Chapter 4 Lake District and northern England

Introduction

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In Ordovician times the Lake District and northern England formed part of the microcontinent of Eastern Avalonia, that comprised southern Britain and adjacent parts of continental Europe. Faunal and palaeomagnetic evidence show that in the early Ordovician, Eastern Avalonia was attached to the supercontinent of Gondwana in a high southern latitude. Avalonia–Gondwana was separated from Laurentia to the north by the Iapetus Ocean (Figure 2.1). Avalonia then rifted from the supercontinent in the mid-Ordovician, drifted northwards during closure of the Iapetus and eventually collided with Laurentia in tropical latitudes during the Silurian. The line of closure of the ocean now lies beneath the Solway Firth (Figure 4.1).

During the Palaeozoic, from Late Cambrian to early Llanvirn times, deep-marine turbidites of the Skiddaw Group were deposited on the passive margin of Eastern Avalonia (Cooper *et al.,* 1995). Regional uplift from this non-volcanic, deep oceanic environment to a subaerial one was the prelude to volcanism. Subsequently, two episodes of intense igneous activity occurred in the Lake District. Firstly, during the Ordovician (Llandeilo-Ashgill), basaltic, ande-sitic and rhyolitic lavas and voluminous pyroclastic rocks were erupted at the continental margin of Avalonia, above a subduction zone in which the Iapetus Ocean was being consumed (Fitton *et al.,* 1982). The Eycott Volcanic Group (EVG) and the Borrowdale Volcanic Group (BVG) represent two contemporaneous volcanic fields (Figure 4.2). This phase of magmatism culminated in the emplacement of much of the Lake District granitic batholith (Hughes *et al.,* 1996). Secondly, in late Silurian to Early Devonian times, additional granitic plutons were emplaced in the Lake District and northern England subsequent to the closure of the Iapetus.

The volcanoes were subaerial (Branney, 1988a), of low relief and probably located within extensional basins, a feature illustrated by the single marine incursion in the upper BVG. The earliest known terrestrial trace fossils in the world occur in volcaniclastic sedimentary rocks from the BVG (Johnson *et al.,* 1996). The oldest record of volcanism is in the western Lake District where phreatomagmatic tuff cones were eroded and redeposited. The main part of the lower BVG is dominated by andesite block lavas that built up sub-horizontal plateaux (Petterson *et al.,* 1992). The lavas emanated from many vent sites and pyroclastic deposits and volcanic mudflows locally filled valleys; unconsolidated volcaniclastic deposits were reworked by rivers and sheet floods. At the end of the effusive phase the terrain had a relative relief of no more than 110 m. Though of subtly different geochemical composition, the EVG had an evolution comparable to this lower part of the BVG.

A widespread voluminous andesitic ash-fall deposit heralded a major change to explosive volcanism that dominated the later part of the BVG episode. The succession of lavas, overlain by thick, ponded silicic ignimbrites and followed by lava domes and lacustrine sedimentary strata is typical of a caldera cycle (Branney and Soper, 1988). In the central Lake District the recently discovered Scafell Caldera contains a thick pyroclastic fill (Branney and Kokelaar, 1994a). Caldera collapse developed through incremental, piecemeal subsidence with many closely spaced faults. The waning stage of the collapse phase comprised small-volume pyroclastic flows and lava domes and the broad depression that marked the site of the caldera was then filled with lake sediments. The low-relief crustal sag that resulted from caldera collapse following the paroxysmal eruption of voluminous pyroclastic flows is seen today tectonically tightened into the Scafell Syncline (Figure 4.3).

In the SW Lake District repeated cycles of pyroclastic eruptions and volcaniclastic sedimentation succeed the Scafell Caldera succession in the Duddon Basin, the volcanotectonic sag that was later deformed as the Ulpha Syncline (Millward *et al.,* in press). Calderas were probably formed, though the geometry of these is less well understood than in the Scafell Caldera. Also, regional subsidence and extensional faulting may have contributed to develop ment of the basin and marine conditions were established for a short time. After the events of the Duddon Basin succession, fluvial and lacustrine sedimentation became widespread throughout the Lake District. Contemporaneous pyroclastic activity continued, producing ash-fall tuffs and generating sediment-gravity flows that contained juvenile material. Basaltic andesite and andesite sills were emplaced into unconsolidated, wet sediments. Further extensive silicic pyroclastic eruptions periodically interrupted the dominantly sedimentary regime.

As the Eycott and Borrowdale volcanic episodes waned, marine conditions became established across the eroded and thermally subsiding volcanic pile and lasted for more than 40 million years from late Ordovician to the Early Devonian. The earliest Ashgill rocks are shallow marine and carbonate rich. Silicic volcanic eruptions occurred in the east of the Lake District and, in the SW, tuff-turbidites were deposited. A marked increase in subsidence and sedimentation rate during the Ludlow epoch has been associated with a foreland basin migrating southward across the Lake District during the final stages in the closure of the Iapetus Ocean (Kneller, 1991). This was initiated when the northern margin of Eastern Avalonia collided with the margin of Laurentia producing a flexural basin ahead of a SE-propagating thrust sequence (Kneller *et al.,* 1993a). Final inversion of the foreland basin and development of typical 'slate belt' structures, folds, cleavage and associated faults appears to have climaxed during the Acadian Event in the Early Devonian. Cleavage formation was synchronous with emplacement of the Early Devonian Shap and Skiddaw granites and associated dykes (Soper and Kneller, 1990).

The sequence of igneous events in the Lake District and northern England is summarized in (Figure 4.4) and the sites selected to represent the magmatic evolution of this area are located on (Figure 4.2).

Volcanic rocks in the Skiddaw Group

The Skiddaw Group contains few volcanic rocks. The middle part of the Llanvirn, Tarn Moor Formation comprises mudstone with up to 5% volcaniclastic beds, including bentonite and tuffaceous, turbiditic sandstone (Cooper *et* al., 1995). Several igneous sheets in the succession, for many years regarded as lavas and considered to represent the earliest record of volcanism in the Lake District, were recently shown to be sills and probably related to the later, more substantial, subduction-related volcanic episodes described below (Hughes and Kokelaar, 1993).

Eycott Volcanic Group (EVG)

In the northern part of the Lower Palaeozoic inli-er the Skiddaw Group is overlain unconformably by the EVG, comprising at least 3200 m of sub-aerial medium-K, continental margin, tholeiitic volcanic rocks (Cooper *et al.,* 1993). The succession comprises basaltic andesite, andesite and dacite lavas and sills along with interbedded tuff, lapilli-tuff and volcaniclastic sedimentary rocks. Massive intermediate and acidic lithic-rich and vitric lapilli-tuff comprise the uppermost 800 m of the group. The type section for the EVG is described in the Eycott Hill GCR site report, which also contains examples of the distinctive plagioclase-megaphyric basaltic and-esite. Volcaniclastic sedimentary rocks at the base of the EVG contain a marine microflora indicating that the volcanic rocks are not older than late Llanvirn and possibly of Llandeilo–Caradoc age (Millward and Molyneux, 1992).

Borrowdale Volcanic Group (BVG)

The BVG forms the high fells of the central Lake District and occurs in the Cross Fell and Teesdale inliers (Figure 4.1). The succession comprises about 8 km of subaerial, calc-alkaline continental-margin lavas, sills, pyroclastic and volcaniclastic rocks associated with caldera development (Millward *et al.,* 1978; Branney and Soper, 1988). The rocks are unusual among volcanic suites worldwide because of the presence of almandine–pyrope garnet phenocrysts that occur in andesite, dacite and rhyolite (Fitton, 1972). The BVG is generally considered to be Llandeilo or early Caradoc (Wadge, 1978). The Holehouse Gill Formation, within the upper part of the BVG, is probably Caradoc (Harnagian–Soudleyan) on the basis of its marine microflora (Molyneux, 1988). The radiometric date of 457 ± 4 Ma for the BVG (Sm-Nd on garnet–whole-rock pairs; Thirlwall and Fitton, 1983) is compatible with the Caradoc biostratigraphical age.

Subaerial volcanic successions, such as the BVG, are rare in the geological record. Volcanic landforms, particularly those constructed with abundant pyroclastic deposits, are not generally preserved because of explosive disintegration, weathering and erosion; most are represented by volcaniclastic and tuffaceous sedimentary rocks within subaqueous sequences. However, the extensional tectonic regime and successive episodes of caldera collapse ensured preservation of the BVG. Many primary volcanic features are exquisitely preserved on the weather-worn exposures in the fells. The combination, therefore, of volcanic processes, tectonism, uplift and erosion during the last 450 Ma provides a unique insight into the deeper levels of, and processes that occur within, this type of volcanic province.

Up to 2.8 km of andesite block lavas with subordinate basalt, dacitic and rhyolitic lavas and sills comprise the lower part of the BVG (Petterson *et al.,* 1992). Andesitic, dacitic and rhyolitic ash-fall tuff, pyroclastic surge deposits and ignimbrites constitute small parts of the succession and provide important stratigraphical markers. Interbedded sedimentary rocks mostly comprise tephra which has been reworked, redeposited and lithified to form volcaniclastic siltstone, sandstone, conglomerate and breccia. The more resistant andesites typically form trap-like topography locally, and an excellent example is well illustrated in the Falcon Crag GCR site. Extensive tabular lavas emanating from many eruption centres are characteristic of this plateau-andesite province. Fine examples of plateau-basalt sequences occur in the British Tertiary Igneous Province, but the BVG is the best-preserved example of a calc-alkaline, Palaeozoic plateau-andesite province. More recent examples are known from the USA, Mexico, South America and New Zealand, but these are largely concealed by intracaldera successions. The superb exposure of the lower BVG provides a three-dimensional picture of this type of volcanic province.

The upper part of the BVG developed through intermediate and silicic explosive volcanism and caldera formation (Branney and Soper, 1988), the products of which, together with extensive intercalated volcaniclastic sedimentary rocks, form a succession two to five kilometres thick. Though volcaniclastic rocks comprise most of the upper BVG, sills are very abundant locally. A number of volcaniclastic successions, probably associated with major eruption centres, are recognized in the western Lake District, but correlation of these with sequences of similar lithologies in the east has yet to be made. The oldest of the successions occurs in the Scafell area in the central Lake District. In the SW this is overlain by the pyroclastic and volcaniclastic sedimentary succession in the Duddon Basin which is up to 3 km thick. The youngest part of the BVG overlies both the Scafell Caldera and Duddon Basin successions, and predominantly comprises volcaniclastic sedimentary rocks with intercalated thick ignimbrite sheets (Millward *et al.,* in press). A significant and dominantly andesitic welded ignimbrite succession is largely concealed beneath Permo-Triassic cover rocks in west Cumbria (Millward *et al.,* 1994).

The best known of the pyroclastic successions is that in the central Lake District fells. Pyroclastic rocks there were described as 'streaky' by Walker (1904) and Green (1915a). Marr (1916) included these rocks within his Sty Head Garnetiferous Group, but was uncertain whether many were extrusive or intrusive. Walker (1904) postulated an extrusive origin for the 'streaky' rocks of Rosthwaite Fell in Borrowdale (see the Rosthwaite Fell GCR site report). The occurrences in the Crinkle Crags and Langdale area were interpreted as intrusive rhyolites by Hartley (1932) (see the Ray Crag and Crinkle Crags GCR site report). One of the most significant contributions to the understanding of the BVG was the interpretation of the 'streaky' rocks as welded tuff by Oliver (1954). He postulated that these rocks, which constituted his Airy's Bridge Group and Lincomb Tarns Formation (Oliver, 1961), were formed from nu& ardentes or incandescent ash-flows (now known as pyroclastic flows) and compared them with welded tuff or ignimbrite from his native New Zealand. At the time these Lower Palaeozoic welded tuffs from the Lake District, along with similar rocks from Wales, were the oldest known examples of this rock type.

The complex sequence of garnet-bearing andesitic to rhyolitic pyroclastic rocks in the central Lake District was recently interpreted to be part of the Scafell Caldera, a unique example of an exhumed hydrovolcanic caldera (Branney and Kokelaar, 1994a). This structure is of international interest because the level of erosion provides a superb insight into its well-layered caldera-fill succession and the mechanisms of piecemeal caldera collapse. It is also important because of the repeated involvement of water during eruption, causing abrupt alternations between magmatic and hydromagmatic explosions. In contrast to most of the massive caldera-fill successions that have been studied elsewhere, the dramatic lateral variations in the intracaldera strata of the Scafell sequence show how different parts of the caldera subsided at different times and at different rates. The piecemeal nature of the collapse contrasts with popular models of simple, piston-like collapse (Lipman, 1984; c.f. Ben Nevis and Allt a' Mhuilinn and five Glencoe GCR sites, this volume).

The piecemeal caldera model with its layered silicic caldera-fill pyroclastic rocks, the progressive deformation of the welded tuffs and the formation of volcanotectonic faults is developed in the Ray Crag and Crinkle Crags GCR site. The other sites within the central Lake District illustrate significant variations in different parts of the caldera. A proximal volcanic lake environment for the initial phase of the volcanism occurs in the Sour Milk Gill GCR site. The eruption of silicic lava during the waning stage of this eruptive cycle is a major topic of the Rosthwaite Fell GCR site, and the Langdale Pikes GCR site superbly illustrates the post-collapse caldera lake succession. Though the Side Pike GCR site illustrates the volcanic megabreccia associated with the Scafell Caldera, it also provides probably the best locality in Britain where the characteristics of rocks with pyroclastic fall, flow and surge origin may be contrasted.

An example of the alternation of pyroclastic and volcaniclastic sedimentary rocks from the Duddon Basin is given by the Coniston GCR site. In the past, andesite in the BVG has been assumed to be largely lava, but the Pets Quarry GCR site illustrates that many may be high-level sills.

Volcanic rocks in the Windermere Supergroup

Two episodes of acid volcanism are preserved in the Dent Group (Figure 4.4). The first is the major silicic, early Cautleyan, Yarlside Volcanic Formation, north of Kendal (Stockdale Beck, Longsleddale GCR site). The second includes thin, widespread volcaniclastic successions of late Rawtheyan age, represented by the High Haume Tuff and Appletreeworth Volcanic formations in the south and SW of the Lake District respectively, and the Cautley Volcanic Member in the Cautley and Dent inliers. Contemporaneous volcanism from unknown sources is recorded by thin K-metabentonite beds in the Skelgill, Browgill and Brathay formations of early Llandovery to Wenlock age in the southern Lake District and in the Cautley and Dent inliers (Fortey *et al.,* 1996). Though turbidite sedimentation hindered preservation of ash-fall layers in the upper part of the Windermere Supergroup, early Ludlow K-metabentonites are recorded from the Ribblesdale (Craven) inlier ((Figure 4.1); Romano and Spears, 1991).

Threlkeld intrusions

East of Keswick, microgranite outcrops on Low Rigg, Threlkeld Knotts and Bramcrag are sufficiently similar to suggest that they are part of a single, irregular body intruded into the Skiddaw Group and the base of the Borrowdale Volcanic Group (BVG). Geophysical modelling shows that it is a laccolith (Lee, 1989). The calc-alka-line intrusion is geochemically similar to acidic BVG rocks and is distinct from the other Lake District granites (O'Brien *et* al., 1985). The Rb-Sr isochron age of 438 ± 6 Ma (Rundle, 1981) is Ordovician. The microgranite and its relationships with the Skiddaw Group and BVG are only exposed in the Bramcrag Quarry GCR site.

Lake District batholith

An elongate multicomponent batholith occurs at shallow depths beneath the central Lake District (Bott, 1974; Lee, 1986). This was probably emplaced as a set of stacked laccoliths (Evans *et al.,* 1993). The batholith is exposed in the west as the Eskdale and Ennerdale intrusions. Geological relationships (Branney and Soper, 1988) and their Caradoc age (452–450 Ma; U-Pb on zircon; Hughes *et al.,* 1996) suggest that these were subvolcanic, though they are geochemically distinct from the volcanic suites (O'Brien *et al.,* 1985).

The Ennerdale intrusion is well illustrated by the Bowness Knott GCR site, and lies to the west and NW of Wast Water (Figure 4.2). The intrusion is mostly in contact with the Skiddaw Group and BVG, but at the southern end of Wast Water it is possibly faulted against the Eskdale granite. It is a relatively thin tabular body, less than 2 km thick (Lee, 1989; Evans *et al.,* 1993). Granophyric-textured porphyritic granite is dominant, but dolerite, dioritic, and hybridized dioritic, granodioritic and melanocratic granitic rocks occur locally, adjacent to the margin of the intrusion.

The Eskdale intrusion comprises the Eskdale granite and the Eskdale granodiorite. The southern part of the granite is at the base, or within the lowest part, of the BVG, but northwards the contact rises to within a few hundred metres of the base of the Scafell Caldera succession. The granodiorite is a discordant intrusion that cuts through from the base of the BVG to the Duddon Basin succession. The Eskdale granite consists of medium-grained muscovite granite, aphyric and megacrystic microgranite, and coarse- to very coarse-grained granite.

Microgranite is most common in the northern part where the low-dipping contacts and inliers of hornfelsed volcanic rocks suggest that the roof zone of the intrusion is exposed. Xenoliths of country rock are extremely rare in the Eskdale granite and a thin zone of microgranite occurs at the margin. The main features of the intrusion are illustrated by the Beckfoot Quarry GCR site. Metasomatic recrystallization of the granite to quartz-white mica greisen occurs locally within all but the coarse facies of the Eskdale granite (Young *et al.,* 1988). Topaz is abundant in some greisens with accessory fluorite. A distinctive quartz-andalusite rock is associated with topaz greisen adjacent to the contact with the Skiddaw Group near Devoke Water [SD 1529 9733]. The Eskdale granodiorite is typically medium grained, with hornblende and locally abundant biotite; it lacks muscovite. A marginal microgranodiorite is developed along the contact. Almandine garnet is locally present, particularly in rock exposed in the Waberthwaite Quarry GCR site.

Carrock Fell Complex

The multiple intrusions of the dyke-like Carrock Fell Complex were emplaced at the boundary between the Skiddaw Group and EVG in the north of the Lake District (Figure 4.4). It is the largest mafic intrusion in the Lake District; the characteristics of this layered intrusion are superbly illustrated in the Carrock Fell GCR site, but also feature in the Grainsgill GCR site. The layered cumulate gabbros of the Mosedale division are genetically related to the EVG (Hunter, 1980). Microgabbro, apatite-bearing ferrodioritic rocks and granophyric microgranite forming the Carrock division are related by fractional crystallization of a tholeiitic parent magma and were emplaced as a later dyke complex (Hunter, 1980). In the NW, later silicic bodies include the Harestones Rhyolite and lenticular micrographic microgranite intrusions emplaced along the Roughton Gill Fault. Radiometric dates of 468 ± 9 Ma (K-Ar, whole rock) and 435 ± 9 Ma (Rb-Sr, whole rock) for the Mosedale. and Carrock divisions respectively probably indicate an Ordovician emplacement age (Rundle, 1979). The Silurian isochron for the Harestones Rhyolite (419 ± 4 Ma; Rb-Sr, whole rock) may be reset.

Haweswater basic intrusions

Gabbro, dolerite and dioritic rocks, cut by aplitic veins, and forming small outcrops totalling 2.6 km^2 are spread out over 19 km^2 on both sides of Haweswater ((Figure 4.2); Haweswater GCR site). The intrusions were emplaced into the BVG. No radiometric date has been obtained, but cleavage in the rocks indicates an Early Palaeozoic emplacement age.

Late Caledonian intrusions

In the northern part of the Lake District the roof zone of the broadly cylindrical Skiddaw granite is exposed in the River Caldew, Grainsgill Beck and Sinen Gill (Lee, 1986). It is a coarse-grained biotite granite. At the northern end of the Grainsgill outcrop the granite passes into greisen, associated with mineralization that cuts both the granite and the adjacent Carrock Fell Complex. This significant feature is described in the Grainsgill GCR site report. The granite was emplaced into the Skiddaw Group and is surrounded by a classic, concentrically zoned aureole that grades outwards from cordierite–andalusite hornfels through cordierite-chiasto-lite and cordierite hornfels zones to spotted slates.

The sub-cylindrically shaped Shap granite cuts the BVG and adjacent Windermere Supergroup in the eastern Lake District (Figure 4.2). An extensive subcrop is present to the north of the outcrop (Lee, 1986). The pink and grey granite contains orthoclase megacrysts that are a distinctive and important petrogenetic feature (Shap Fell Crags GCR site). The intrusion is late Caledonian (397 ± 7 Ma; K-Ar; Rundle, 1992).

To the north of the Ennerdale intrusion an ENE-trending elongate zone of bleached and recrystallized Skiddaw Group rocks defines the Crummock Water aureole (Cooper *et al.,* 1988; (Figure 4.2), (Figure 4.4). The metasomatic event has been dated at *c.* 400 Ma. The aureole is believed to be associated with a buried, highly evolved granite intruded along the northern margin of the Lake District batholith.

In the northern Pennines, the Lower Palaeozoic basement of the Alston Block is underpinned by the buried Weardale granite (Figure 4.1). The existence of this batholith was detected by geophysical surveys and confirmed by the Rookhope borehole (Dunham *et al.,* 1965; Bott, 1967). It is an aphyric two-mica granite, with pegmatitic and aplitic facies, and a sub-horizontal foliation. It is peraluminous and geochemically similar to the Skiddaw granite, a correlation that is supported by the Rb-Sr whole-rock isochron age of 410 ± 10 Ma (Holland and Lambert, 1970). The batholith is 60 x 25 km in extent, with cupolas such as the pink Dufton microgranite of the Cross Fell inlier (Hudson, 1937), rising from it. A further negative gravity anomaly over the Askrigg Block and the Raydale borehole confirmed the presence of the Wensleydale intrusion comprising pink, medium-grained granite ((Figure 4.1); 400 ± 10 Ma; Rb-Sr, whole rock; Dunham and Wilson, 1985).

Minor intrusions

Suites of minor intrusions of diverse composition cut the Lower Palaeozoic rocks. Many of these are spatially and genetically linked with the major intrusions, but others illustrate a significantly greater range of magmatic compositions than is represented by the larger bodies. High-level intrusions associated with the Eycott and Borrowdale volcanic groups are intimately part of those groups. A brief description of the other suites is given below but no GCR sites specifically relate to the minor intrusions. Minor igneous intrusive bodies that crop out within GCR sites are described where appropriate.

Throughout the Skiddaw Group there are dykes, sheets and small plutons of porphyritic hornblende diorite, including augite spessartite, microdiorite, dolerite and olivine-augite hornblendite. These are calc-alkaline and are geochemically similar to the BVG; the K-Ar hornblende age of 458 ± 9 Ma supports the connection (Rundle, 1979). East of Cockermouth a suite of sills and stock-like intrusions of aphyric basalt, andesite and microgranodiorite is compositionally similar to the EVG and the Mosedale division of the Carrock Fell Complex. The Embleton Diorite from this suite has been dated at 444 ± 24 Ma by Rb-Sr (Rundle, 1979).

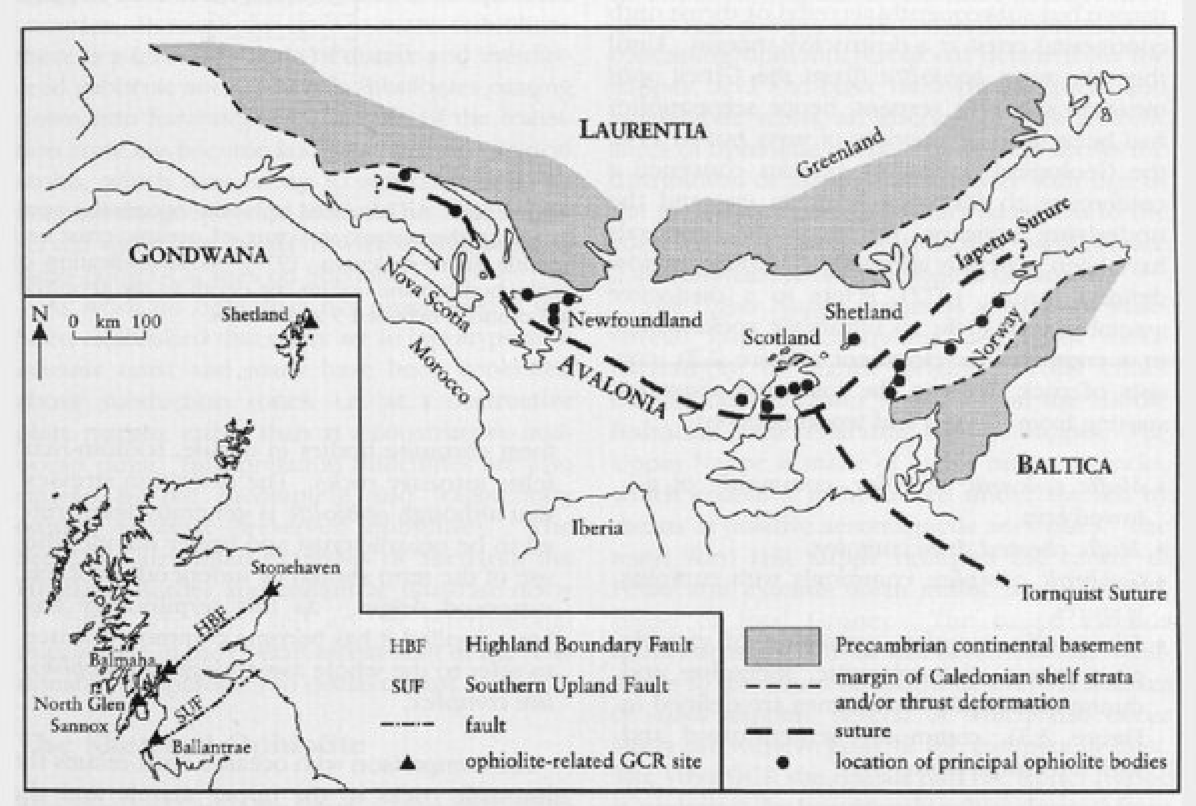
Aphyric basalt and dolerite dykes are abundant within the BVG around the Eskdale granite in Eskdale and Wasdale. The suite comprises high-Fe-Ti tholeiitic, and calc-alkaline, groups (Macdonald *et al.,* 1988). The latter may be associated with basalt lavas in the BVG, but the other is unique. No radiometric ages have been determined, but they are believed to span emplacement of the Eskdale granite.

Aphyric and sparsely microporphyritic rhyolite dykes are locally abundant within the BVG near the Eskdale and Ennerdale intrusions. The rocks are fine grained to cryptocrystalline and spherulitic. The dykes are genetically linked with the Ennerdale intrusion and the Rb-Sr isochron ages of 436–428 Ma are probably reset (Al Jawadi, 1987; Rundle, 1992).

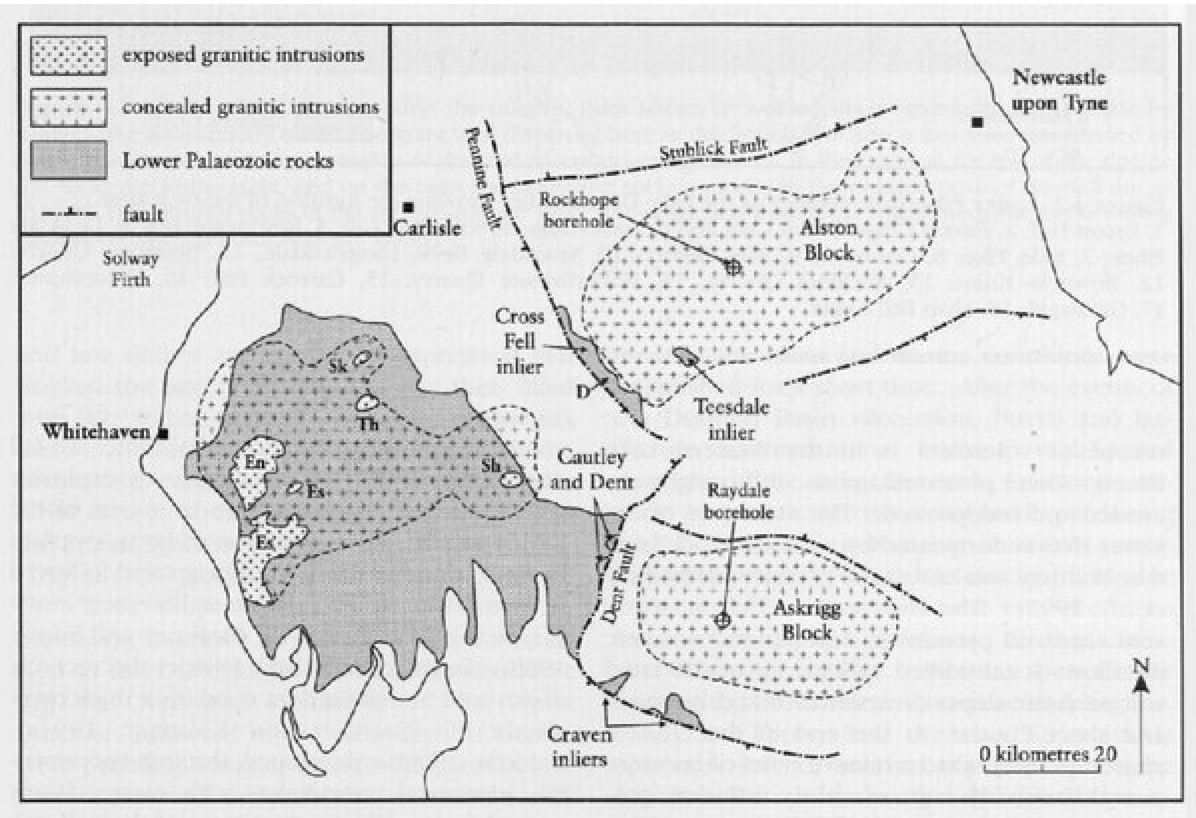
Distinctive quartz-feldspar porphyry dykes occur sporadically throughout the Lake District. A geochemically variable suite of microdiorite–microgranite porphyry minor intrusions crop out in the Scafell area, in the Duddon valley and in the Windermere Supergroup. These may be linked with the Skiddaw–Shap intrusive episode as indicated by their geochemistry and by similar Rb-Sr isochron ages (Al Jawadi, 1987; Rundle, 1992).

Sparse, uncleaved, lamprophyre dykes cut all lithostratigraphical units within the Lake District and Cross Fell inliers. They are probably Early Devonian (Macdonald *et al.,* 1985). The Sale Fell minette (Eastwood *et al.,* 1968) is part of this suite.

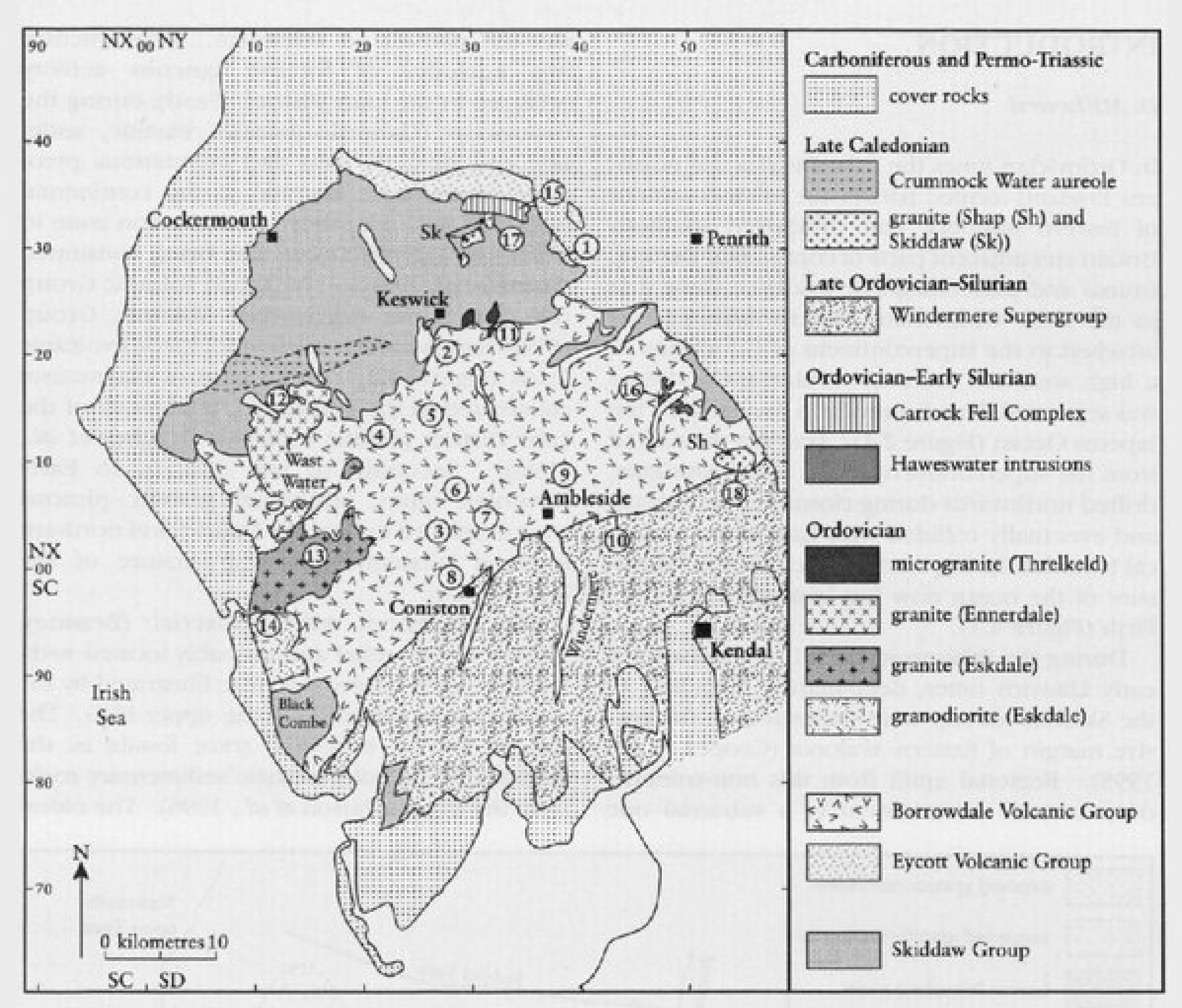
References



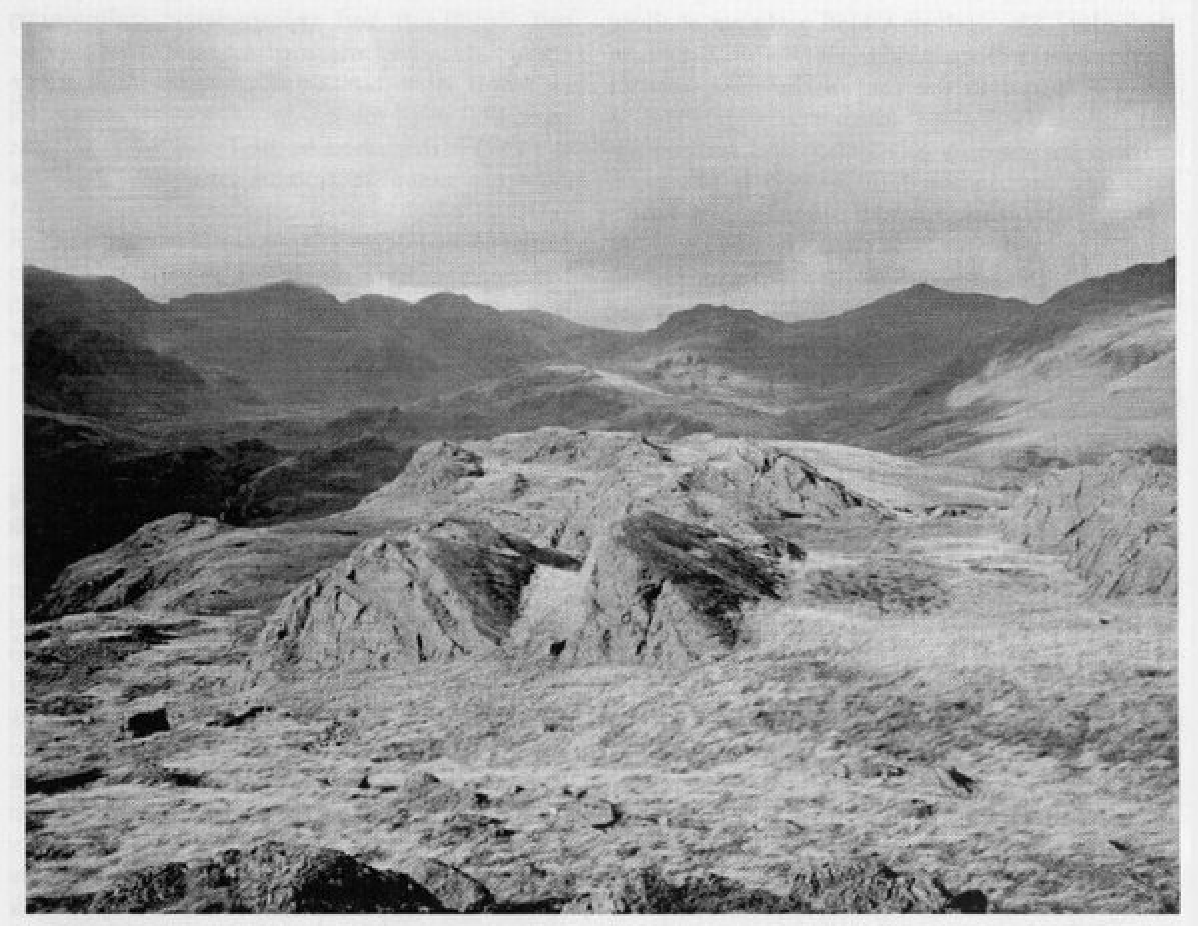
(Figure 2.1) A pre-Atlantic reconstruction of the Caledonian Orogen showing the positions of the principal ophi-olite complexes. A location map for the Scottish examples is shown inset.



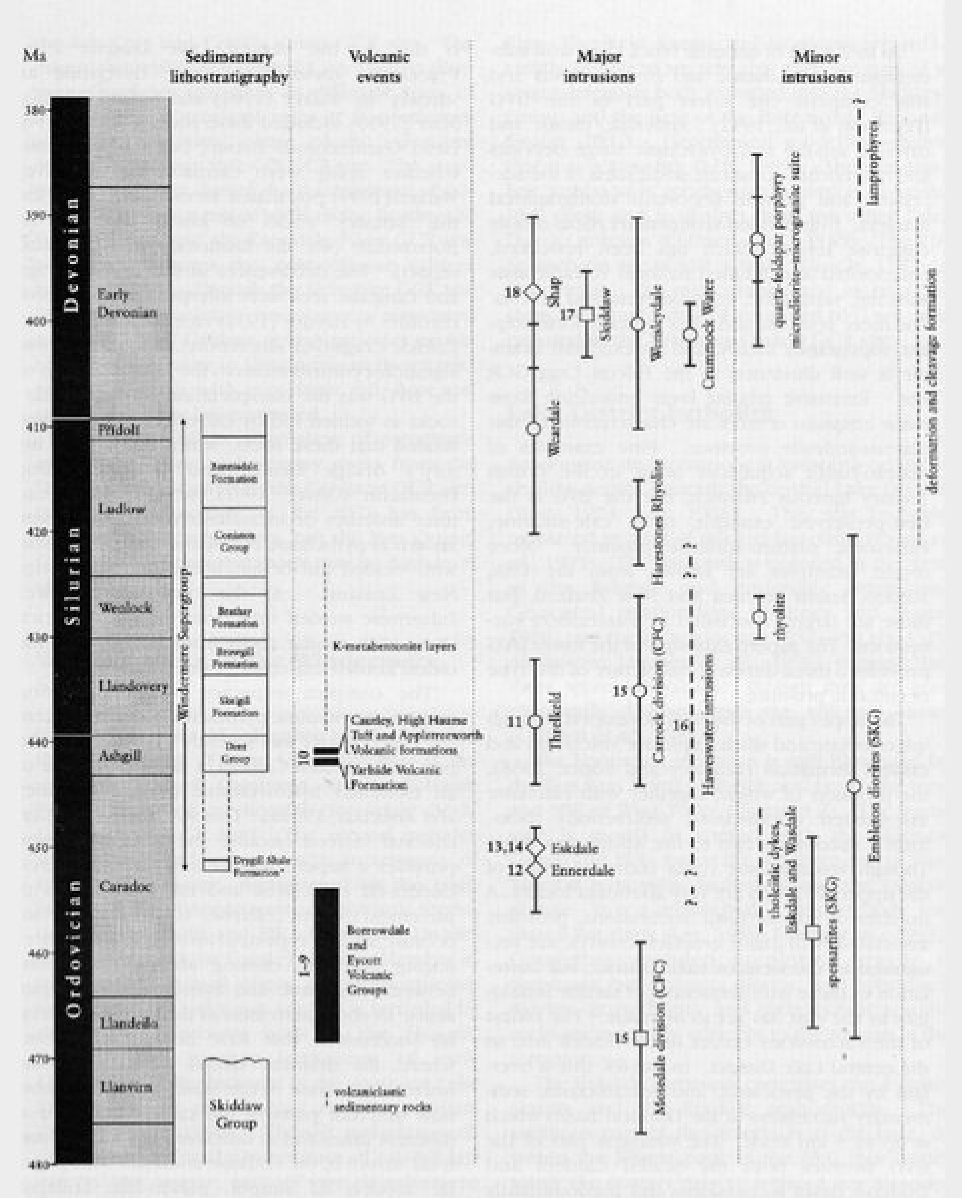
(Figure 4.1) Lower Palaeozoic inliers of northern England and locations of the major, buried batholiths. Exposed granitic intrusions: En, Ennerdale; Es, Eskdale; Sh, Shap; Sk, Skiddaw; Th, Threlkeld; D Dufton.



(Figure 4.2) Lower Palaeozoic geology of the Lake District inlier showing the location of the GCR sites. 1, Eycott Hill; 2, Falcon Crags; 3, Ray Crag and Crinkle Crags; 4, Sour Milk Gill; 5, Rosthwaite Fell; 6, Langdale Pikes; 7, Side Pike; 8, Coniston; 9, Pets Quarry; 10, Stockdale Beck, Longsleddale; 11, Bramcrag Quarry; 12, Bowness Knott; 13, Beckfoot Quarry; 14, Waberthwaite Quarry; 15, Carrock Fell; 16, Haweswater; 17, Grainsgill; 18, Shap Fell Crags.



(Figure 4.3) The Scafell Caldera: within the caldera, thick sheets of welded silicic ignimbrite are overlain by caldera-lake sedimentary rocks. These are well displayed here in the Scafell Syncline, a structure that formed by Early Devonian tectonic compression of the Ordovician downsag caldera. In the crags on the left of the skyline the rocks dip to the right, and on the right the lacustrine rocks exposed in the pointed peak of Bowfell dip to the left. The bedded rocks in the foreground are breccias avalanched from local volcanotectonic faults during caldera collapse. (Photo: BGS no. D4031.)



(Figure 4.4) Summary chart of Lake District Caledonian igneous rocks. Bold numbers are GCR sites (numbers as per Figure 4.2). Radiometric dates: diamonds U-Pb; circles Rb-Sr; squares K-Ar; see text for sources. lo error bars are shown. Period of deformation and cleavage formation from Merriman et al. (1995). CFC Carrock Fell Complex; SKG Skiddaw Group. *Note: In the northern Lake District the base of the Windermere Supergroup is at the base of the Drygill Shale Formation; in the central/southern Lake District the base of the supergroup coincides with the base of the Dent Group (Kneller et al., 1994).