotic. Pebbly beds also occur and thin units of accretionary lapilli can be seen at intervals. These units have been interpreted as primary airfall and surge deposits although locally some reworking has taken place. Disruption may have been due to wet-sediment deformation. Volcaniclastic rocks on Glenridding Common [354 170] are thinly horizontally laminated with beds truncated by massive coarse-grained sandstone units with a pitted appearance. This may represent deposition in a lacustrine environment with occasional mass flows supplying coarser material.

The dominantly andesitic to dacitic succession in the northern part of the area is characterised by a lack of volcaniclastic rocks. The succession is locally well featured but poorly exposed suggesting that there may be thin units of sedimentary rocks between the sheets. However, exposures on the lake shoreline also lack sedimentary units. Only at the brecciated margins of some sheets some fine-grained sandstones and siltstones may be observed between the clasts.

The paucity of sedimentary rocks suggests that this succession was rapidly emplaced and probably comprises mainly lava flows rather than intrusions.

3.2.2 Lincomb Tarns Formation (LTa)

The Lincomb Tarns Formation predominantly consists of lithic-rich, dacitic, eutaxitic lapilli-tuff (McConnell, 1993). It is well exposed on the western slopes of Birkhouse Moor [360 165], in Red Tarn Beck [357 165], in Glenridding Beck [352 165], in Blea Cove [367 168] and on Glenridding Common [365 169]. In the Keswick district, the Lincomb Tarns Formation has been divided into a number of members (e.g. Woodhall, 1998). The exposures on sheet NY31NE have been interpreted as belonging to the Thirlmere Member (e.g. Figure 2 of Woodhall, 1998).

BASAL CONTACT

The base of the formation is faulted throughout the area (Figure 1). Elsewhere in the Keswick district, the basal contact is conformable with the underlying Seathwaite Formation or is unconformable and lies on a low-angle erosion surface.

THICKNESS AND DISTRIBUTION

The formation may be up to 600 m thick in places (Woodhall, 1998) and formed mainly by deposition from large volume pyroclastic flows. The thickness of the Lincomb Tarns Formation west of Birkhouse Moor is up to 230 m.

In the Glenridding area, the Lincomb Tarns Formation occurs mainly south of the Birkhouse Moor Fault where it was deposited in a fault-bound basin. Nevertheless, sporadic fault-bound outcrops of Lincomb Tarns Formation occur north of the fault, for example at [351 170]. Isolated outcrops of garnetiferous dacitic tuff on Hart Side may belong to the Thirlmere Member but poor exposure and extensive alteration make this difficult to confirm.

LITHOLOGY

The bulk of the Lincomb Tarns Formation west of Birkhouse Moor comprises eutaxitic lapilli-tuff, lithic lapilli-tuff and in places parataxitic tuff. Parataxitic tuff is most common towards the base of the succession adjacent to the Birkhouse Moor Fault. The top of the Lincomb Tarns

Formation in the upper parts of Blea Cove comprises about 20 m of crudely stratified non-welded lapilli-tuff, lithic lapilli-tuff and breccia. Lithic clasts less than 10 cm in diameter typically show normal grading. Further to the east, the top of the Lincomb Tarns Formation also comprises lithic lapilli-tuff; lithic clasts present include angular glassy feldspar-phyric dacite and eutaxitic dacitic lapilli-tuff. Sparse garnet occurs in the shard-rich matrix which suggests correlation with the Thirlmere Member farther to the west. Lithic clasts include accessory and accidental clasts eroded from the substrate. The lithic-rich nature of some deposits may reflect loss of ash-grade material by elutriation.

A fault-bound block of dacitic tuff north of the Birkhouse Moor Fault [352 168] comprises well bedded tuff. Bedding is horizontal and beds are 1-5 cm thick. Angular to subrounded lithic clasts occur < 1cm, but generally beds are well-sorted. Pebbly beds also contain high concentrations of heterogeneously distributed, rounded garnet crystals. Most of these units are probably primary airfall and surge deposits, but it is possible that some layers may represent minor reworking of pyroclastic deposits.

DEPOSITIONAL ENVIRONMENT

The parataxitic lapilli-tuff was probably emplaced rapidly during low-level fountaining resulting in ponding at high temperatures. Other lithologies provide evidence of airfall, and surge deposits and cooler pyroclastic density currents that generated weakly or non-welded ignimbrites. Aggradation from a single fluctuating ash flow is unlikely because of the localised presence of co-ignimbrite ash deposits and aqueous reworking between some flow units (McConnell, 1993).

3.2.3 Esk Pike Formation (EsP)

At the type section (McConnell, 1993), the Esk Pike Formation is dominated by massive, bedded or laminated mudstone and siltstone commonly with distinctive white weathering (hornstone). Further to the east around Wythburn, the average grainsize of the Esk Pike Formation increases and is dominated by sand-grade material (McConnell, 1993). In the Helvellyn area, the Esk Pike Formation is dominated by sandstone, coarse sandstone and conglomeratic sandstone implying that the ‘type locality’ in fact comprises only distal deposits.

BASAL CONTACT

The basal contact is not exposed although its location is clearly marked by a bench feature across the north flanks of Birkhouse Moor. The upper part of the Lincomb Tarns Formation comprises distinctive pale-coloured lapilli-tuff. The basal units of the Esk Pike Formation are dominated by bedded volcaniclastic sandstones and massive pebbly sandstones. Woodhall (1998) described the contact as sharp, in many places with an erosion surface on the Lincomb Tarns Formation. However, locally the contact is indistinct because reworking of the Lincomb Tarns Formation tuffs has occurred (Figures 1 and 2).

THICKNESS AND DISTRIBUTION

The Esk Pike Formation crops out almost continuously from the northern slopes of Catstye Cam [352 162] and Birkhouse Moor [364 167] to the slopes just above Mires Beck [375 167]. The thickness of the EsP in this area is roughly constant at 200 m along its outcrop and individual recognisable units can be traced laterally for up to 2 km.

LITHOLOGY

Bedded volcaniclastic sandstone, massive coarse-grained sandstone, conglomeratic sandstone, tuff and lapilli-tuff are interbedded with finer grained siltstone and mudstone. Erosive contacts between successive units are common. The finer grained material dominates only the upper 50 m of the succession, where low-angle cross-bedding and horizontal lamination are commonly obscured by soft-sediment deformation structures. Loose blocks reveal horizons of accretionary lapilli, perhaps resedimented in a subaqueous environment.

Locally, there is evidence of andesitic volcanic activity within the sedimentary succession. In Glenridding valley [375 168] a garnetiferous andesite several metres thick occurs towards the base of the succession. It is strongly flow laminated with elongate vesicles on its upper surface. It is overlain by about 2 m of volcaniclastic sandstone. Above this, thin units of feldspar and garnet crystal-rich tuff (< 80 cm) are interstratified with grey, thinly bedded sandstones.

DEPOSITIONAL ENVIRONMENT

Deposition probably took place in a fluvio-lacustrine environment with transportation by mass flow, traction and suspension. The coarse, massive deposits are probably subaqueous mass flows and/or channel fills. Contemporaneous volcanism included explosive and probably also effusive activity of andesite/dacite composition. Woodhall (1998) noted that massive units of pebbly sandstone and breccia reached maximum thickness and grain size near major faults suggesting that deposition was fault controlled.

3.2.4 Middle Dodd Dacite (MdD)

The Middle Dodd Dacite lies conformably on the Esk Pike Formation throughout the Ambleside (British Geological Survey, 1996) and Keswick (British Geological Survey, 1999) districts (Figure 1). Millward et al. (2000) found no evidence for interaction between the dacite and the underlying sedimentary rocks of the Esk Pike Formation and therefore considered it to be extrusive. There is evidence of auto-brecciation, folding of flow lamination and locally dacitic tuffs in association with the dacite, so it is considered here to be a lava.

In the Glenridding area there are at least two dacite lavas. A thick, flow-laminated and locally auto-brecciated lava dominates the succession. This has been tentatively correlated with the Middle Dodd Dacite. Overlying it is a massive feldspar-crystal-rich dacite lava. There are also isolated outcrops of dacite tuff.

BASAL CONTACT

On Catstye Cam the basal contact is exposed at [359 164] where massive, glassy dacite lies directly on a low-relief erosion surface of the Esk Pike Formation. The contact with the underlying sandstones of the Esk Pike Formation is sharp. There is no evidence of loading or interaction between the two rock types suggesting the Esk Pike Formation was lithified and may have undergone uplift and minor erosion prior to emplacement of the dacite.

Elsewhere, the basal contact is not exposed but is marked by a distinct platform feature (e.g. Birkhouse Moor [367 166]).

THICKNESS AND DISTRIBUTION

The dacite succession is between 70 and 160 m thick. The thickness varies along outcrop and this may be because of ponding in an irregular topography caused by either erosion or fault movement.

LITHOLOGY

The lower dacite lava on Catstye Cam [351 161] and Birkhouse Moor [370 165] is dominantly white to grey weathered, commonly with distinctive flow-banding and planar jointing parallel to the flow-foliation. There is a distinctive and pervasive centimetre-scale pattern of blocky jointing and the weathered surface is commonly pitted where feldspar phenocrysts have been weathered out. Fresh surfaces are pale green/grey, glassy with up to 10 % by volume of euhedral feldspars (< 2 mm). On Catstye Cam and the north-facing crags on Birkhouse Moor, the basal few metres of dacite is either flow-banded or massive. In contrast, the basal 10-20 m of the dacite in Little Cove is brecciated. The breccia occurs at the base of one of the thicker parts of the dacite succession. Clasts are angular, < 30 cm in diameter and there are abundant quartz nodules in this brecciated zone. The breccia passes rapidly up into a regularly flow-banded dacite. This zone of autobrecciation may have formed in response to a change in the properties of the substrate (e.g. slope) or perhaps the flow passed over a small fault scarp. Autobreccia also occurs farther west, at [358 161], a site that is also at the base of a thick section of dacite. Clasts show parallel and folded flow-lamination. Sparse garnets > 1.5 mm also occur here.

Across much of the area, the flow-laminated pale grey dacite is overlain by a massive, grey-orange weathered dacite with < 30 % feldspar phenocrysts. This lava forms a distinct feature on the summit of Birkhouse Moor [367 164] and is up to 10 m thick. A platform feature farther west [352 160] marks the base of a massive dacitic lava containing < 20% feldspars <3mm in length. The feldspars commonly occur in clusters with Fe-oxides and chlorite pseudomorphs (after amphibole?). The increase in volume per cent of feldspar phenocrysts upwards through the dacite lava pile suggests that magma in the conduit was cooling, crystallising and becoming more viscous.

On Catstye Cam, the pale lower dacite lava is locally overlain by dacitic lapilli-tuff for example at [354 160]. These localised outcrops may have been preserved in hollows in the topography. The tuff is pale weathered like the underlying dacite but contains abundant sub-angular dacitic clasts < 3 cm across. This suggests that low-intensity explosive activity also occurred during this dominantly effusive eruptive phase.

ERUPTIVE ENVIRONMENT

The sandstones underwent some low-relief erosion before emplacement of the lavas. The local formation of autobreccia at the base of the lavas suggests steep slopes and/or fault scarps may have been present.

ERUPTIVE STYLE AND EMPLACEMENT

The lower, thick dacite was a viscous, effusive lava flow that developed planar flow-lamination and locally, chaotic flow-lamination, the latter probably related to flow over steep slopes or fault scarps. Thickness variations along strike relate to variations in the basal topography and support the interpretation that this is a lava flow. The upper, feldspar crystal-rich lava is less extensive and less voluminous, and was probably also substantially more viscous.

3.2.5 Helvellyn Formation (Hlv)

The Helvellyn Formation was described first by Woodhall (1998) and includes the middle and upper parts of the ‘Felsitic and Basic Tuffs’ of Hartley (1941). The type area occurs on the eastern side of Helvellyn and includes Nethermost Cove [350 145] (Figure 1). The base is locally well-exposed on the western side of Grisedale [354 131].

The Helvellyn Formation comprises up to 400 m of dacitic lapilli-tuff interpreted as ignimbrite (63-65% SiO2) and crops out extensively between the Coniston Fault and Deepdale Hause faults (Woodhall, 1998). The ignimbrite units are 10-130 m thick and each is composed of massive feldspar crystal-rich dacitic lapilli-tuff. Units are commonly separated by bedded coarse-grained tuff and lithic-rich lapilli-tuff which become more abundant up the succession.

BASAL CONTACT

Woodhall (1998) described the basal contact of the Helvellyn Formation against the Esk Pike Formation at locations in Grizedale. He found low-relief erosion surfaces from which he inferred that regional uplift and moderate erosion of the Esk Pike Formation occurred before ignimbrite emplacement. Irregular loading surfaces also occur locally and he suggested that in some areas the Esk PikeFormation remained unconsolidated during ignimbrite emplacement (and therefore also during eruption of the Middle Dodd Dacite and correlatives).

In the Glenridding area, the Helvellyn Tuff rests directly on dacites tentatively correlated with the Middle Dodd Dacite. The contact is not exposed but is locally defined by a striking feature (e.g. Birkhouse Moor [367 164]). Based on landscape features and the attitude of the flow-foliation in the dacites the contact appears to be conformable. The contact represents a rapid change in eruption style from effusive to explosive.

DISTRIBUTION AND THICKNESS

In the Glenridding area, the Helvellyn Formation is estimated to reach a maximum thickness of 340 m at Grizedale Brow [365 155] but faulting makes an accurate assessment difficult. The maximum thickness of 400 m was recorded nearby between Helvellyn and Grizedale (Woodhall, 1998). The formation occurs mainly to the west of the Deepdale Hause Fault forming the summit and south flanks of Catstye Cam and Birkhouse Moor. East of the Deepdale Hause Fault the Helvellyn Formation has been faulted down and only the upper 100-200 m are exposed in the lower slopes south of Glenridding village, west of the Trough Head Fault.

LITHOLOGY

Typical outcrops west of the Deepdale Hause Fault comprise fiamme and lithic-rich lapilli-tuff. Lithic clasts are pale, glassy dacite and feldspar-phyric dacite and typically vary from less than 5 mm in some units up to 4cm in others. Single units 2-3 cm thick may contain abundant clasts up to 15 cm or in some cases up to 40cm. These clasts are angular to sub-rounded, dacitic and typically normally graded. Fiamme are black but weather to brown, with feldspar crystals and ragged margins. They define a weak eutaxitic fabric but the degree of flattening tends to be greater in the lower part of the succession. Fiamme may reach 10 cm in diameter with aspect ratios of 1:3 to 1:10 in these lower units. Larger fiamme commonly occur towards the top of individual units representing reverse grading of pumice.

Locally, units of volcanic breccia occur containing lithic clasts up to 15 cm or even 40 cm in diameter in a dark, glassy and feldspar phyric matrix. These may represent lag breccias deposited at the base of ignimbrites.

On the lower part of Striding Edge [355 151], in the upper part of the succession, units of well bedded lapilli-tuff and tuff are intercalated with massive lapilli-tuff. Bedding comprises planar lamination and low-angle cross stratification. The rocks commonly have a pitted appearance where glassy lapilli have been weathered out. There is no evidence of eutaxitic fabric or welding although some pumice lapilli have a slightly flattened appearance. These rocks are typically strongly cleaved.

East of the Deepdale Hause Fault exposures of Helvellyn Formation are different in appearance. Eutaxitic fabric/welding appears to be absent and massive volcanic units are rarely more than 10 m thick. Brown-weathered pumiceous fragments occur in most units and are commonly weathered out giving rocks a pitted appearance. Some bed- ded tuff units attain a thickness of 2.5 m and contain dacitic lapilli and pumices which are aligned with bedding. Planar bedding and low-angle cross stratification were also observed. Lithic-rich horizons occur and the lithic clasts (<10cm) are commonly aligned with their long axes parallel to bedding. Locally there are abundant siliceous nodules. These non-welded units typically have a strongly developed cleavage.

DEPOSITIONAL ENVIRONMENT

The Helvellyn Formation lies directly on dacite lava in the Glenridding district, whereas elsewhere the ignimbrites were emplaced on sandstones of the Esk Pike Formation that had undergone uplift and minor erosion (Woodhall, 1998). The ground surface was probably low relief *in this area* with some localised standing water suggested by loading structures at the base of the Helvellyn Formation. Woodhall (1998) noted that the Helvellyn Formation thins rapidly to the south and this may reflect accummulation on a block-faulted terrain. The very localised outcrop of the formation and substantial thickness suggest deposition in a deep basin but it is unknown how much of the formation has been removed by erosion.

ERUPTIVE STYLE AND EMPLACEMENT

Eruptive activity began with large volume plinian explosions that had a high temperature and probably a high eruption rate/ and or relatively low fountain height. The voluminous pyroclastic flows generated by fountain collapse formed extensive ignimbrites that developed welding. Activity progressed to either higher eruption columns and/or lower eruption rates which inhibited welding of the deposits. Pyroclastic fall-out and surge deposition occurred contemporaneously with the pyroclastic flows. With time, eruption rate decreased and explosions were less violent. Pyroclastic flows were less voluminous and fall and surge deposits became more significant.

This is a sudden change in eruption style from the underlying dacite lavas. The increasing crystal content of the lavas in the upper part of the dacite succession indicates that magma was becoming more viscous. This would have enhanced the probablitity of an explosive eruption.

3.2.6 Deepdale Formation (Dpd)

The Deepdale Formation was defined by Woodhall (1998) and incorporates some of the highest strata in the Borrowdale Volcanic Group (Figure 1). The formation comprises up to 650 m of sandstone, pebbly sandstone, breccia and pyroclastic rocks deposited in a fluvio-lacustrine environment. The Deepdale Formation closely resembles the Esk Pike and Seathwaite Fell formations in appearance. Andesite and dacite sheets are common within the succession and have been interpreted as penecontemporaneous high-level intrusions (Woodhall, 1998).

The main outcrop extends from Rydal Head to Ullswater with several outliers on the peaks of Fairfield, Dollywaggon Pike, Nethermost Pike and Helvellyn. Abrupt lateral and vertical facies variations make correlations across the outcrop difficult. In the Glenridding area only the basal part of the formation is present (Thornhow End Member of Woodhall, 1998).

BASAL CONTACT

Throughout the Glenridding area the Deepdale Formation overlies the Helvellyn Formation. The basal contact is not clearly exposed and the distinct, high-relief erosion surface described west of Mart Crag [3707 1241] by Woodhall (1998) was not observed. However, the facies change between massive lapilli-tuff of the Helvellyn Formation to well bedded sandstone and massive pebbly sandstone of the Deepdale Formation is marked. Locally, the basal beds of the Deepdale Formation comprise volcaniclastic sandstone, tuff and lapilli-tuff and the contact is indistinct. On Striding Edge the lower units of the Deepdale Formation comprise weakly stratified to massive volcaniclastic sandstone. The bedded units are mostly planar bedded with some low-angle cross stratification. The massive beds are pitted in appearance with scoriaceous clasts and some chloritised black, feldspar-phyric lapilli.

DISTRIBUTION AND THICKNESS

The Deepdale Formation is exposed in the southern part of the area, on Striding edge [355 152], south of Glenridding village on Keldas [373 160] to [388 164], in Grisedale and on Patterdale Common. At its type locality Thornhow End [385 154] the member reaches its maximum thickness of approximately 300 m.

LITHOLOGY

The formation consists mainly of massive, coarse-grained sandstone and pebbly sandstone with thin intercalations of planar and occasionally cross-bedded sandstone. Volcaniclastic sandstone and dacitic tuff also occur and are commonly weakly planar bedded. Bedded successions are typically normally graded. Locally, conglomeratic units occur. On Keldas [385 167], just south of Glenridding, bedded sandstones dominate the succession. Most units in the succession are strongly cleaved. Lateral and vertical facies variations are abrupt.

Clasts in the sandstones comprise two types: pale rounded silicic clasts typically < 1 cm but sometimes < 10 cm, and irregular scoriaceous dark fragments with orange weathering < 0.5 cm. The latter may be derived from the underlying Helvellyn Formation or from contemporaneous andesitic/dacitic volcanic activity.

Dacitic tuffs are distinctly pale grey to white, fine-grained and strongly cleaved [387 163] and [383 153], they are commonly associated with tuffaceous sandstone of pale colour but coarser grain size. Dark chloritised feldspar-phyric fragments are common within the tuffaceous units. Locally, tuffs are highly feldspar crystal-rich. Volcaniclastic sandstones are dominated by re-worked tuffs of the Helvellyn Formation.

DEPOSITIONAL ENVIRONMENT

The Deepdale Formation comprises mainly subaqeously deposited volcaniclastic sediments. Deposition was in a fluvio-lacustrine environment and took place by traction, mass flow and suspension similar to the Esk Pike Formation.

4 Intrusions

4.1 MICROGRANITE

Two apparently separate microgranite dykes occur in the survey area. On the south side of Sheffield Pike, a roughly NW-trending dyke up to 8 m wide extends for 1.5 km across the hillside (Figure 1). It is weakly offset by a series of minor NE–SW faults. Farther north, in the vicinity of Greenside Mine, a similar dyke has a distinct 'dog-leg' in its outcrop. It follows part of the N–S Greenside vein for 600 m (Figure 4), then sharply turns and follows an E–W fault for 300 m at which point it curves round to a NE–SW orientation.

The dykes form distinctive low, rounded outcrops of pink-grey colour with numerous rounded quartz crystals that commonly stand proud of the rock surface.

These dykes are similar in many respects to the Armboth dyke (Beddoe-Stephens, 1996) and an unnamed 40 m wide microgranite dyke (Millward, 1998) on the adjacent NY31NW sheet. The unnamed dyke is not cleaved suggesting an Early Devonian or younger age (Millward, 1998). The dykes in this area also lack a cleavage. The general orientation of the dyke outcrops suggests they were emplaced during a period of NE–SW extension. The northern dyke segment in the Glenridding area utilised pre-existing conjugate N–S and E–W faults. This N–S emplacement later proved critical to the mineralisation of the Greenside vein. The intrusions are shallow level as mine plans show that the dyke does not occur in the lower levels of the mine. This implies shallow lateral emplacement of the intrusion.

Minor quartz and mica-phyric micrograntic intrusions also occur on Glenridding Common [e.g. 353 165] where they have been intruded locally along a NE-SW trending fault splay in the Birkhouse Moor Fault Zone.

4.2 ANDESITE

Penecontemporaneous intrusions are common in the Deepdale Formation and in this area they tend to intrude the succession along the fine-grained and commonly bedded dacitic tuff horizons (Figure 1). The contacts at the base are commonly sharp but irregular. Peperitic breccias are present at some locations at the contact between the cleaved tuffs and lapilli-tuffs and the massive uncleaved andesite [3748 1602]. The sheets are transgressive in places [near Thornhow End] and may reach at least 100 m in thickness. They commonly show well developed columnar jointing (e.g. Raven Crag [387 164]). The andesite is crystal-rich with abundant large phenocrysts of plagioclase feldspar and pyroxene.

4.3 BASALT

There are very few basalt dykes in the district but these are all aphyric, vesicular or amygdaloidal and orientated approximately E–W or N–S (Figure 1).

One E–W, narrow dyke is parallel to the microgranite dyke at Glenridding Mine (above). It intrudes feldspar-phyric andesites of the Birker Fell Formation to the east of the Glenridding vein. The dyke is aphyric, vesicular and dark grey in colour.

A second dyke occurs nearby at Nick Head just 300 m to the SE. This dyke is 4-5 m wide, aphyric with round and irregular amygdales up to 13 mm in diameter. It intrudes garnetiferous, feldspar-phyric andesites of the Birker Fell Formation. The rock has a distinctive orange-brown weathering, a deeply pitted surface and well developed fractures parallel to the dyke margins. The dyke trends at 187°, roughly N–S and fracture surfaces commonly reveal slickensides. The dyke was probably emplaced along a N–S fault that has been re-activated since emplacement. The amygdales are filled with chlorite and some quartz. Fluids moving along this fault zone may have been responsible for the deposition of amygdales.

A third, minor E–W dyke, probably basaltic andesite, occurs at Little Cove [372 164] farther south. It is also aphyric and amygdaloidal but its extent is very limited. It intrudes ignimbrites of the Helvellyn Formation.

It is possible that some of the basalt sheets in the Birker Fell Formation are intrusive but poorly exposed contacts make this difficult to confirm.

5 Structure

5.1 STRATIGRAPHICAL DIP

Dips across the area are generally less than 50º and dip directions, although mainly to the south and SE, vary widely (Figure 3). Within fault blocks the degree of dip tends to be roughly consistent as does the dip direction. The variation in dip direction between fault blocks implies brittle fracture and rotation of rigid blocks (Firman and Lee, 1986).

5.2 CONTACT RELATIONSHIPS BETWEEN THE SKIDDAW GROUP AND THE BORROWDALE VOLCANIC GROUP

At outcrop in the survey area (the southern part of the Ullswater inlier), the contact between the Skiddaw Group and the Borrowdale Volcanic Group (Figure 1) was interpreted as a fault by Moseley (1960, 1964). In Glencoyne Park the contact is not exposed but is marked by a distinctive bench-like feature. Here and south-east of Ullswater the contact was interpreted by Moseley (1960) as a thrust. Moseley (1964) described feldspar-phyric andesite outcrops at Middle Swan Beck [3877 1954] as 'flow-brecciated andesite' with a cleavage at a high angle to the regional cleavage. He suggested that this was evidence that the outcrops were within a thrust sheet of Borrowdale Volcanic Group rocks emplaced within rocks of the Skiddaw Group. Neither Hughes (1995) nor the author could find evidence for the extrusive origin of these rocks. Hughes (1995) interpreted this andesite as a minor andesitic intrusion, common in the Glencoyne area.

The only locality in this inlier where the contact is exposed at surface is in Aira Beck [400 204] where the contact is a sub-vertical normal fault. Wadge et al. (1972) and Wadge (1972) described the contact exposed in the Tarn Moor Tunnel south-east of Ullswater as a steeply dipping normal fault. Evidence from plans of Greenside Mine suggests that the contact is faulted and dips at between 65°E to vertical. W.C.C. Rose (unpublished data) visited the mine and described at least one example where the contact was steeply inclined. Gough (1965) described the contact as 'irregular in form but essentially dome-like, having an approximately N-S long axis' (see Figure 3).

Hughes (1995) summarised the evidence available and presented a number of problems with the thrust theory:

a) The stratigraphy is not inverted.

b) Andesite sheets at Glencoyne Park are locally abruptly terminated by faults and these appear to be steeply dipping structures.

c) Although Moseley (1964) did not discuss the amount and direction of translation of the thrusts, a north-westward translation of the thrust on the south-east side of Ullswater is implicit in his descriptions. On the north-west side of Ullswater, southerly to easterly translation must be assumed. These opposing translation directions would result in the convergence of thrusts along the axis of Ullswater.

d) Moseley's thrust slice of Borrowdale Volcanic Group andesites within the Skiddaw Group at Glencoyne Park cannot be substantiated.

Hughes (1995) and Campbell (1995) interpreted the contact in the Ullswater inlier as a set of steeply-dipping normal faults, probably with an early north-east trending set and a later north-west trending set. Some of the steeply dipping faults in the Glencoyne area may have been initiated as volcanotectonic growth faults during development of the lower Borrowdale Volcanic Group (Campbell, 1995).

5.3 FAULTS

The area is dominated by major normal and/or strike-slip faults of roughly ENE–WSW to ESE–WNW orientation (Figure 3). North of the Glenridding Fault most other major fractures are oriented roughly N-S. The N-S fault strands in the eastern part of the area are part of the Troutbeck Fault System, a major structure that cuts through the entire Borrowdale Volcanic Group. South of the Glenridding Fault the orientation of other major structures is closer to NNE–SSW, for example the Deepdale Hause and Trough Head faults (Woodhall, 1998). These are all mainly pre-Acadian and may be re-activated basement structures.

5.3.1 Glenridding Fault

The trace of the Glenridding Fault crosses the centre of the area from between Raise and Stybarrow Dodd, through Glenridding village towards the southern tip of Ullswater (Figure 3). It has a WNW–ESE orientation and is a continuation of the Sticks Fault to the west (Millward, 1998). It appears to terminate against the N-S Troutbeck Fault. In the western part of the area, basic andesites with abundant mafic phenocrysts occur south of the fault and plagioclase-phyric andesites crop out to the north. The basic andesites are thought to be from the lower part of the Birker Fell Formation succession (based on the succession observed in the Greenside Mine, see section 6) and the plagioclase-phyric andesites from the middle part of the succession; downthrow was therefore to the north. In the vicinity of Glenridding, the Glenridding Fault joins up with the curvilinear but roughly E–W Birkhouse Moor Fault.

5.3.2 Birkhouse Moor Fault

The curvilinear Birkhouse Moor Fault is a major feature with mainly andesitic rocks of the Birker Fell Formation to the north and dacitic rocks of the upper parts of the Borrowdale Volcanic Group succession to the south (Figure 3). It is a normal fault with a downthrow of several hundred metres to the south. This fault delineates the northern margin of a large depositional basin containing Lincomb Tarns Formation, Esk Pike Formation, Helvellyn Formation and Deepdale Formation (Woodhall, 2000). Within this basin there are a number of NNE-SSW trending faults (e.g. Trough Head Fault, Deepdale Hause Fault) that are associated with thickness and facies variations in the Esk Pike, Helvellyn and Deepdale formations, suggesting that they are syn-depositional structures.

The Birkhouse Moor Fault is exposed in a tributary of Glenridding Beck [357 166] where three diverging fault splays are exposed. Three fault breccias 1-2 m wide each with an orange carbonate matrix mark the three diverging faults. The fault breccias are 10 m apart and the jointing and orientation of the central fault trends at approximately 082º. At this locality intensely fractured rock is exposed in a series of waterfalls in the beck over a distance of about 30m. The country rock is so heavily fractured and stained that lithologies cannot be distinguished. However, outside the fault zone, there are andesites of the Birker Fell Formation exposed to the north and eutaxitic dacite tuff of the Lincomb Tarns Formation to the south.

Farther west at Glenridding Common [353 165], three fault zones are exposed separately in Glenridding Beck and a further unexposed fault zone is inferred. The northernmost fault splay has a 2 m wide fault breccia with sharp margins against slickensided andesite. The breccia comprises angular dark purple-green andesitie clasts in a pale carbonate matrix stained orange. The breccia associated with the second fault splay is 3 m wide but is otherwise similar to the northernmost fault splay. The actual faulted contact between andesites of the Birker Fell Formation and dacitic tuffs of the Lincomb Tarns Formation is not exposed, although pale strongly eutaxitic dacitic tuff outcrops in the stream bed just a few tens of metres south of the second fault breccia. The southernmost fault splay passes through eutaxitic to parataxitic dacite tuffs and the corresponding fault breccia is ~50 cm wide. North of this fault, slivers of andesite crop out between lenses of dacitic lapilli-tuff. A coarsely feldspar, quartz and mica-phyric microgranite appears to have intruded along the fault (E71165).

5.3.3 Unnamed faults

An unnamed fault cuts approximately E–W through Glencoynedale in the north and is probably associated with critical E–W fractures in the Greenside Mine area (e.g. Johnston's Cross Back Fault, see section 6, Figure 3)). This fault throws down to the north but maybe only a few tens of metres. North of the fault, garnetiferous andesite and dacite at the top of the Birker Fell Formation succession are exposed. A number of minor N–S orientated faults occur in the northern part of the area but displacement across the faults is minimal. The faults bounding the Skiddaw Group exposure are orientated NE–SW and E–W throwing down to the NW and S respectively.

5.4 CLEAVAGE AND S-C FABRICS

A single cleavage is observed throughout the area and is ENE to north-east-trending throughout (Figure 3). The fabric is penetrative or spaced and commonly vertical or steeply dipping to the north-west or south-east. Siltstones, sandstones and volcaniclastic rocks show an intense cleavage whereas more massive lavas or sills do not show a well developed cleavage. The consistent orientation of the cleavage is superimposed on widely varying stratigraphical dip directions implying that fault-block fracture and rotation of the Birker Fell Formation occurred before the cleavage forming event. Intersection lineations of cleavages in Glencoyne Beck (Skiddaw Group lithologies) consistently plunge at 26° and 50° to azimuths between 222° and 246° suggesting upright folds with axes plunging gently to the south-west (Hughes, 1995).

Hughes (1995) described S-C tectonite fabrics in andesites at Middle Swan Beck, Glencoyne Park. The andesites are highly altered but the fabric can be seen in hand specimen and thin section (E70352). The S component dips at 80° to 222° and the C component dips at 74° to 230°.

6 Mineralisation

Stanley and Vaughan (1982) classified the major mineral veins in the Lake District on the basis of mineralogy, geological relations and radiometric ages. They recognised two major groups of veins: 'chalcopyrite-pyrite-arsenopyrite type' mineralisation and 'galena-sphalerite type' mineralisation. Both these mineralisation types occur within the survey area, mainly associated with the Greenside lead vein. For a further discussion of the regional significance of the mineralisation episodes see Stanley and Vaughan (1982).

Some of the most important deposits in the Lake District are characterised by an assemblage of chalcopyrite, pyrite, arsenopyrite and minor sphalerite and galena. In the central Lake District the veins are typically orientated E–W and it is believed that the underlying granite batholith controlled their emplacement (Stanley and Vaughan, 1982). They were believed to be Early Devonian (Caledonian) in age (Ineson and Mitchell, 1974) based on K-Ar dating of hydrothermal clay minerals in the wall rock. Halliday (1977), Ineson (1980) and Rundle (1981) all pointed out the limitations of this dating method and suggested that this should be interpreted as a minimum age for ore deposition. However, Millward et al. (1999) demonstrated that the Coniston Suite is cleaved and hence pre-Devonian. They suggested that this suite could have been emplaced shortly after the late-Ordovician episode of volcanism.

The galena-sphalerite suite includes the lead-zinc veins that occur principally at Greenside, near Keswick and in the Caldbeck Fells along N–S, NE–SW or NW–SE orientated normal faults. The suite is characterised by galena, sphalerite, barite and chalcopyrite, and the galena commonly contains inclusions of antimony and tetrahedrite. The batholith does not affect the distribution of these veins but Early Carboniferous E–W extension may have been responsible for the opening of the fractures (Stanley and Vaughan, 1982). Ineson and Mitchell (1974) suggested an Early Carboniferous age of c. 330–360 Ma for this mineralisation.

A later 'barite-type' mineralisation has also been identified along E–W normal faults in the N and central Lake District. This is characterised by baryte, quartz, carbonates and galena. Ineson and Mitchell (1974) used K-Ar dating to suggest a Late Carboniferous to Permian age of 260–290 Ma.

6.1 GREENSIDE VEIN

The Greenside lead vein contains an assemblage of galena, sphalerite and minor chalcopyrite and silver. It is considered to belong to the Early Carboniferous Suite (Stanley and Vaughan, 1982) and cuts and displaces an important suite of Lower Devonian (Caledonian) E–W faults (Figure 3).

The Greenside vein developed along a roughly north-south orientated normal fault and hades east at about 70° (Figure 5 in Gough 1965). The throw across the fault is considered to be only up to 30 m down to the east, but this is difficult to assess because of a lack of marker horizons. There is a small strike slip component of 0-3 m (Gough, 1965). Ore shoots are present mainly along steeper sections of the vein (Gough, 1965). The vein was over 18 m wide in parts of the upper workings but in deeper workings the thickness was about 2.5 m (Adams, 1995).

A quartz-phyric microgranite dyke is closely associated with the N-S fault zone (Figure 5 in Gough, 1965). The contacts of the competent dyke form either the footwall, hanging wall or both. The dyke has a dog-leg shape at surface outcrop with N-S and E-W orientated portions. The dyke is not present at lower levels in the mine.

The veins show no apparent relationship to the wall rock type or their orientation (Gough, 1965). Below the 90 fathom level (c.185 m above sea level) wall rocks are mainly basaltic andesite lavas with tuff and breccia intercalations, whereas above the 90 fathom level andesite and dacite dominate the succession (Gough, 1965). The Borrowdale Volcanic Group in this area dips between 30-60° to the south or south-east. However, there is some change of mineralisation with vertical position in the mine. Baryte with some manganese oxides and some sulphides occur in the higher workings and can be found in spoil heaps at the Glencoyne adit. Deeper workings have a more sulphide-rich assemblage and increased sphalerite and chalcopyrite.

The Skiddaw Group was reached in Greenside Mine between the 200 and 217 fathom levels (c.30 m below sea level). The contact, where exposed, is typically faulted at a moderately steep angle (>60°). The contact between the Skiddaw Group and the Borrowdale Volcanic Group localised the Greenside vein (Gough, 1965) since the Skiddaw Group is not conducive to mineralisation.

The Clay Fault (delimiting the southern extent of the vein) and the North Fault (that influenced development of an important ore shoot) are Caledonian in age, E–W trending with localised quartz-pyrite-dolomite-ankerite-calcite mineralisation (Gough, 1965). The North Fault is an important pre-mineralisation structure that developed along the E–W part of the dyke.

6.2 HISTORY OF GREENSIDE MINE

Although it is probable that the Greenside lead vein has been worked sporadically since Roman times, as is the case at other Lake District mines, the earliest operations were dated at c. 1750 (Adams, 1995). The mine was worked almost continuously from 1827 until 1935 by the Greenside Mining Company and then by Basinghall Mining Syndicate (Greenside Mines Ltd) until 1962 (Blundell, 1994). In total 2,400,000 tons (~ 2.44 x 109 kg) of ore yielding 200,000 tons (~2.03 x 108 kg) of lead concentrates and 2,000,000 ounces (56,700 kg) of silver were extracted from the vein (Adams, 1995).

The earliest workings at Greenside Mine were from levels high on the hillside, for example the Glencoyne Level with its adit at [360 190] (Figure 3) but as the mine got deeper, progressively lower and longer levels were driven (Adams, 1995). The Lucy Tongue Level [361 179] (Figure 3) is the lowest and was started in 1853 and completed in 1869. However, by 1962, the deepest workings were 433 m below Lucy Tongue Level (Adams, 1995).

7 Drift deposits

Quarternary glaciation and post-glacial fluvial and mass movement processes have had a major effect on the landscape. Evidence of these processes in the form of Quaternary deposits and land-forms are present throughout the Glenridding area. In the last few hundred years mining has also had a significant effect on the local landscape.

7.1 DIMLINGTON STADIAL LANDFORMS AND DEPOSITS

Ullswater lies in a broad, flat-based N–S to NE–SW glaciated valley. Grisedale is also a mature glacial valley orientated NE–SW. The smooth sides of these valleys are covered in till. The E–W valleys in the survey area including Glenridding Valley and Glencoynedale also contain abundant evidence of glaciation but the flat-based, steep-sided form is not so well developed and the valleys are short. Glencoynedale is a hanging valley.

Glacial deposits include extensive till emplaced by the valley glaciers during the Devensian (probably Late Devensian Dimlington Stadial, 26-13 ka BP; Boardman, 1991). It comprises poorly sorted, polymict diamictite, with clasts from sand to cobble size. The matrix is typically silt although locally a clay-rich matrix may be present. On the western banks of Ullswater, below Glencoynedale, boulder-sized clasts are common in the till.

7.2 YOUNGER DRYAS (LOCH LOMOND) STADIAL DEPOSITS AND LANDFORMS

Distinctive Younger Dryas Stadial (11,000 to 10,000 BP) landforms and deposits provide evidence of a limited glaciation that mainly affected north- and east-facing valley heads. Small glaciers formed in these valley heads and generated corries with steep head walls, and some of these corries now contain tarns (e.g. Red Tarn).

Hummocky moraine deposits are typically found in high corries or hanging valleys (e.g. Red Tarn, [351 153]; Greenside, [353 182]; Glencoynedale, [187 369]; Deepdale, [353 195] and Grisedale, [367 150]. Each of these deposits corresponds to the siting of a Younger Dryas glacier (see for example Sissons, 1980). The 'hummocks' are generally circular to elongate in shape and are commonly superimposed one on another, the largest are up to 10 m high. No end moraines were observed in these areas but it may be assumed that the downhill limit of the hummocky moraine is close to the former limit of the glacier (Sissons, 1980).

7.3 QUATERNARY POSTGLACIAL AND PERIGLACIAL DEPOSITS

Postglacial and periglacial deposits include fluvial deposits (alluvium, alluvial fans, river terraces), lacustrine deposits peat, head, debris cones and scree.

Alluvium deposits are best developed on the floors of the broad glacial valleys for example at the south end of Ullswater (Patterdale) and on the floor of Grisedale. These flat-lying fertile areas are invariably used for agriculture, mainly grazing.

Alluvial fans have developed at the mouths of the narrower E–W valleys of Glencoynedale and Glenridding where each river enters Ullswater. These fans are mainly composed of gravel to cobble-sized fragments of Borrowdale Volcanic Group rocks and are still active. These fans are also valuable fertile agricultural land, used mainly for grazing. In the lower reaches of the rivers where they have developed a weak meandering habit there are narrow river terraces.

Lacustrine deposits can be found at Greenside (Greenside, [353 182]) in association with hummocky glacial deposits. It is common for small lakes to develop in this corrie environment, although at this site the lake has silted up.

The high plateaux above the valleys have a gently undulating topography with generally patchy peat. The most extensive peat development is on the lower parts of Striding Edge and around Red Tarn [362 160] to [350 155]. The peat typically lies directly on the bedrock but locally lies on till or hummocky moraine deposits. It is usually between 0.5 and 1 m thick.

Scree deposits are typically clast-supported and generated by grain flow. Patches of active scree occur on many of the steep slopes and below large crags exposed in the survey area. The most significant developments are around Red Tarn ([351 151] and [351 157]) and the 'Glenridding Screes' which extend along most of the northern slopes of Glenridding valley. Patches of inactive vegetated scree are present on the north side of Glencoyne valley [367 191] and on the east side of Glenridding Dodd [386 175] where it is hidden in thick woodland.
Debris cones mainly occur down slope from deep gullies associated with major fault zones. The fractured rock fragments are washed out of the gully, building high profile matrix-supported deposits below. Debris cones occur on the north and south sides of Glencoyne valley [380 188] and [375 184].

Head deposits are locally abundant on steep glaciated slopes (e.g. [354 169]). They comprise mainly gravel derived from the solifluction of till deposits or as hillwash.

Landslip has occurred along Grisedale Beck [388 159] where the meandering stream has cut into steep banks of till overlying well cleaved siltstone and sandstone of the Esk Pike Formation.

7.4 ARTIFICIAL DEPOSITS

The long history of the Greenside Mine resulted in the formation of large spoil heaps in Glenridding valley. Attempts were made to vegetate these piles of mine waste as early as 1940 but the attempts were unsuccessful. In the mid 1950s sewage was sprayed across the heaps and this enabled some plant life to take a hold (Adams, 1995), but despite this the sides of the vast heaps are still largely barren of life. Smaller spoil heaps occur at a higher elevation, near the southern limit of the Greenside vein and also at the adit at the head of Glencoynedale. Locally the Greenside vein has been quarried from above, leaving deep steep-sided pits (e.g. [359 181]).
On the slopes above Patterdale village there are numerous small quarries, pits, adits and minor tips left by the removal of cleaved siltstone and sandstone of the Borrowdale Volcanic Group for building purposes. There are also a number of small quarries and tips on Keldas, south of Glenridding where cleaved siltstones were quarried as slate.

Appendix 1

THIN SECTIONS

The following samples are representative of the lithologies in the Glenridding area and are included in the English Sliced Rock Collection of the BGS.

BGS Section No.	Grid Ref.	Locality	Lithology
E71134	NY 3570 1611	SL 16	sandstone
E71135	NY 3580 1610	SL 19	dacite autobreccia
E71136	NY 3586 1637	SL 21	lapilli-tuff
E71137	NY 3586 1637	SL 22	coarse sandstone
E71138	NY 3620 1676	SL 31	basaltic andesite
E71139	NY 3507 1673	SL 45	lapilli-tuff
E71140	NY 3696 1814	SL 61	sandstone
E71141	NY 3687 1780	SL 62	quartz microgranite
E71142	NY 3730 1685	SL 75	volcanic breccia
E71143	NY 3652 1694	SL 78	andesite
E71144	NY 3677 1697	SL 79	tuff/lapilli-tuff
E71145	NY 3655 1604	SL 81	lapilli-tuff/ breccia
E71146	NY 3534 1670	SL 82	basaltic andesite
E71147	NY 3530 1676	SL 84	andesite
E71148	NY 3509 1695	SL 85	tuff/sandstone
E71149	NY 3509 1695	SL 85	tuff/sandstone
E71150	NY 3543 1598	SL 89	lapilli-tuff
E71151	NY 3524 1603	SL 92	dacite
E71152	NY 3518 1607	SL 93	dacite
E71153	NY 3624 1718	SL 96	andesite
E71154	NY 3637 1716	SL 97	andesite
E71155	NY 3643 1718	SL 100	andesite
E71156	NY 3659 1710	SL 101	tuff
E71157	NY 3682 1694	SL 103	lapilli-tuff
E71158	NY 3661 1695	SL 104	andesite
E71159	NY 3653 1686	SL 105	tuff/sandstone
E71160	NY 3721 1660	SL 109	dacite autobreccia
E71161	NY 3698 1851	SL 110	dacite
E71162	NY 3753 1625	SL 112	andesite

BGS Section No.	Grid Ref.	Locality	Lithology
E71163	NY 3790 1608	SL 119	tuff/sandstone
E71164	NY 3774 1598	SL 120	tuff/lapilli-tuff
E71165	NY 3522 1652	SL 42	mica microgranite
E71166	NY 3698 1851	SL 110	dacite
E71460	NY 3747 1681	SL 77	gt andesite
E71461	NY 3716 1646	SL 123	dacite
E71462	NY 3720 1636	SL 124	basaltic andesite
E71463	NY 3695 1518	SL 157	andesite
E71464	NY 3870 1646	SL 144	andesite
E71465	NY 3851 1630	SL 148	andesite
E71466	NY 3754 1590	SL 153	lapilli-tuff
E71467	NY 3754 1575	SL 154	eutaxitic lapilli-tuff
E71468	NY 3805 1741	SL 159	andesite lava/tuff
E71469	NY 3620 1760	SL 2	basatic andesite
E71470	NY 3852 1766	SL 170	tuff
E71471	NY 3847 1766	SL 170	andesite
E71472	NY 3619 1863	SL 182	andesite
E71473	NY 3612 1861	SL 184	basalt
E71474	NY 3721 1930	SL 194	andesite
E71475	NY 3867 1766	SL 205	andesite
E71476	NY 3848 1779	SL 207	andesite
E71477	NY 3753 1903	SL 229	andesite
E71478	NY 3740 1999	SL 228	andesite
E71479	NY 3640 1993	SL 236	gt andesite/dacite
E71480	NY 3788 1967	SL 242	lapilli-tuff
E71481	NY 3637 1829	SL 261	andesite
E71482	NY 3637 1829	SL 261	basalt
E71483	NY 3570 1991	SL 311	gt andesite
E71484	NY 3612 1861	SL 184	andesite
E71485	NY 3612 1905	SL 321	andesite
E71486	NY 3633 1920	SL 232	gt dacite
E71487	NY 3671 1914	SL 322	gt andesite
E71488	NY 3598 1895	SL 323	andesite
E71489	NY 3770 1702	SL 326	andesite
E71490	NY 3822 1732	SL 329	dacite

Appendix 2

INFORMATION SOURCES

Old series 1:10 560 Geological maps
Cumberland Series 65.
Westmorland Series 12.

New Series 1:10 000 Geological map
NY 31 NE (field slips and standard).

1:50,000 -scale sheet
Keswick. England and Wales Sheet 29. Solid and Drift geology editions, 2000.

Field notes
Field notes covering the area mapped are archived at BGS.
NY 31 NE SL1 –299.

Mine plans

The British Geological Survey holds mine plans of Greenside Mine together with notes and correspondence concerning the mine.

Geochemical data

The Geochemical Baseline Survey of the Environment (G-BASE) is based on the collection of stream sediment and stream water samples t an average density of one sample per 1.5 km^2. Fine fractions of the stream sediment samples are analysed for a wide range of elements.

Sample from the Lake District were collected in 1978-80. The analytical data for Ag, As, Ba, Be, Bi, B, CaO, Cd, Co, Cr, Cu, Fe2O3, Ga, K2O, La, Li, MgO, Mn, Mo, Ni, Pb, Rb, Sb, Sn, Sr, TiO2, U, V, Y, Zn, and Zr in stream sediments and pH, conductivity, fluoride, bicarbonate and U for stream waters are published in atlas form.

British Geological Survey, 1992. Regional geochemistry of the Lake District and adjacent areas. (Keyworth, Nottingham: British Geological Survey).

References

ADAMS, J. 1995. Mines of the Lake District Fells. 160 pp. Dalesman.

BEDDOE-STEPHENS, B. 1996. Mapping petrology and geochemistry of the Borrowdale Volcanic Group on 1:10 000 cheets NY21NE and NY21NW. Part of the 1:50k Sheet 29 (Keswick). *British Geological Survey; Mineralogy and Petrology Short Report, MPSR/96/16.*

BLUNDELL, D. J. 1994. Greenside Mining Accidents. *The Mine Explorer* (Journal of Cumbria Amenity Trust Mining History Society), 4, 73-75.

BOARDMAN, J. 1991. Glacial deposits in the English Lake District. 175-83 in Glacial Deposits in Great Britain and Ireland. EHLERS, J., GIBBARD, P.L. AND ROSE, J. (eds). (Rotterdam: Balkema).

BRITISH GEOLOGICAL SURVEY. 1996. Ambleside. England and Wales Sheet 38. Solid and Drift. 1:50 000. (Keyworth, Nottingham: British Geological Survey).

BRITISH GEOLOGICAL SURVEY. 1999. Keswick. England and Wales Sheet 29. Solid. 1:50 000. (Keyworth Nottingham: British Geological Survey).

BRITISH GEOLOGICAL SURVEY. (in press). Appleby. England and Wales Sheet 30. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey).

CAMPBELL, S. D. G. 1995. The Borrowdale Volcanic Group and related geology on 1:10,000 sheets NY32SW and SE. *British Geological Survey Technical Report*, WA/95/02.

COOPER, A. H., RUSHTON, A. W. A., MOLYNEUX, S. G., HUGHES, R. A., MOORE, R. M. AND WEBB, C. 1995. The stratigraphy, correlation, provenance and palaeogeography of the Skiddaw Group (Ordovician) in the English Lake District. *Geological Magazine*, 132, 185-211.

DAKYNS, J. R., TIDDEMAN, R. H. AND GOODCHILD, J. G. 1897. The geology of the country between Appleby, Ullswater and Haweswater. (Quarter Sheet 102SW). *Memoir of the Geological Survey of Great Britain.*ISBN.

EASTWOOD, T. 1921. The lead and zinc ores of the Lake District. Special Report on the Mineral Resources of Great Britain. *Memoir of the Geological Survey of Great Britain*, 22, ISBN.

FIRMAN, R. J. AND LEE, M. K. 1986. The age and structure of the concealed English Lake District batholith and its probable influence on subsequent sedimentation, tectonics and mineralisation. 117-127 in *Geology in the Real World - the Kingsley Dunham volume.* R. W. Nesbitt and J. Nichol (eds.) (London, Institution of Mining and Metallurgy).

GOUGH, D. 1965.Structural analysis of ore shoots at Greenside Lead Mine, Cumberland, England. *Economic Geology*, 60, 1459-1477.

GREEN, J. F. N. 1915. The structure of the eastern part of the Lake District*.* *Proceedings of the Geologists Association*, 26, 195-223.

HALLIDAY, A. N. 1977. K-Ar dating of mineralization episodes – a discussion. *Economic Geology*, 72, 870-871.

HARTLEY, J. J. 1941. The geology of Helvellyn and the southern part of Thirlmere. *Quarterly Journal of the Geological Society of London*, 97, 129-162.

HUGHES, R. A. 1995. The Skiddaw Group and its contact with the Borrowdale Volcanic Group in the Ullswater inlier. *British Geological Survey Technical Report*, WA/95/59.

INESON, R. A. AND MITCHELL, J. G. 1974. K-Ar isotopic age determinations from some Lake District mineral localities.*Geological Magazine*, 111, 521-537.

INESON, P. R. 1980. Conference Report. Dating mineralization. *Journal of the Geo;ogical Society of London*, 137, 101-102.

MCCONNELL, B. J. 1993. The Lincomb Tarns and Esk Pike Formations. *British Geological Survey Technical Report, WA/93/44*.

MILLWARD, D. 1998. Summary of the geology east of Thirlmere. Part of 1:10,000 Sheet NY31NW. Part of Keswick 1:50,000 Sheet 29 (England and Wales). BRITISH GEOLOGICAL SURVEY TECHNICAL REPORT, WA/98/17.

MILLWARD, D, BEDDOE-STEPHENS, B AND YOUNG B. 1999. Pre-Acadian copper mineralisation in the English Lake District. *Geological Magazine,* 136, 159-176.

MILLWARD, D. and 22 others. 2000. The geology of the Ambleside district. *Memoir of the British Geological Survey, Sheet 38 (England and Wales).*

MOSELEY, F. 1960. The succession and structure of the Boroowdale Volcanic rocks south-east of Ullswater. *Quarterly Journal of the Geological Society of London*, 116, 55-84.

MOSELEY, F. 1964. The succession and structure of the Borrowdale Volcanic rocks north-west of Ullswater. *Geological Journal*, 4, 127-142.

PETTERSON, M. G., BEDDOE-STEPHENS, B., MILLWARD, D., AND JOHNSON, E. W. 1992. A pre-caldera plateau-andesite field in the Borrowdale Volcanic Group of the English Lake District. Journal of the Geological Society of London, 149, 889-906.

RUNDLE, C. C. 1981. The significance of isotopic dates from the English Lake District for the Ordovician-Silurian time-scale. *Journal of the Geological Society of London*, 138, 569-572.

SISSONS, J. B. 1980. The Loch Lomond Advance in the Lake District, northern England. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, 71, 13-27.

STANLEY, C. J. AND VAUGHAN, D. J. 1982. Copper, lead, zinc and cobalt mineralisation in the English Lake District: classification, conditions of formation and genesis. *Journal of the Geological Society of London*, 139, 569-579.

WADGE, A. J. 1972. Sections through the Skiddaw-Borrowdale unconformity in eastern Lakeland. *Proceedings of the Yorkshire Geological Society*, 39, 179-198.

WADGE, A. J., MC NUTT, M. J. C., SKEVINGTON, D. 1972. Geology of the Tarn Moor Tunnel in theLake District. *Bulletin of the Geological Survey of Great Britain*, 41, 55-73.

WARD, J. C. 1876. The geology of the northern part of the English Lake District. *Memoir of the Geological Survey of Great Britain*. ISBN.

WOODHALL, D. G. 1998. The Geology of Wythburn, Thirlmere and Fairfield areas of the north-eastern Lake District. *British Geological Survey Technical Report, WA/98/07*

WOODHALL, D. G. 2000. Geology of the Keswick district. *Sheet description of the British Geological Survey,* 1:50,000 Series Sheet 29 Keswick (England and Wales) 48pp.

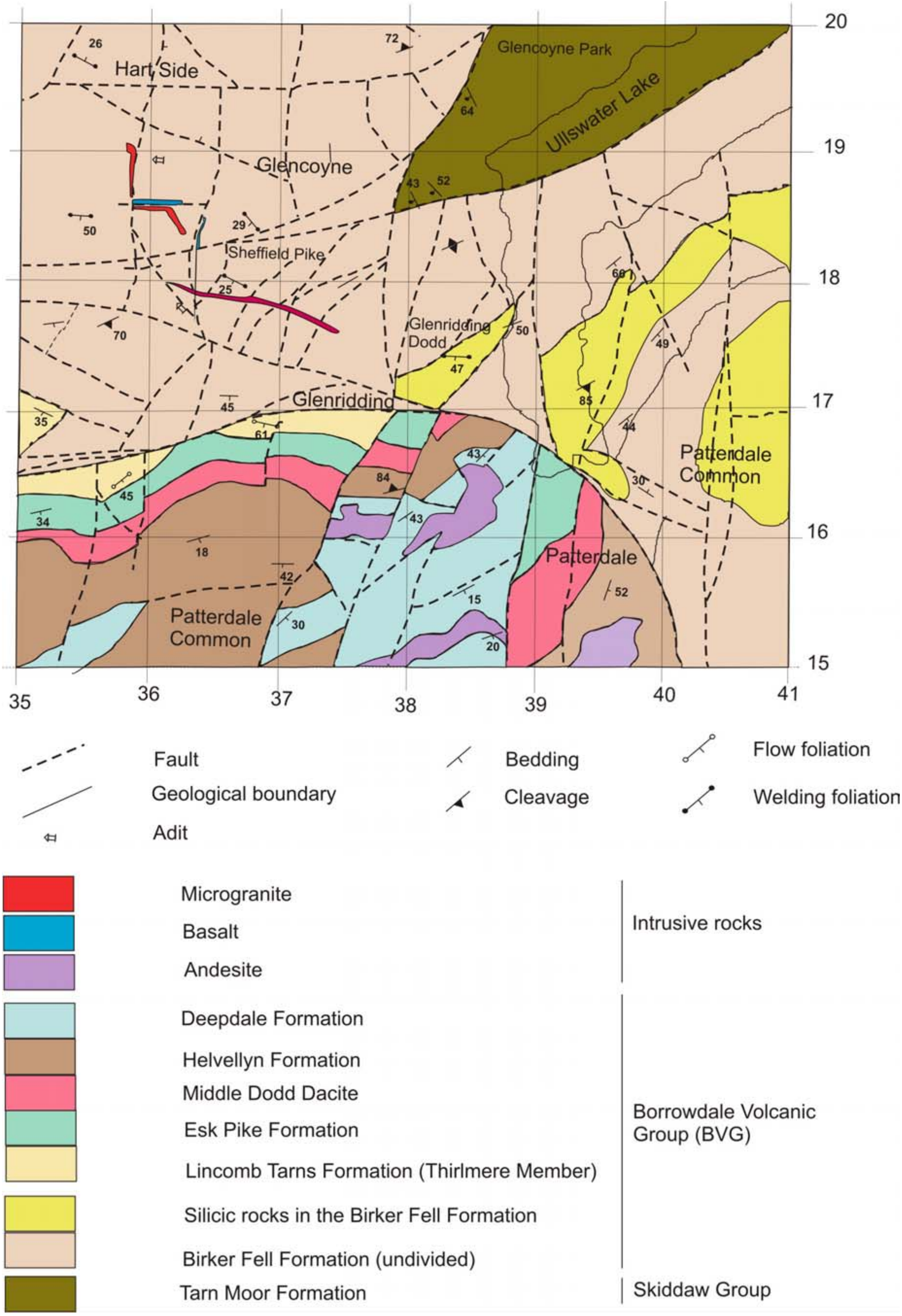

Fig. 1 . Sketch geological map of sheet NY31NE and part of NY41NW.

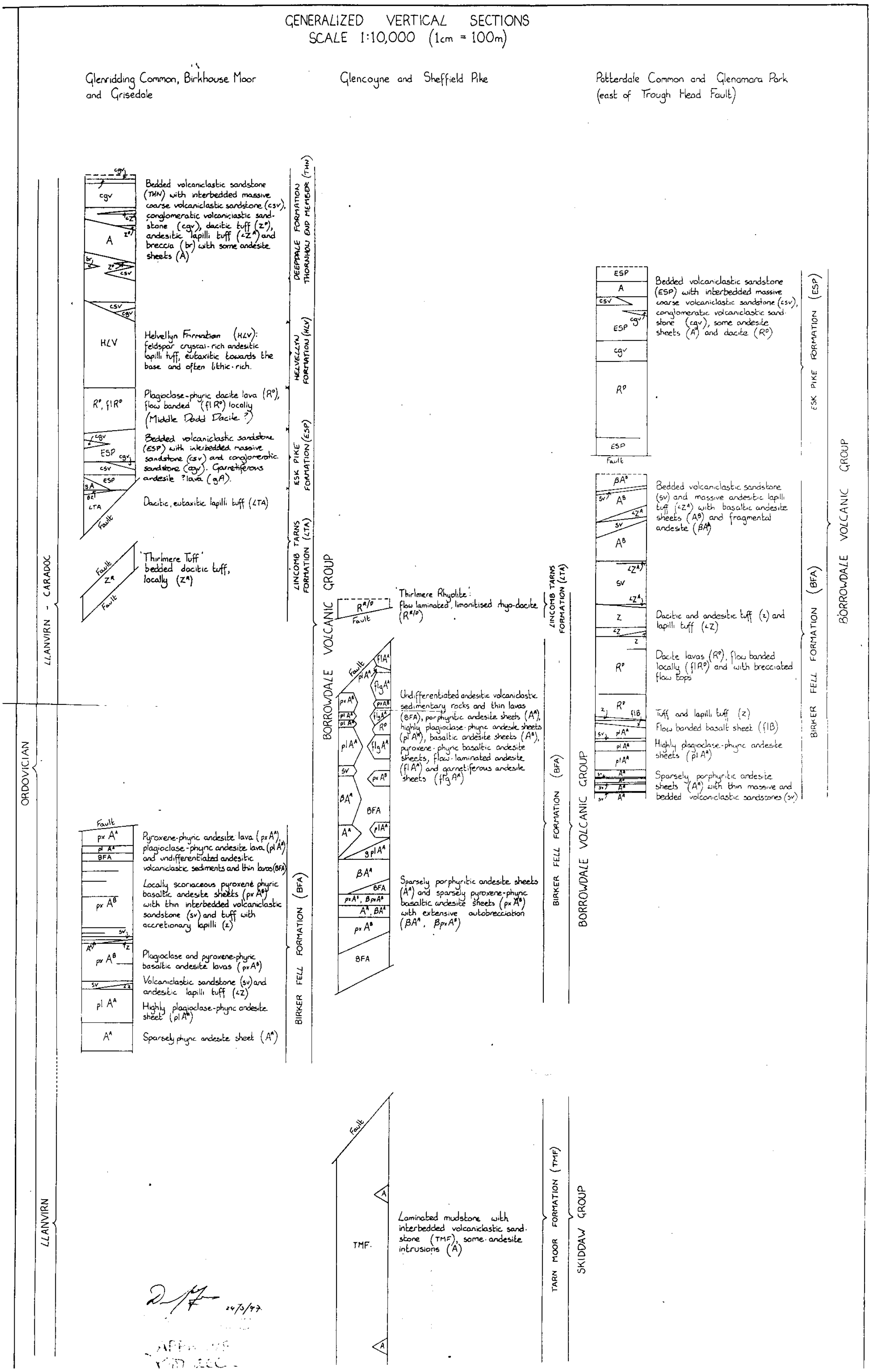

Fig. 2. Generalised vertical sections of sheet NY31NE.

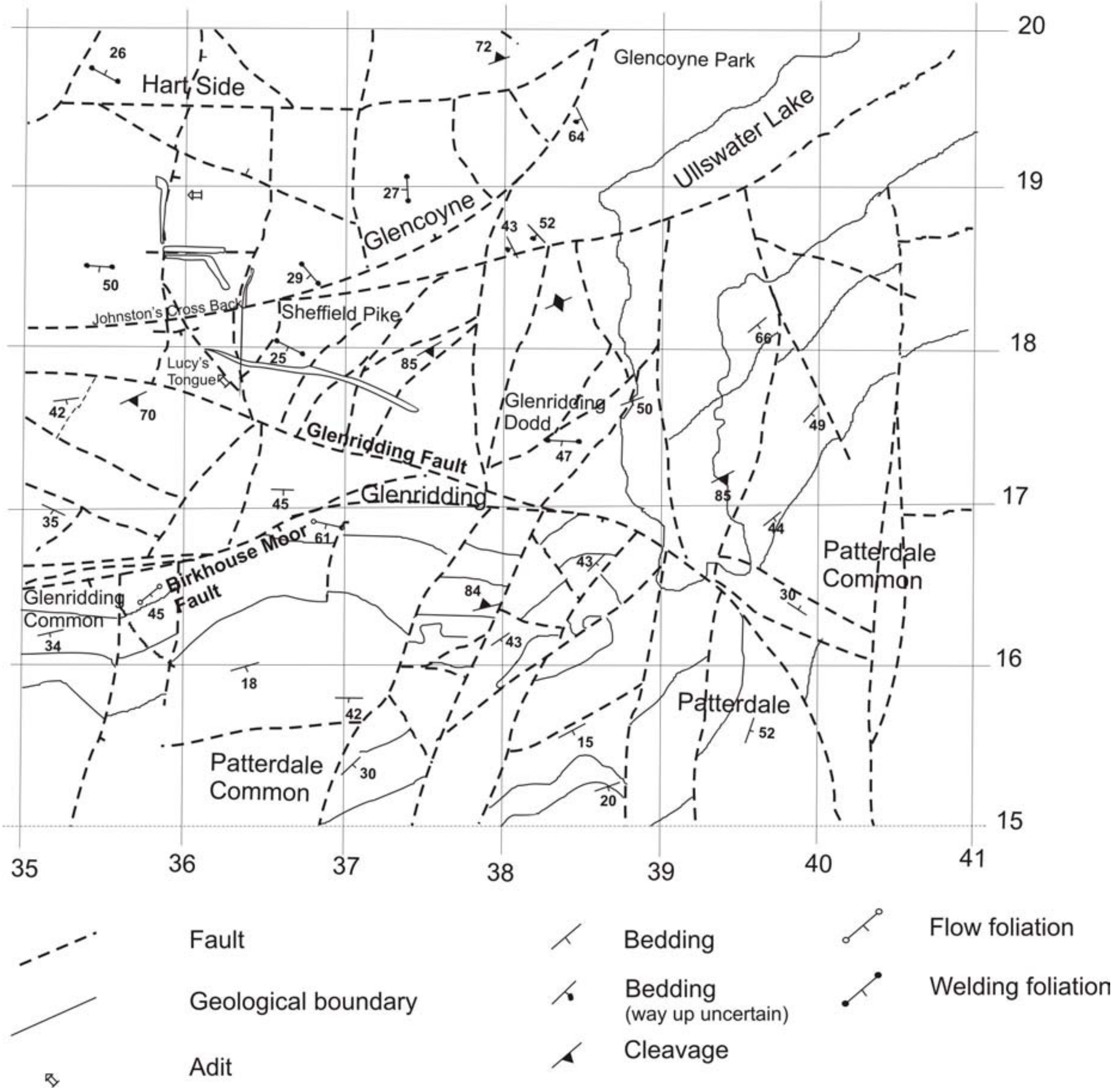

Fig. 3. Structure of sheet NY31 NE and part of NY41NW.