Chapter 3 Dinantian volcanic rocks of the Northumberland, Solway and Tweed basins

Introduction

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Tournaisian to early Visean basaltic volcanism occurred locally along the margins of the Northumberland, Solway and Tweed basins during the initial phase of rapid, fault-controlled back-arc extension of the crust to the north of the Variscan Front. The E–W-orientated basins are markedly asymmetrical and lie between 'blocks' of deformed and weakly metamorphosed Lower Palaeozoic basement rocks. To the north lies the Southern Uplands, to the south are the Lake District and Alston blocks, and separating the Tweed and Northumberland basins is the Cheviot Block, which also comprises a succession of Early Devonian lavas ((Figure 3.1); Kimbell *et al.,* 1989; Leeder *et al.,* 1989; Chadwick *et al.,* 1995). Ordovician to Early Devonian granitic plutons are major intrusions within the Cheviot, Lake District and Alston blocks.

The Northumberland and Solway basins lie above the inferred line of the Iapetus Suture, marking the junction of the former continents of Laurentia and Avalonia, which were finally locked together during the latest phase of the Caledonian Orogeny (see Chapter 1). Leeder (1971, 1974) was the first to propose that Dinantian magmatism preceded the structural development of the basins, invoking Bott's (1964) model of mantle flow. Since then, studies of subsidence history (e.g. Leeder and McMahon, 1988; Kimbell *et al.,* 1989) have shown that the development of these basins fits well with the uniform lithospheric extension model proposed by McKenzie (1978). In this model, magmatism resulting from partial melting of the upper mantle is a common feature of the early phase of rapid extension. Fracturing along the main hinge lines during this initial stage not only controlled basin development, but is also thought to have allowed the magmas to reach the surface (e.g. Leeder, 1971, 1974; Macdonald and Walker, 1985; Chadwick *et al.,* 1995).

Growth faults controlling the Carboniferous basins of northern Britain were formed by re-activation of earlier faults and thrusts with general ENE Caledonian orientations. The southern margin of the Solway and Northumberland basins is taken at the *en échelon* set of normal faults that includes the Maryport Fault in Cumbria and the Stublick and Ninety Fathom faults in Northumberland. The thickest Lower Carboniferous strata in these basins occur adjacent to these faults and the maximum fault displacement, measured from the top of the Lower Palaeozoic basement, is 5000 m down to the north. The Lower Carboniferous sedimentary succession thins markedly towards the northern, hinge-like margin, and the faults there are interpreted to be antithetic structures to the southern faults; syn-extensional displacement locally exceeds 1000 m down to the south ((Figure 3.1); Lumsden *et al.,* 1967; Chadwick *et al.,* 1995). The southern margin of the Tweed Basin is taken at the Pressen–Flodden–Ford faults, but its northern margin does not appear to be fault-controlled (Chadwick and Holliday, 1991). The geometry of the basins controlled both facies development and sediment accumulation (Leeder *et al.,* 1989).

The dominantly effusive basaltic volcanism occurred in two broad sets of events, first during Tournaisian time as subaerial outpourings in an essentially fluvial setting at the onset of subsidence, and secondly during Visean time as intercalations within the dominantly marine basin succession (Figure 3.2). The initial phase is represented along the southern margin of the basins only by the Cockermouth Lavas, whereas on the northern margin, adjacent to the Southern Uplands, there are the Birrenswark Volcanic Formation and the Kelso Lavas. The Cottonshope basalts, located on the southwestern flanks of the Cheviot Block, also belong to this episode. The later phase is known only from the northern margins and comprises the Kershopefoot basalts and the Glencartholm Volcanic Beds. In the Isle of Man, basalt and basaltic pyroclastic rocks of the Brigantian Scarlett Volcanic Formation (Dickson *et al.,* 1987) may also be part of this phase. A substantial number of intrusive bodies, commonly referred to in the literature as 'volcanic necks', form a broad arc linking the outcrops of the Birrenswark Volcanic Formation and the Kelso Lavas, and are probably associated with both volcanic episodes (Figure 3.1). Vent structures are not known from the Cockermouth Lavas, though pyroclastic rocks and basalt dykes within the Lake District Block, some 27 km to the ESE of the lavas, may have been part of such features.

Isopachytes on the Birrenswark Volcanic Formation show that these rocks form an elongated, localized structure parallel to the basin margin (Leeder, 1974). It seems likely that the other volcanic formations have similar distributions. It is not known whether volcanic rocks are present in the axial part of the Solway and Northumberland basins because the base of the Dinantian succession in this area is not seen. Kimbell *et al.* (1989) interpreted strong reflectors in the basal part of the succession in Northumberland as possibly from a basaltic unit, though there could be other causes.

The Lower Carboniferous volcanic units and the GCR sites are introduced briefly below in relation to their regional context; the GCR sites are located on (Figure 3.1).

Cockermouth Lavas

In north Cumbria, the Cockermouth Lavas are the only exposed remnants of Early Carboniferous volcanism that occurred on the southern margin of the Northumberland and Solway basins. The sequence of tholeiitic, olivine-phyric basalt and subordinate andesite, up to 105 m thick, crops out for about 12 km northeastwards from Cockermouth. These rocks form a southerly facing escarpment on the northern side of the River Derwent, only a few kilometres to the south of the Gilcrux and Maryport faults that mark the basin margin (Figure 3.1). The subcrop extent of the Cockermouth Lavas is unknown; a prominent magnetic anomaly in this area is more likely to be attributable to the concealed westward extent of the Ordovician Eycott Volcanic Group, than to the weakly magnetic Cockermouth Lavas (Millward *et al.,* 1999).

The volcanic rocks are within the basal part of the Dinantian succession in Cumbria, resting conformably on conglomerate and sandstone of the Basal Beds, and overlain by the lowest strata of the Chief Limestone Group. The sedimentary rocks above and below the lavas have been identified as Courceyan (C.E. Butcher, pers. comm. in Mitchell *et al.,* 1978). This tightly constrains the age of the volcanic episode.

The Cockermouth Lavas are not well exposed, but probably comprise between four and six flows, based on the trap-like topography and the patchy distribution of clinkery, scoriaceous zones (Eastwood *et al.,* 1968; Macdonald and Walker, 1985). No pyroclastic rocks are preserved within the sequence. The formation thins north-eastwards from its maximum of about 105 m in the Cockermouth area to 30 m near Sunderland [NY 170 352] and 40 m near Bothel Craggs [NY 149 342] (Macdonald and Walker, 1985). A little to the north of Bothel Craggs the lavas are overstepped by the basal beds of the Chief Limestone Group. The Gill Beck GCR site provides a representative section through most of the succession.

Macdonald and Walker (1985) identified tholeiitic andesite in the Cockermouth Lavas, indicating limited fractionation of the tholeiitic magmas. Compared with other Early Carboniferous volcanic sequences of northern Britain, these rocks therefore represent a transitional state of evolution between sequences of the Midland Valley of Scotland, where intermediate and felsic compositions are common, and those of Derbyshire, where such compositions are apparently absent. The tholeiitic andesite in the Bothel Craggs Quarry GCR site highlights this significance.

Basalt dykes cropping out on Little Mell Fell, 27 km to the ESE of the Cockermouth Lavas, were first described by Capewell (1954). He suggested that these rocks were associated with the early Dinantian volcanic activity. Macdonald and Walker (1985) later recognized geochemical similarities between the dykes and the Cockermouth Lavas, which supported this theory. The basalt dykes are represented by the Little Mell Fell Quarry GCR site, which also includes exposures of unbedded lapilli-tuff. These are the only recorded occurrence of pyroclastic rocks associated with Early Carboniferous volcanism on the southern side of the basin.

Birrenswark Volcanic Formation and Kelso Lavas

The earliest volcanic eruptions on the northern margin of the basin are represented by the Birrenswark Volcanic Formation and the Kelso Lavas. Both sequences consist predominantly of subaerial basaltic lavas, with rare hawaiite or mugearite. Individual flows have massive central portions, scoriaceous upper parts and lobate or rubbly bases. Some lava surfaces are reddened and locally they are overlain by thin palaeosols (boles). The lavas are intercalated with thin beds of sedimentary or pyroclastic rock. For example, the Birrenswark Volcanic Formation includes thin beds of red sandstone and siltstone (Pallister, 1952; Elliott, 1960; Lumsden *et al.,* 1967), and interbedded volcaniclastic rocks are reported from parts of the Kelso Lavas (Eckford and Ritchie, 1939; Tomkeieff, 1945, 1953).

The Birrenswark Volcanic Formation comprises a series of unconnected NE-trending outcrops, extending for a distance of over 70 km from Kirkbean, south of Dumfries, to near Saughtree south-east of Hawick (Figure 3.1). These rocks overlie either Lower Palaeozoic basement or Lower Carboniferous rocks of Upper Old Red Sandstone facies, and are overlain conformably by Tournaisian sedimentary rocks of the Lower Border Group (Lumsden *et al.,* 1967). The succession of olivine basalt, basaltic hawaiite and hawaiite lavas is intercalated with some reddened siltstone and sandstone beds up to 10 in thick. A whole-rock K-Ar radiometric age of 361 ± 7 Ma for the Birrenswark Volcanic Formation was obtained by De Souza (1982). The Langholm–Newcastleton Hills GCR site is representative of the Birrenswark Volcanic Formation and contains several excellent stream sections through this otherwise poorly exposed formation.

The maximum thickness of the formation, *c.* 90 in, is recorded around Birrenswark Hill, south-west of Langholm. Leeder (1974) showed that the thickness of the lavas varies systematically across the area, and that the lavas originally extended over an area of approximately 1830 km^2. This inferred distribution coincides broadly with the south-west part of the Upper Old Red Sandstone fluvial basin (Leeder, 1974). However, the isopachytes also show that the lavas occur in two distinct areas, south-west and north-east of Langholm, separated by a narrow zone just west of the town where Tournaisian sedimentary rocks rest directly on Silurian basement (Nairn, 1956). Leeder (1974) attributed this either to the persistence of a topographical high, implying two separate basins, or to uplift and erosion after the volcanism.

The Kelso Lavas form a roughly horseshoe-shaped outcrop between the Blackadder Water near Duns and Carham-on-Tweed, north-west of the Cheviot massif in the Tweed Basin. The lavas overlie Upper Old Red Sandstone sedimentary rocks and are thought to be of Tournaisian age (Figure 3.2). A succession of up to 12 basalt, basaltic hawaiite and hawaiite lavas are intercalated with thin tuffs and sedimentary rocks (Smedley, 1986a). The sequence is generally poorly exposed, though in some parts a terraced or 'trap' topography is well developed locally. According to Eckford and Ritchie (1939), the succession is about 120 m thick. Tomkeieff (1953) showed that the lower flows are mostly feldspar phyric in contrast to the upper ones, which contain olivine and clinopyroxene phenocrysts. The rocks are pervasively altered. The Kelso Lavas are represented by the Lintmill Railway Cutting GCR site, which is situated alongside the Blackadder Water.

The Birrenswark Volcanic Formation and the Kelso Lavas clearly accumulated at separate centres (Leeder, 1974), though they were probably erupted penecontemporaneously. The presence of palaeosols and interbedded sedimentary rocks is taken to indicate a subaerial environment with periods of relative quiescence between eruptions. Most of the volcanic activity is inferred to have been quietly effusive.

Cottonshope basalts

On the south-western flanks of the Cheviot massif, relatively small outcrops of amygdaloidal tholeiitic, olivine-phyric basalt are present in Cottonshope Burn, Spithope Burn, at Hungry Law and between the Bareinghope Burn and the Chattlehope Burn. These are the Cottonshope basalts, which comprise three lavas with a total thickness of 24 m. These volcanic rocks are represented by the Cottonshope Head Quarry GCR site. They are interbedded with fluvial and lagoonal sedimentary rocks of the Cementstone Group of Northumberland (Miller, 1887; Taylor *et al.,* 1971), which is probably equivalent to the Lower Border Group farther west. Some uncertainty has surrounded the age of the Cottonshope basalts. They lie only about 100 m beneath the top of the Cementstone Group in this area and this datum probably corresponds approximately with the top of the Tournaisian Series. However, evidence first recorded here in the GCR site report suggests that the basalts may be early Tournaisian in age and therefore probably part of the Birrenswark–Kelso event.

Kershopefoot basalts

The Kershopefoot basalts crop out in the area between Langholm and Kershope Burn on the Anglo–Scottish border. The volcanic rocks are interbedded with the uppermost strata of the Visean Middle Border Group and represent a resurgence of volcanic activity following the widespread marine sedimentation that inundated the earlier Birrenswark Volcanic Formation. Numerous flows of either basalt, basaltic hawaiite or hawaiite composition (Smedley, 1986a) comprise a succession that is generally 30–36 m thick (Lumsden *et al.,* 1967; Day, 1970). These rocks have generally been assumed to be extrusive, though some doubt was expressed by Lumsden *et al.* (1967) because contacts are not exposed. These rocks are particularly well exposed at the Kershope Bridge GCR site.

Glencartholm Volcanic Beds

At the base of the Upper Border Group in the Langholm district, the Glencartholm Volcanic Beds are the youngest known products of syn-extensional volcanism associated with the Solway, Northumberland and Tweed basins. In contrast to the earlier phases of Dinantian volcanism, the formation almost entirely comprises interbedded basaltic and trachytic pyroclastic rocks, along with other volcaniclastic and sedimentary units (Lumsden *et al.,* 1967). There are a few local occurrences of basaltic lavas, up to 15 m thick. The thickness of the Glencartholm Volcanic Beds locally reaches about 180 m. Bedded volcaniclastic rocks in a similar stratigraphical position have been proved in the Archerbeck borehole about 8 km south of Langholm (Lumsden and Wilson, 1961), and are represented in the Bewcastle area, by the Oakshaw Tuff (Day, 1970), suggesting that these volcanic deposits are widespread. The volcanism occurred within a mainly marine environment, though periodic emergence is shown by the presence of seatearths and coals (Lumsden *et al.,* 1967).

The Glencartholm Volcanic Beds are of Visean age, though the ages determined by different palaeontological methods are not consistent. Dineley and Metcalf (1999) suggested an early Visean age based on the faunal macropalaeontology, whereas according to Cleal and Thomas (1995), a late Visean age is more consistent with palaeobotanical data; foraminiferans from the sequence suggest a position near the Holkerian–Asbian boundary (George *et al.,* 1976).

The fragmental volcanic rocks are readily weathered and thus poorly exposed, except in stream sections. The River Esk, Glencartholm GCR site is representative of the Glencartholm Volcanic Beds. This site is also highly significant because of the unusual fish and arthropod fauna from shallow marine or lagoonal mudstone inter-beds; these were first reported by Peach and Horne (1903) (see Dineley and Metcalf, 1999).

Volcanic necks

More than 50 pipe-like bodies of pyroclastic rocks lie within an arc that broadly connects the outcrops of the Birrenswark Volcanic Formation and the Kelso Lavas ((Figure 3.1); Leeder, 1974). Some of the pipes are cut by plugs of basalt and some of the intrusions are composite. They occur within Dinantian or adjacent Silurian rocks, though none cut strata younger than the Glencartholm Volcanic Beds and they are not known from Dinantian rocks in the centre and south of the basin (Lumsden *et al.,* 1967). These masses have long been interpreted as marking the site of volcanic conduits, and this remarkable development was referred to as the 'Border Puy-country' by Geikie (1897), because of the perceived similarity with the spectacular Puy landscape in central France.

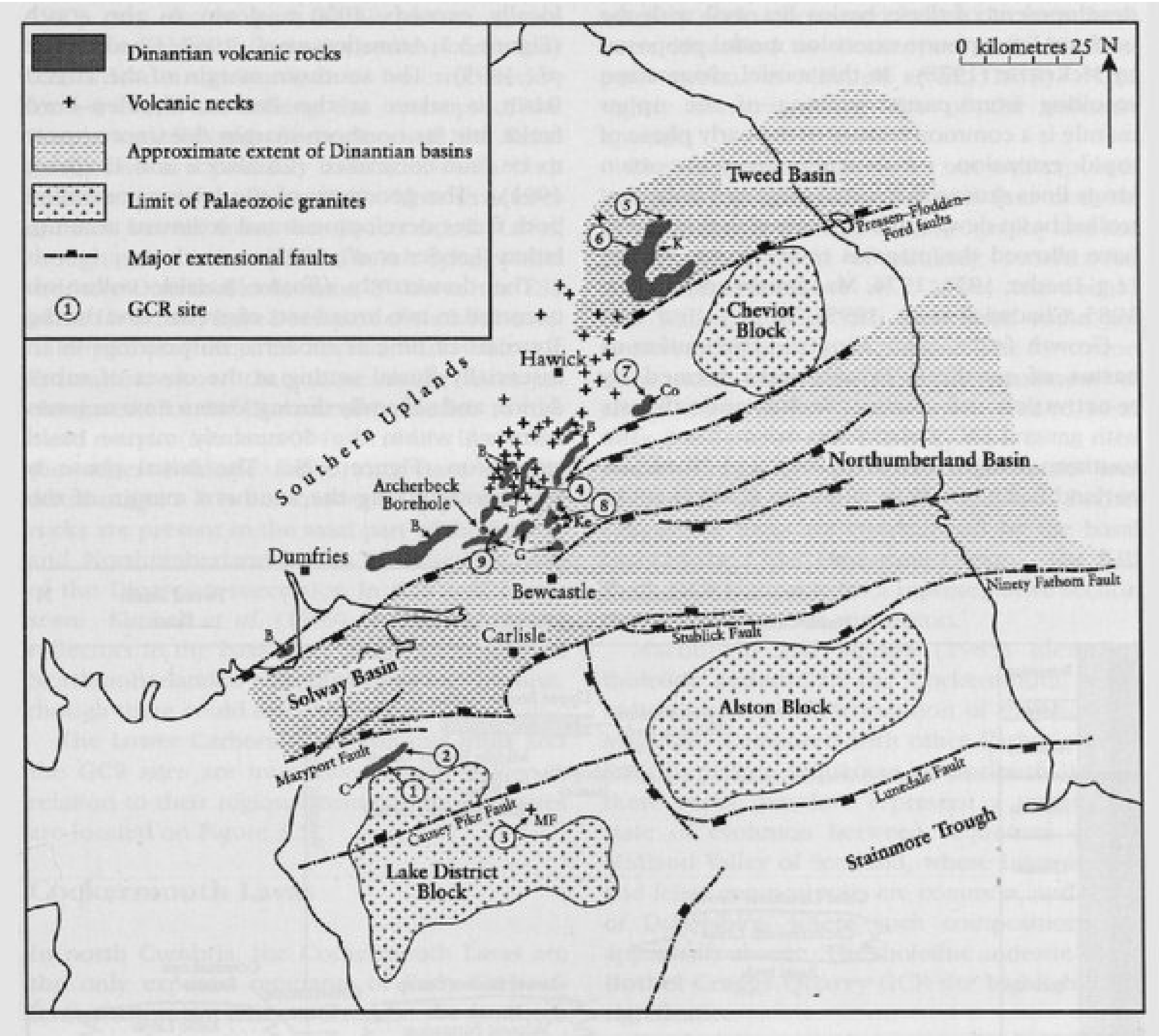
Plugs of basaltic rocks are numerous and some of these, particularly in the Kelso area, are composite intrusions of basalt, hawaiite and/or mugearite (Macdonald, 1975). However, in contrast to the entirely basic lava successions, the intrusions also include a number of alkaline and peralkaline felsic rocks. For example, the well-known laccolith complex of the Eildon Hills, near Melrose, comprises basaltic, trachytic and riebeckite-microgranitic components (McRobert, 1914) and other alkaline felsic intrusions occur south-west of Duns (Irving, 1930). About 10 km SSW of Hawick, the Skelfhill Pen intrusion is significant because of the association there of quartz-trachyte, aegirine trachyte and riebeckite-aegirine phonolite (McRobert, 1920). Many of the felsic intrusions are aligned about major NE-trending faults and some dykes define a diffuse swarm with a similar trend, suggesting structural control on their emplacement, as in the Campsie Fells and Garleton Hills (Upton, 1982).

The igneous clasts in the breccia-filled pipes include vesicular basaltic glass and crystalline olivine basalt, most of which is thoroughly decomposed. A single block of altered perido-tite is recorded from the Black Burn–Rough Gill Vent (Lumsden *et al.,* 1967). There are also variable quantities of sedimentary rock fragments, including sandstone, mudstone, limestone and chert.

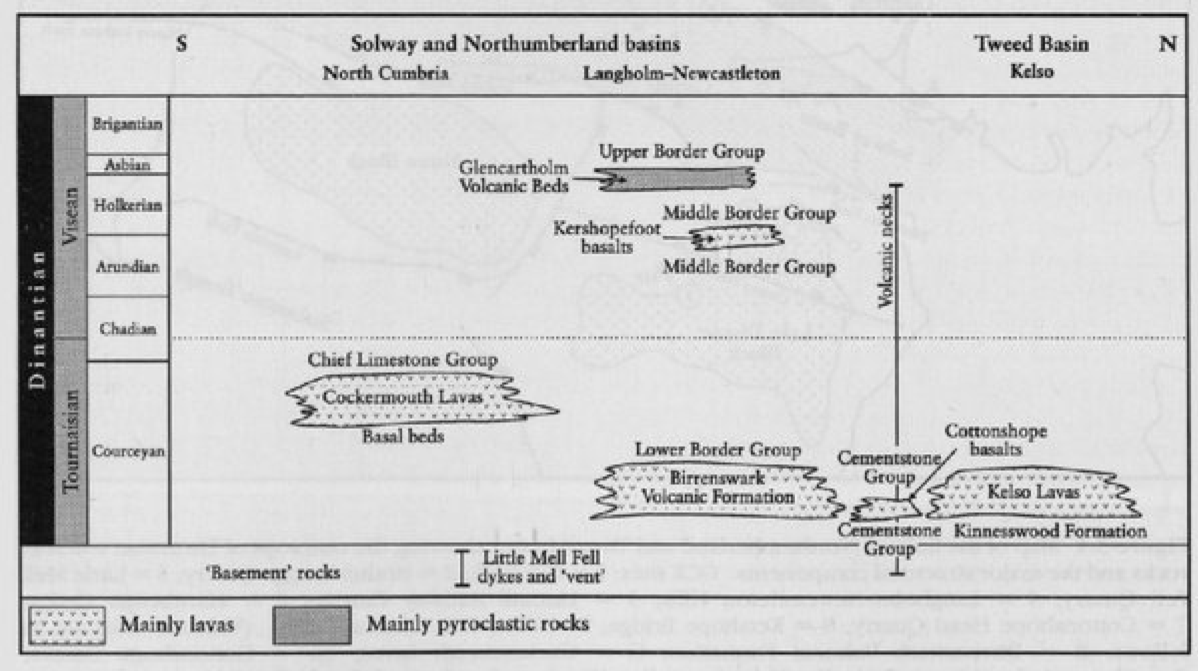
The basaltic to mugearitic volcanic necks in the Scottish Borders region have long been considered the most likely sources of the lavas and pyroclastic rocks of the Tournaisian Birrenswark Volcanic Formation and Kelso Lavas (e.g. McRobert, 1920). It is also possible that the felsic intrusions may be associated with this early volcanism, since an Ar-Ar date of 352.5 ± 1.4 Ma has been obtained recently from sanidine in a trachyte from the Eildon Hills (A.A. Monaghan and M.S. Pringle, pers. comm., 2002). However, many of the pyroclastic breccia-filled bodies north-east of Langholm cut upper Tournaisian sedimentary rocks and hence these may represent the sub-volcanic sources of the Glencartholm Volcanic Beds and perhaps the Kershopefoot basalts (McRobert, 1920).

Volcanic necks cutting the Birrenswark Volcanic Formation are described in the Langholm–Newcastleton Hills GCR site. The Hareheugh Craigs GCR site is a particularly good example of a composite intrusion, possibly associated with emplacement of the Kelso Lavas.

[References](#)



(Figure 3.1) Map of the Solway, Northumberland and Tweed basins showing the outcrops of Dinantian volcanic rocks and the major structural components. GCR sites: 1 = Gill Beck; 2 = Bothel Craggs Quarry; 3 = Little Mel Fell Quarry; 4 = Langholm–Newcastleton Hills; 5 = Lintmill Railway Cutting; 6 = Hareheugh Craigs; 7 = Cottonshope Head Quarry; 8 = Kershope Bridge; 9 = River Esk, Glencartholm. (Volcanic units are as follows: B = Birrenswark Volcanic Formation; C = Cockermouth Lavas; Co = Cottonshope Basalts; G = Glencartholm Volcanic Beds; K = Kelso Lavas; Ke = Kershopefoot Lavas; MF = Mell Fell Vent.) Information from published sources including Chadwick and Holliday (1991); Chadwick et al. (1995); Leeder (1974); and British Geological Survey (Tectonic map of Britain, Ireland and adjacent areas, 1996).



(Figure 3.2) Stratigraphy of the volcanic rocks of the Solway, Northumberland and Tweed basins. The range of strata cut by intrusions and volcanic rocks is also shown. After Gawthorpe et al. (1989).