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A stratigraphical framework for the upper Ordovician and Lower Devonian volcanic and intrusive rocks in the English Lake District and adjacent areas

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Research Report RR/01/07

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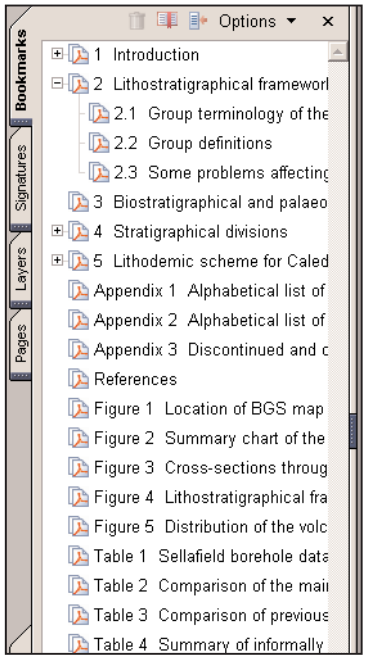

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BRITISH GEOLOGICAL SURVEY

RESEARCH REPORT RR/01/07

A stratigraphical framework for the upper Ordovician and Lower Devonian volcanic and intrusive rocks in the English Lake District and adjacent areas

D Millward

Keywords

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Front cover

View over the Scafell Caldera. BGS Photo D4011.

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D G Woodhall
B Beddoe-Stephens

Development of the lithodemic scheme for the intrusive rocks has resulted directly from the huge effort put into the preparation of the Geological Conservation Review volume '*Caledonian Igneous Rocks of Great Britain*', led by D Stephenson. I am grateful to D Stephenson for many hours of helpful discussion on the application of a formal lithodemic scheme to the Lake District rocks.

The report has been edited by P Stone and has benefitted from the comments from members of the BGS Stratigraphy Committee and from external reviews by P Brenchley and A J Reedman on behalf of the Geological Society of London's Stratigraphy Commission.

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Summary

This Research Report discusses the lithostratigraphical framework of all the Lower Palaeozoic volcanic and intrusive rocks in the English Lake District, and their correlatives in the nearby Cross Fell and Teesdale inliers. The volcanic rocks belong to three of the major groups recognised in the Lake District: Eycott and Borrowdale Volcanic groups, and the Windermere Supergroup. Summary definitions of more than 40 constituent formations and the many more members are given. The BGS map and Stratigraphical Lexicon codes for all the units are given in appendices.

The large number of formations present within a subaerial volcanic unit such as the Borrowdale Volcanic Group is difficult to summarise within a formal lithostratigraphical framework. Thus, an attempt is made to group formations into informal groupings with recognised associations through their eruptive or depositional histories. These are referred to in this report as 'successions' and ten are proposed.

A lithodemic scheme for the intrusive igneous rocks of the area is presented, based on work carried out in preparation for the Geological Conservation Review series publication on the Caledonian Igneous Rocks of Great Britain. The plutonic rocks and minor intrusions in northern England are grouped within a number of suites under the umbrella of the Caledonian Igneous Supersuite, which includes all intrusive igneous rocks associated with events that led to the Caledonian Orogeny.

The schemes presented are a contribution to the stratigraphical framework report for the Ordovician and Silurian rocks of northern England and are regarded as an essential precursor to any process-orientated account of the Lower Palaeozoic magmatism within the Lake District. This overview was undertaken as one of the concluding products of the Regional Geological Survey of the Lake District which lasted from 1981 until 1999.

1 Introduction

This report summarises the upper Ordovician volcanic stratigraphy in the English Lake District, and its probable correlatives in the nearby Cross Fell, Cautley, Dent, Craven and Teesdale inliers. It also introduces a lithodemic scheme for the Lower Palaeozoic intrusive igneous rocks of the region. These igneous rocks were emplaced at the margin of Eastern Avalonia during closure of the Iapetus Ocean and the subsequent collision with Laurentia-Baltica which resulted in the Acadian Orogeny. The schemes presented herein and summarised in Fortey et al. (2000) and by Millward (2002), are intended as a contribution to the stratigraphical framework report for the Ordovician and Silurian rocks of northern England and are regarded as an essential precursor to any process-orientated account of the Lower Palaeozoic magmatism within the Lake District. The overview is based on the modern 1:10 000-scale geological mapping undertaken by the British Geological Survey as part of the Lake District Regional Geological Survey from 1981 until 1999.

The primary survey, from 1860 until 1890, produced the first complete geological maps of the Lake District.

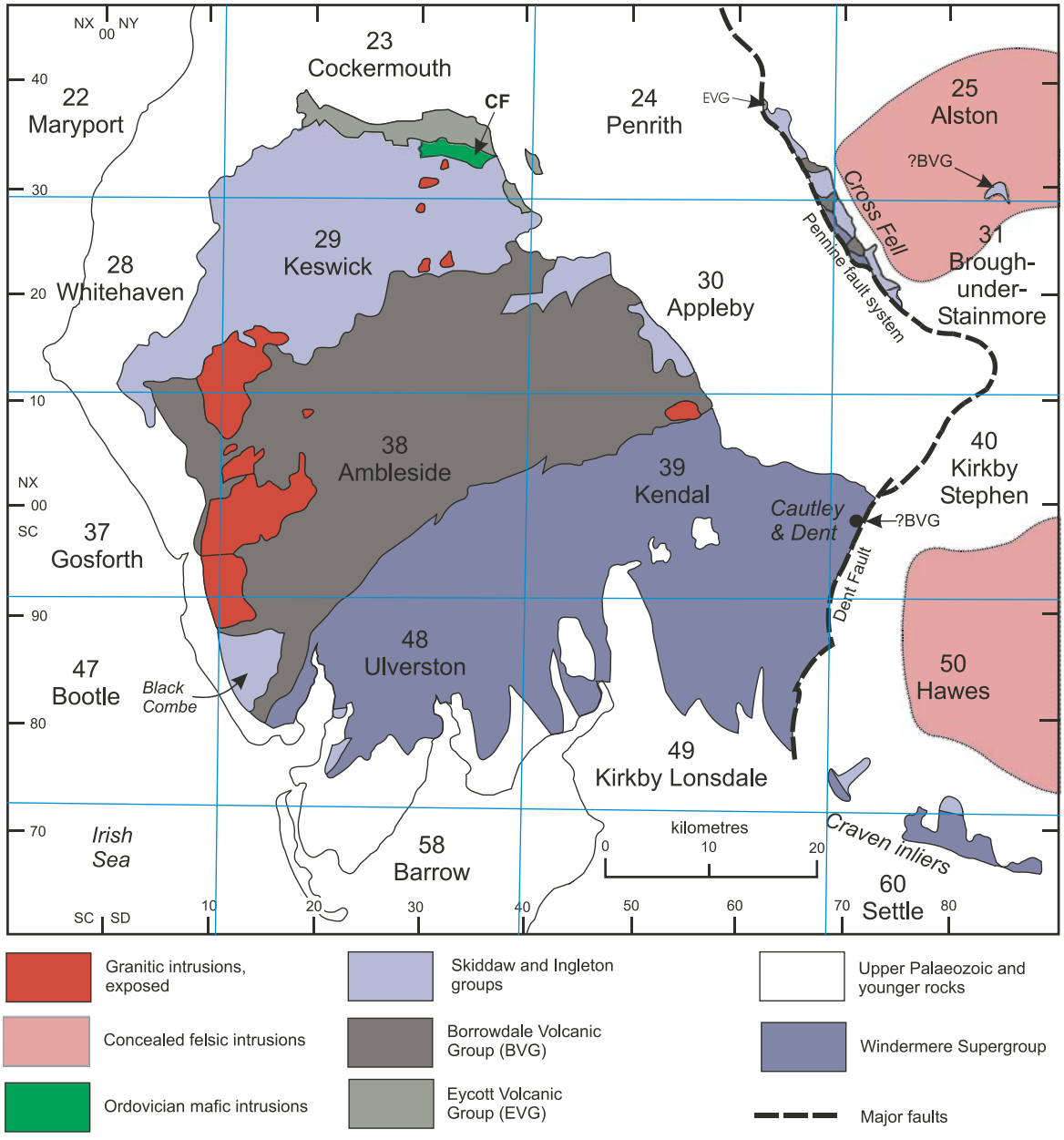

Figure 1 The Lake District Lower Palaeozoic Inlier, showing the outcrops of the Skiddaw, Eycott Volcanic and Borrowdale Volcanic groups, the Windermere Supergroup, and major igneous intrusions. BGS 1:50 000 geological sheets are overlain.

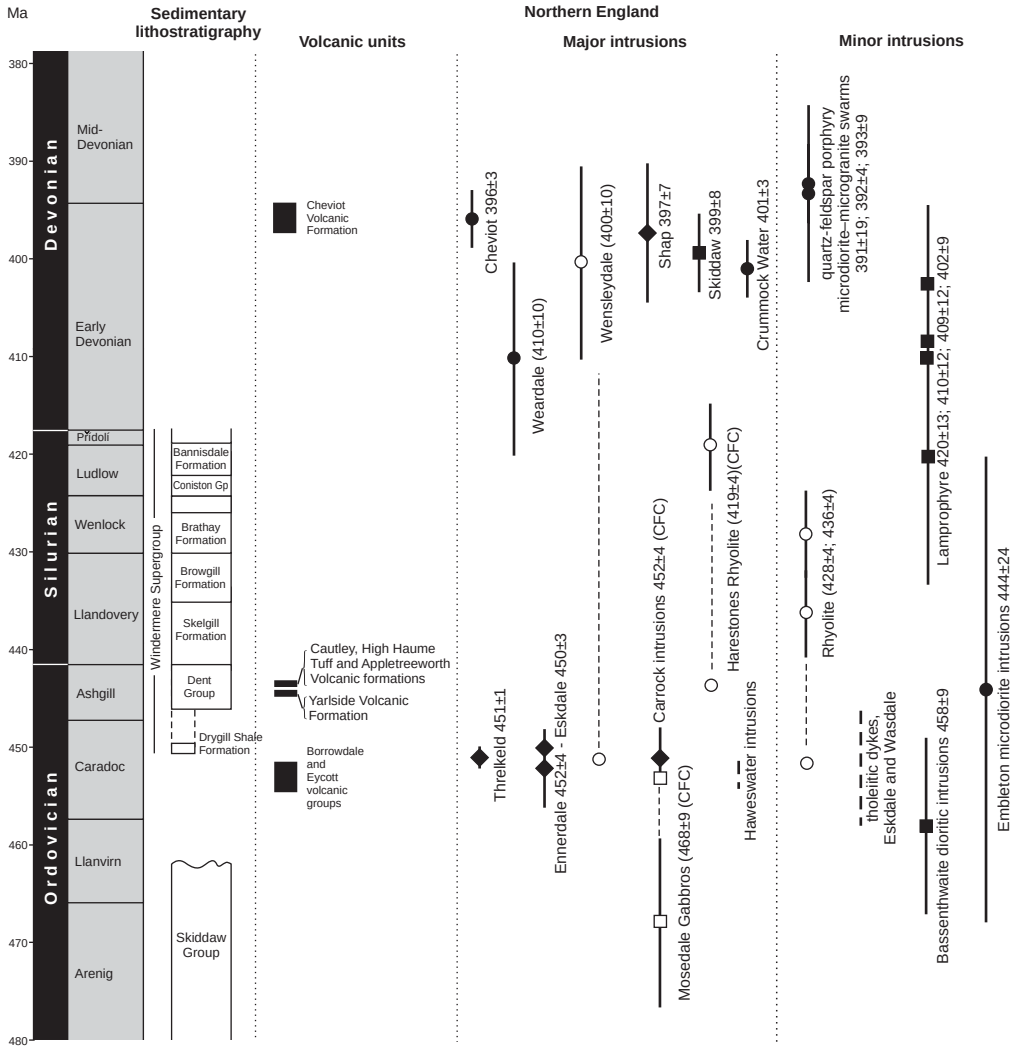

Figure 2 Summary chart showing the stratigraphical distribution and radiometric ages of igneous rocks in northern England. Radiometric dates are in Ma with errors quoted as 2 standard deviations: diamonds U-Pb, circles Rb-Sr, squares K-Ar. Open symbols represent radiometric data for igneous bodies, the ages of which are considered to have been reset; the inferred emplacement age is shown without errors. No radiometric ages have been determined for the Haweswater Intrusions and the tholeiitic dykes. See text for explanation of the inferred ages of Wensleydale Intrusion, Mosedale Gabbros and Harestones Rhyolite. The age of the Weardale Intrusion has been recalculated using more recent constants; the rhyolite minor intrusions are geochemically similar to the Ennderdale Intrusion (Millward et al. 2000a). CFC Carrock Fell Complex. Modified from Millward (2002).

However, it was some time before Marr (1900) and Green (1919), among others, applied a formal lithostratigraphy. During the ensuing 50 years almost all of the Borrowdale Volcanic Group was reinvestigated and major advances in the understanding of the lithostratigraphy were made by such notable researchers as J J Hartley, G H Mitchell and R L Oliver. In most of their works, a local lithostratigraphy was established for each area, each with its own terminology. In many cases precise correlation with adjacent areas was not made. Further, the complex, isoclinal fold model for the volcanic rocks proposed by Green (1920) strongly influenced lithostratigraphical interpretation. For example, Mitchell's (1940) interpretation of the Coniston area is difficult to reconcile with his later contributions on the Dunnerdale and Seathwaite fells (1956a, 1963) (see Millward and Soper, 2000). Attempts at resolving correlation problems between areas have been made by Mitchell (1956b), Millward et al. (1978) and Moseley and Millward (1982), though the plethora of local names was rationalised in the recent publication of the Ambleside memoir (Millward et al., 2000a). The Borrowdale Volcanic Group-wide lithostratigraphical models produced by Millward et al. (1978), and Moseley and Millward (1982) were not based on new field surveys and contained much uncertainty caused mainly by the lack of fossiliferous strata, the lateral impersistence of many units and the complex faulting. The presence of many sills, previously identified as lavas and ascribed to stratigraphical formations poses further limits on these models (Branney and Suthren, 1988).

It is clear from previous work that abrupt variations in facies and thickness present a severe test in setting up a usable, unified stratigraphy across the inlier. Thus, the British Geological Survey mapping programme has provided a unique opportunity to establish a coherent stratigraphy of the volcanic successions and to provide a

sound basis for interpretation of their facies. As a result of progress in the western part of the Lake District, there have been considerable advances in the understanding of Caradoc magmatism on the northern flanks of Avalonia in late Ordovician times (e.g. Petterson et al., 1992; Branney and Kokelaar, 1994; Beddoe-Stephens et al., 1995). Moreover, the work has a wider significance than the Lake District, because preservation of such subaerial volcanic successions in the geological record is unusual. The contribution made, for example by Branney and Kokelaar (1994), to the understanding of caldera development was fundamentally based on a stratigraphical approach.

1.1 SCOPE

1.1.1 Geographical coverage

The area considered in this report is the English Lake District and Cross Fell, in Cumbria. The resurvey of the major outcrops of igneous rocks in the Lake District by the British Geological Survey and its collaborators in several British universities started in 1981 and was completed in 1999; the area is covered by eight 1:50 000 geological maps (Figure 1). Resurvey of the Cross Fell area was carried out from 1963 to 1967; it has not been re-examined and recommendations in this report are taken from published works. Lower Palaeozoic volcanic rocks are also known to occur in the Teesdale inlier of the northern Pennines and in the Cautley, Dent and Craven inliers.

1.1.2 Stratigraphical scope

Volcanic rocks in the Lake District and Cross Fell form two major, middle Ordovician volcanic successions, fomalised as the Eycott and Borrowdale volcanic groups. Lower Palaeozoic volcanic rocks are also known to occur in the Teesdale inlier of the northern Pennines and these are taken to be part of the Borrowdale Volcanic Group (Dunham, 1990). Relatively thin volcanic formations representing the waning stages of Ordovician volcanism in northern England are also present within the overlying Dent Group, which forms the lower part of the Windermere Supergroup (Figure 2).

A lithodemic scheme for the intrusive igneous rocks is proposed in Chapter 5 of this report. This is part of a framework for all igneous rocks within the British Caledonides and is based on contributions made to the Geological Conservation Series Volume 17 which covers these rocks (Stephenson et al., 1999; Millward, 2002).

2 Lithostratigraphical framework

Lower Palaeozoic volcanic rocks in the Lake District are represented principally by two lithostratigraphical units, the Eycott and Borrowdale volcanic groups. They form a major part of the sequence and contrast starkly with the marine sedimentary successions above and below, and from which they are separated by major, regional, unconformities (Wadge, 1978; Millward and Molyneux, 1992). In the northern part of the inlier the Eycott Volcanic Group has an outcrop of about 50 km^2 and a thickness of 3200 m (Millward et al., 1999, 2000b). The much thicker Borrowdale Volcanic Group (with a composite thickness of probably more than 6000 m) has an outcrop area of about 750 km^2. These figures compare with about 530 km^2 and at least 5000 m for the underlying Skiddaw Group, and 1050 km^2 and more than 8000 m for the overlying Windermere Supergroup respectively. The Skiddaw Group and Windermere Supergroup were each deposited over about 40 Ma, but the volcanism may have lasted for less than 5 Ma (Piper et al., 1997; Millward and Evans, 2003). A number of minor volcanic units are included within the Windermere Supergroup (Kneller et al., 1994).

2.1 GROUP TERMINOLOGY OF THE VOLCANIC DIVISIONS

Until relatively recently, the volcanic rocks of the northern and central Lake District were considered to be part of a single unit which was originally referred to by Sedgwick (1832) and Aveline and Hughes (1872) as the 'Green Slates and Porphyries', and then successively as the 'Lower Silurian Volcanic Series' of Borrowdale by the Geological Survey (Ward, 1876; Aveline and Hughes, 1888), 'Borrowdale Series' by Marr (1916) and 'Borrowdale Volcanic Series' by Dakyns et al. (1897) and Green (1920). More than 50 years later the name was changed from 'Series' to 'Group' as required by modern lithostratigraphical usage (Wadge, 1978; Moseley, 1984). Nomenclature of the small number of volcanic units within the younger Windermere Supergroup herein generally follows the recommendations of Kneller et al. (1994).

Fitton and Hughes (1970) first recognised that the rocks forming the Eycott Volcanic Group are geochemically distinct from the rest of the Borrowdale Volcanic Group, but it was Downie and Soper (1972) who first used the term 'Eycott Volcanic Group'. Wadge (1978) shortened the name to 'Eycott Group', incorporating parts of the Skiddaw Group considered by him to be the same age as the volcanic rocks; this included the Tarn Moor Formation and mudstones in the Ullswater, Bampton, Furness and Millom inliers. Moseley (1984) did not support such a chronostratigraphical approach, preferring the lithostratigraphical definition set out by Downie and Soper. The original definition of the Eycott Volcanic Group is recommended in this report, as argued by Millward et al. (1999, 2000b), though new subdivisions replacing the Binsey and High Ireby formations of Downie and Soper (1972) are preferred.

Moseley (1984) considered it important to maintain a uniform approach to the overall lithostratigraphy within the Lake District Lower Palaeozoic inlier. He thus resisted the temptation to consider the 'Borrowdale Volcanic Group' as a supergroup, despite previous use of the term 'group' for parts of the succession (e.g. Ullswater Group, Marr, 1900; Airy's Bridge Group, Oliver, 1961; Place Fell Group, Moseley, 1960). Recently, Kneller et al. (1994) established the mudstones and sandstone that overlie the volcanic rocks as the Windermere Supergroup. Although of similar thickness to the Windermere Supergroup, the volcanic rocks are restricted in distribution to the Lake District, Cross Fell and Teesdale, and do not have direct correlatives elsewhere in the Lower Palaeozoic of Great Britain. Thus, it is recommended herein that group status is retained for the volcanic rocks.

2.2 GROUP DEFINITIONS

2.2.1 Eycott Volcanic Group (EVG)

Distribution
Main outcrop in the northern Lake District from Bothel to the Caldbeck Fells; small inliers at Eycott Hill, Greystoke Park and Melmerby Fell (Cross Fell inlier).

Stratotype
Type area on Binsey [NY 2200 3500 to NY 2400 3600]. Reference area on Eycott Hill [NY 3800 2900 to NY 3950 3100].

Lithology
Dominantly sheets of andesite with some basalt and dacite; mostly considered to be lava flows, but with interbedded penecontemporaneous sills. Dacitic pyroclastic rocks of the Potts Ghyll Formation occur at the top of the group. Geochemically the volcanic rocks are characterised as medium K, and transitional between continental margin tholeiitic and calc-alkaline. The sequence also contains thin interbeds of volcaniclastic rocks. Basal tuffaceous sandstones constitute the Overwater Formation.

Lower boundary
Angular unconformity, with a profound change from deep marine mud-dominated sedimentary rocks of the Skiddaw Group, to volcanic rocks.

Upper boundary
Unconformably overlain by Carboniferous strata.

Thickness
Up to 3200 m.

Remarks
Originally included within the Borrowdale Volcanic 'Series' (e.g. Eastwood et al., 1968), but shown to be geochemically distinct from those rocks. Also included with Llanvirn mudstones within the Eycott Group of Wadge (1978). Lithologically very similar to the Birker Fell Formation of the Borrowdale Volcanic Group (Millward et al., 1999, 2000b). The Eycott Volcanic Group

rocks have geochemical characteristics that are transitional between calc-alkaline and tholeiitic.

References
Downie and Soper (1972); Wadge (1978); Millward and Molyneux (1992); Millward et al. (1999, 2000b).

Maps
Cockermouth (23), Penrith (24), Keswick (29).

2.2.2 Borrowdale Volcanic Group (BVG)

Distribution
Extensive outcrop forming the craggy fells of the central Lake District, extending south-west to Millom Park; also crops out within the Furness inliers and the faulted inliers in Cross Fell and Teesdale. A small exposure of purple andesite in a stream north-north-east of Foggygill Farm [SD 722 988] in the Murthwaite Inlier at Cautley also probably belongs to the Borrowdale Volcanic Group. A concealed succession has been proved in west Cumbria, beneath Carboniferous and Permo-Triassic cover rocks.

Stratotype
No stratotype specifically defined. Except for some borehole successions in west Cumbria (Millward et al., 1994), no major parts of the group are undesignated and thus definitions of component formations apply.

Lithology
Medium to high K, continental-margin calc-alkaline basalt, andesite, dacite and rhyolite volcanic association of lavas, sills and pyroclastic rocks. Includes abundant intercalations of volcaniclastic sedimentary rocks. Many of the units of intermediate and silicic lavas and pyroclastic rocks contain phenocrysts of almandine–pyrope garnet (Fitton, 1972).

Lower boundary
Taken at the regional unconformity where there is a profound change from the marine mudrock succession of the Skiddaw Group to volcanic strata. Over most of the region this coincides with the base of the Birker Fell Formation. However, in the west of its outcrop the base of the group is defined by the base of the Latterbarrow Sandstone Formation.

Upper boundary
Unconformity, defined by the base of the Windermere Supergroup.

Thickness
Probably in excess of 6000 m, though much less locally.

Reference
Moseley (1984); Millward et al. (1994, 2000a).

Maps
Penrith (24), Alston (25), Whitehaven (28), Keswick (29), Appleby (30), Brough-under-Stainmore (31), Gosforth (37), Ambleside (38), Kendal (39), Ulverston (48).

2.3 SOME PROBLEMS AFFECTING THE NATURE OF THE LITHOSTRATIGRAPHICAL FRAMEWORK

Subaerial volcanic sequences present a severe test of lithostratigraphical methodology (e.g. Fisher and Schminke, 1984). Interdigitation of units, the restricted nature of some units, lateral thickness and facies changes, and the presence of penecontemporaneous intrusions all contribute to complexity. Furthermore, correlation between areas is not always possible because of contemporaneous erosion, synvolcanic faulting and the interdigitation of products from contemporaneous adjacent volcanic centres.

The proposed lithostratigraphy of the Lake District volcanic rocks is centred upon widespread lithologically distinctive mappable units (Figure 3). Of particular value in this respect are the thick ignimbrite sheets which blanket the underlying formations: for example, the Airy's Bridge, Whelter Knotts, Froswick and Lincomb Tarns formations. However, only the last named unit is sufficiently widespread to be of value throughout the Lake District. Relative to other units within the sequences the ignimbrite units were formed during major eruptions and can be regarded geologically as almost instantaneous events. By contrast, the sheeted andesite successions that comprise most of the Eycott Volcanic Group and Birker Fell Formation (Borrowdale Volcanic Group) contain few units that are widespread enough to provide a coherent internal stratigraphy. These units are generally undivided on the geological maps, despite their very thick successions, for example, 2400 m for the undivided part of the Eycott Volcanic Group (see Cockermouth, Sheet 23) and 1800 to 2700 m for the Birker Fell Formation (Ambleside, Sheet 38). These units are discussed further below, along with two other significant aspects of the lithostratigraphy.

2.3.1 Andesite sheets

Tabular andesite sheets form a significant proportion of the Borrowdale and Eycott volcanic groups. Interpretation of these bodies as lava or intrusion is of considerable stratigraphical significance. Stemming originally from Green's (1919) work comparing brecciated andesite in the group with modern, autobrecciated lava, most researchers have assumed that most of the sheets are lava (e.g. Firman, 1957; Oliver, 1961; Mitchell, 1963; Clark, 1964; Millward et al., 1978). However, Green was also in no doubt that many sills are present. The lava only interpretation was challenged by Branney and Suthren (1988) who documented a number of andesite sheets that showed evidence of near surface intrusion and proposed that sills might constitute a significant proportion of the succession.

Results from the Lake District Regional Geological Survey show that within volcaniclastic sedimentary units in the upper part of the Borrowdale Volcanic Group there are many andesite, basaltic andesite and dacite sills. Evidence for this is normally clear cut and this radically alters previous interpretations of the stratigraphy. One such example is the 'Wrengill Andesites', a unit that featured in many early accounts, which must now be an inappropriate lithostratigraphical division because most of its components are intrusions. The abundant andesite sills are not considered within this stratigraphical framework, though they contribute significantly to the development of the volcanic succession and are included within the lithodemic scheme for intrusive igneous rocks of the region.

Particular difficulty is presented by the sequence of tabular andesite sheets that constitutes the Birker Fell Formation. Petterson et al. (1992) and Beddoe-Stephens et al. (1995) concluded that, although sills are present in the formation, most of the sheets are lava. However, field evidence does not always provide a clear origin for each sheet, and opinions vary among workers as to the relative proportions of lava and sills. It is nevertheless important to recognise that a part of the

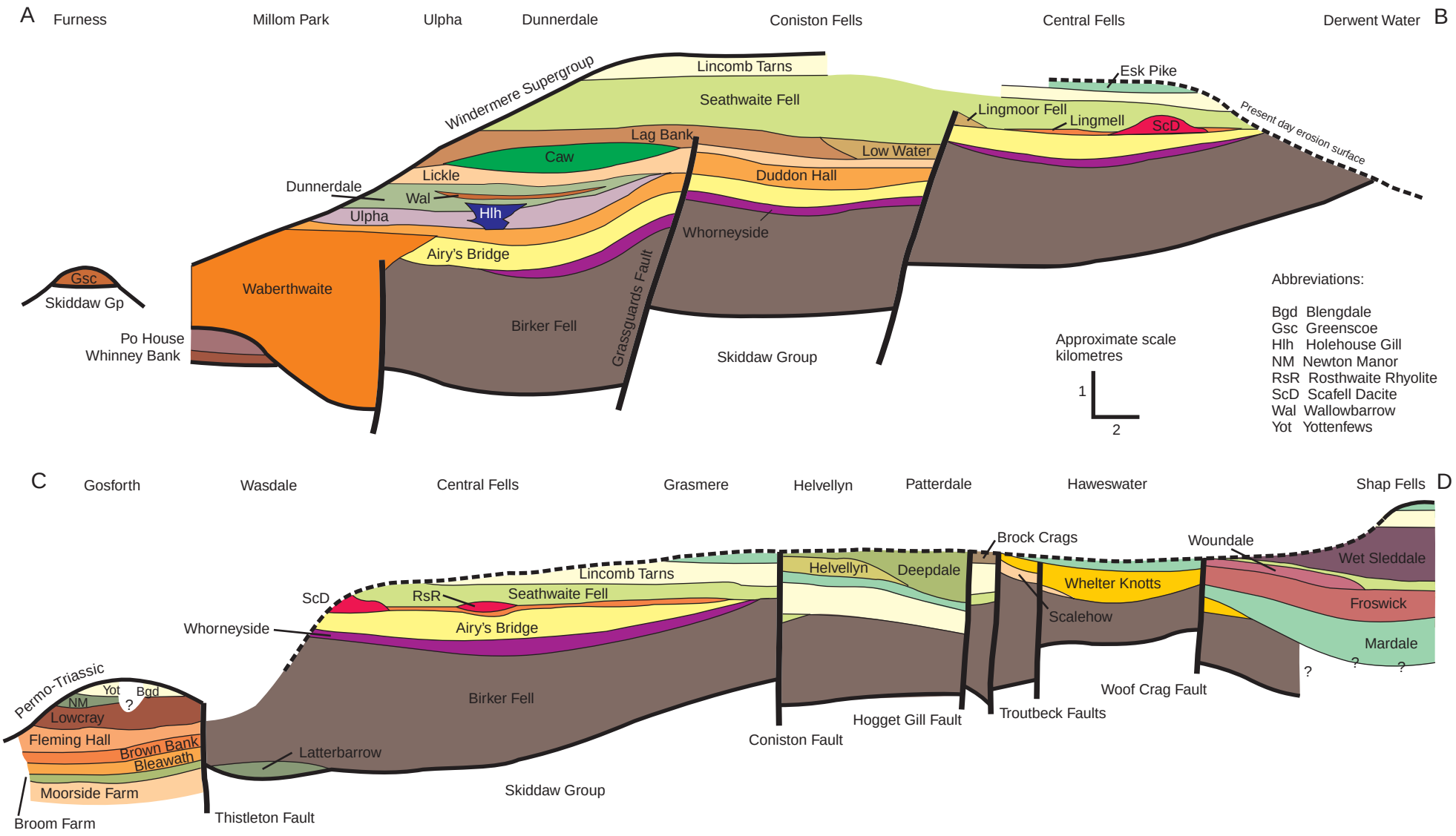

Figure 3 Generalised cross-sections through the BVG showing the relationships of the various lithostratigraphical units. Sills are omitted. All units shown are formations, except where stated otherwise. Approximate lines of cross-sections are shown in Figure 5.

Table 1 Sellafield borehole data.

Sellafield borehole number	BGS reference number	National grid reference [NY]	Elevation (m above OD)	Drilled length in BVG (metres)	Trajectory	Formations present
2	NY 00 SE 28	5543 3412	60.2	1143.5	Vertical	Fleming Hall, Brown Bank, Bleawath, Broom Farm, Moorside Farm
3	NY 00 SW35	2596 2646	9.1	329.5	Vertical	BVG undivided
4	NY 00 SE 29	5639 3457	68.6	848.3	Vertical	Fleming Hall, Brown Bank, Bleawath
5	NY 00 NE 30	5160 3872	80.6	770.2	Vertical	Fleming Hall, Brown Bank, Bleawath
7A	NY 00 SE 36	3857 4903	46.9	432.1	Vertical	Yottenfews, Newton Manor
8A	NY 00 SE 38	7208 4983	163	792	Vertical	Fleming Hall, ?Brown Bank
8B	NY 00 NE 30	7214 5015	163	67.9	Vertical	Lowcray, Fleming Hall
9A	NY 00 SE 43	8525 4269	116.4	485	Vertical	Fleming Hall, ?Brown Bank
10A	NY 00 SW 38	4312 3061	35.5	608.8	Vertical	Fleming Hall, Brown Bank, Bleawath
11A	NY 00 SE 34	6792 1663	44.6	207.2	Vertical	BVG undivided
12A	NY 00 SW 39	4934 2644	38.5	219.3	Vertical	Fleming Hall
13A	NY 00 SW 41	4521 0146	18.5	104.4	Vertical	BVG undivided
14A	NY 00 NW 451	2486 5692	41.2	200.9	Vertical	Newton Manor
RCF1	NY 00 SE 35	5795 3907	95.9	610.9	Deviated	Fleming Hall, Brown Bank
RCF2	NY 00 SE 36	5506 4170	94.9	616.6	Deviated	Fleming Hall
RCF3	NY 00 SE 37	5565 3932	84.5	463.5	Vertical	Fleming Hall, ?Brown Bank
RCM1	NY 00 SE 41	5568 3961	84.5	463.8	Vertical	Fleming Hall, Brown Bank
RCM2	NY 00 SE 40	5598 3942	84.5	462.4	Vertical	Fleming Hall, Brown Bank
RCM3	NY 00 SE 39	5785 3896	95.9	477.2	Deviated	Fleming Hall
PRZ1	NY 00 SE 45	5475 3425	60.2	216.5	Inclined	Fleming Hall
PRZ2	NY 00 SE 44	5661 3444	68.5	100.3	Inclined	Fleming Hall
PRZ3	NY 00 SE 42	5186 3852	84.9	186.7	Inclined	Fleming Hall

formation consists of sills. Beddoe-Stephens et al. considered the sills within the Birker Fell Formation succession to be co-magmatic and probably contemporaneous with the lavas.

2.3.2 Concealed volcanic rocks in west Cumbria

The existence of buried, pre-Carboniferous volcanic rocks in west Cumbria has been known for many years from borings, mainly for hematite exploration (Smith, 1924; Eastwood et al., 1931). However, the recent investigations near Gosforth, undertaken by Nirex as part of an assessment of that area as a possible site for the construction of an underground disposal facility for nuclear waste, have shown the presence of a complex volcanic lithostratigraphy, mostly concealed beneath Permo-Triassic and Carboniferous cover rocks (Bowden et al., 1998). More than 9800 m of volcanic rock cores were obtained from 22 of the 29 deep boreholes drilled; individual volcanic sequences varied from 67 m to 1143 m (uncorrected for dip) (Table 1; borehole locations are given in Akhurst et al., 1997, fig. 3). The cleaved volcanic rocks are considered to be part of the Borrowdale Volcanic Group (Millward et al., 1994; Akhurst et al., 1997). The stratigraphical sequences from many of these boreholes can be matched, at least in part, with the succession at outcrop east of Gosforth and in the Bleng valley (Akhurst et al., 1997). However, several boreholes contain volcaniclastic rocks that cannot be correlated with the successions proved at outcrop or even within other boreholes. Such sequences are seen for example in Sellafield 3, 11A and 13A boreholes and their stratigraphy remains undesignated at present (Table 1; Millward et al., 1994). It has been argued that the west Cumbria succession contains

some of the youngest units within the Borrowdale Volcanic Group (Akhurst et al., 1997).

2.3.3 Side Pike volcanic complex (SIPI)

Branney and Kokelaar (1994) described an exceptionally coarse and chaotic volcanotectonic megabreccia (sensu Lipman, 1984), covering an area of more than 5 km^2 between Great Langdale and Wrynose Pass [NY 280 057 to NY 300 030], as the Side Pike complex (see 1:50 000 Sheet 38, Ambleside, for location). This is bounded to the north and west by faults, and passes southward and eastward into structurally more coherent blocks cut by volcanotectonic faults. The megabreccia comprises blocks up to more than 500 m across, composed of a variety of pyroclastic and volcaniclastic sedimentary lithofacies associations. Many of the larger blocks have a coherent stratigraphy that can be matched with parts of the succession elsewhere. However, though the internal stratigraphy of some other large blocks can be correlated from one block to another, they cannot be matched with any part of the regional stratigraphy. These 'exotic' blocks were derived either from formations not otherwise preserved in the district, or from known formations with unrecorded local facies variations. The name 'Side Pike complex' is used on Sheet 38 (Ambleside) and is described in Millward et al. (2000a). Side Pike volcanic complex is a useful informal stratigraphical division and is therefore retained.

3 Biostratigraphical and palaeomagnetic correlation

In the Lake District, the age and time span of the Borrowdale Volcanic Group is poorly constrained between the Llanvirn Tarn Moor Formation (Skiddaw Group; Cooper et al., 1995) and the Ashgill (Cautleyan) Dent Group, and has been assigned customarily to the Llandeilian and early Caradoc interval (chronostratigraphy sensu Fortey et al., 2000). However, in the Cross Fell Inlier, silicic tuffs of the uppermost Borrowdale Volcanic Group are overlain by shelly siltstones of the '*corona facies*' at the base of the Dufton Shale Formation (Dent Group) (Burgess and Holliday, 1979). The faunas in the siltstones are Longvillian (upper Caradoc) and indicate an upper limit on the age of the volcanic sequence in that area.

Dark grey mudstone (Holehouse Gill Formation) from Holehouse Gill in the Ulpha valley (Figure 3), first reported by Numan (1974), contains an acritarch microflora that was interpreted as probably Caradoc (Harnagian–Soudleyan) in age by Molyneux (1988). Re-examination of the microflora in the light of recent work elsewhere now casts doubt on this interpretation (S G Molyneux, pers. comm. 2001). Thus, there is no biostratigraphically significant unit within the Borrowdale Volcanic Group.

The absolute age of the Borrowdale Volcanic Group is constrained by radiometric dates on the volcanic rocks of 457 ± 4 Ma (Sm-Nd on garnet-whole-rock pairs; Thirlwall and Fitton, 1983), and 451.0 ± 1.4 and 452.8 ± 0.73 Ma (U-Pb zircon; Millward and Evans, 2003). These are Caradoc according to the most recent comparative timescales (Compston, 2000; Fortey et al., 2000).

Biostratigraphical evidence for the age of the Eycott Volcanic Group comes from palynological assemblages recorded from the Overwater Formation at the base of the group by Downie and Soper (1972), and Millward and Molyneux (1992). The earliest Llanvirn (Abereiddian) age deduced by Downie and Soper (1972) could not be substantiated by Millward and Molyneux (1992), who concluded that the volcanic rocks could not be older than Llanvirn and might be Caradoc. At the eastern extent of the largest outcrop of the Eycott Volcanic Group is a small outlier of the Caradoc Dent Group; contacts of this unit, the Drygill Formation (Dean, 1963), are partly faulted and partly intrusive, but it is clearly younger than the volcanic rocks (Millward et al., 1999). Rundle (1979) obtained a K-Ar age of 468 ± 10 Ma for the Mosedale Gabbros (Carrock Fell Complex), which is considered by Hunter (1980) to be contemporaneous with the volcanic rocks. This date is within the error range of the Sm-Nd garnet age obtained from the Borrowdale Volcanic Group.

Palaeomagnetic data from both the Eycott and Borrowdale volcanic groups reported by Piper (1997) and Piper et al. (1997) show that the two groups exhibit uniform normal polarity and have a relatively strong and stable remanent magnetisation dominated by a single characteristic component acquired during cooling on emplacement. Together with the radiometric ages on the Borrowdale Volcanic Group, this strongly supports the hypothesis that the two groups were emplaced contemporaneously in Caradoc times during a period lasting no more than 5 Ma.

4 Stratigraphical divisions

The preferred stratigraphical divisions of the Eycott and Borrowdale volcanic groups and the volcanic units in the Windermere Supergroup in Cumbria are arranged below by group, in roughly ascending stratigraphical order. The stratigraphy of the Eycott Volcanic Group has been described in detail recently by Millward et al. (1999). The stratigraphical relationships within the Borrowdale Volcanic Group are illustrated in Figure 3. The volcanic units within the Dent Group of the Windermere Supergroup are shown in Figure 2.

The stratigraphy of the Borrowdale Volcanic Group is described in detail in the Ambleside and Ulverston memoirs with additions included in the Keswick sheet description (Millward et al., 2000a; Johnson et al., 2001; Woodhall, 2000a). Where possible, previously well established unit names in common usage are retained. Approximate comparison between the new and old units within the Borrowdale Volcanic Group is summarised in Tables 2 and 3. Superficially, these charts suggest that much of the previous lithostratigraphy remains little changed. However, considerable differences between old and new units are revealed. Old names are commonly redefined; for example, in part of the Seathwaite Fells, Mitchell's (1963) Kidson How Tuffs belong to the newly defined Whorneyside and Airy's Bridge tuff formations but, elsewhere, to the Low Water Tuff Formation. Furthermore, many of the definitions of the base of formations have changed. As a result of this revision it has been necessary to abandon some terms used previously.

More than 40 formations and a large number of members have been erected within the Borrowdale Volcanic Group. Informal groupings of formations into larger units have proved to be useful in the interpretation of the development of the volcanic succession. In their attempts at producing a unified lithostratigraphy for the Borrowdale Volcanic Group, Millward et al. (1978), and Moseley and Millward (1982) noted that the succession comprised two distinctive parts; a lower one comprising dominantly andesite lavas and an upper one of intermediate and silicic pyroclastic rocks, and volcaniclastic sedimentary rocks. This division is recognised throughout the entire outcrop and is referred to informally as the 'lower' and 'upper' Borrowdale Volcanic Group respectively.

In attempting to provide a framework for the interpretation of the development of the volcanic field Millward (2002) proposed ten informal groupings that he referred to informally as 'successions'. The definitions of these are set out in Table 4, which shows the constituent formations, the main lithofacies associations present, approximate thickness and the definitions of the base and top; a summary of the main styles of volcanic and/or sedimentary processes that occurred is also given. The relationships between the successions present in the central Lake District are shown diagrammatically in Figure 4 and the approximate distributions of all but the succession in Cross Fell in Figure 5.

A summary of the formal definitions of the volcanic lithostratigraphical units in the Lake District is given below. British Geological Survey Lexicon codes are given after the formal names. Appendices 1 and 2 list the lexicon and map codes for this succession. Appendix 3 gives a summary of unit names that are no longer required.

4.1 EYCOTT VOLCANIC GROUP

4.1.1 Overwater Siltstone Formation (OV)

Stratotype
Type section in the Overwater spillway, between the confluence of the River Ellen and the southern end of Chapelhouse Reservoir [NY 2582 3551].

Lithology
Grey, laminated siltstone and tuffaceous fine-grained sandstone with channel fills of sedimentary breccia. The formation is intruded by sills. Composed mostly of siliciclastic material; with minor reworked contemporaneous tephra.

Ranking
Locally, the basal division of the Eycott Volcanic Group.

Lower boundary
Defined by the base of the lowest bed of breccia or siltstone overlying the angular unconformity on the Skiddaw Group.

Upper boundary
Overlain locally by conglomerate or by basaltic andesite and andesite within the undivided part of the group.

Thickness
About 8 m in the type section, but up to 10 m elsewhere.

Remarks
Previously considered to be a passage sequence between the Skiddaw Group and overlying volcanic rocks; included previously within the now obsolete Binsey Formation. Occupies a similar position to the Latterbarrow Sandstone Formation at the base of the Borrowdale Volcanic Group.

References
Millward and Molyneux (1992); Millward et al. (1999).

Map
Cockermouth (23).

4.1.2 Potts Ghyll Tuff Formation (POG)

Stratotype
Type section in Gill Beck, 500 m upstream from Potts Gill (2.5 km south-south-west of Caldbeck) [NY 3189 3688 to NY 3190 3669].

Lithology
Massive vitroclastic and lithic-rich acid andesitic to dacitic lapilli-tuff (interpreted as non-welded ignimbrite).

Ranking
Locally the uppermost exposed division of the Eycott Volcanic Group.

Table 2 Comparison of the main lithostratigraphical classifications of the Borrowdale Volcanic Group in the western part of the Lake District (west of the Coniston Fault).

Formations used in this report	Coniston (Mitchell, 1940)	Dunnerdale (Mitchell, 1956a)		Seathwaite (Mitchell, 1963)		Wastwater to Duddon (Firman, 1957)	Langdale and Grasmere (Hartley, 1925, 1932)	Scafell (Oliver, 1961)
Tarn Hows								
Esk Pike								Esk Pike Hornstone
Lincomb Tarns	Yewdale Breccia						Felsitic & Basic Tuffs & Steel Fell Rhyolite	Lincomb Tarns Formation
Seathwaite Fell	Yewdale Bedded Tuffs							Seathwaite Fell Tuffs
	Wrengill Andesites @	Wrengill Andesites @		Wrengill Andesites @			Wrengill Andesites @	
	Upper Tilberthwaite Tuffs	Tilberthwaite Tuffs	White Pike Andesites	Tilberthwaite Group	White Pike & Dow Crag Andesites @		Bedded Tuffs	
			Walna Scar Quarries Tuffs		Walna Scar Quarries Tuffs			
Low Water					Kidson How Tuffs		Langdale Rhyolite	
Lag Bank			Lag Bank Tuffs		Lag Bank Tuffs			
Caw			Caw Tuffs		Caw Tuffs			
Lickle	Paddy End Rhyolites	Lickle Rhyolites		Lickle Rhyolites		Wallowbarrow Crag Group		
Dunnerdale		Dunnerdale Tuffs		Dunnerdale Group	Dunnerdale Tuffs	Duddon Hall Tuffs		
Wallowbarrow						Wallowbarrow Crag Group		
Ulpha		Ulpha Andesites (Bleamsley Bank flows)			Ulpha Andesites	Ulpha Andesites		
Holehouse Gill								
Duddon Hall	Lower Tilberthwaite Tuffs & Dow Crag Andesites	Ulpha Andesites (Ivenscar flows) & Duddon Bridge Tuffs		Dunnerdale Group		Duddon Hall Tuffs		
Waberthwaite						Waberthwaite Tuffs		
Lingmell							Langdale Rhyolite	Airy's Bridge Group
Airy's Bridge	Paddy End Rhyolites			Kidson How Tuffs		Waberthwaite Tuffs & Worm Crag Group		
Whorneyside								
Birker Fell				Cockley Beck Group & Seathwaite Tarn Andesites		Lower Andesites	Mosedale Andesites	Birker Fell Andesite Group

@ The Wrengill, Dow Crag and White Pike andesites are interpreted entirely as syn-Borrowdale Volcanic Group sills. Shaded areas indicate that the newly defined formation is either not present in the area or was not differentiated. After Millward et al. (2000a).

Table 3 Comparison of previous lithostratigraphical classifications of the Borrowdale Volcanic Group in the eastern Lake District with the recommended scheme.

Formation	Helvellyn (Hartley, 1941)	NW Ullswater (Moseley, 1964)	SE Ullswater (Moseley, 1960)	NW Hawes-water (Nutt, 1970)	SE Hawes-water (Nutt, 1970)	Kentmere (Soper and Numan, 1974)	Kentmere-Longsleddale (Mitchell, 1929)	Longsleddale & Shap (Mitchell, 1934)
Deepdale	Felsitic and Basic Tuffs Helvellyn Andesites[1]							
Helvellyn								
Brock Crag Andesite								
Middle Dodd Dacite								
Garburn						Garburn Formation	Upper Rhyolites & Upper Andesites[1]	Upper Andesites[1]
Esk Pike								
Lincomb Tarns	Thirlmere Rhyolite (intrusion)					Kentmere Formation	Coarse Tuffs	Coarse Tuffs
Wet Sleddale						Wren Gill Formation	Wrengill Andesites[1]	Wrengill Andesites[1] Bedded Tuffs
Kentmere Pike							Kentmere Pike Rhyolites	
Seathwaite Fell	Bedded Tuff with lava flow						Bedded Tuffs Harter Fell Andesites[1]	Wrengill Andesites Bedded Tuffs
Woundale						Nan Bield Formation[1]	Froswick Tuffs	
Froswick				Atkinson & Fordingdale Ignimbrite Groups				Froswick Tuffs
Mardale			Place Fell Group	Keasgill Tuffs Cawdale Tuffs	Bedded Tuffs Thorney Knott Andesites Hareshaw Tuffs, Nan Bield Andesites		Nan Bield Andesites[1]	Coarse Tuffs
Whelter Knotts				Atkinson & Fordingdale Ignimbrite Groups Stanegarth & Whelter Knotts Ignimbrite Groups	Hugh's Laithes Pike Ignimbrite Group Haweswater Ignimbrite Group			Bedded Tuffs Wrengill Andesites[1] Haweswater Rhyolites Froswick Tuffs
Scalehow			Birk Fell Group					
Birker Fell	Bedded Tuff with lava flow	Birk Fell Group Ullswater Group	Angle Tarn Andesites Ullswater Group	Lad Crags Andesites Bampton Howes Andesite Group Bampton Conglomerate	High Naddle Andesites Haweswater Dam Andesites Frith Crag Tuffs Scalebarrow Andesites			Wrengill Andesites Ralfland Forest Andesites

1 Most of the andesite in these units have been shown to be intrusions.
Shaded areas indicate that the newly defined formation is either not present in the area, or was not differentiated.

Table 4 Summary of informally defined lithostratigraphical successions within the Borrowdale Volcanic Group of the English Lake District.

Succession		Formation	Principal lithofacies and structure	Definition of base and top	Thickness	Volcanism and depositional history
Upper Borrowdale Volcanic Group	Cross Fell	Studgill, Knock Pike, Harthwaite ***(10)***	Stratified sequence of volcaniclastic sedimentary and pyroclastic rocks, with one major sheet of silicic lapilli-tuff	Base, not top, seen; occurs only within fault blocks	>1100 m	Volcaniclastic sedimentation, interspersed with sporadic pyroclastic eruptions; one major ignimbrite; contains some of the most chemically evolved ignimbrites in BVG
	Gosforth	Yottenfews, Blengdale, Newton Manor, Lowcray, Fleming Hall, Brown Bank, Bleawath, Broom Farm, Moorside Farm ***(9)***	Stratified sequence of andesitic and dacitic lapilli-tuff with subordinate volcaniclastic sedimentary rocks and andesite sills	Base not seen; overlain unconformably by Carboniferous or Permian strata; faulted contact to east with Lower BVG succession (Thistleton Fault)	>2500 m	Welded and high-grade ignimbrite sheets; some non-welded pyroclastic density current deposits; probably caldera-related; some mass-flow and tractional sediments with high-level sills; probably some of the youngest formations in BVG
	Helvellyn Basin	Garburn Dacite, Brock Crags, Middle Dodd Dacite, Deepdale, Helvellyn, Esk Pike, Tarn Hows ***(3, 6, 7)***	Stratified units of volcaniclastic sandstone and breccia, with subordinate pyroclastic units and a silicic lava	By base of Lincomb Tarns Formation; top not seen	At least 1600 m	Rapid mass-flow and tractional sedimentation in a fluvio-lacustrine environment within fault-bound basin; small and medium volume ignimbrites, and pyroclastic fall-out and surge deposits. Abundant contemporaneous andesitic sills
	Rydal	Lincomb Tarns ***(3, 6, 8)***	Dacitic lapilli-tuff, typically lithic rich	Generally overlies Seathwaite Fell Formation and overlain by Helvellyn basin succession	Up to 800 m	Large volume welded to non-welded ignimbrite sequence; ?'plateau' ignimbrite; the only ignimbrite sheet to occur throughout the Lake District BVG
		Seathwaite Fell ***(3)***	Mainly bedded units of volcaniclastic sedimentary rocks; contains some pyroclastic units including Glaramara Tuff near top; much reworked juvenile clasts; abundant mainly andesite sills	Conformable in Central Fells, elsewhere low- to high-relief erosion surface; strongly diachronous base; time-equivalent of all of the Duddon Basin and much of Kentmere Basin successions	300 to >1100 m; locally <30 m	Rapid mass-flow and tractional sedimentation in a fluvio-lacustrine environment, some alluvial fans; minor pyroclastic flow, fall-out and surge deposits. Abundant contemporaneous andesitic sills
	Kentmere Basin	Mardale, Froswick, Woundale, Wet Sleddale, Kentmere Pike ***(7, 8)***	Bedded units of volcaniclastic sedimentary rocks, intercalated with sheets of pyroclastic rocks, substantial andesite sills and ?lavas	Overlies Haweswater caldera succession; overlain by Lincomb Tarns Formation	At least 2800 m	Rapid mass-flow and tractional sedimentation in a fault-bound basin; significant pyroclastic flow and fall-out eruptions; ?andesite lava shield, abundant contemporaneous intrusions
	Haweswater Caldera	Whelter Knotts, Scalehow ***(7)***	Stratified sheets of dacitic to rhyolitic pyroclastic rocks; thickness and lithofacies variations across complex fault systems; garnetiferous	Overlies Lower BVG; lateral relationship with Scafell Caldera succession unknown, but probably equivalent. Overlain by Kentmere succession	Up to 650 m	Large-volume ignimbrite eruptions with associated volcanotectonic faulting; similar stratigraphical level to Scafell Caldera succession
	Duddon Basin	Lingmoor Fell, Low Water, Lag Bank, Caw, Lickle ***(3)*** Dunnerdale, Wallowbarrow, Holehouse Gill, Ulpha, Duddon Hall, Waberthwaite	Stratified sequence of volcaniclastic sedmentary rocks, andesitic and silicic pyroclastic rocks, andesite lavas and sills	Overlies Scafell caldera succession, overstepping south-west onto Lower BVG succession; equivalent laterally to lower part of Rydal succession	Up to 3000 m	Mass-flow and tractional sedimentation within fault-bound basin; interrupted by eruption of small and medium-volume ignimbrites, formation of low-profile andesite volcano. Abundant contemporaneous sills
	Scafell Caldera	Lingmell, Airy's Bridge, Whorneyside ***(3, 5, 6)***	Stratified sheets of andesitic, dacite and rhyolitic pyroclastic rocks, and some dacitic and rhyolitic lavas; garnetiferous	Base defined by first widespread sheet of pyroclastic rocks, overlain by Seathwaite Fell Formation and Duddon basin succession	At least 700 m	Sequence of large-volume ignimbrite eruptions associated with development of piecemeal hydrovolcanic caldera and post-caldera lavas; lowest unit (Whorneyside Formation) marks major change in eruption style
Lower BVG		Birker Fell, Po House, Whinney Bank, Greenscoe ***(3, 4)***	Andesite lavas and sills (proportion unknown), some of basaltic andesite and dacite; some interbedded tuff, lapilli-tuff, breccia and sandstone locally; sporadically garnetiferous	Oversteps Latterbarrow Sandstone to overlie Skiddaw Group with angular unconformity; top defined by overlying successions	700 to 2700 m	Phreatomagmatic deposits at outset, followed by lavas forming low-profile volcanoes; pyroclastic eruptions preserved sporadically; ephemeral fluvio-lacustrine reworking of tephra. 'Lower' BVG of previous authors
Latterbarrow		Latterbarrow Sandstone ***(1, 2)***	Quartz-wacke and quartz-arenite sandstone with some siltstone	Overlies Skiddaw Group with angular unconformably; overlain by Lower BVG	0 to 400 m	Sandy estuarine environment; source as for Skiddaw Group sediment; some distal volcanic input. Post-uplift of Skiddaw Group but pre-BVG sedimentation

1. Allen & Cooper 1986; ***2.*** Akhurst et al. 1997; ***3.*** Millward et al. 2000a; ***4.*** Johnson et al. 2000; ***5.*** Branney & Kokelaar 1994; ***6.*** Woodhall 2000a; ***7.*** British Geological Survey 2004, Sheet 30; ***8.*** British Geological Survey, unpublished data; ***9.*** Millward et al. 1994; ***10.*** Burgess & Holliday 1979.

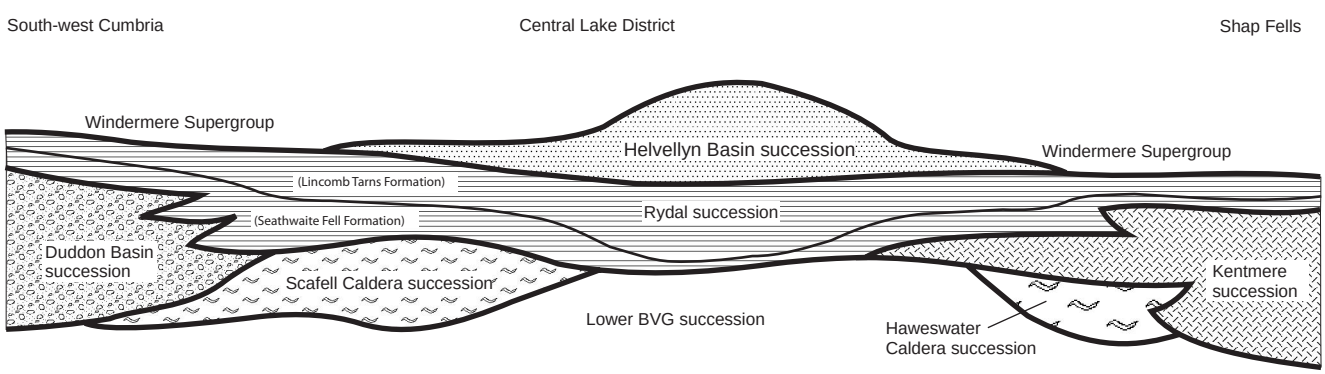

Figure 4 Diagrammatic lithostratigraphical framework for the pyroclastic and sedimentary formations within the upper part of the Borrowdale Volcanic Group. Not to scale. Relative thickness is schematic only. Line of section approximately west to east. The successions in west Cumbria and Cross Fell are now shown. In the northern part of the central Lake District the Rydal succession rests on the Lower BVG. However, farther south in the Ambleside area, the base of the Rydal succession is nowhere seen.

Lower boundary
Not exposed in detail; taken at upward change from dominantly andesite to volcaniclastic deposits within the Eycott Volcanic Group.

Upper boundary
Overlain unconformably by Carboniferous strata.

Thickness
The maximum thickness is at least 800 m, though the upper boundary is concealed beneath Carboniferous rocks.

Remarks
Lithology depicted on older versions of Cockermouth sheet but previously included as part of the now obsolete 'High Ireby Formation'.

Reference
Millward et al. (1999).

Map
Cockermouth (23).

4.2 'LOWER' BORROWDALE VOLCANIC GROUP

4.2.1 Latterbarrow Sandstone Formation (LAS)

Stratotype
None given by Allen and Cooper (1986); recommend type area between the River Calder and Latterbarrow Beck [NY 066 117 to NY 077 109].

Lithology
Bedded quartz-wacke sandstone with intercalated mudstone in the upper part.

Ranking
Locally significant, non-volcanic basal formation of the Borrowdale Volcanic Group in west Cumbria.

Lower boundary
Taken at the marked change to sandstone from silty mudstone containing an acritarch assemblage of Tremadoc to Arenig age. The junction is nowhere exposed, but has been interpreted as an unconformity on mapping evidence.

Upper boundary
Defined by the base of Devoke Water Member of the Birker Fell Formation.

Thickness
0 to c. 400 m.

Remarks
Previous authors (e.g. Eastwood et al., 1931; Jackson, 1978; Wadge, 1978; Moseley, 1984) included these rocks in the Skiddaw Group. Following Simpson (1967), and Allen and Cooper (1986) this should be regarded as the basal formation of the Borrowdale Volcanic Group.

References
Allen and Cooper (1986); Akhurst et al. (1997).

Maps
Whitehaven (28), Gosforth (37).

4.2.2 Greenscoe Tuff Formation (GCOE)

Stratotype
Type area at Greenscoe Quarry [SD 222 760] and at nearby Greenscoe Cragg.

Lithology
Crudely stratified units of silty mudstone, andesitic lapilli-tuff and tuff-breccia; cut by andesite intrusions.

Ranking
Basal formation of the Borrowdale Volcanic Group in the Furness Inlier, south-west Cumbria.

Lower boundary
Unconformably overlies the Skiddaw Group.

Upper boundary
Unconformably overlain by the Dent Group (Windermere Supergroup).

Thickness
0 to 300 m.

Remarks
Interpreted as a vent filling by Soper (1970) and as a maar deposit by Johnson (1997) and Johnson et al. (2001), but

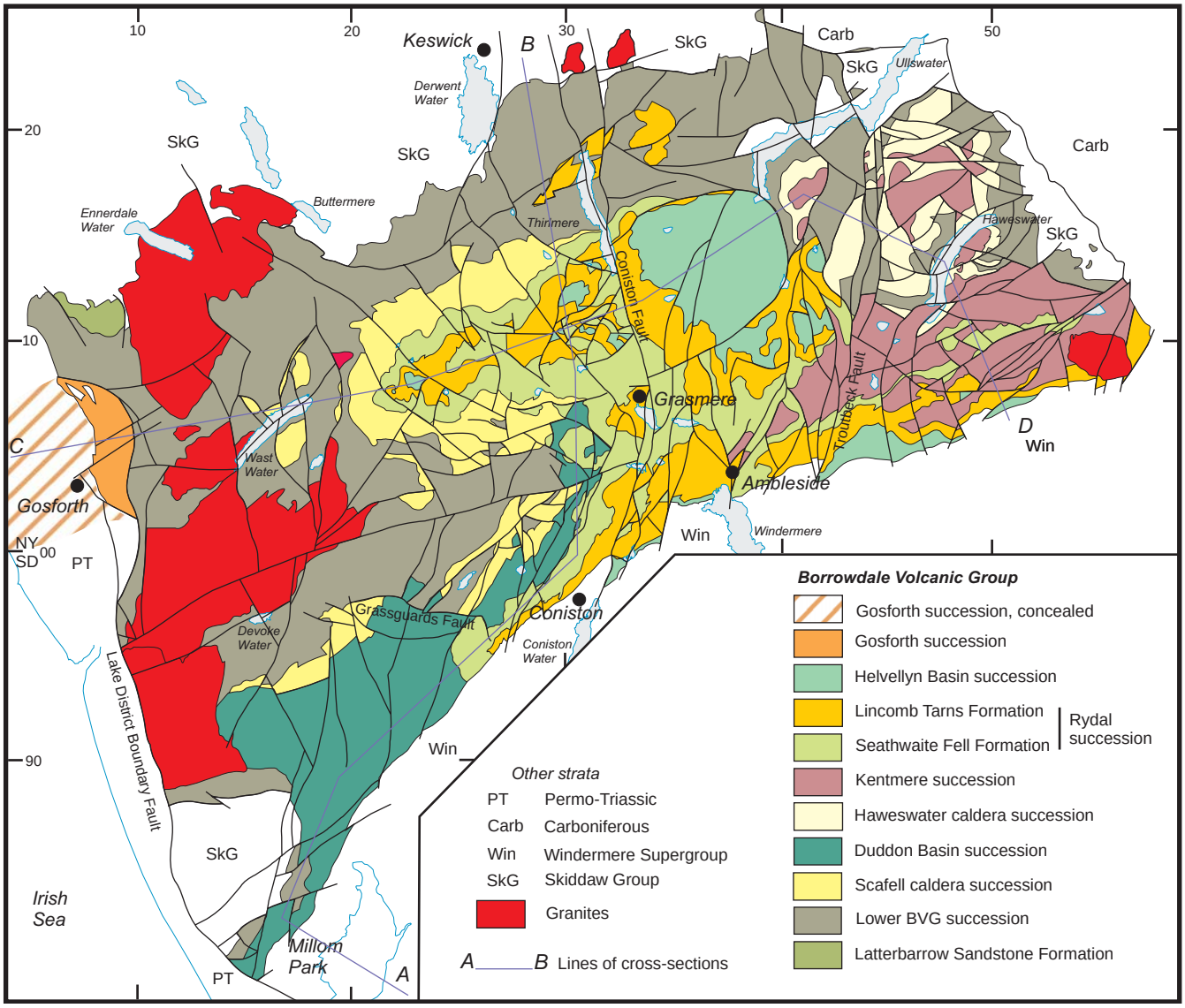

Figure 5 Lithostratigraphy of the Borrowdale Volcanic Group showing the distribution of informally designated successions within the predominantly volcaniclastic upper part of the group. Approximate lines of section shown in Figure 3 are indicated.

alternatively could be a valley-fill sequence of debris-flow deposits.

Reference
Johnson et al. (2001).

Map
Ulverston (48).

4.2.3 Whinny Bank Tuff Formation (WNB)

Stratotype
Type area on Whinny Bank, 1 km west of The Green, Millom [SD 169 845].

Lithology
Bedded units of andesitic tuff and lapilli-tuff with large amounts of grey silty mudstone pyroclasts, particularly at the base, but with an increasing juvenile pyroclast component upwards.

Ranking
Basal formation of the Borrowdale Volcanic Group in Millom Park, south-west Cumbria.

Lower boundary
Taken at the base of the lowest volcanic unit above the unconformity with the Skiddaw Group.

Upper boundary
Defined by the base of either the Po House or Waberthwaite formations.

Thickness
100 to 170 m.

Remarks
Previously known as the Mottled Shale (Green, 1913) and Whinnybank Tuffite (Mathieson, 1986). Interpreted as phreatomagmatic fall-out and surge deposits.

Reference
Johnson et al. (2001).

Map
Ulverston (48).

4.2.4 Po House Tuff Formation (PHT)

Stratotype
Type area at Po House Bank, Whicham Valley [SD 151 823].

Lithology
Parallel, thin- and medium-bedded andesitic tuff and lapilli-tuff. Interpreted as pyroclastic fall-out deposits, with a named ignimbrite at the base.

Ranking
Formation near the base of the Borrowdale Volcanic Group in Millom Park; overlies the Whinny Bank Formation.

Lower boundary
Taken at the base of a lapilli-tuff unit (pyroclastic flow deposit) that marks the change to tuff and lapilli-tuff from strata of the Whinney Bank Formation. The Po House Tuff lacks the grey silty mudstone component of the unit beneath.

Upper boundary
Defined by the base of Waberthwaite Formation.

Thickness
Up to 400 m.

References
Mathieson (1986); Johnson et al. (2001).

Map
Ulverston (48).

4.2.4.1 Dog Crag Tuff Member (DCT)

Stratotype
Type area on Dog Crag, Po House Bank, Whicham Valley [SD 149 823].

Lithology
Massive, eutaxitic dacitic lapilli-tuff (ignimbrite).

Ranking
Basal member of the Po House Formation.

Remarks
Not used on the Ulverston sheet (48) where the formation remains undivided, but the member is described by Johnson et al. (2001).

4.2.5 Birker Fell Andesite Formation (BFA)

Stratotype
Type area at Devoke Water to Yoadcastle and Stainton Pike [SD 145 967 to SD 154 940]. Reference sections/areas at: High Rigg [NY 300 225 to NY 315 200]; Haycock to Red Pike [NY 140 100 to NY 160 100]; Cockley Beck to Grey Friar [NY 247 017 to NY 262 004]; Hallin Fell [NY 426 190 to NY 440 205].

Lithology
Predominantly a tabular, sheeted succession of feldspar-phyric andesites, usually with blocky autobreccia at the base and top and massive to flow-banded and flow-jointed centres. Includes locally restricted sequences of basalt and dacite lavas, including for example the Throstle Garth Basalt and Great Whinscale Dacite members respectively. Interbedded units of pyroclastic and volcaniclastic sedimentary rocks are designated as members where they are distinctive, laterally extensive and recognised as stratigraphical markers. Examples of pyroclastic units include the Cockley Beck, Craghouse and Little Stand tuffs; sedimentary units include the Eagle Crag and Blisco sandstone members. Some units of andesite, dacite and pyroclastic rocks are garnetiferous, notably the Cockley Beck Tuff.

Ranking
Major formation comprising most of the lower part of the Borrowdale Volcanic Group.

Lower boundary
Oversteps the Latterbarrow Formation eastwards to overlie the Skiddaw Group.

Upper boundary
Defined by the base of the overlying pyroclastic and sedimentary formations.

Thickness
From about 980 m in the north-eastern part of the outcrop to 2700 m in Eskdale.

Remarks
Interpreted mainly as a succession of lavas forming a major, low-profile, plateau-andesite volcanic field (Petterson et al., 1992). Includes contemporaneous sills (see section 2.3.1.)

References
Petterson et al. (1992); Millward et al. (2000a); Beddoe-Stephens (2000a, b); Campbell (1995); Loughlin (2002), Millward (2003); Woodhall (2000a, b).

Maps
Whitehaven (28), Keswick (29), Appleby (30), Gosforth (37), Ambleside (38), Ulverston (48).

4.2.5.1 Grange Crags Andesite Member (GCG)

Stratotype
Reference section on Grange Crags near and around the village of Grange [NY 253 173 to 260 178].

Lithology
White to pink-weathered, very fine-grained, aphyric andesite lava flow with some flow foliation and autobreccia.

Ranking
Local member near the base of the Birker Fell Formation west of Keswick.

Reference
Beddoe-Stephens (1997); Woodhall (2000a).

Map
Keswick (29).

4.2.5.2 Ashness Tuff Member (AHT)

Stratotype
Reference section on crags next to the campsite at Ashness Farm [NY 272 193] and adjacent to the car park at the top of Lodore Wood Crags [NY 269 194].

Lithology
Massive to weakly eutaxitic, lithic-rich lapilli-tuff (ignimbrite).

Ranking
Local member near the base of the Birker Fell Formation west of Keswick.

Reference
Beddoe-Stephens (1997); Woodhall (2000a).

Map
Keswick (29).

4.2.5.3 Devoke Water Tuff Member (DKT)

Stratotype
Type area on Birkby Fell and Stord's Hill, south and south-west of Devoke Water [SD 146 965 to SD 155 960]; reference area on Capel Crag [NY 071 102].

Lithology
Poorly bedded, basic lapilli-tuff with substantial content locally of pyroclasts of Skiddaw Group rocks.

Ranking
Local member at the base of the Birker Fell Formation in Eskdale and the Bleng valley.

Remarks
Interpreted as phreatomagmatic fall-out and surge deposits, possibly reworked.

References
Petterson et al. (1992); Akhurst et al. (1997); Millward et al. (2000a).

Maps
Whitehaven (28), Gosforth (37), Ambleside (38).

4.2.5.4 Little Meldrum Tuff Member (LMEL)

Stratotype
Type area on Little Meldrum [NY 422 227], Ullswater.

Lithology
Coarse tuff, lapilli-tuff and lapillistone with abundant pyroclasts from the Skiddaw Group.

Remarks
Interpreted as phreatomagmatic deposits, reworked locally.

Ranking
Local member at the base of the Birker Fell Formation north-west of Ullswater.

Reference
Beddoe-Stephens (2000a).

Map
Appleby (30).

4.2.5.5 Lanty Crag Breccia Member (LTY)

Stratotype
Type area on Lanty Crag [NY 500 202], 2 km south-south-west of Helton, Shap.

Lithology
Heterogeneous succession of volcaniclastic breccia and conglomerate with some bedded volcaniclastic sandstone. Associated with aphyric andesite sheets.

Ranking
Local member at the base of the Birker Fell Formation in the north-eastern Lake District.

Remarks
Previously known as the Bampton Conglomerate (Nutt, 1970); the name 'Bampton' has been used elsewhere in British stratigraphy and is unavailable. Interpreted as phreatomagmatic deposits, possibly with substantial sedimentary reworking.

Reference
Beddoe-Stephens (2000b).

Map
Appleby (30).

4.2.5.6 Birkby Fell Andesite Member (BKB)

Stratotype
Type area on Birkby Fell and Woodend Height, south-west and south of Devoke Water [SD 1475 9600 to SD 1550 9535].

Lithology
Sheets of dark grey to greenish grey, porphyritic basaltic andesite and subordinate andesite with clinkery autobreccia (aa-lava flows). Interbedded volcaniclastic sedimentary and pyroclastic rocks.

Ranking
Local member in the lower part of the Birker Fell Formation south of Devoke Water.

References
Petterson et al. (1992); Millward et al. (2000a).

Maps
Gosforth (37), Ambleside (38).

4.2.5.7 Cockley Beck Tuff Member (CKT)

Stratotype
Type area between Cockley Beck and Dale Head Close [NY 240 010 to NY 240 000].

Lithology
Massive, garnetiferous, eutaxitic lapilli-tuff (ignimbrite), with some interbedded units of low-angle cross-laminated tuff (pyroclastic surge deposits).

Ranking
Local tuff marker member within the lower part of the Birker Fell Formation; widespread in Eskdale and the upper Duddon Valley.

Remarks
Usually referred to as Cockley Beck Tuff.

References
Petterson et al. (1992); Millward et al. (2000a).

Maps
Ambleside (38).

4.2.5.8 Dale Head Breccia Member (DHD)

Stratotype
Dale Head to Rowantree How [NY 241 006 to NY 249 006].

Lithology
Massive units of heterolithic volcaniclastic breccia and sandstone, interpreted as debris-flow deposits.

Ranking
Local member of the Birker Fell Formation in the upper Duddon valley.

Reference
Millward et al. (2000a).

Map
Ambleside (38).

4.2.5.9 Nettle Crags Tuff Member (NCT)

Stratotype
Type area at Nettle Crags, 1 km east-north-east of Bootle [SD 1160 8864 to SD 1166 8872].

Lithology
Massive, eutaxitic to parataxitic dacitic lapilli-tuff (ignimbrite).

Ranking
Local member of the Birker Fell Formation in the area to the north of Black Combe.

Reference
Johnson et al. (2001).

Map
Ulverston (48).

4.2.5.10 Eagle Crag Sandstone Member (EAGC)

Stratotype
Type area on High Stile [NY 167 148] to Comb Crags [NY 175 145]; reference area on Fleetwith Pike and Honister Quarries [NY 210 140].

Lithology
Bedded succession of volcaniclastic siltstone, sandstone, conglomerate and breccia; subordinate tuff, eutaxitic lapilli-tuff and accretionary lapilli-tuff.

Ranking
Local member within the Birker Fell Formation in the west of the outcrop.

Remarks
Subaqueous sequence of reworked volcaniclastic detritus and subaerially erupted pyroclastic deposits. Intruded by many shallow-level sills.

References
Petterson et al. (1992); McConnell and Kneller (1993); Woodhall (2000a).

Map
Keswick (29).

4.2.5.11 Seatallan Dacite Member (STAD)

Stratotype
Type area on Seatallan, 4.5 km west of Wasdale Head [NY 140 084]; reference area between summit of Haycock and Scoat Tarn [NY 145 104 to NY 154 102].

Lithology
White to pink-weathered flow-foliated feldspar-phyric dacite lava.

Ranking
Local member within the Birker Fell Formation of the Wasdale area.

References
Petterson et al. (1992); Millward et al. (2000a); Woodhall (2000a).

Maps
Keswick (29), Gosforth (37), Ambleside (38).

4.2.5.12 Craghouse Tuff Member (CHT)

Stratotype
Type area in Crag House Park, north of Santon Bridge, west Cumbria [NY 112 028].

Lithology
Massive, eutaxitic, andesitic to dacitic lapilli-tuff (ignimbrite).

Ranking
Local member of substantial thickness within the Birker Fell Formation of the Wasdale and western fells area.

References
Petterson et al. (1992); Akhurst et al. (1997); Millward et al. (2000a).

Maps
Keswick (29), Gosforth (37), Ambleside (38).

4.2.5.13 Little Stand Tuff Member (LIT)

Stratotype
Type area on Little Stand [NY 2464 0334].

Lithology
White-weathered, massive, crystal (K-feldspar)-rich, vitroclastic rhyolitic tuff (ignimbrite), locally with abundant lithophysae.

Ranking
Widespread member within the south-western part of the Birker Fell Formation outcrop.

Remarks
Usually referred to as the Little Stand Tuff. U-Pb zircon age of 451.6 ± 1.4 Ma (Millward and Evans, 2003).

References
Petterson et al. (1992); Millward et al. (2000a).

Maps
Ambleside (38).

4.2.5.14 Great Whinscale Dacite Member (GWD)

Stratotype
Type area on Crook Crag and Great Whinscale, south of Eskdale [SD 197 990].

Lithology
Single unit of white-weathered, platy flow-foliated and autobrecciated aphyric dacite lava.

Ranking
Widespread member within the south-western part of the Birker Fell Formation outcrop; overlies the Little Stand Tuff.

Remarks
Usually referred to as Great Whinscale Dacite.

References
Kanaris-Sotiriou et al. (1991); Millward et al. (2000a).

Map
Ambleside (38).

4.2.5.15 Grey Friar Tuff Member (GY)

Stratotype
Type area from Grey Friar to Seathwaite Tarn [NY 250 000 to SD 240 980].

Lithology
Massive, very lithic-rich dacitic lapilli-tuff (ignimbrite).

Ranking
Local member within the south-western part of the Birker Fell Formation outcrop.

Remarks
Usually referred to as the Grey Friar Tuff. Locally overlies Great Whinscale Dacite, but provides marker unit in areas where Little Stand Tuff and Great Whinscale Dacite are missing.

Reference
Millward et al. (2000a).

Map
Ambleside (38).

4.2.5.16 Blisco Sandstone Member (BCO)

Stratotype
Type area on Pike of Blisco [NY 271 042].

Lithology
Bedded succession of fine to very coarse-grained volcaniclastic sandstone with interbeds of tuff and lapilli-tuff.

Ranking
Member within the Birker Fell Formation; overlies the Little Stand Tuff.

Remarks
Blisco Formation of Branney and Soper (1988). Sequence of reworked and re-sedimented tephra with intercalations of pyroclastic rocks.

Reference
Millward et al. (2000a).

Map
Ambleside (38).

4.2.5.17 Haystacks Andesite Member (HAYS)

Stratotype
Reference sections on crags at Seat [NY 186 134] and on Haystacks [NY 195 133].

Lithology
Columnar and flow-jointed porphyritic andesite lava flows with intercalations of volcaniclastic rocks.

Ranking
Local member of the Birker Fell Formation south of Buttermere.

Reference
McConnell and Kneller (1993); Woodhall (2000a).

Map
Keswick (29).

4.2.5.18 Round How Breccia Member (RND)

Stratotype
Reference section on crags on Little Round How [NY 208 132].

Lithology
Poorly- to well-bedded, volcaniclastic sandstone and breccia, locally slumped.

Ranking
Local member of the Birker Fell Formation south-east of Buttermere.

Remarks
Overlies the Haystacks Member.

Reference
McConnell and Kneller (1993); Woodhall (2000a).

Map
Keswick (29).

4.2.5.19 Wrighthow Basalt Member (WGTB)

Stratotype
Type area at Wrighthow Crags, north of Hollins Farm, west Cumbria [NY 107 037].

Lithology
Clinopyroxene and plagioclase-phyric basalt lava flows. Lenses of massive basalt are intercalated with scoriaceous autobreccia.

Ranking
Local member within the upper part of the Birker Fell Formation in the Wasdale area, west Cumbria.

References
Petterson et al. (1992); Akhurst et al. (1997); Millward et al. (2000a).

Maps
Gosforth (37), Ambleside (38).

4.2.5.20 Throstle Garth Basalt Member (TGH)

Stratotype
Type area at Throstle Garth [NY 226 040] and the river Esk nearby.

Lithology
Scoriaceous aphyric to sparsely olivine-phyric basalt lava flows.

Ranking
Local member of the Birker Fell Formation in Eskdale.

References
Petterson et al. (1992); Beddoe-Stephens et al. (1995); Millward et al. (2000a).

Map
Ambleside (38).

4.2.5.21 Frith Crag Breccia Member (FRCR)

Stratotype
Type area on Swindale Foot Crag [NY 5190 1383].

Lithology
Unit of massive, matrix- to clast-supported tuff-breccia.

Ranking
Local member within the Birker Fell Formation east of Haweswater.

Remarks
Previously Frith Crag Tuffs of Nutt (1970).

Reference
Millward (2003).

Map
Appleby (30).

4.3 'UPPER' BORROWDALE VOLCANIC GROUP: SCAFELL CALDERA SUCCESSION

4.3.1 Whorneyside Tuff Formation (WNY)

Stratotype
Type section at Whorney Side waterfall, Crinkle Crags [NY 261 054].

Lithology
Unit of brown-weathered, massive, eutaxitic andesitic lapilli-tuff (Wet Side Edge Member; ignimbrite) overlain by laminated and thinly bedded tuff containing many units of accretionary lapilli (phreatoplinian fall-out deposit).

Ranking
Widespread pyroclastic formation in the western Lake District, forming the basal unit of the Scafell Caldera succession.

Lower boundary
Taken at the base of lapilli-tuff and tuff resting markedly unconformably on andesite sheets of the Birker Fell Formation.

Upper boundary
Defined by the base of the overlying Airy's Bridge Formation.

Thickness
0 to 450 m.

Remarks
Marks the base of the 'upper' Borrowdale Volcanic Group in the western part of the Borrowdale Volcanic Group outcrop and records a fundamental change in eruption style from dominantly lava to explosive, pyroclastic.

References
Branney (1991); Branney and Kokelaar (1993); Millward et al. (2000a).

Maps
Keswick (29), Ambleside (38).

4.3.1.1 Wet Side Edge Tuff Member (WSE)

Stratotype
Type area on Wet Side Edge [SD 270 020].

Lithology
Brown-weathered, massive, eutaxitic andesitic lapilli-tuff (ignimbrite). The upper part is abruptly transitional into the overlying bedded tuff.

Ranking
Basal member of the Whorneyside Formation.

Remarks
Whorneyside Ignimbrite of Branney (1991).

Reference
Millward et al. (2000a).

4.3.2 Airy's Bridge Tuff Formation (AIB)

Stratotype
Type area from Long Top to Crinkle Crags [NY 240 040 to NY 250 050].

Lithology
White to pink-weathered, massive, eutaxitic and foliated, garnetiferous rhyodacitic tuff and lapilli-tuff (ignimbrites). The sequence is stratified and divided into two members; the lower one, the Long Top Tuff, dominantly of eutaxitic ignimbrites and the higher one, the Crinkle Tuff comprising very densely welded ignimbrites. The boundary between the members is also a marked geochemical break (Beddoe-Stephens and Mason, 1991).

Ranking
Pyroclastic formation in the western Lake District, and forming the major part of the Scafell Caldera succession.

Lower boundary
Taken at the base of the lowest dacitic lapilli-tuff unit; abruptly transitional from the Whorneyside Formation locally, elsewhere unconformable on the Whorneyside and Birker Fell formations.

Upper boundary
Defined by the base of various pyroclastic and sedimentary formations that overstep onto it.

Thickness
0 to 1010 m.

Remarks
The first major silicic pyroclastic unit in the western Lake District. U-Pb zircon age of 452.8 ± 0.7 Ma determined on the Crinkle Tuff Member (Millward and Evans, 2003).

References
Branney et al. (1993); Branney and Kokelaar (1994); Millward et al. (2000a).

Maps
Keswick (29), Ambleside (38).

4.3.2.1 Long Top Tuff Member (LTT)

Stratotype
Type area as for formation.

Lithology
Bedded units of massive, eutaxitic tuff and lapilli-tuff (ignimbrite). Includes, locally, a basal unit of densely welded ignimbrite (Oxendale Tuff, see below). Intercalated thin units of bedded tuff and lapilli-tuff, interpreted as phreatomagmatic surge and fall-out deposits (Stonesty, Cam Spout and Hanging Stone tuffs, see below).

Ranking
Basal member of the Airy's Bridge Formation.

Stonesty Tuff (STF)

Stratotype
Representative section at Stonesty Pike [NY 2489 0401].

Lithology
White-weathered, flinty, bedded and cross-bedded accretionary lapilli-tuff-bearing unit.

Ranking
Widespread marker bed, locally seen at the base of the Long Top Member.

Remarks
Not seen where the Oxendale Tuff is present.

Oxendale Tuff (OXT)

Stratotype
Representative sections are in Hell Gill [NY 2590 0545], on the south side of The Band [NY 2670 0546], and south-east of Seathwaite Tarn [SD 256 976 to SD 259 980].

Lithology
Pink-weathered, lava-like rhyodacitic welded tuff.

Ranking
Bed, locally seen at the base of the Long Top Member in Langdale, Wrynose and the central fells.

Cam Spout Tuff (CPT)

Stratotype
Representative section at Cam Spout [NY 2145 0478].

Lithology
Cream- and brown-weathered, bedded fine tuff with accretionary lapilli.

Ranking
Widespread thin marker bed within the Long Top Member.

Hanging Stone Tuff (HNG)

Stratotype
Representative section on Base Brown [NY 2295 1195].

Lithology
Cream- and brown-weathered, bedded fine tuff with accretionary lapilli.

Ranking
Widespread marker bed at the top of the Long Top Member.

4.3.2.2 Crinkle Tuff Member (CRK)

Stratotype
Type area on the summit of Crinkle Crags between Long Top and Shelter Crags [NY 2485 0475 to NY 2495 0580].

Lithology
White-weathered, eutaxitic, parataxitic and foliated lapilli-tuff with interbeds of mesobreccia (interpreted as densely welded ignimbrites), and thin units of bedded tuff (interpreted as pyroclastic fall-out and surge deposits).

Ranking
Upper member of the Airy's Bridge Formation. Includes a distinctive named ignimbrite unit (Bad Step Tuff) and a named marker bed (Rest Gill Tuff).

Bad Step Tuff (BDP)

Stratotype
Representative section on Bad Step, near the summit of Crinkle Crags [NY 2487 0485].

Lithology
Pink to white-weathered, lava-like rhyolitic tuff, locally with heterolithic pyroclastic breccia and autobreccia.

Ranking
Distinctive bed within the Crinkle Member.

Reference
Branney et al. (1992).

Rest Gill Tuff (REG)

Stratotype
Representative section in Rest Gill, Crinkle Crags [NY 2446 0558 to NY 2500 0536].

Lithology
Brown and turquoise-weathered, stratified tuff with common scour and fill structures.

Ranking
Widespread marker bed overlying the Bad Step Tuff.

4.3.3 Lingmell Tuff Formation (LME)

Stratotype
Type area from Lingmell to Scafell and Great Gable [NY 200 080 to NY 200 060 to NY 210 100].

Lithology
Pale-weathered, stratified sequence of garnetiferous tuff, lapilli-tuff and pyroclastic breccia (intercalated thin ignimbrites and pyroclastic surge deposits); subordinate reworked volcaniclastic sedimentary rocks. Includes named dacite and rhyolite lavas.

Ranking
Uppermost, dominantly pyroclastic, formation in the Scafell Caldera succession.

Lower boundary
Taken at the change in lithology from massive, very densely welded lapilli-tuff of the upper part of the Airy's Bridge Formation, to a diverse sequence of dominantly thin units of less densely welded lapilli-tuff and tuff.

Upper boundary
Defined by the base of the sedimentary Seathwaite Fell Formation.

Thickness
0 to 450 m.

Remarks
Represents the waning phases of activity within the Scafell Caldera succession.

References
Kneller et al. (1993); Millward et al. (2000a).

Maps
Keswick (29), Ambleside (38).

4.3.3.1 SCAFELL DACITE MEMBER (SCD)

Stratotype
Type area from Little Narrow Cove to Aaron Crags [NY 2250 0675 to NY 215 085].

Lithology
Pale-weathered, flow-foliated, garnetiferous dacite lava, locally with autobreccia.

Ranking
Member within the Lingmell Formation.

4.3.3.2 ROSTHWAITE RHYOLITE MEMBER (RSR)

Stratotype
Type area on Rosthwaite Fell [NY 255 116].

Lithology
Pinkish weathered, flow-foliated crystal-poor rhyolite lava with autobreccia.

Ranking
Member within Lingmell Formation, associated with an intrusion.

4.4 'UPPER' BORROWDALE VOLCANIC GROUP: DUDDON BASIN SUCCESSION

4.4.1 Waberthwaite Tuff Formation (WB)

Stratotype
Type area on Corney Fell, west Cumbria [SD 151 902 to SD 161 917].

Lithology
Massive, poorly sorted, generally lithic-rich andesitic to dacitic lapilli-tuff and tuff with intercalations of pyroclastic breccia (ignimbrite).

Ranking
Major pyroclastic formation confined to the south-west Lake District.

Lower boundary
Taken at the marked change in lithology at the base of lithic-rich lapilli-tuff; in part oversteps the Airy's Bridge Formation to rest on andesites of the Birker Fell Formation.

Upper boundary
Defined by the base of the Duddon Hall Formation.

Thickness
Up to 1900 m.

Remarks
Included within the Airy's Bridge Formation on the 1:25 000 map Devoke Water and Ulpha [SD19], but shown to be distinct lithologically and geochemically; the Waberthwaite Tuff is generally more lithic rich. Laterally equivalent to the Millom Park Formation (name now obsolete) as used on the Ulverston sheet.

Reference
Millward et al. (2000a); Johnson et al. (2001).

Maps
Ambleside (38), Ulverston (48).

4.4.1.1 WRAYSLACK TUFF MEMBER (WRT)

Stratotype
Type area on Wrayslack, c. 1 km west of Duddon Bridge [SD 186 882].

Lithology
Massive, andesitic lapilli-tuff (ignimbrite).

Ranking
Local member within the Waberthwaite Formation.

4.4.1.2 BARROW TUFF MEMBER (BART)

Stratotype
Type area on Barrow, 1.2 km north-west of Duddon Bridge [SD 186 887].

Lithology
Pink-weathered, foliated, lava-like dacitic lapilli-tuff with autobreccia at top (ignimbrite).

Ranking
Local member within the Waberthwaite Formation.

4.4.1.3 HARRATH TUFF MEMBER (HHT)

Stratotype
Type area between Harrath and Corner Croft, near Millom [SD 1570 8105 to SD 1783 8387].

Lithology
White-weathered, densely welded, foliated rhyolitic tuff (ignimbrite).

Ranking
Local member within the Waberthwaite Formation.

4.4.1.4 BECK WOOD TUFF MEMBER (BWT)

Stratotype
Type area in Beck Wood, 500 m west of Beck Farm, near Millom [SD 1600 8100 to SD 1560 8057].

Lithology
Densely welded rhyolitic tuff (ignimbrite).

Ranking
Local member within the Waberthwaite Formation.

4.4.1.5 DUDDON BRIDGE TUFF MEMBER (DBT)

Stratotype
Type area between Barrow and Duddon Hall [SD 186 887 to SD 193 996].

Lithology
Massive, andesitic lapilli-tuff (ignimbrite).

Ranking
Locally, the uppermost member of the Waberthwaite Formation.

4.4.2 Duddon Hall Tuff Formation (DH)

Stratotype
Type area from Wallowbarrow Heald to Hollin House Tongue in the Duddon Valley [SD 210 970 to SD 220 960]; reference section near Goat's Hause, Coniston [SD 266 982].

Lithology
Planar-bedded andesitic tuff, massive units of lapilli-tuff and some of pyroclastic breccia.

Ranking
Pyroclastic formation within the Duddon Basin succession.

Lower boundary
Taken at the base of the succession of bedded tuffs, overlying massive dacitic or rhyodacitic lapilli-tuff of the Airy's Bridge and Waberthwaite formations.

Upper boundary
Defined by the base of various overlying formations.

Thickness
200 to 450 m.

Remarks
Resembles the Whorneyside Formation; the bedded part of the sequence is interpreted as a phreatoplinian fall-out deposit and the lapilli-tuff and breccia units as pyroclastic flow deposits. Intruded by andesite sills locally.

Reference
Millward et al. (2000a); Johnson et al. (2001).

Maps
Ambleside (38), Ulverston (48).

4.4.3 Holehouse Gill Mudstone Formation (HLH)

Stratotype
Type section in Holehouse Gill [SD 190 926 to SD 181 932].

Lithology
Dark grey, silty mudstone with interbeds of sandstone and granule conglomerate.

Ranking
Non-volcanic formation confined to the Duddon Basin.

Lower boundary
Taken at the base of dark grey silty mudstones resting unconformably on bedded andesitic tuffs of the Duddon Hall Formation.

Upper boundary
Defined by the base of the overlying Ulpha, Wallowbarrow and Dunnerdale formations.

Thickness
0 to 450 m.

Remarks
Described as the only biostratigraphically significant formation within the Borrowdale Volcanic Group by Molyneux (1988), though this is now in doubt (S G Molyneux, pers. comm., 2001).

Reference
Millward et al. (2000a).

Maps
Ambleside (38).

4.4.4 Ulpha Andesite Formation (ULP)

Stratotype
Type area south-east of Ulpha [SD 190 920 to SD 20 920].

Lithology
Plagioclase-phyric andesite lavas with autobreccia.

Ranking
Lava formation confined to the Duddon Basin.

Lower boundary
Taken at the base of the lowest lava overlying bedded andesitic tuff of the Duddon Hall Formation, or mudstones of the Holehouse Gill Formation.

Upper boundary
Defined by the base of the overlying Wallowbarrow and Dunnerdale formations.

Thickness
0 to 800 m.

Reference
Millward et al. (2000a); Johnson et al. (2001).

Maps
Ambleside (38), Ulverston (48).

4.4.5 Wallowbarrow Tuff Formation (WAL)

Stratotype
Type area near Wallowbarrow Crag [SD 222 967].

Lithology
Massive, andesitic lapilli-tuff and pyroclastic breccia (ignimbrite).

Ranking
Pyroclastic formation confined to the Duddon Basin.

Lower boundary
Taken at the base of the distinctive lithology overlying the Duddon Hall and Holehouse Gill formations.

Upper boundary
Defined by the base of the overlying Dunnerdale and Lickle formations.

Thickness
0 to 70 m.

Reference
Millward et al. (2000a).

Maps
Ambleside (38), Ulverston (48).

4.4.6 Dunnerdale Sandstone Formation (DNF)

Stratotype
Type area on Dunnerdale Fells between Yew Pike and Croglinhurst [SD 203 925 to SD 212 898].

Lithology
Coarsening upward unit of bedded volcaniclastic sandstone, local intercalations of sedimentary breccia. Bed thickness

changes from thin at base to thick and very thick towards top. Synsedimentary deformation and water-escape structures are common, particularly in uppermost part. Contains ichnofossils (Johnson et al., 1994).

Ranking
Volcaniclastic formation confined to the Duddon Basin.

Lower boundary
Taken at the base of the sandstone resting unconformably on the Wallowbarrow, Ulpha and Holehouse Gill formations.

Upper boundary
Defined by the base of the overlying Lickle Formation.

Thickness
0 to 400 m.

References
Millward et al. (2000a); Johnson et al. (2001).

Maps
Ambleside (38); Ulverston (48).

4.4.7 Lickle Tuff Formation (LICK)

Stratotype
Type area on the Dunnerdale Fells to the south-west of Caw [SD 230 944]; reference sections between Yew Pike and Stickle Tarn [SD 204 925 to SD 213 928] and from Tarn Hill to Great Stickle [SD 2080 9197 to SD 2117 9159].

Lithology
Three units of massive dacitic and rhyolitic tuff and lapilli-tuff (ignimbrite) with subordinate intercalated volcaniclastic sandstone that has been intruded locally by andesite and basaltic andesite sills.

Ranking
Pyroclastic formation confined to the Duddon Basin and Coniston Fells.

Lower boundary
Defined by the base of the pyroclastic Kiln Bank Member overlying the Dunnerdale Formation in the Duddon Basin and by the base of the Paddy End Member overlying the Duddon Hall Formation in the Coniston Fells.

Upper boundary
Defined by the base of the overlying Caw, Lag Bank and Low Water formations.

Thickness
200 to 500 m.

Reference
Millward et al. (2000a); Johnson et al. (2001).

Maps
Ambleside (38), Ulverston (48).

4.4.7.1 Kiln Bank Tuff Member (KLN)

Stratotype
Type area as for the formation.

Lithology
Massive, crystal-rich eutaxitic dacitic lapilli-tuff (ignimbrite).

Ranking
Basal, pyroclastic member of the Lickle Formation confined to the Duddon Basin.

4.4.7.2 Paddy End Tuff Member (PER)

Stratotype
Type area Old Man of Coniston between Goats Water and Levers Water [SD 266 976 to SD 280 993]; reference section as for formation.

Lithology
Pink-weathered, densely welded, foliated rhyolitic tuff locally with very coarse pyroclastic breccia at the base (densely welded ignimbrite, in part lava-like).

Ranking
Pyroclastic member of the Lickle Formation in the Duddon Basin and Coniston Fells.

Remarks
Generally referred to as the Paddy End Rhyolite.

4.4.7.3 Stickle Pike Tuff Member (STPI)

Stratotype
As for the formation.

Lithology
Pale-weathered, eutaxitic to parataxitic, rhyolitic lapilli-tuff (densely welded ignimbrite). Geochemically very similar to the Paddy End Tuff.

Ranking
Pyroclastic member of the Lickle Formation overlying the Paddy End Tuff, but confined to the Duddon Basin.

4.4.8 Caw Sandstone Formation (CAW)

Stratotype
Type area on Caw [SD 230 944].

Lithology
Coarsening upwards unit of bedded volcaniclastic sandstone and breccia. A basal unit comprises laminated and thinly bedded medium to coarse-grained sandstone that includes several beds of accretionary lapilli-tuff. Passes gradationally into massive to impersistently bedded heterolithic breccia in the rest of the formation.

Ranking
Volcaniclastic formation confined to the Duddon Basin.

Lower boundary
Taken at the base of the sandstone or breccia sequence that overlies rhyolitic lapilli-tuff of the Lickle Formation.

Upper boundary
Defined by the base of the overlying Lag Bank Formation.

Thickness
0 to 700 m.

Remarks
Sedimentary formation entirely within the Duddon Basin.

Reference
Millward et al. (2000a).

Maps
Ambleside (38).

4.4.9 Lag Bank Tuff Formation (LBT)

Stratotype
Type area near Lag Bank [SD 240 930 to SD 237 947].

Lithology
Poorly sorted, massive dacitic lapilli-tuff containing abundant white-weathered plagioclase-phyric dacite lapilli (ignimbrite).

Ranking
Pyroclastic formation within the Duddon Basin and Coniston Fells.

Lower boundary
At the base of the lapilli-tuff unconformably overlying sandstone of the Caw Formation or densely welded tuff of the Paddy End Member (Lickle Formation).

Upper boundary
Defined by the base of the overlying Seathwaite Fell Formation.

Thickness
0 to 600 m.

Reference
Millward et al. (2000a).

Maps
Ambleside (38).

4.4.10 Low Water Tuff Formation (LWW)

Stratotype
Lad Stones, above Beck Fells, Coniston [NY 2953 0010 to SD 2940 9930].

Lithology
Sheets of uniform, massive, welded dacitic lapilli-tuff (ignimbrite) separated by units of bedded volcaniclastic sandstone and tuff.

Ranking
Pyroclastic formation in the Coniston Fells.

Lower boundary
Taken at the lowest extent of dacitic lapilli-tuff overlying rhyolitic tuff of the Paddy End Member or at the base of sandstones underlying the lapilli-tuff where present.

Upper boundary
Unconformably overlain by the Seathwaite Fell Formation.

Thickness
0 to 400 m.

Remarks
Includes the Lingmoor Fell Formation (now obsolete) as used on the Ambleside map.

Reference
Millward et al. (2000a).

Maps
Ambleside (38).

4.5 'UPPER' BORROWDALE VOLCANIC GROUP: HAWESWATER CALDERA SUCCESSION

4.5.1 Scalehow Tuff Formation (SCW)

Stratotype
Type area on Birk Fell, Ullswater, from Hare Shaw to Scalehow Beck [NY 4015 1775 to NY 4110 1840].

Lithology
Stratified sequence of andesitic and dacitic lapilli-tuff and intercalated tuff, including some accretionary lapilli-tuff (interpreted as a mixed sequence of pyroclastic density current deposits and pyroclastic fall-out deposits. The upper part of the formation contains some bedded volcaniclastic sandstone produced as a result of reworking by tractional currents and mass-flow processes.

Ranking
Volcaniclastic formation in the Borrowdale Volcanic Group of the Ullswater to Haweswater area.

Lower boundary
Taken at the sharp change from andesitic and dacitic sheets of the Birker Fell Formation to a dominantly pyroclastic succession.

Upper boundary
Defined by the base of the Whelter Knotts Formation.

Thickness
0 to 340 m.

Remarks
Previously included in the Birk Fell Group of Moseley (1960). Not distinguished on the current printed edition of Sheet 29.

Reference
Woodhall (2000b).

Maps
Keswick (29), Appleby (30).

4.5.2 Whelter Knotts Tuff Formation (WLT)

Stratotype
Type area from Kidsty Pike to Whelter Knotts, west of the Haweswater reservoir [NY 227 125 to NY 473 137].

Lithology
White- to pink-weathered, massive, garnetiferous silicic tuff and eutaxitic lapilli-tuff (ignimbrite), with subordinate foliated vitrophyric tuff (densely welded ignimbrite) and bedded units of lithic-rich tuff and lapilli-tuff (phreatomagmatic fall-out and surge deposits).

Ranking
Major stratified pyroclastic succession east of Ullswater.

Lower boundary
Taken at the abrupt change to silicic pyroclastic rocks from the andesite of the Birker Fell Formation or volcaniclastic rocks of the Scalehow Formation.

Upper boundary
Defined by the base of the Mardale Formation.

Thickness
Up to 300 m.

Remarks
Previously part of the Place Fell Group (Moseley, 1960); Atkinson and Fordingdale, Stanegarth and Whelter Knotts, Hugh's Laithes Pike and Haweswater ignimbrite groups (Nutt, 1970). Not distinguished on the current printed edition of Sheet 29.

Reference
Beddoe-Stephens (2000a); Woodhall (2000b); Millward (2003).

Maps
Keswick (29), Appleby (30).

4.5.2.1 Powley's Hill Tuff Member (PLH)

Stratotype
Type area west of Powley's Hill, Naddle Forest, Haweswater [NY 502 136].

Lithology
Heterogeneous succession of massive and bedded units of crystal, pumice and lithic-rich silicic tuff and lapilli-tuff; significantly garnetiferous in places. Interpreted as a mixed sequence of pyroclastic density current deposits and pyroclastic fall-out deposits.

Ranking
Pyroclastic member at the base of the Whelter Knotts Formation.

4.5.2.2 Pinnacle Howe Tuff Member (PNH)

Stratotype
Type area on Pinnacle Howe, 2.2 km south-west of Bampton [NY 497 167].

Lithology
Pink-weathered, foliated, crystal poor, vitrophyric tuff (densely welded ignimbrite).

Ranking
Pyroclastic member of the Whelter Knotts Formation.

4.6 'UPPER' BORROWDALE VOLCANIC GROUP: KENTMERE BASIN SUCCESSION

4.6.1 Mardale Sandstone Formation (MRL)

Stratotype
Type area on the fellside on the south-east side of Swindale, near Shap [NY 510 122 to NY 521 133].

Lithology
Mixed succession of generally bedded volcaniclastic sandstone comprising reworked and re-sedimented detritus mainly of andesitic composition; localised soft-sediment deformation. Intercalated units of volcaniclastic breccia, tuff and lapilli-tuff, the most prominent of which have been designated as members.

Ranking
Volcaniclastic formation in the area south-east of Ullswater.

Lower boundary
Taken at the abrupt change from silicic tuff and lapilli-tuff of the Whelter Knotts Formation to generally well bedded volcaniclastic rocks.

Upper boundary
Defined by the base of the overlying Froswick Formation.

Thickness
Probably up to 980 m; much faulted and further inflated by andesite sills.

Remarks
Includes the Keasgill Tuffs of Nutt (1970).

References
Millward (2003); Beddoe-Stephens (2000a); Woodhall (2000b).

Maps
Appleby (30), Kendal (39).

4.6.1.1 Brown Howe Tuff Member (BNH)

Stratotype
Type area on the fellside of Mardale Banks, south-east of Haweswater reservoir [NY 479 122 to NY 485 130].

Lithology
Pale grey, parallel-bedded acid andesitic/dacitic coarse tuff and fine lapilli-tuff; locally intercalated thin units of pyroclastic breccia containing ragged bombs of scoriaceous andesite/dacite. Interpreted as pyroclastic fallout and density current deposits.

Ranking
Pyroclastic member at the base of the Mardale Formation.

4.6.1.2 Cawdale Tuff Member (CAWD)

Stratotype
Type area on Four Stones Hill, Bampton [NY 492 163].

Lithology
Massive coarse tuff and tuff-breccia, locally with pyroclastic breccia and pebbly volcaniclastic sandstone. Interpreted dominantly as pyroclastic density current deposits, but with some reworking by tractional currents.

Ranking
Pyroclastic member of the Mardale Formation.

4.6.1.3 Rowantreethwaite Tuff Member (RWT)

Stratotype
Type section on Ritchie Crag, 1.7 km south-south-east of the Haweswater Hotel, Haweswater [NY 490 123].

Lithology
Well bedded (striped) dacitic lapilli-tuff and tuff, with some pyroclastic breccia and accretionary lapilli-tuff. Interpreted as pyroclastic fall-out and surge deposits.

Ranking
Pyroclastic member of the Mardale Formation.

4.6.1.4 Gouther Crag Breccia Member (GRCG)

Stratotype
Type area on Gouther Crag, 500 m south of Truss Gap, Swindale [NY 514 126].

Lithology
Massive poorly sorted volcaniclastic breccia containing abundant pink-weathered rhyolite clasts. Interpreted as mass flow deposit, probably derived from the collapse of a lava.

Ranking
Volcaniclastic member of the Mardale Formation.

4.6.1.5 Great Ladstones Breccia Member (GTLA)

Stratotype
Type area on Great Ladstones, Rafland Forest, near Shap [NY 532 122 to NY 536 127].

Lithology
Massive to weakly bedded volcaniclastic breccia and pebbly coarse-grained sandstone. Interpreted as mass-flow deposits.

Ranking
Volcaniclastic member of the Mardale Formation.

4.6.2 Froswick Tuff Formation (FSW)

Stratotype
Type section on Swindale Common, from Fewling Stones to High Wether Howe [NY 5130 1175 to NY 5145 1080]; reference section on eastern slopes of Froswick [NY 437 085], west of the river Kent, Kentmere.

Lithology
Pale-weathered, eutaxitic to parataxitic andesitic to dacitic lapilli-tuff (ignimbrite), locally passes into tuff-breccia and includes thin units of bedded tuff and lapilli-tuff.

Ranking
Major pyroclastic formation extending from the eastern part of the Ambleside area through Troutbeck and Long Sleddale to Wet Sleddale.

Lower boundary
Marked by the abrupt change from bedded volcaniclastic rocks of the Mardale Formation to massive pyroclastic rocks.

Upper boundary
Defined by the base of the overlying Woundale or Seathwaite Fell formations.

Thickness
Up to 640 m.

Remarks
Previously Froswick Tuffs (Mitchell, 1929).

References
Beddoe-Stephens (2000a); Woodhall (2000b); Millward (2003).

Maps
Appleby (30), Kendal (39).

4.6.3 Woundale Tuff Formation (WOU)

Stratotype
Type area in Woundale, north of Troutbeck [NY 410 070 to 425 100].

Lithology
Andesitic tuff and lapilli-tuff, heterogeneous with interbedded volcaniclastic sandstone in the upper part of the formation.

Ranking
Local pyroclastic formation extending from the eastern part of the Ambleside area through Troutbeck, Kentmere and Longsleddale.

Lower boundary
Marked by the abrupt change from uniform massive dacitic tuff of the Froswick Formation to a variable succession of pyroclastic rocks.

Upper boundary
Defined by the base of the overlying Seathwaite Fell Formation.

Thickness
Up to 800 m.

Remarks
Previously the upper part of the Froswick Tuffs of Mitchell (1929). Considered to represent the product of phreatomagmatic volcanism that formed a tuff-ring that was contemporaneously reworked.

Reference
Woodhall (2000b).

Maps
Appleby (30), Kendal (39).

4.6.3.1 Doup Crag Tuff Member (DPT)

Stratotype
Type area from Doup Crag to Hart Crag on the west side of the Troutbeck valley, Windermere [NY 419 092 to NY 412 083].

Lithology
Bedded and cross-bedded, andesitic lapilli-tuff.

Ranking
Member of the Woundale Formation.

4.6.4 Kentmere Pike Tuff Formation (KMR)

Stratotype
Type area on Kentmere Pike and Hallow Bank Quarter, Kentmere [NY 468 081 to NY 453 074].

Lithology
Dacitic lapilli-tuff, massive (ignimbrite); some interbedded tuff, lapilli-tuff and volcaniclastic sandstone.

Ranking
Densely welded ignimbrite formation within the Borrowdale Volcanic Group.

Lower boundary
Taken at the base of the dacitic lapilli-tuff overlying volcaniclastic sedimentary rocks; boundary usually obscured by penecontemporaneous andesite intrusions.

Upper boundary
Defined by the base of the overlying Lincomb Tarns Formation, but relationships commonly obscured by intrusions.

Thickness
Up to 350 m.

Remarks
Kentmere Pike Rhyolites of Mitchell (1929); Kentmere Formation (in part) of Soper and Numan (1974).

Map
Kendal (39).

4.6.5 Wet Sleddale Andesite Formation (WETS)

Stratotype
Type area on the fellside from Tod Crags south to Little Saddle Crag, Shap Fells [NY 520 103 to NY 528 083].

Lithology
Dark-grey and blue-grey, porphyritic andesite and basaltic andesite sheets with abundant scoriaceous autobreccia and thin intercalations of bedded volcaniclastic sandstone and tuff.

Ranking
Lava formation or sill complex within the Borrowdale Volcanic Group.

Lower boundary
Taken at the base of the lowest andesite sheet in a thick sequence of andesite sheets.

Upper boundary
Defined by the base of the overlying Lincomb Tarns Formation.

Thickness
Possibly up to 1200 m; uncertainty due to faulting.

Remarks
Mechanism of emplacement not certain because of poor exposure. Part of the Wrengill Andesites of Mitchell (1929).

Reference
Millward (2003).

Maps
Appleby (30), Kendal (39).

4.7 'UPPER' BORROWDALE VOLCANIC GROUP: RYDAL SUCCESSION

4.7.1 Seathwaite Fell Sandstone Formation (SET)

Stratotype
Type area on Seathwaite Fell, Borrowdale [NY 220 090 to NY 240 110]; important reference sections at Walna Scar Quarries and Torver High Common [SD 248 958 to SD 266 953], and Great Intake to Holme Fell (including the Tilberthwaite Quarries) [NY 304 020 to NY 318 012].

Lithology
Bedded to massive units of fine to coarse-grained volcaniclastic sandstone with intercalations of tuff, lapilli-tuff, pyroclastic breccia, pebbly sandstone and conglomerate. In the Central Fells area, the formation is divided into members, only some of which have been depicted on the 1:50 000-scale maps. Few of these units have been extended beyond the Scafell Syncline.

Ranking
A major volcaniclastic formation within the upper Borrowdale Volcanic Group.

Lower boundary
In the type area, a facies transition or a sharp contact with Lingmell Formation pyroclastic rocks; overlaps the Scafell Dacite and the Rosthwaite Rhyolite. In the Coniston Fells the formation overlies the pyroclastic Low Water and Lag Bank formations unconformably. Around High Street the Seathwaite Fell Formation rests on the Woundale Formation.

Upper boundary
Defined by the base of the Lincomb Tarns Formation, or in the Kentmere area by the Kentmere Pike Formation.

Thickness
About 300 to 540 m in the central fells; 30 m on Lingmoor Fell; possibly greater than 1100 m in the Tilberthwaite area.

Remarks
A formation that occurs throughout much of the Lake District. The base is diachronous and facies controlled. The sequence in the central fells seems to be condensed following eruption of the pyroclastic rocks of the Scafell caldera succession. By contrast, in the Duddon Basin and Coniston Fells much of the Duddon Basin succession is equivalent to the lower members of the Seathwaite Fell Formation and the upper members are greatly thickened.

The formation was emplaced by a mixture of tractional and mass-flow processes in a lacustrine environment. The volcaniclastic material was derived from active fault scarps, topographical highs and contemporaneous eruptions.

References
Kneller and McConnell (1993); Millward et al. (2000a); Woodhall (1998, 2000b).

Maps
Keswick (29), Appleby (30), Ambleside (38), Kendal (39).

4.7.1.1 Three Tarns Sandstone Member (TTA)

Stratotype
Not defined by Kneller and McConnell (1993). Recommend type area from Pike o' Stickle to Harrison Stickle [NY 274 074 to NY 284 073].

Lithology
Well bedded, predominantly white-weathered fine-grained sandstones and siltstones.

Ranking
Basal member of the Seathwaite Fell Formation in the south and east of the Scafell Syncline.

4.7.1.2 Bell Crags Breccia Member (BCR)

Stratotype
Type area around Bell Crags [NY 298 148], near Thirlmere.

Lithology
Matrix-supported, pebble to cobble-grade breccia and pebbly to coarse-grained sandstone.

Ranking
Member within the Seathwaite Fell Formation. Represents deposition from mass flows

4.7.1.3 Cam Crags Sandstone Member (CCR)

Stratotype
Type area from Thorneythwaite Fell to Glaramara [NY 240 120 to NY 247 105].

Lithology
Dark brown weathered, coarse-grained volcaniclastic sandstone to breccia.

Ranking
Member within the Seathwaite Fell Formation confined to the northern side of the Scafell Syncline.

4.7.1.4 Harrison Stickle Breccia Member (HTK)

Stratotype
Type area on Harrison Stickle [NY 282 073].

Lithology
Pebble-grade breccia to pebbly sandstone; some lapilli-tuff.

Ranking
Member within the Seathwaite Fell Formation in the Scafell Syncline.

4.7.1.5 Dungeon Ghyll Sandstone Member (DGY)

Stratotype
Type area around Langdale Pikes [NY 275 070 to NY 281 075].

Lithology
Bedded siltstone, sandstone and breccia with widespread slumping and disruption.

Ranking
Member within the Seathwaite Fell Formation in the Scafell Syncline.

4.7.1.6 Pavey Ark Breccia Member (PAV)

Stratotype
Type area on Pavey Ark [NY 285 078].

Lithology
Brown-weathered, massive to poorly bedded, pebbly volcaniclastic sandstone to breccia, in the type area containing ragged vesicular andesite spatter. Interpreted as the product of an eruption-generated subaqueous gravity flow.

Ranking
Member of the Seathwaite Fell Formation widespread between Scafell and Grasmere

4.7.1.7 Bowfell Links Sandstone Member (BFL)

Stratotype
Not defined by Kneller and McConnell (1993). Recommend type area on Bowfell Links [NY 247 063].

Lithology
Thin-bedded, parallel and ripple-cross-laminated siltstone and fine-grained sandstone.

Ranking
Member within the Seathwaite Fell Formation.

4.7.1.8 Cockley Pike Sandstone Member (CPK)

Stratotype
Not defined by Kneller and McConnell (1993). Recommend type area Stake Pass to High Raise [NY 265 088 to NY 281 095].

Lithology
Coarse to very coarse-grained sandstones, commonly massive or weakly stratified over tens of metres.

Ranking
Member within the Seathwaite Fell Formation.

4.7.1.9 Sprinkling Tarn Sandstone Member (SPR)

Stratotype
Not defined by Kneller and McConnell (1993). Recommend type area near Sprinkling Tarn [NY 228 091].

Lithology
Bedded, coarse-grained and pebbly sandstones interbedded with various pyroclastic rocks and their reworked equivalents.

Ranking
Member within the Seathwaite Fell Formation; includes the Glaramara Tuff, a widespread marker unit.

Glaramara Tuff (GMT)

Stratotype
Type area on the summit of Glaramara [NY 2460 1050].

Lithology
Bedded sequence of white to pale buff weathered, silicic tuff, eutaxitic lapilli-tuff and accretionary lapilli-tuff.

Ranking
Kneller and McConnell (1993) and Millward et al. (2000a) designate this as having bed status within the Sprinkling Tarn Member.

4.7.1.10 St Raven's Edge Tuff Member (SRE)

Stratotype
St Raven's Edge [NY 405 085], east side of Kirkstone Pass, Cumbria.

Lithology
Massive andesitic lapilli-tuff, in part eutaxitic (ignimbrite).

Ranking
Member within the Seathwaite Fell Formation in the eastern Lake District.

4.7.2 Lincomb Tarns Tuff Formation (LTA)

Stratotype
Type area from Glaramara to Allen Crags [NY 246 103 to NY 238 088]; reference sections in Torver Beck [SD 2717 9644 to SD 2753 9622], Wythburn Fells [NY 3060 1350 to NY 3015 1270], Pass of Dunmail Raise to Seat Sandal [NY 3340 1045 to NY 3440 1150] and Threshthwaite Cove [NY 415 103].

Lithology
Eutaxitic, dacitic lapilli-tuff (ignimbrite), typically lithic rich with both silicic and mafic lithic clasts. In part stratified with distinctive units designated as members; elsewhere massive.

Ranking
The most widespread ignimbrite formation of the Borrowdale Volcanic Group.

Lower boundary
Rests sharply on sandstones of the Seathwaite Fell Formation and taken at a sharp change to pyroclastic rocks. In parts the contact is conformable, but in other areas there is an angular discordance.

Upper boundary
Defined by base of the Esk Pike or Tarn Hows formation.

Thickness
Varies form about 170 m near Scafell in the west of the outcrop to more than 800 m north-east of Tarn Hows. There are significant changes across some faults.

References
McConnell (1993); Woodhall (1998, 2000b); Millward et al. (2000a); Millward (2003).

Maps
Keswick (29), Appleby (30), Ambleside (38), Kendal (39).

4.7.2.1 Tarn Crags Tuff Member (TNCR)

Stratotype
Type section along Tarn Crags [NY 3032 1351 to NY 3085 1348].

Lithology
Bedded coarse dacitic tuff and lapilli-tuff, sparsely garnetiferous. Interpreted as pyroclastic density current and fall-out deposits.

Ranking
Locally, basal member of the Lincomb Tarns Formation.

4.7.2.2 Thirlmere Tuff Member (TMR)

Stratotype
Type area between Whelpside and Dunmail Raise [NY 3250 1450 to NY 3345 1110]; reference sections on the east side of Steel Fell [NY 320 115] and Thirlmere to Dunmail Raise [NY 3340 1045 to NY 3300 1585].

Lithology
White- to pink-weathered, parataxitic garnetiferous tuff and lapilli-tuff, locally with mesobreccia (densely welded, rheomorphic ignimbrite).

Ranking
High-grade ignimbrite within the Lincomb Tarns Formation, but locally occurs at its base.

Remarks
Referred to as the Thirlmere Rhyolite by Hartley (1941).

4.7.2.3 Raisebeck Volcaniclastic Member (RABK)

Stratotype
Type section in Raise Beck [NY 3351 1195 to NY 3406 1208].

Lithology
Massve to bedded tuff and bedded volcaniclastic sandstone. Interpreted as mass-flow and tractional sediments deposited during hiatus in explosive silicic eruption.

Ranking
Member within the Lincomb Tarns Formation.

4.7.2.4 Goat Scar Dacite Member (GSD)

Stratotype
Type area on Goat Scar [NY 476 068] on the west side of Longsleddale.

Lithology
Dacite, in part interpreted as lava dome and coulee-type flow; partly intrusive and part extrusive with thin interbeds of lapilli-tuff.

Ranking
Member in the Lincomb Tarns Formation.

4.8 'UPPER' BORROWDALE VOLCANIC GROUP: HELVELLYN BASIN SUCCESSION

4.8.1 Esk Pike Sandstone Formation (ESP)

Stratotype
Type section on Esk Pike [NY 236 075]; reference sections on Wythburn Fells [NY 300 117 to NY 308 128], Calf Cove (Rydal Head) [NY 3575 1075] and Black Crag (Rydal Head) [NY 3610 1075 to NY 3615 1105].

Lithology
Volcaniclastic sandstone and mudstone in the type area. Bedded and massive volcaniclastic sandstone with intercalations of breccia, tuff and lapilli-tuff in areas to the east.

Ranking
Volcaniclastic sedimentary formation within the upper Borrowdale Volcanic Group.

Lower boundary
Taken at a change in lithology at an erosion surface on lapilli-tuff of the underlying Lincomb Tarns Formation to dominantly sandstone.

Upper boundary
Not seen in the type area. In the area around Helvellyn, it is defined by the base of various overlying formations, including the Middle Dodd Dacite, Deepdale and Helvellyn formations.

Thickness
At least 170 m in the central fells and up to 200 m in the Helvellyn area.

Remarks
Marked facies variation between the central fells and the area east of the Coniston Fault. Sediments emplaced in a fluviolacustrine environment by mass-flow and tractional processes with volcaniclastic material derived from active fault scarps and contemporaneous explosive volcanism.

References
McConnell (1993); Millward et al. (2000a); Woodhall (1998, 2000b).

Maps
Keswick (29), Appleby (30), Ambleside (38), Kendal (39).

4.8.2 Middle Dodd Dacite Formation (MDD)

Stratotype
Type area on the summit of Middle Dodd [NY 397 096] and a reference section on Little Hart Crag [NY 3885 1010], Kirkstone Pass.

Lithology
White-weathered, flow-foliated, feldspar-phyric dacite lava.

Ranking
Formation within the upper Borrowdale Volcanic Group.

Lower boundary
Taken at the base of the dacite resting on volcaniclastic sedimentary rocks of Esk Pike Formation.

Upper boundary
Top not seen in the type area or reference section. Probable equivalent lithologies to the north are overlain by the Helvellyn and Deepdale formations.

Thickness
0 to 170 m.

References
Millward et al. (2000a); Woodhall (1998).

Maps
Keswick (29), Appleby (30), Ambleside (38), Kendal (39).

4.8.3 Garburn Dacite Formation (GAD)

Stratotype
Type area at Garburn, between Troutbeck and Kentmere [NY 432 043 to NY 440 048].

Lithology
Plagioclase-phyric dacite lavas, in part autobrecciated.

Ranking
Local formation within the upper Borrowdale Volcanic Group of Kentmere.

Lower boundary
Taken at the base of the dacite on volcaniclastic sedimentary rocks of the Esk Pike Formation. In part separated by andesite intrusions.

Upper boundary
Unconformably overlain by the Windermere Supergroup.

Thickness
0 to 100 m.

Remarks
Upper Rhyolites of Mitchell (1929) and, in part, the Garburn Formation of Soper and Numan (1974).

Map
Kendal (39).

4.8.4 Brock Crags Andesite Formation (BKCG)

Stratotype
Type area on Brock Crags about 1 km north-east of Hartsop, Ullswater [NY 418 136].

Lithology
Andesite lavas, in part autobrecciated, with thin intercalations of lapilli-tuff and volcaniclastic sandstone.

Ranking
Local formation within the upper Borrowdale Volcanic Group of the Ullswater area.

Lower boundary
Taken at the base of the lowest andesite on a few metres of volcaniclastic sedimentary rocks assigned to the Esk Pike Formation. In some poorly exposed parts it may overlie silicic tuff of the Lincomb Tarns Formation.

Upper boundary
Top not seen in the type area.

Thickness
0 to 290 m.

Reference
Woodhall (2000b).

Map
Appleby (30).

4.8.5 Tarn Hows Tuff Formation (THW)

Stratotype
Type area from Tarn Hows to Iron Keld Plantation [NY 330 000 to NY 338 008].

Lithology
Massive to very weakly stratified, andesitic coarse tuff and lapilli-tuff, with a very rough weathered surface exhibiting conspicuous surface holes. Emplacement dominantly from pyroclastic density currents.

Ranking
Highest formation in the Borrowdale Volcanic Group in the Coniston area, only occurring east of the Coniston Fault.

Lower boundary
Taken at the change from dacitic to andesitic pyroclastic rocks; overlies the Lincomb Tarns Formation.

Upper boundary
Not seen; overlain by the lowest formation of the Dent Group (Windermere Supergroup).

Thickness
0 to 420 m.

Remarks
Similar stratigraphical position to the Esk Pike Formation, with which it may be laterally equivalent.

Reference
Millward et al. (2000a).

Map
Ambleside (38).

4.8.6 Helvellyn Tuff Formation (HLV)

Stratotype
Type area in the Helvellyn range includes Nethermost Cove [NY 350 145], Ruthwaite Cove [NY 350 136] and Cock Cove [NY 350 132].

Lithology
Massive, dacitic lapilli-tuff (ignimbrite), eutaxitic in its lower part.

Ranking
Major pyroclastic formation within the Helvellyn range.

Lower boundary
Rests sharply on sandstones of the Esk Pike Formation.

Upper boundary
Defined by basal beds of the Deepdale Formation, representing one of the highest units proved in the Borrowdale Volcanic Group.

Thickness
From about 80 m at Rydal Head to 400 m between Helvellyn and Grisedale; maximum unknown.

Remarks
Equates with the middle and upper parts of the Felsitic and Basic Tuffs of Hartley (1941).

Reference
Woodhall (1998).

Map
Keswick (29).

4.8.7 Deepdale Sandstone Formation (DPD)

Stratotype
Type section in the western part of Deepdale from Mart Crag [NY 372 124] to Greenhow End [NY 371 121], The Step [NY 369 119], Link Cove [NY 371 117] and Hart Crag [NY 368 113]. Important reference section on St Sunday Crag [NY 367 136], Grisedale.

Lithology
Bedded and massive volcaniclastic sandstone with intercalations of pebbly sandstone, breccia, tuff and lapilli-tuff.

Ranking
Volcaniclastic formation within the Helvellyn range, restricted between the Deepdale Hause and Hoggett Gill faults.

Lower boundary
In the west of the outcrop, taken at the erosion surface on top of the Helvellyn Formation where the lapilli-tuff is succeeded by pebbly sandstone; elsewhere, overstep on to the Middle Dodd Dacite and Esk Pike Formation where the base of the formation is defined by the base of the Cawk Cove Member.

Upper boundary
Not seen.

Thickness
Greater than 650 m.

Remarks
Stratigraphically the youngest unit seen at outcrop in the central Lake District. Lithologically similar to both the Seathwaite Fell and Esk Pike formations. Sediments emplaced in fluvial and lacustrine environment by mass-flow and tractional processes, with material derived from active fault scarps and contemporaneous volcanism. Also includes intercalations of ignimbrite.

Reference
Woodhall (1998).

Maps
Keswick (29), Appleby (30).

4.8.7.1 Cawk Cove Sandstone Member (CWK)

Stratotype
Type section between Mart Crag and the south side of Mossydale [NY 3766 1225].

Lithology
Stratified pebbly volcaniclastic sandstone and some bedded coarse-grained volcaniclastic sandstone.

Ranking
Basal member of the Deepdale Formation in the central and south-west part of its outcrop.

4.8.7.2 Blind Cove Sandstone Member (BLCV)

Stratotype
Reference section on prominent north to north-west-facing crags (St Sunday Crag and Blind Cove) [NY 3740 1410] 2.7 to 4 km south-west of Patterdale.

Lithology
Pebbly volcaniclastic sandstone with intercalations of fine to coarse-grained volcaniclastic sandstone in units 2 to 30 m thick.

Ranking
Member within the Deepdale Formation.

4.8.7.3 St Sunday Crag Tuff Member (SSC)

Stratotype
Reference section on crags on the south side of Lord's Seat, Deepdale [NY 3793 1325 to NY 3805 1335]; reference section on St Sunday Crag [NY 3694 1385 to NY 3695 1382].

Lithology
Massive, rhyodacitic tuff and lapilli-tuff with abundant fiamme (ignimbrite).

Ranking
Pyroclastic member within the upper part of the Deepdale Formation, resting on the Blind Cove Member.

4.8.7.4 Cockley How Tuff Member (CKY)

Stratotype
Reference section on crags adjacent to Cockley How, 1.8 km south-south-west of Deepdale [NY 3940 1290].

Lithology
Dacitic lapilli-tuff, parataxitic at its base (ignimbrite).

Ranking
Pyroclastic member within the upper part of the Deepdale Formation.

4.8.7.5 Blake Brow Breccia Member (BLBR)

Stratotype
Type section at Link Cove [NY 367 115 to NY 372 115]; reference section at Blake Brow [NY 367 115 to NY 372 115], 3.5 km south-west of Deepdale.

Lithology
Volcaniclastic breccia and pebbly sandstone in units up to 75 m thick.

Ranking
Member of the Deepdale Formation; interdigitates with the Greenhow End Member.

4.8.7.6 Dove Crag Tuff Member (DOCR)

Stratotype
Type section at Hart Crag [NY 370 111] and reference section at Dove Crag [NY 374 106].

Lithology
Eutaxitic, andesitic lapilli-tuff (ignimbrite).

Ranking
Pyroclastic member of the Deepdale Formation; the highest unit seen.

4.9 'UPPER' BORROWDALE VOLCANIC GROUP: THE GOSFORTH SUCCESSION

4.9.1 Moorside Farm Tuff Formation (MOF)

Stratotype
Partial type section in Sellafield No. 2 Borehole [NY 00 SE 28] 1495.5 to 1520.2 m below rotary table elevation.

Lithology
Welded lithic-rich lapilli-tuff and pyroclastic breccia (ignimbrite).

Ranking
Oldest formation seen in the volcanic succession west of the Thistleton Fault, in west Cumbria.

Lower boundary
Not seen.

Upper boundary
Overlain by volcaniclastic sandstones of the Broom Farm Formation.

Thickness
Greater than 114 m (core length).

Remarks
Only seen in cores from the base of Sellafield No. 2 Borehole.

References
Millward et al. (1994); Akhurst et al. (1997).

4.9.2 Broom Farm Sandstone Formation (BRFA)

Stratotype
Type section in Sellafield No. 2 Borehole [NY 00 SE 28] 1482.37 to 1495.5 m below rotary table elevation.

Lithology
Bedded coarse-grained and pebbly volcaniclastic sandstone, intercalated with laminated fine-grained volcaniclastic sandstone and siltstone. The coarser units are medium and thick bedded, commonly with convolutions.

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Placed at the sharp base of a siltstone bed marking a downward change from bedded volcaniclastic sedimentary rocks to lapilli-tuff.

Upper boundary
Overlain by welded lapilli-tuff of the Bleawath Formation.

Thickness
Borehole core length of 13.5 m.

Remarks
Only seen in cores from Sellafield No. 2 Borehole.

References
Millward et al. (1994); Akhurst et al. (1997).

4.9.3 Bleawath Tuff Formation (BLEA)

Stratotype
Type section in Sellafield No. 2 Borehole [NY 00 SE 28] 1066.5 to 1482.37 m below rotary table elevation.

Lithology
Massive, fiamme-rich, eutaxitic to parataxitic, andesitic to dacitic lapilli-tuff (densely welded ignimbrites).

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Taken at a sharp base of lithic-rich welded lapilli-tuff overlying volcaniclastic sandstone.

Upper boundary
Defined by the base of the Brown Bank Formation.

Thickness
A core length of 416 m recorded in the Sellafield No. 2 Borehole.

Remarks
Seen in cores from Sellafield No. 2, 4, 5 and 10A boreholes; not seen at outcrop. Type section represents the only complete section through the formation.

References
Millward et al. (1994); Akhurst et al. (1997).

4.9.4 Brown Bank Tuff Formation (BBA)

Stratotype
Type section in Sellafield 10A Borehole [NY 00 SW 38] 1053.0 to 1408.5 m below rotary table elevation; reference section in the Sellafield RCF1 Borehole [NY 00 SE 35] 908.7 to 1150 m (section incomplete) below rotary table elevation.

Lithology
Heterogeneous stratified succession of massive units of lithic-rich tuff, lapilli-tuff, tuff-breccia and pyroclastic breccia (ignimbrites). Most of the units are andesitic in composition, though there are also important dacitic/rhyolitic units of densely welded lapilli-tuff, including the important marker unit of the Seascale Hall Member. There are several thin units of bedded lapilli-tuff (pyroclastic fall-out deposits) and volcaniclastic sandstone.

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Taken at the lowest occurrence of lithic-rich lapilli-tuff overlying the pumice-rich lapilli-tuff of the Bleawath Formation.

Upper boundary
Defined by the base of the Fleming Hall Formation.

Thickness
From 45 to more than 250 m (uncorrected core lengths).

Remarks
Seen in Sellafield boreholes 2, 4, 5, 10A, RCF1, RCM1, RCM2, and possibly in boreholes 8A, 9 and RCF3.

References
Millward et al. (1994); Akhurst et al. (1997).

4.9.4.1 Seascale Hall Tuff Member (SEHA)

Stratotype
Type section in the Sellafield 10A Borehole [NY 00 SW 38]; reference section in the Sellafield RCF1 Borehole [NY 00 SW 35] 908.71 to 994.09 m below rotary table elevation.

Lithology
Eutaxitic to parataxitic rhyolitic lapilli-tuff with pale coloured rhyolitic clasts (ignimbrite).

Ranking
Within the Gosforth sequence this unit has very distinctive wireline log characteristics that, along with its lithology, make it the most important unit for correlation (Millward et al. 2002).

4.9.5 Fleming Hall Tuff Formation (FLH)

Stratotype
Type locality at Table Rock [NY 0885 0360]; reference section in Sellafield No. 5 Borehole [NY 00 SE 30] 489.83 to 892.42 m below rotary table elevation.

Lithology
Eutaxitic and parataxitic andesitic tuff and lapilli-tuff (rheomorphic ignimbrite); has high magnetic susceptibility.

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Defined by the base of the Town End Farm Member.

Upper boundary
Not seen in the Sellafield boreholes; poorly exposed at outcrop, but defined by the base of the Lowcray Formation.

Thickness
180 to more than 380 m.

Remarks
The only formation in this succession proved at outcrop and in the Sellafield boreholes 2, 4, 5, 10A, 11A, 12A, RCF1, RCF2, RCF3, RCM1, RCM2, RCM3.

References
Millward et al. (1994); Akhurst et al. (1997).

Map
Gosforth (37).

4.9.5.1 Town End Farm Tuff Member (TOEF)

Stratotype
Type section in Sellafield No. 5 Borehole [NY 00 SE 30] 736.95 to 892.42 m below rotary table elevation.

Lithology
Eutaxitic and parataxitic andesitic lapilli-tuff (rheomorphic ignimbrite).

Ranking
Basal member of the Fleming Hall Formation.

4.9.5.2 Sides Farm Breccia Member (SIFA)

Stratotype
Type section in the Sellafield Borehole 5 [NY 00 SE 30] 669.18 to 736.95 m below rotary table elevation; reference section in the Sellafield RCM3 Borehole [NY 00 SE 39] 811.08 to 887.00 m below rotary table elevation.

Lithology
Clast-supported blocky breccia in the Sellafield No. 5 Borehole; in the Sellafield RCF and RCM boreholes comprises thick beds of graded clast and matrix supported, pumice and/or lithic-rich lapilli-tuff, tuff-breccia and pyroclastic breccia.

Ranking
Member within the Fleming Hall Formation.

4.9.5.3 Longlands Farm Tuff Member (LOFA)

Stratotype
Partial type section in the Sellafield No. 4 Borehole [NY 00 SE 29] 411.75 to 795.90 m below rotary table elevation.

Lithology
Geochemically homogeneous, eutaxitic and parataxitic andesitic tuff and lapilli-tuff (rheomorphic ignimbrite); some coignimbrite breccia.

Ranking
Only member of the Fleming Hall Formation at outcrop; best seen in borehole cores.

Remarks
Lithologically very similar to the Town End Farm Member.

4.9.6 Lowcray Tuff Formation (LOCY)

Stratotype
Poorly exposed, mainly in lower reaches of the River Bleng [NY 088 063 to NY 085 053], which is taken as the type section.

Lithology
Crystal-rich parataxitic tuff and lithic-rich coarse lapilli-tuff. Locally there is a weak eutaxitic fabric, suggesting that these rocks were emplaced as pyroclastic flows (ignimbrites).

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Not seen but mapped at the lowest lapilli-tuff above the densely welded tuffs of the Fleming Hall Formation.

Upper boundary
Defined by the base of the overlying Blengdale Formation.

Thickness
About 650 m.

Reference
Akhurst et al. (1997).

Map
Gosforth (37).

4.9.7 Blengdale Tuff Formation (BGD)

Stratotype
Type area in Blengdale Forest with numerous small quarries north-west of forestry track south-west of Gait Kirk; reference section on Ponsonby Fell [NY 0803 0735], near Gosforth.

Lithology
Rhyolitic parataxitic tuff (rheomorphic ignimbrite), overlain by pyroclastic breccia locally.

Ranking
Uppermost formation of the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Taken at base of the distinctive lithology.

Upper boundary
Top not seen; unconformably overlain by Permo-Triassic strata.

Thickness
About 250 m.

Remarks
One of the most compositionally differentiated units within the Borrowdale Volcanic Group and possibly the youngest. May be equivalent to the Yottenfews Formation in the Sellafield No. 7 Borehole to the west.

Reference
Akhurst et al. (1997).

Map
Gosforth (37).

4.9.8 Newton Manor Sandstone Formation (NEM)

Stratotype
Partial type section in the Sellafield No. 7A Borehole [NY 00 SE 36] 771.5 to 1010.00 m below rotary table elevation.

Lithology
Dominantly bedded volcaniclastic sandstone, mainly coarse and very coarse grained, medium and thick beds; a variety of other facies are also present, including parallel laminated siltstone and well sorted fine to medium- grained sandstone with soft-sediment deformation, and units of cross-bedded sandstone. Some intercalated thin units in the upper part of tuff and lapilli-tuff interpreted as pyroclastic fall-out and flow deposits.

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Not reached in boreholes.

Upper boundary
Defined by the base of the Yottenfews Formation in Sellafield No. 7A Borehole.

Thickness
At least 200 m of core length are seen, including andesite sills, in the Sellafield No. 14A Borehole.

Remarks
Only known from the Sellafield No. 7A and 14A boreholes.

References
Millward et al. (1994); Akhurst et al. (1997).

4.9.9 Yottenfews Tuff Formation (YOT)

Stratotype
Partial type section in the Sellafield No. 7A Borehole [NY 00 SE 36] 577.83 to 718.15 m below rotary table elevation.

Lithology
Eutaxitic to parataxitic rhyolitic tuff and lapilli-tuff. A stratified sequence of ignimbrites that includes the distinctive, spherulitic Sella Park Member.

Ranking
Formation within the volcanic succession west of the Thistleton Fault in west Cumbria.

Lower boundary
Defined by the base of the Sella Park Member resting on bedded volcaniclastic sandstones.

Upper boundary
Not seen; overlain by Carboniferous strata.

Thickness
At least 143 m in core length.

Remarks
Not seen at outcrop, but from the geochemistry it may be correlated with the Blengdale Formation.

References
Millward et al. (1994); Akhurst et al. (1997).

4.9.9.1 Sella Park Tuff Member (SEP)

Stratotype
Type section in the Sellafield No. 7A Borehole [NY 00 SE 36] 680.96 to 771.5 m below rotary table elevation.

Lithology
High-silica rhyolitic eutaxitic to parataxitic tuff (ignimbrite) with abundant spherulites.

Ranking
Member at the base of the Yottenfews Formation.

4.10 'UPPER' BORROWDALE VOLCANIC GROUP: SUCCESSION IN THE CROSS FELL INLIER

4.10.1 Studgill Tuff Formation (SGIL)

Stratotype
Not defined by Burgess and Holliday (1979). Crops out on the north-east face of Dufton Pike [NY 699 267] which is recommended as the type area.

Lithology
Lapilli-tuff and volcaniclastic sandstone.

Ranking
Local formation within the Borrowdale Volcanic Group in the Cross Fell inlier.

Boundaries
The lower boundary is not seen. The upper boundary is mapped at the base of the overlying Knock Pike Formation.

Thickness
About 300 m.

Remarks
Not designated on the published 1:50 000-scale maps, but described by Burgess and Holliday (1979). This unit is very poorly exposed and details of the lithofacies seen are not given.

Reference
Burgess and Holliday (1979).

Maps
Penrith (24), Appleby (30), Brough-under-Stainmore (31).

4.10.2 Knock Pike Tuff Formation (KNPK)

Stratotype
Not defined by Burgess and Holliday (1979). It is best exposed in the large roadstone quarry on the north-east side of Knock Pike [NY 6870 2850], which is recommended as a partial type area.

Lithology
Massive, pale-grey, eutaxitic and parataxitic, silicic lapilli-tuff and tuff; most is interpreted as densely welded ignimbrite, though some may be lava.

Ranking
Local formation within the Borrowdale Volcanic Group in the Cross Fell inlier.

Boundaries
The poorly exposed base is mapped at the change from intercalated volcaniclastic rocks of the Studgill Formation to densely welded silicic tuff. The top of the formation is defined by the base of the overlying Harthwaite Formation.

Thickness
About 500 m.

Remarks
Not designated on the published 1:50 000-scale maps, but described by Burgess and Holliday (1979).

References
Burgess and Wadge (1974); Burgess and Holliday (1979).

Maps
Penrith (24), Appleby (30), Brough-under-Stainmore (31).

4.10.3 Harthwaite Tuff Formation (HAWT)

Stratotype
Not defined by Burgess and Holliday (1979). There is a good section in Harthwaite Sike [NY 7084 2484 to NY 7079 2481] which is recommended as a partial type section; a section in the lowest part of the formation is seen in a small quarry [NY 7103 2524] on Dod Hill and is recommended as a reference section.

Lithology
Silicic lapilli-tuff, volcaniclastic sandstone and banded siltstone.

Ranking
Uppermost formation with the Borrowdale Volcanic Group locally in the Cross Fell inlier.

Boundaries
The base is mapped at the change from densely welded silicic tuff to a mixed sequence of volcaniclastic rocks. The formation is overlain by sedimentary rocks of the Dent Group.

Thickness
About 300 m.

Remarks
Not designated on the published 1:50 000-scale maps, but described by Burgess and Holliday (1979). Though not stated, descriptions of this unit imply that the various lithofacies are interbedded.

Reference
Burgess and Holliday (1979).

Maps
Penrith (24), Appleby (30), Brough-under-Stainmore (31).

4.11 VOLCANIC UNITS IN THE DENT GROUP (WINDERMERE SUPERGROUP)

4.11.1 Yarlside Volcanic Formation (YRL)

Stratotype
Type section in Stockdale Beck, Longsleddale [NY 4920 0558].

Lithology
Pink to pale grey, flow-banded silicic vitrophyre, locally includes massive tuff and lapilli-tuff, particularly at the base.

Ranking
Volcanic formation within the Dent Group (Windermere Supergroup).

Lower boundary
Taken at the base of the volcanic rocks resting on siltstone and sandstone of the Stile End Formation. In places overlies andesite within the Borrowdale Volcanic Group.

Upper boundary
Defined by the base of the overlying Kirkley Bank Formation.

Thickness
Up to 325 m.

Age
Ashgill (Cautleyan).

Remarks
Previously known as the Stockdale or Yarlside Rhyolite, the latter being the older term (Marr, 1892). Other rocks are classified as Stockdale Group, therefore previous designation as Stockdale Rhyolite Formation/Member now must be changed (Kneller et al., 1994). Interpreted as a succession of lavas by many authors, though a pyroclastic origin (rheomorphic ignimbrite) has been proposed (see discussion in Stephenson et al., 1999).

References
Kneller et al. (1994); Lawrence et al. (1986); Millward and Lawrence (1985).

Map
Appleby (30), Kendal (39).

4.11.2 High Haume Tuff Formation (HHR)

Stratotype
Type area near High Haume Farm, north-east of Dalton in Furness [SD 227 762].

Lithology
Massive coarse, rhyolitic crystal-lithic tuff with a weak eutaxitic texture.

Ranking
Volcanic formation within the Dent Group (Windermere Supergroup).

Lower boundary
Base of rhyolitic tuff on calcareous silty mudstone of the Kirkley Bank Formation.

Upper boundary
Defined by the base of the overlying Ashgill Formation.

Thickness
Up to 25 m.

Age
Ashgill (Rawtheyan; Zone 6).

Remarks
Previously the High Haume Rhyolite (Rose and Dunham, 1977). Interpreted as an ignimbrite.

References
Johnson et al. (2001); Kneller et al. (1994); Rose and Dunham (1977).

Map
Ulverston (48).

4.11.3 Appletreeworth Volcanic Formation (AVF)

Stratotype
Type area near Appletreeworth [SD 2444 9254].

Lithology
Pervasively altered and resedimented rhyolitic tuff; crudely bedded with locally disrupted bedding.

Ranking
Volcanic formation within the Dent Group (Windermere Supergroup).

Lower boundary
Taken at the base of the tuff overlying calcareous siltstone and limestones of the Broughton Moor Formation.

Upper boundary
Defined by the base of the overlying Ashgill Formation.

Thickness
Up to 5 m.

Age
Ashgill (Rawtheyan; Zone 6).

Remarks
Equivalent to the 'Rhyolitic Ash' of Marr (1916) and McNamara (1979). Emplaced as sediment–gravity flows.

Reference
Kneller et al. (1994); Millward et al. (2000a)

Map
Ambleside (38), Ulverston (48).

4.11.4 Sowerthwaite Formation (SOW)

The Sowerthwaite Formation occurs within the Dent Group of the Austwick and Crummack anticlines (Craven inliers) (Arthurton et al., 1988). At the base of the formation, the sequence of siltstones and mudstones contains a unit dominated by volcaniclastic rocks.

4.11.4.1 Dam House Bridge Tuff Member (DHBT)

Stratotype
Type section in Austwick Beck at Dam House Bridge [NY 7798 6953 to NY 7799 6957].

Lithology
Siltstone and mudstone with interbedded units of lithic crystal tuff, probably of silicic composition.

Ranking
Basal member of the Sowerthwaite Formation.

Lower boundary
Taken at the base of the lowest bed of tuff overlying calcareous siltstones and argillaceous limestones of the Norber Formation.

Upper boundary
Taken at the top of the last bed of tuff where it is overlain by siltstone and mudstone within the main part of the Sowerthwaite Formation.

Thickness
Up to 40 m.

Age
Ashgill (Rawtheyan; Zone 6).

Reference
Arthurton et al. (1988).

Maps
Settle (60).

4.11.5 Cautley Mudstone Formation (CMU)

The Cautley Mudstone Formation occurs within the Dent Group of the Cautley and Dent inliers. The formation contains a single unit of volcaniclastic rocks near to its top.

4.11.5.1 Cautley Volcanic Member (CTV)

Stratotype
Type area of Wandale Beck (Murthwaite Inlier) and its tributaries on its western bank between the Odd Gill and the confluence with the River Rawthey [SD 707 980 to

SD 713 990]; reference section in Backside Beck (Westerdale Inlier) [SD 696 992].

Lithology
Silicic tuffs, buff to pink in colour; thickly bedded at base becoming finer grained and thinly bedded at the top.

Ranking
Member near the top of the Cautley Mudstone Formation.

Lower boundary
Taken at the base of the lowest bed of volcaniclastic rock overlying grey flaggy mudstones of the main part of the formation.

Upper boundary
The tuffs pass upwards into grey splintery mudstone.

Thickness
Up to 24 m; 12.2 m in type area.

Age
Ashgill (Rawtheyan; Zone 6).

Reference
Ingham (1966).

Map
Kirkby Stephen (40).

5 Lithodemic scheme for Caledonian intrusive rocks in the Lake District and northern England

Formalised schemes in lithostratigraphy are now widely accepted and are used on all modern British Geological Survey maps. By contrast, intrusive igneous rocks have not been subjected to such rigorous treatment previously. However, development of the digital geological map of Great Britain (DigMapGB), and major reviews of the igneous rocks of Great Britain undertaken as part of the Geological Conservation Review have provided both the driving force and the opportunity to develop a formal lithodemic scheme.

At present, the British Geological Survey's Stratigraphy Committee has not published guidelines for lithodemic nomenclature. Lithodemic schemes produced for DigMapGB follow the recommendations of the North American Stratigraphic Code, as far as is practicable. The hierarchical scheme used is contained in the corporate dictionary BGS_DIC_LITHOSTRAT_RANK. In this table, the most significant departure from the North American code concerns the rank of 'lithodeme', which under the North American Code is considered to be equivalent to 'formation'. For pragmatic reasons, in our schemes 'lithodeme', regarded as the fundamental unit, is equivalent to the lithostratigraphical rank of 'bed'.

An extensive programme of geochemical analysis and radiometric dating of Lake District intrusive rocks has provided a wealth of data on the timing of episodes of intrusion relative to the sedimentary and extrusive igneous rocks. Various aspects of this study have been reported in papers by, among others, Rundle (1979, 1981, 1987, 1992), Hughes et al. (1996) and Millward and Evans (2003).

Large volumes of magma were intruded into the Lake District crust during Early Palaeozoic times. The intrusions with the largest outcrops are shown in Figure 1, but in addition there are concealed plutons and many minor intrusions. Many of the exposed plutonic rocks in this region form a batholith that underpins an area of at least 1500 km^2. Surface observations and interpretation of available potential field and seismic data indicate that a considerable number of granitic intrusions may be present, many of which are concealed (M K Lee, in Millward et al., 2000a). The radiometric dates on exposed components of the batholith indicate that it was built up during several magmatic episodes. Hence, 'Lake District batholith' is not given lithodemic significance.

Millward (2002) and Millward and Evans (2003) recognised three phases of plutonic and minor intrusion emplacement (Figure 2). These were associated with both Caradoc and Ashgill volcanism, and with the Acadian phase of deformation in Early Devonian times. Because these events can be considered to have occurred as part of the Caledonian Orogeny, the intrusive rocks are assigned as components of the **Caledonian Igneous Supersuite**. The Caledonian Orogeny was defined by Stephenson et al. (1999) to include all of the convergent tectonic and magmatic events arising from the closure of the Iapetus Ocean in which many of the Upper Proterozoic and Lower Palaeozoic rocks of Great Britain had been deposited.

A formal lithodemic framework for the Lower Palaeozoic intrusive rocks of northern England has evolved during preparation of the Geological Conservation Review volume on the Caledonian igneous rocks of Great Britain (Stephenson et al., 1999); this review placed the Lake District rocks within the context of the Caledonian igneous rocks of Great Britain. Millward (2002) proposed a formalised scheme which is adopted here with some modification.

Suites of intrusive rocks in northern England are defined using three factors, the type of intrusion (pluton, sill or minor intrusion), its age (Ordovician or Devonian) and, in some cases, the composition (mafic or felsic). All of the Ordovician granitic plutonic rocks are included within the *Lake District Ordovician Felsic Plutonic Suite* (5.2, below), and the Early Devonian granitic plutons in the *Northern England Devonian Plutonic Suite* (5.5). One major, Early Devonian granite, the Cheviot Pluton, is similar in age and composition to the Shap, Skiddaw and Weardale granites in the latter suite, but because of its geographical position within the Southern Uplands, it is included in the Galloway Suite and is not defined here.

The many dykes and other minor intrusive bodies in the Lake District are treated in a manner similar to the plutonic rocks (5.4, 5.6, 5.7). The small number of mafic Ordovician plutonic bodies are included within the *Lake District Ordovician Mafic Plutonic Suite* (5.3). The large number of basaltic, andesitic and rhyolitic sills associated with the Borrowdale Volcanic Group constitute the *Borrowdale Sill Suite* (5.1).

5.1 BORROWDALE SILL SUITE (BVGS)

Includes all contemporaneous sills within the Borrowdale Volcanic Group. These range in composition from basalt to rhyolite. At present no individual sills or groupings of sills have been formally recognised as subsuites or sill complexes, though there is scope for such a development.

Stratotype
Type section in Pets Quarry, Kirkstone Pass [NY 392 073].

Lithology
Basalt, basaltic andesite, andesite, dacite and rhyolite, commonly with peperitic breccia margins.

Age
No radiometric ages have been determined, but features such as peperitic margins imply emplacement into unlithified sediment during the Borrowdale Volcanic episode.

References
Millward (2002); Millward et al. (2000); Johnson et al. (2001); Branney and Suthren (1988).

Maps
Penrith (24), Keswick (29), Appleby (30), Gosforth (37), Ambleside (38), Kendal (39), Ulverston (49).

5.2 LAKE DISTRICT ORDOVICIAN FELSIC PLUTONIC SUITE (LDFP)

This suite includes all felsic plutons of known and inferred Ordovician age within the region. Most are components of the Lake District batholith, though the Threlkeld Intrusion is a laccolith intruded at levels above the batholith. Though it is clearly not in the Lake District, the concealed Wensleydale Intrusion within the Askrigg Block was included within this suite by Millward (2002), based on evidence cited by Kirby et al. (2000).

5.2.1 Ennerdale Microgranite Intrusion (ENIN)

Stratotype
Type area on Bowness Knott [NY 112 156].

Lithology
Micrographic microgranite, with some diorite, and doleritic and dioritic hybrid rocks.

Radiometric age
452 ± 4 Ma (U-Pb, zircon).

Remarks
Commonly referred to as the Ennerdale Granophyre. Intruded into the Skiddaw Group and lower part of the Borrowdale Volcanic Group.

References
Hughes et al. (1996); D J Fettes, in Stephenson et al. (1999); Millward et al. (2000a); Akhurst et al. (1997).

Maps
Whitehaven (28), Keswick (29), Gosforth (37), Ambleside (38).

5.2.2 Eskdale Granite Pluton (ESK)

Stratotype
Type area Beckfoot Quarry, Eskdale [NY 164 003].

Lithology
Medium and coarse granite and various types of microgranite.

Radiometric age
450 ± 3 Ma (U-Pb, zircon).

Remarks
The Eskdale Granite is intruded into the uppermost Skiddaw Group and lower part of the Borrowdale Volcanic Group. The granite is cleaved locally. The Rb-Sr isochron age for the granite (429 ± 4 Ma) is considered to have been reset. The relative emplacement ages of the Broad Oak Granodiorite and the Ennerdale Microgranite have not been resolved.

References
Hughes et al. (1996); B Young, in Stephenson et al. (1999); Millward et al. (2000a); Akhurst et al. (1997); Rundle (1979).

Maps
Gosforth (37), Ambleside (38).

5.2.3 Broad Oak Granodiorite Pluton

Stratotype
Type area Waberthwaite (Broad Oak) Quarry [SD 112 944].

Lithology
Granodiorite and microgranodiorite.

Radiometric age
The Rb-Sr isochron age of 428 ± 71 Ma (Rundle, 1979) is considered to have been reset, and that this pluton was emplaced during Ordovician times.

Remarks
Emplaced into the Lower BVG and Duddon Basin succession. Its emplacement age relative to the Eskdale Granite Pluton has not been resolved because of lack of exposure of the contact. Previously grouped with the Eskdale Granite Pluton as the Eskdale intrusions, but the Broad Oak Granodiorite is a separate pluton emplaced at a higher structural level.

References
B Young, in Stephenson et al. (1999); Millward et al. (2000a); Johnson et al. (2001); Rundle (1979).

Map
Gosforth (37), Ambleside (38), Bootle (49), Ulverston (48).

5.2.4 Threlkeld Microgranite Intrusion (THKD)

Stratotype
Type area in Bramcrag Quarry [NY 320 220].

Lithology
Microgranite; quartz and garnet microphyric.

Radiometric age
451.0 ± 1.1 Ma (U-Pb, zircon).

Remarks
Emplaced into the Skiddaw and Borrowdale Volcanic groups adjacent to the unconformity. The geochemistry and style of mineralogical alteration seen in the mass are similar to silicic rocks within the Borrowdale Volcanic Group. A Rb-Sr age of 438 ± 6 Ma is shown to have been reset.

References
Millward and Evans (2003); Rundle (1981); S C Loughlin, in Stephenson et al. (1999); Hughes et al. (1996).

Map
Keswick (29).

5.3 LAKE DISTRICT ORDOVICIAN MAFIC PLUTONIC SUITE (LDMP)

There are only two mafic plutonic bodies in the Lake District, the Carrock Fell Complex and the Haweswater intrusions. The former comprises a number of intrusions of distinct geochemical affinity and probable differing ages. Some aspects of the emplacement ages within the complex remain poorly understood. The age of the Haweswater intrusions is inferred because there is no radiometric-age determination.

5.3.1 Carrock Fell Intrusion-complex (CFCO)

Stratotype
Type area on Carrock Fell [NY 340 320 to NY 360 342].

Lithology
Layered gabbro–microgranite complex.

Remarks
Includes a number of component intrusions, named below, with varying geochemical affinity. These have proved or inferred Ordovician ages.

Radiometric ages
See component units.

References
Millward and Evans (2003); Rundle (1979, 1992); Hunter (1980); D Millward, in Stephenson et al. (1999).

Map
Cockermouth (23).

5.3.1.1 Mosedale Gabbros (CFCOM)

Stratotype
As for the Carrock Fell Complex.

Lithology
Layered cumulate gabbro and hypersthene gabbro; quartz gabbro; xenoliths of hornfelsed basalt common and large adjacent to contact.

Radiometric age
468 ± 9 Ma (K-Ar, whole rock).

Remarks
The oldest intrusion in the complex. Geochemically similar to the Eycott Volcanic Group and interpreted to have been emplaced as a near-horizontal sill at the base of the volcanic group. Within error, the radiometric age is comparable with the probable biostratigraphical age of the Eycott Volcanic Group.

5.3.1.2 Carrock Gabbro–Microgranite Intrusions (CFCOC)

Stratotype
As for the Carrock Fell Complex.

Lithology
Separate intrusions of granophyric microgranite, microgabbro, and a marginal zone comprising apatite-bearing iron-rich microgabbro, microdiorite, micromonzodiorite and microgranite.

Radiometric age
452.4 ± 4.1 Ma (U-Pb, zircon) on the main microgranite mass.

Remarks
Main mass commonly referred to as the Carrock Granophyre, and the microgabbro as Carrock Diabase. Cross-cutting intrusive contact with Mosedale Gabbros. Believed to have been emplaced as a near-vertical sheet-like body in which crystal fractionation of an evolved, low-Mg tholeiitic basalt magma had occurred. Rb-Sr, whole rock isochron age of 435 ± 9 Ma reset.

5.3.1.3 Iron Crag Microgranite (CFCOI)

Stratotype
Type area Roughton Gill [NY 304 342 to NY 307 344].

Lithology
Microgranite, forming an elongate, faulted mass.

Radiometric age
None determined.

Remarks
Cross-cutting, intrusive contacts with the Carrock intrusions.

Reference
Millward, in Stephenson et al. (1999).

5.3.1.4 Harestones Rhyolite (CFCOH)

Stratotype
Type area fell side north-east of Great Lingy Hill [NY 312 345].

Lithology
Quartz-phyric rhyolite.

Radiometric age
419 ± 4 Ma (Rb-Sr, whole rock), believed to be reset.

Remarks
Intruded into mudstones of the Longvillian Drygill Shale Formation. The mudstones are bleached at the contact with the rhyolite and similar apophyses, giving a maximum age for emplacement. Faulted contact with other components of the complex. This is the only extant Silurian radiometric age for igneous rocks in the Lake District and is probably reset. A late Ordovician (Ashgill) age is thought more likely (Millward and Evans, 2003).

5.3.2 Haweswater Dolerite Intrusions (HAWS)

Stratotype
Type area on Wallow Crag to Kit Crag, south-east of Haweswater [NY 491 145 to 496 151].

Lithology
Eight main plugs and dyke-like masses of dolerite with subordinate gabbro and microdiorite; minor intrusive breccia.

Radiometric age
None determined.

Remarks
Localised within an area of 19 km^2 around Haweswater and intruded into the Borrowdale Volcanic Group. An Ordovician age is considered probable because the rocks are cleaved and are geochemically similar to the Borrowdale Volcanic Group.

Reference
Millward and Beddoe-Stephens (1998).

Map
Appleby (30).

5.4 LAKE DISTRICT ORDOVICIAN MINOR INTRUSION SUITE (LDOMI)

Minor intrusions of Ordovician age are widespread throughout the Lake District inlier. Included are basalt and dolerite dykes (Macdonald et al., 1988), garnetiferous rhyodacite dykes (Beddoe-Stephens and Mason, 1991), dacite, rhyolite, and andesite and hybridised andesite dykes, associated with intrusive breccia (McConnell et al., 2002; Millward et al., 2000a). There are few reliable

radiometric dates, though many of these rocks are considered to be associated with the Borrowdale Volcanic Group or Eskdale and Ennerdale intrusions. At present, two groups of mafic intrusions are formally defined within the suite:

5.4.1 Embleton Microdiorite Intrusions (EMBL)

Stratotype
Type area in Close Quarry, Embleton [NY 175 309], near Cockermouth.

Lithology
Microdiorite.

Radiometric age
444 ± 24 Ma (Rb-Sr, whole rock).

Remarks
Occurs within the Skiddaw Group, localised to an area of about 13 km^2 adjacent to the Watch Hill Thrust.

Reference
Rundle (1979).

Map
Cockermouth (23).

5.4.2 Bassenthwaite Diorite Intrusions (BADIN)

Stratotype
Type intrusion at Great Cockup [NY 271 324].

Lithology
Porphyritic hornblende diorite, microdiorite and hornblendite.

Radiometric age
458 ± 9 Ma (K-Ar, whole rock).

Remarks
Widespread, within the Skiddaw Group of the main outcrop and in the Black Combe Inlier.

Reference
Rundle (1979).

Maps
Cockermouth (23), Keswick (29), Ulverston (48).

5.5 NORTHERN ENGLAND DEVONIAN PLUTONIC SUITE (NEDP)

In the Lake District, this suite comprises two exposed granitic bodies, the Skiddaw and Shap plutons. In addition, one concealed mass, the elongate Crummock Water Intrusion is inferred to have been emplaced at this time. Millward (2002) also postulated that the concealed Ulpha 'Granite' of Lee (in Millward et al., 2000b) could also have been emplaced at this time. The Weardale Granite, beneath the north Pennines, is also included in the suite but it is not defined here. This suite is equivalent in age to the Cheviot Volcanic Formation and the Galloway Suite of southern Scotland which includes the Cheviot Granite Pluton.

5.5.1 Shap Granite Pluton (SHAP)

Stratotype
Type area in Shap Pink Quarry, Shap [NY 557 084].

Lithology
K-feldspar megaphyric granite, forming a cylindrical pluton.

Radiometric age
397 ± 7 Ma (K-Ar, biotite).

References
Rundle (1992); see also S C Loughlin in Stephenson et al. (1999).

Maps
Appleby (30), Kendal (39).

5.5.2 Skiddaw Granite Pluton (SKID)

Stratotype
Type area Grainsgill and River Caldew [NY 327 327].

Lithology
Granite, some quartz-muscovite rock (greisen).

Radiometric age
399 ± 8 Ma (K-Ar, biotite).

References
Shepherd et al. (1976); S C Loughlin, in Stephenson et al. (1999).

Maps
Cockermouth (23), Keswick (29).

5.5.3 Crummock Water Felsic Intrusion

Lithology
Concealed, but probably granitic, as inferred from the major metasomatic aureole at the surface and from interpretation of geophysical data.

Radiometric age
401 ± 3 Ma (Rb-Sr, whole rock), determined on aureole rocks.

Reference
Cooper et al. (1988).

Map
Whitehaven (28), Keswick (29).

5.6 LAKE DISTRICT DEVONIAN MINOR INTRUSION SUITE (LDDMI)

Comprises dykes and minor intrusions throughout the Lake District of two main rock types: quartz-feldspar-phyric microgranite and porphyritic microgranodiorite-microgranite. All probably are related to the event which included emplacement of the Shap Pluton. The first rock type is distinctive, occurring for example in the Scafell

area and one dyke there has a radiometric age of 393 ± 9 Ma (Rb-Sr, whole rock; Al Jawadi, 1987). Microgranodiorite-microgranite dykes from Lingmell on Scafell have given an age of 392 ± 4 Ma (Rb-Sr, whole rock; Al Jawadi, 1987) and a red microgranite from Holehouse Gill area (Ambleside sheet) has an age of 391 ± 19 Ma (Rb-Sr, whole rock; Rundle, 1987). Microgranite dykes cutting the Windermere Supergroup probably have a similar age (Soper and Kneller, 1990). A detailed study of the distribution and geochemistry of these dykes may enable recognition of swarms within the suite.

5.7 NORTH BRITAIN SILURO-DEVONIAN CALC-ALKALINE DYKE SUITE (SDCAD)

Calc-alkaline dykes are widespread throughout the Caledonides of northern Britain. In the Lake District this suite is represented by lamprophyre dykes. These rocks are seen sporadically in the central Lake District, but are more widespread in the northern Pennine inliers (Macdonald et al., 1985). The K-Ar ages determined by Nixon et al. (1984), span the range 420–402 Ma, and are latest Silurian to Early Devonian. No formal division of the suite is proposed in this report.

Appendix 1 Alphabetical list of Ordovician lithostratigraphical and lithodemic units referred to in this report

Obsolete stratigraphical terms are given thus [ ] and are detailed in Appendix 3.

Name	*Map code*	*Lexicon code*	*Parent unit*	*Page*
Airy's Bridge Tuff Formation	AiB	AIB	Borrowdale Volcanic Group	20
Appletreeworth Volcanic Formation		AVF	Dent Group	37
Ashness Tuff Member	AHT	AHT	Birker Fell Andesite Formation	16
Bad Step Tuff	Bdp	BDP	Airy's Bridge Tuff Formation	21
Barrow Tuff Member	BarT	BART	Waberthwaite Tuff Formation	22
Bassenthwaite Dioritic Intrusions		BADIN	Lake District Ordovician Minor Intrusion Suite	42
Beck Wood Tuff Member	BWT	BWT	Waberthwaite Tuff Formation	22
Bell Crags Breccia Member [Binsey Formation]	BCr	BCR	Seathwaite Fell Sandstone Formation	28
Birkby Fell Andesite Member	Bkb	BKB	Birker Fell Andesite Formation	17
Birker Fell Andesite Formation	BFA	BFA	Borrowdale Volcanic Group	16
Blake Brow Breccia Member	Blk	BLBR	Deepdale Sandstone Formation	32
Bleawath Tuff Formation		BLEA	Borrowdale Volcanic Group	33
Blengdale Tuff Formation	Bgd	BGD	Borrowdale Volcanic Group	35
Blind Cove Sandstone Member	Bld	BLCV	Deepdale Sandstone Formation	32
Blisco Sandstone Member	Bco	BCO	Birker Fell Andesite Formation	19
Borrowdale Sill Suite		BVGS	Caledonian Igneous Supersuite	39
Borrowdale Volcanic Group	BVG	BVG		5
Bowfell Links Sandstone Member		BFL	Seathwaite Fell Sandstone Formation	29
Broad Oak Granodiorite Pluton			Lake District Ordovician Felsic Plutonic Suite	40
Brock Crags Andesite Formation	BkCg	BKCG	Borrowdale Volcanic Group	31
Broom Farm Sandstone Formation		BRFA	Borrowdale Volcanic Group	33
Brown Bank Tuff Formation		BBA	Borrowdale Volcanic Group	33
Brown Howe Tuff Member	BnH	BNH	Mardale Sandstone Formation	26
Caledonian Igneous Supersuite		CIGSS		39
Cam Crags Sandstone Member	CCr	CCR	Seathwaite Fell Sandstone Formation	28
Cam Spout Tuff		CPT	Airy's Bridge Tuff Formation	21
Carrock Fell Intrusion-complex		CFCO	Lake District Ordovician Mafic Plutonic Suite	40
Carrock Gabbro-Microgranite Intrusions		CFCOC	Carrock Fell Intrusion-complex	41
Cautley Mudstone Formation	CMu	CMU	Dent Group	37
Cautley Volcanic Member	CtV	CTV	Cautley Mudstone Formation (Dent Group)	37
Caw Sandstone Formation	CwT	CWT	Borrowdale Volcanic Group	24
Cawdale Tuff Member	Cawd	CAWD	Mardale Sandstone Formation	26
Cawk Cove Sandstone Member	Cwk	CWK	Deepdale Sandstone Formation	32
Cockley Beck Tuff Member	CkT	CKT	Birker Fell Andesite Formation	17
Cockley How Tuff Member	Cky	CKY	Deepdale Sandstone Formation	32
Cockley Pike Sandstone Member	CPk	CPK	Seathwaite Fell Sandstone Formation	29
Craghouse Tuff Member	ChT	CHT	Birker Fell Andesite Formation	18
Crinkle Tuff Member	Crk	CRK	Airy's Bridge Tuff Formation	21
Crummock Water Felsic Intrusion			Northern England Devonian Plutonic Suite	42
Dam House Bridge Tuff Member	DHBT	DHBT	Sowerthwaite Formation (Dent Group)	37
Dale Head Breccia Member	DHd	DHD	Birker Fell Andesite Formation	17
Deepdale Sandstone Formation	Dpd	DPD	Borrowdale Volcanic Group	32
Devoke Water Tuff Member	DkT	DKT	Birker Fell Andesite Formation	17
Dog Crag Tuff Member		DCT	Po House Tuff Formation	16
Doup Crag Tuff Member	DpT	DPT	Woundale Tuff Formation	27
Dove Crag Tuff Member	Dvd	DOCR	Deepdale Sandstone Formation	32
Duddon Bridge Tuff Member	DBT	DBT	Waberthwaite Tuff Formation	22
Duddon Hall Tuff Formation	DH	DH	Borrowdale Volcanic Group	22
Dungeon Ghyll Sandstone Member		DGY	Seathwaite Fell Sandstone Formation	29
Dunnerdale Sandstone Formation	DnF	DNF	Borrowdale Volcanic Group	23
Eagle Crag Sandstone Member	Eag	EAGC	Birker Fell Andesite Formation	18
Embleton Microdiorite Intrusions	EMBL		Lake District Ordovician Minor Intrusion Suite	42
Ennerdale Microgranite intrusion		ENIN	Lake District Ordovician Felsic Plutonic Suite	40
Esk Pike Sandstone Formation	EsP	ESP	Borrowdale Volcanic Group	30

Name	*Map code*	*Lexicon code*	*Parent unit*	*Page*
Eskdale Granite Pluton		ESK	Lake District Ordovician Felsic Plutonic Suite	40
Eycott Volcanic Group [Fell Green Formation]		EVG		4
Fleming Hall Tuff Formation	FlH	FLH	Borrowdale Volcanic Group	34
Frith Crag Breccia Member	FrCr	FRCR	Birker Fell Andesite Formation	19
Froswick Tuff Formation	Fsw	FSW	Borrowdale Volcanic Group	27
Garburn Dacite Formation	GaD	GAD	Borrowdale Volcanic Group	31
Glaramara Tuff	GmT	GMT	Seathwaite Fell Sandstone Formation	29
Goat Scar Dacite Member	GSD	GSD	Lincomb Tarns Tuff Formation	30
Gouther Crag Breccia Member	GrCg	GRCG	Mardale Sandstone Formation	26
Grange Crags Andesite Member	GCg	GCG	Birker Fell Andesite Formation	16
Great Ladstones Breccia Member	GtLa	GTLA	Mardale Sandstone Formation	27
Great Whinscale Dacite Member [Greenhow End Member]	GWD	GWD	Birker Fell Andesite Formation	18
Greenscoe Tuff Formation	GSC	GCOE	Borrowdale Volcanic Group	10
Grey Friar Tuff Member	Gy	GY	Birker Fell Andesite Formation	19
Hanging Stone Tuff		HNG	Airy's Bridge Tuff Formation	21
Harestones Rhyolite		CFCOH	Carrock Fell Intrusion-complex	41
Harrath Tuff Member	HhT	HHT	Waberthwaite Tuff Formation	22
Harrison Stickle Breccia Member		HTK	Seathwaite Fell Sandstone Formation	29
Harthwaite Tuff Formation	Hawt	HAWT	Borrowdale Volcanic Group	36
Haweswater Dolerite Intrusions	Haws	HAWS	Lake District Ordovician Mafic Plutonic Suite	41
Haystacks Andesite Member	Hys	HAYS	Birker Fell Andesite Formation	19
Helvellyn Tuff Formation [High Ireby Formation]	Hlv	HLV	Borrowdale Volcanic Group	31
High Haume Volcanic Formation	HHT	HHR	Dent Group	37
Holehouse Gill Mudstone Formation	Hlh	HLH	Borrowdale Volcanic Group	23
Iron Crag Microgranite		CFCOI	Carrock Fell Intrusion-complex	41
Kentmere Pike Tuff Formation	Kmr	KMR	Borrowdale Volcanic Group	27
Kiln Bank Tuff Member	Kln	KLN	Lickle Tuff Formation	24
Knock Pike Tuff Formation	KnPk	KNPK	Borrowdale Volcanic Group	36
Lag Bank Tuff Formation	LBT	LBT	Borrowdale Volcanic Group	25
Lake District Devonian Minor Intrusion Suite		LDDMI	Caledonian Igneous Supersuite	42
Lake District Ordovician Felsic Plutonic Suite		LDFP	Caledonian Igneous Supersuite	40
Lake District Ordovician Mafic Plutonic Suite		LDMP	Caledonian Igneous Supersuite	40
Lake District Ordovician Minor Intrusion Suite		LDOMI	Caledonian Igneous Supersuite	41
Lanty Crag Breccia Member	Lty	LTY	Birker Fell Andesite Formation	17
Latterbarrow Sandstone Formation	LaS	LAS	Borrowdale Volcanic Group	14
Lickle Tuff Formation	Lick	LICK	Borrowdale Volcanic Group	24
Lincomb Tarns Tuff Formation [Lingcove Formation]	LTa	LTA	Borrowdale Volcanic Group	29
Lingmell Tuff Formation [Lingmoor Fell Formation]	Lme	LME	Borrowdale Volcanic Group	21
Little Meldrum Tuff Member	Lmel	LMEL	Birker Fell Andesite Formation	17
Little Stand Tuff Member	LiT	LIT	Birker Fell Andesite Formation	18
Longlands Farm Tuff Member	LoFa	LOFA	Fleming Hall Tuff Formation	34
Lowcray Tuff Formation	LoCr	LOCY	Borrowdale Volcanic Group	34
Long Top Tuff Member	LTT	LTT	Airy's Bridge Tuff Formation	20
Low Water Tuff Formation	LwW	LWW	Borrowdale Volcanic Group	25
Mardale Sandstone Formation	Mrl	MRL	Borrowdale Volcanic Group	26
Middle Dodd Dacite Formation [Millom Park Formation]	MdD	MDD	Borrowdale Volcanic Group	30
Moorside Farm Tuff Formation [Mosedale Andesite Formation]		MOF	Borrowdale Volcanic Group	33
Mosedale Gabbros [Napes Needle Member]		CFCOM	Carrock Fell Intrusion-complex	40
Nettle Crags Tuff Member	NCT	NCT	Birker Fell Andesite Formation	18
Newton Manor Sandstone Formation		NEM	Borrowdale Volcanic Group	35
North Britain Siluro-Devonian Calc-alkaline Dyke Suite		SDCAD	Caledonian Igneous Supersuite	43
Northern England Devonian Plutonic Suite		NEDP	Caledonian Igneous Supersuite	42

Name	*Map code*	*Lexicon code*	*Parent unit*	*Page*
Overwater Siltstone Formation	OV	OV	Eycott Volcanic Group	10
Oxendale Tuff	OxT	OXT	Airy's Bridge Tuff Formation	21
Paddy End Tuff Member	PER	PER	Lickle Tuff Formation	24
Pavey Ark Breccia Member	Pav	PAV	Seathwaite Fell Sandstone Formation	29
Pinnacle Howe Tuff Member	PnH	PNH	Whelter Knotts Tuff Formation	26
Po House Tuff Formation	PHT	PHT	Borrowdale Volcanic Group	16
Potts Ghyll Tuff Formation	PoG	POG	Eycott Volcanic Group	10
Powley's Hill Tuff Member	PlH	PLH	Whelter Knotts Tuff Formation	26
Raisebeck Volcaniclastic Member	RBk	RABK	Lincomb Tarns Tuff Formation	30
Rest Gill Tuff		REG	Airy's Bridge Tuff Formation	21
Rosthwaite Rhyolite Member	RsR	RSR	Lingmell Tuff Formation	22
Round How Breccia Member	Rnd	RND	Birker Fell Andesite Formation	19
Rowantreethwaite Tuff Member	Rwt	RWT	Mardale Sandstone Formation	26
St Raven's Edge Tuff Member	SRE	SRE	Seathwaite Fell Sandstone Formation	29
St Sunday Crag Tuff Member	SSC	SSC	Deepdale Sandstone Formation	32
Scalehow Tuff Formation	Scw	SCW	Borrowdale Volcanic Group	25
Scafell Dacite Member	ScD	SCD	Lingmell Tuff Formation	22
Seascale Hall Tuff Member		SEHA	Brown Bank Tuff Formation	34
Seatallan Dacite Member	StaD	STAD	Birker Fell Andesite Formation	18
Seathwaite Fell Sandstone Formation	Set	SET	Borrowdale Volcanic Group	28
Sella Park Tuff Member		SEP	Yottenfews Tuff Formation	35
Shap Granite Pluton		SHAP	Northern England Devonian Plutonic Suite	42
Side Pike volcanic complex		SIPI	Borrowdale Volcanic Group	8
Sides Farm Breccia Member		SIFA	Fleming Hall Tuff Formation	34
Skiddaw Granite Pluton		SKID	Northern England Devonian Plutonic Suite	42
Sowerthwaite Formation	Sow	SOW	Dent Group	37
Sprinkling Tarn Sandstone Member		SPR	Seathwaite Fell Sandstone Formation	29
Stickle Pike Tuff Member [Stockdale Rhyolite Formation] [Stoneside Hill Formation]	StPi	STPI	Lickle Tuff Formation	24
Stonesty Tuff		STF	Airy's Bridge Tuff Formation	21
Studgill Tuff Formation	Sgil	SGIL	Borrowdale Volcanic Group	35
Tarn Crags Tuff Member	TCr	TNCR	Lincomb Tarns Tuff Formation	30
Tarn Hows Tuff Formation	THw	THW	Borrowdale Volcanic Group	31
Thirlmere Tuff Member [Thornhow End Member]	Thl	TMR	Lincomb Tarns Tuff Formation	30
Three Tarns Sandstone Member		TTA	Seathwaite Fell Sandstone Formation	28
Threlkeld Microgranite Intrusion		THKD	Lake District Ordovician Felsic Plutonic Suite	40
Throstle Garth Basalt Member [Tongue House Member]	TGh	TGH	Birker Fell Andesite Formation	19
Town End Farm Tuff Member		TOEF	Fleming Hall Tuff Formation	34
Ulpha Andesite Formation	Ulp	ULP	Borrowdale Volcanic Group	23
Waberthwaite Tuff Formation	Wb	WB	Borrowdale Volcanic Group	22
Wallowbarrow Tuff Formation	Wal	WAL	Borrowdale Volcanic Group	23
Wet Side Edge Tuff Member	WSE	WSE	Whorneyside Tuff Formation	20
Wet Sleddale Andesite Formation	WetS	WETS	Borrowdale Volcanic Group	28
Whelter Knotts Tuff Formation	Wlt	WLT	Borrowdale Volcanic Group	25
Whinny Bank Tuff Formation	WnB	WNB	Borrowdale Volcanic Group	15
Whorneyside Tuff Formation [Worm Crag Formation]	Wny	WNY	Borrowdale Volcanic Group	20
Woundale Tuff Formation	Wou	WOU	Borrowdale Volcanic Group	27
Wrayslack Tuff Member	WrT	WRT	Waberthwaite Tuff Formation	22
Wrighthow Basalt Member	WgtB	WGTB	Birker Fell Andesite Formation	19
Yarlside Volcanic Formation	Yrl	YRL	Dent Group	36
Yottenfews Sandstone Formation		YOT	Borrowdale Volcanic Group	35

Appendix 2 Alphabetical list of abbreviations used for the Ordovician volcanic rocks (map codes) on British Geological Survey 1:50 000 and 1:25 000-scale maps of the Lake District.

Obsolete stratigraphical terms are given thus [ ] and are detailed in Appendix 3.

Map code	*Unit name*	*Parent unit*
AHT	Ashness Tuff Member	Birker Fell Andesite Formation
AiB	Airy's Bridge Tuff Formation	Borrowdale Volcanic Group
BarT	Barrow Tuff Member	Waberthwaite Tuff Formation
Bco	Blisco Sandstone Member	Birker Fell Andesite Formation
BCr	Bell Crags Breccia Member	Seathwaite Fell Sandstone Formation
Bdp	Bad Step Tuff	Airy's Bridge Tuff Formation
BFA	Birker Fell Andesite Formation	Borrowdale Volcanic Group
Bgd	Blengdale Tuff Formation	Borrowdale Volcanic Group
Bkb	Birkby Fell Andesite Member	Birker Fell Andesite Formation
BkCg	Brock Crags Andesite Formation	Borrowdale Volcanic Group
Bld	Blind Cove Sandstone Member	Deepdale Sandstone Formation
Blk	Blake Brow Breccia Member	Deepdale Sandstone Formation
BnH	Brown Howe Tuff Member	Mardale Sandstone Formation
BVG	Borrowdale Volcanic Group	
BWT	Beck Wood Tuff Member	Waberthwaite Tuff Formation
Cawd	Cawdale Tuff Member	Mardale Sandstone Formation
CCr	Cam Crags Sandstone Member	Seathwaite Fell Sandstone Formation
ChT	Craghouse Tuff Member	Birker Fell Andesite Formation
CkT	Cockley Beck Tuff Member	Birker Fell Andesite Formation
Cky	Cockley How Tuff Member	Deepdale Sandstone Formation
Crk	Crinkle Tuff Member	Airy's Bridge Tuff Formation
CtV	Cautley Volcanic Member	Cautley Mudstone Formation
Cwk	Cawk Cove Sandstone Member	Deepdale Sandstone Formation
CwT	Caw Sandstone Formation	Borrowdale Volcanic Group
DBT	Duddon Bridge Tuff Member	Waberthwaite Tuff Formation
DH	Duddon Hall Tuff Formation	Borrowdale Volcanic Group
DHBT	Dam House Bridge Tuff Member	Sowerthwaite Formation
DHd	Dale Head Breccia Member	Birker Fell Andesite Formation
DkT	Devoke Water Tuff Member	Birker Fell Andesite Formation
DnF	Dunnerdale Sandstone Formation	Borrowdale Volcanic Group
Dpd	Deepdale Sandstone Formation	Borrowdale Volcanic Group
DpT	Doup Crag Tuff Member	Woundale Tuff Formation
Dvd	Dove Crag Tuff Member	Deepdale Sandstone Formation
Eag	Eagle Crag Sandstone Member	Birker Fell Andesite Formation
EsP	Esk Pike Sandstone Formation	Borrowdale Volcanic Group
EVG	Eycott Volcanic Group	
FlH	Fleming Hall Tuff Formation	Borrowdale Volcanic Group
FrCr	Frith Crag Breccia Member	Birker Fell Andesite Formation
Fsw	Froswick Tuff Formation	Borrowdale Volcanic Group
GaD	Garburn Dacite Formation	Borrowdale Volcanic Group
GCg	Grange Crags Andesite Member	Birker Fell Andesite Formation
GmT	Glaramara Tuff	Seathwaite Fell Formation
GrCg	Gouther Crag Breccia Member	Mardale Sandstone Formation
GSC	Greenscoe Tuff Formation	Borrowdale Volcanic Group
GsD	Goat Scar Dacite Member	Lincomb Tarns Tuff Formation
GtLa	Great Ladstones Breccia Member	Mardale Sandstone Formation
GWD	Great Whinscale Dacite Member	Birker Fell Andesite Formation
Gy	Grey Friar Tuff Member	Birker Fell Andesite Formation
Hawt	Harthwaite Tuff Formation	Borrowdale Volcanic Group
HHT	High Haume Volcanic Formation	Dent Group
HhT	Harrath Tuff Member	Waberthwaite Tuff Formation
Hlh	Holehouse Gill Mudstone Formation	Borrowdale Volcanic Group
Hlv	Helvellyn Tuff Formation	Borrowdale Volcanic Group
Hys	Haystacks Andesite Member	Birker Fell Andesite Formation
Kln	Kiln Bank Tuff Member	Lickle Tuff Formation
KmR	Kentmere Pike Tuff Formation	Borrowdale Volcanic Group

Map code	*Unit name*	*Parent unit*
KnPk	Knock Pike Tuff Formation	Borrowdale Volcanic Group
LaS	Latterbarrow Sandstone Formation	Borrowdale Volcanic Group
LBT	Lag Bank Tuff Formation	Borrowdale Volcanic Group
LiT	Little Stand Tuff Member	Birker Fell Andesite Formation
Lme	Lingmell Tuff Formation	Borrowdale Volcanic Group
Lmel	Little Meldrum Tuff Member	Birker Fell Andesite Formation
LoCr	Lowcray Tuff Formation	Borrowdale Volcanic Group
LoFa	Longlands Farm Tuff Member	Fleming Hall Tuff Formation
[LrF	Lingmoor Fell Formation]	*now Low Water Tuff Formation*
LTa	Lincomb Tarns Tuff Formation	Borrowdale Volcanic Group
LTT	Long Top Tuff Member	Airy's Bridge Tuff Formation
Lty	Lanty Crag Breccia Member	Birker Fell Andesite Formation
LwW	Low Water Tuff Formation	Borrowdale Volcanic Group
MdD	Middle Dodd Dacite Member	Borrowdale Volcanic Group
[MPa	Millom Park Formation]	*now Waberthwaite Tuff Formation*
Mrl	Mardale Sandstone Formation	Borrowdale Volcanic Group
NCT	Nettle Crags Tuff Member	Birker Fell Andesite Formation
OV	Overwater Siltstone Formation	Eycott Volcanic Group
OxT	Oxendale Tuff	Airy's Bridge Tuff Formation
Pav	Pavey Ark Breccia Member	Seathwaite Fell Formation
PER	Paddy End Tuff Member	Lickle Tuff Formation
PHT	Po House Tuff Formation	Borrowdale Volcanic Group
PlH	Powley's Hill Tuff Member	Whelter Knotts Tuff Formation
PnH	Pinnacle Howe Tuff Member	Whelter Knotts Tuff Formation
PoG	Potts Ghyll Tuff Formation	Eycott Volcanic Group
RBk	Raisebeck Sandstone Member	Lincomb Tarns Tuff Formation
Rnd	Round How Breccia Member	Birker Fell Andesite Formation
RsR	Rosthwaite Rhyolite Member	Lingmell Tuff Formation
Rwt	Rowantreethwaite Tuff Member	Mardale Sandstone Formation
ScD	Scafell Dacite Member	Lingmell Tuff Formation
Scw	Scale How Tuff Formation	Borrowdale Volcanic Group
Set	Seathwaite Fell Sandstone Formation	Borrowdale Volcanic Group
Sgil	Studgill Tuff Formation	Borrowdale Volcanic Group
SRE	St Raven's Edge Tuff Member	Seathwaite Fell Formation
[SRh	Stockdale Rhyolite Member]	*now Yarlside Volcanic Formation*
SSC	St Sunday Crag Tuff Member	Deepdale Sandstone Formation
StaD	Seatallan Dacite Member	Birker Fell Andesite Formation
StPi	Stickle Pike Tuff Member	Lickle Tuff Formation
TCr	Tarn Crags Tuff Member	Lincomb Tarns Tuff Formation
TGh	Throstle Garth Basalt Member	Birker Fell Andesite Formation
Thl	Thirlmere Tuff Member	Lincomb Tarns Tuff Formation
[TnM	Tongue House Member]	*obsolete*
THw	Tarn Hows Tuff Formation	Borrowdale Volcanic Group
Ulp	Ulpha Andesite Formation	Borrowdale Volcanic Group
Wal	Wallowbarrow Tuff Formation	Borrowdale Volcanic Group
Wb	Waberthwaite Tuff Formation	Borrowdale Volcanic Group
WetS	Wet Sleddale Tuff Formation	Borrowdale Volcanic Group
WgtB	Wrighthow Basalt Member	Birker Fell Andesite Formation
Wlt	Whelter Knotts Tuff Formation	Borrowdale Volcanic Group
Wou	Woundale Tuff Formation	Borrowdale Volcanic Group
WnB	Whinny Bank Tuff Formation	Borrowdale Volcanic Group
Wny	Whorneyside Tuff Formation	Borrowdale Volcanic Group
WrT	Wray Slack Tuff Member	Waberthwaite Tuff Formation
WSE	Wet Side Edge Tuff Member	Whorneyside Tuff Formation
Yrl	Yarlside Volcanic Formation	Dent Group

Appendix 3 Discontinued and obsolete stratigraphical terms

The usage of a small number of units included on maps, in the BGS Lexicon and in various accounts should be discontinued as a result of this overview. Such units are listed below along with reasons for this.

BINSEY FORMATION

The lower of two divisions of the Eycott Volcanic Group following Eastwood et al. (1968) and formalised by Downie and Soper (1972), Wadge (1978) and Moseley (1984). The base of the formation was placed at the base of the 'Lower Eycott Lavas' of Eastwood et al. However, Millward et al. (1999) do not follow this stratigraphy. They showed that the Lower Eycott Lavas are sills and that most of the formation as originally defined differs little from the overlying High Ireby Formation.

CROSBY THWAITE FORMATION

There is a Lexicon entry under this name for bedded pyroclastic rocks in the south-western Lake District. These rocks have since been assigned as part of the Whorneyside Formation and the name Crosby Thwaite Formation is regarded as obsolete.

FELL GREEN FORMATION

There is a Lexicon entry for dacitic and basaltic andesite sheets in lower part of Borrowdale Volcanic Group between Crookley Beck and Nettle Crags [SD 1160 8830 to SD 1164 8865]. These rocks are lithologically similar to, and occur at the same stratigraphical level as, the Birker Fell Formation. They are shown as such on the Ulverston map and are described as such in the memoir (Johnson et al., 2001). The name is therefore obsolete.

GREENHOW END MEMBER

Woodhall (1998) described the main part of the Deepdale Formation as the Greenhow End Member. There is no requirement to name all parts of the formation and this member name is not shown on Keswick Sheet 29. The name is obsolete.

HIGH IREBY FORMATION

The upper of two divisions of the Eycott Volcanic Group following Eastwood et al. (1968) and formalised by Downie and Soper (1972), Wadge (1978) and Moseley (1984). The base of the formation was placed at the base of the 'Middle Eycott Lavas' of Eastwood et al. (1968). However, Millward et al. (1999) do not follow these previous workers, arguing that the Middle Eycott Lavas may be sills and that most of the formation, as originally defined, differs little from the underlying Binsey Formation.

LINGCOVE FORMATION

Defined by Branney and Soper (1988), and Branney and Kokelaar (1994) for part of the Birker Fell Formation in the Scafell area. These rocks have been included within the Birker Fell Formation by the BGS and the name Lingcove Formation has not been used by the BGS. It is included here because of its previously published status.

LINGMOOR FELL FORMATION

Designated for use on Sheet 38, Ambleside. Dacitic lapilli-tuff, but the outcrop on Lingmoor Fell is probably equivalent to the Low Water Formation, though this has not been proved geochemically; the outcrop in the Ambleside area is possibly part of the Froswick Formation. The term Lingmoor Fell Formation is considered to be obsolete.

MILLOM PARK FORMATION

Massive dacitic lapilli-tuff of the Millom Park area (Sheet 48 Ulverston). Considered to be laterally equivalent to Waberthwaite Tuff Formation and this name is preferred to Millom Park Formation, which now becomes obsolete.

MOSEDALE ANDESITE FORMATION

A partial Lexicon entry exists under this title for rocks subsequently included within the Birker Fell Formation. Mosedale Andesite Formation has not been published and this term should be considered to be obsolete.

NAPES NEEDLE MEMBER

The Napes Needle Member was formally established by Kneller et al. (1993) to refer to the main part of the Lingmell Tuff Formation: i.e. all except the formally defined Scafell Dacite and Rosthwaite Rhyolite, which are members. Because the definition of the formation carries the main lithologies, this formally defined member is considered unnecessary.

STOCKDALE RHYOLITE FORMATION

Renamed on precedence by Kneller et al. (1994) as the Yarlside Volcanic Formation and referred to as the Yarlside Formation by Fortey et al. (2000). It is recommended that use of the term Stockdale Rhyolite Formation is discontinued.

STONESIDE HILL FORMATION

A formal Lexicon entry exists for the Stoneside Hill Formation to include dacite sheets with intercalated volcaniclastic sandstone and tuff in the lower part of the Borrowdale Volcanic Group in the area north of Black Combe. These rocks are included as part of the Birker Fell Formation on the Ulverston sheet (48) and in the memoir (Johnson et al., 2001). The term is obsolete.

THORNHOW END MEMBER

Used by Woodhall (1998) to refer to the basal part of the Deepdale Formation in northern part of its outcrop. Not

shown on the Keswick map and regarded as the main part of the formation. There is no Lexicon entry.

TONGUE HOUSE MEMBER

The Tongue House Member was established for use on the British Geological Survey (1991) 1:25 000-scale map, Devoke Water and Ulpha, to encompass a widespread silicic volcanic event within the largely andesitic Birker Fell Formation. The member included the Little Stand Tuff, the Great Whinscale Dacite and thin intervening volcaniclastic sedimentary rocks. Outside this limited area this formal term was not found to be useful and each of the constituent units has been raised to member status. The term Tongue House Member is now obsolete

WORM CRAG FORMATION

A partial Lexicon entry exists under this name for rocks subsequently included within the Airy's Bridge and Whorneyside tuff formations. The term Worm Crag Formation is obsolete.

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