Snowdon Massif

[SH 622 562]–[SH 615 524]

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Introduction

During Caradoc times, volcanic activity in Snowdonia migrated spatially within a large graben-like structure, termed the Snowdon Trough (Campbell *et al.,* 1988; Kokelaar, 1988) which was marked by the formation of a series of large caldera centres within a predominantly marine environment. Deep-seated NW-trending fractures influenced both the formation of this trough and the tectonic evolution of individual caldera structures during distinct phases of collapse and resurgence. Of these caldera structures, the Snowdon Centre is the largest and most clearly defined (Howells *et al.,* 1991) and has been the subject of detailed investigation by numerous workers over the last two decades of the 20th century. The GCR site lies within this centre and preserves a thick volcanic succession, recording developments within the northern, deepest part of the caldera, which developed during the 2nd Eruptive Cycle of Howells *et al.* (1991).

The geology of Snowdon was originally described in detail by Williams (1927) and was remapped by the Geological Survey between 1970 and 1983. It is included in the 1:25 000 scale Geological Sheets SH64/65 (Snowdon) (1989) and SH65/66 (Passes of Nant Ffrancon and Llanberis) (1985) and the 1:50 000 scale Geological Sheet 119 (Snowdon) (1997). General field guides are provided by Roberts (1979) and Howells *et al.* (1981) and detailed descriptions for the various parts of the succession, including geochemical analyses, are given by Howells *et al.* (1986, 1991) and Kokelaar (1992).

The succession within the GCR site is contained in three major rock basins or cwms separated by narrow serrated ridges, and comprises three formations belonging to the Snowdon Volcanic Group (Figure 6.44). The lower unit, best exposed in Cwm Llan, Cwm Tregalan, around Llyn Llydaw and Lliwedd, comprises a thick accumulation of acid ash-flow deposits known as the Lower Rhyolitic Tuff Formation (LRTF). This is succeeded by basaltic activity represented by the Bedded Pyroclastic Formation (BPF) which crops out extensively within the north-facing Cwm Glas and Cwm Uchaf, west of Glaslyn, the summit area of Snowdon and the north-eastern flanks of Lliwedd. The youngest strata, the Upper Rhyolitic Tuff Formation (URTF), mark a rcturn to acidic volcanism, possibly related to resurgent caldera activity, and are preserved only around the northern cwms, particularly on Clogwyn y Person and Snowdon summit itself. Numerous rhyolitic sills and domes dominate the northern half of the site and show complex intrusive and extrusive relationships with the above strata.

Volcanogenic quartz–sulphide mineralization is important throughout the Snowdon Massif and has been related to hydrothermal alteration by mineralizing fluids during the waning stages of caldera activity (Reedman *et al.,* 1985). At a regional scale, the rocks are buckled into a series of open NE-trending synclinal and anticlinal fold structures representing the imprint of the Caledonian Orogeny in the area.

Description

The site area exposes strata of the Cwm Eigiau Formation, the three formations of the Snowdon Volcanic Group, and related high-level intrusions (Figure 6.44).

Fine-grained siltstones and mudstones of the Cwm Eigiau Formation are exposed in a number of small quarries in Cwm Llan [SH 6134 5250] and represent the oldest strata in the GCR site area.

They pass upwards into sandstones, locally pebbly, with wave-washed, reworked concentrates of detrital magnetite and ilmenite.

The Lower Rhyolitic Tuff Formation (LRTF) generally rests with sharp conformity on the lower Pitts Head tuffs or sedimentary rocks of the Cwm Eigiau Formation. However, in places, up to 100 m of intrusive and extrusive basaltic sheets, associated with pillow breccias, hyaloclastites and basic tuffaceous sandstones rest with marked discordance on the underlying Pitts Head tuffs. Southwards, they rapidly cut down through to the underlying sandstones. Well exposed in the west wall of Cwm Tregalan, these basic rocks are referred to as the sub-LRTF basalts (Howells *et al.,* 1991) and are comparable to the sub-LRTF basalts in the east limb of the Idwal Syncline.

The basal unit of the LRTF, which crops out around Cwm Llan, comprises a white-weathered, intensely jointed, recrystallized and foliated, welded ash-flow ruff. Immediately south of Cwm Tregalan, at the southern margin of the site (around [SH 618 528]), the basal unit passes laterally into more impersistently welded tuffs with large pods of silicified welded tuff. Finely recrystallized, the basal tuff is seen to be dominated, in thin section, by aggregates of quartz, sericite and chlorite with isolated altered feldspar phenocrysts preserved as remnants of the original fabric.

The basal tuff is overlain by one of the thick est sequences of non-welded intracaldera ash-flow tuffs in central Snowdonia. Magnificently exposed on the north face of Lliwedd (Figure 6.45), the greater part of the formation comprises up to *c.* 500 m of uniform, massive, unbedded, non-welded rhyolitic pumice-lapilli ash-flow tuff with small clasts, up to 4 mm, of tubular pumice. The base of this sequence is exposed farther north in the Pass of Llanberis (Howells and Smith, 1997) and the upper contact with the overlying BPF can be traced around Glaslyn and the SE side of Crib Goch. Petrographically, the tuffs are dominated by varying admixtures of shards and feldspar crystals set in a matrix of sericite and chlorite (see Howells *et al.,* 1986 for further details).

The non-welded tuffs are overlain by 38 m of reworked tuffs that represent the uppermost part of the LRTF and have been described in detail by Fritz *et al.* (1990) and Howells *et al.* (1986). These beds crop out around the Snowdon Massif, but are best exposed along the western shore of Llyn Gwynant immediately to the SE of the GCR site. They comprise coarse-grained tuffaceous sandstones, interlayered with lesser amounts of laminated tuffaceous fine-grained sandstones and mudstones. Sedimentary structures include dune trough cross-stratification, wave ripples, and hummocky cross-stratification. Large concretionary nodules occur as isolated pods near the base of the section and are interpreted by Fritz *et al.* (1990) as early diagenetic features. Contorted bedding and small sedimentary dykes indicate soft-sediment deformation, possibly in response to rapid depositional rates. At 15 m above the base of the reworked tuffs, there is a prominent 12 m-thick bed of acid ash-flow tuff, which in turn is overlain by coarse-grained tuffaceous sandstones with abundant sedimentary structures, including herringbone cross-beds, horizontal lamination and trough cross-stratification; it is extensively bioturbated in the uppermost 3 m.

The Bedded Pyroclastic Formation (BPF) is preserved across Snowdonia, mainly within a series of synclinal inliers, and records the shallow-marine accumulation of basaltic pillow and sheet lavas, breccias, hyaloclastites and basic tuffs from a series of vents. These deposits show complex internal relationships and interdigitate with well-bedded tuffaceous sediments. Around Snowdon, the BPF is preserved high up in the glaciated cwms of Cwm Glas and Cwm Uchaf, in the steep cliffs above Glaslyn, and around the upper flanks of Snowdon summit (Figure 6.46). The complex geological history contained in these sections was described in detail by Kokelaar (1992) and Kokelaar *et al.* (1994) and was summarized by Howells *et al.* (1991). Here, only a brief account of the main lithologies and their geological features is presented and the reader is referred to the above accounts for further information.

The basal units of the BPF, exposed in the NE face of Snowdon above Glaslyn (Figure 6.46), comprise up to 95 m of basaltic tuffs, breccias and hyaloclastites. The contact with the underlying LRTF is marked by 5–6 m of thinly bedded tuff-turbidites and cobble conglomerates with vesicular scoria and glassy shard fragments. Two distinct agglomerate vents or necks, up to 280 m in diameter, have been distinguished by their markedly discordant relationships to the LRTF and the lower tuffs and turbidites (Kokelaar, 1992). The vents consist of subangular to rounded basic lapilli and blocks of basalt, up to 20 cm across, set in a rather indeterminate fine-grained basaltic matrix. The basal beds and the vents are then, in part, cut out by the overlying sequence, which consists of turbidites, conglomerates and breccia deposits. In Cwm Glas this break is marked by a 6 m-thick sequence of flow-banded rhyolite lava and the emplacement of large rhyolite intrusions within the LRTF. The overlying sedimentary strata have a total thickness of 75 m and comprise reworked turbidites, lithic-vitric breccias, and conglomerates. Beds are dominated by basaltic clasts including contorted spatter and bombs, but also include rhyolites and shelly debris.

The above strata are overlain by 190 m of heterolithic sedimentary rock. A basal unit, marked by cross-stratified matrix-supported conglomerates, is succeeded by up to 50 m of coarse- to fine-grained turbiditic sandstones, granule conglomerates and siltstones. Sedimentary structures are abundant and include planar and trough cross-bedding, cross-lamination, hummocky cross-stratification and wave ripples. Separating these beds from the overlying turbidites is a distinctive marker bed, some 4 m thick, of fine- to medium-grained altered sandstones and acid tuffaceous beds with carbonate nodules and brachiopod and crinoid debris. The uppermost beds, which form the crags above Glaslyn and the upper south face of Crib y Ddysgl, are composed of 140 m of massive thickly bedded turbiditic sandstones passing up into more thinly bedded, finer-grained sandstones.

In Cwm Glas, the overlying beds indicate a return to basaltic activity with up to 85 m of basaltic tuffs and lavas interleaved with turbiditic sandstones. The lavas are vesiculated, plagio-clase-phyric, pillowed and often form columnar-jointed sheets up to 4 m thick. Detailed mapping has traced these flows to the vicinity of the earlier vents in Glaslyn (Kokelaar, 1992). Finally, the complete sequence is overlain by up to 6 m of pebbly and turbiditic sandstones, and silicic siltstones. Rich in basalt scoria fragments, these beds also contain a rich derived shelly fauna with brachiopods of a *Dinorthis* assemblage suggesting water depths of less than 10 m.

The final activity of the Snowdon Centre is represented by the Upper Rhyolitic Tuff Formation (URTF) which is restricted in its outcrop to a series of small outliers within central Snowdonia. The formation includes peralkaline acidic ash-flow tuffs, bedded tuffs and tuffaceous sedimentary rocks and rare basaltic beds and can be related compositionally to the last phase of rhyolite intrusion (Howells *et al.*, 1991). Within the GCR site, the formation is superbly exposed on Clogwyn y Person (Figure 6.47) and Crib y Ddysgl, where up to 100 m are preserved and rest with gentle unconformity on the BPF. Pebbly sandstones, with both rhyolitic and basaltic clasts, locally mark the base, but laterally these beds are overstepped by the main ash-flow tuff. The main tuff, up to 35 m thick, has a distinctive, bleached weathered surface with lithic clasts and carbonate nodules, and grades up into fine-grained silicified tuff near the top of the section. Petrographically, the URTF is heterogeneous (Howells *et al.,* 1991) and comprises quartz, feldspar, sericite and chlorite with dispersed shards and a few lithic clasts of acid tuff, perlitic glass and chloritized basaltic fragments. On Crib y Ddysgl, the welded tuff is overlain by up to 40 m of fine-grained, bedded tuffs, tuffaceous siltstones and thin intercalations of basaltic tuff. The siltstones are silicified, with planar and low-angle cross-lamination. Snowdon summit is composed of a small outlier, some 25 m thick, of flaggy, acid tuffs and tuffaceous siltstones which are assigned to the URTF.

Both intrusive and extrusive rhyolite bodies are intimately associated with the LRTF and were emplaced prior to, during and after the deposition of the ash-flow tuffs. They are clearly exposed on the northern flanks of Snowdon, typically forming the serrated ridges south of the Llanberis Pass, such as Crib Goch. The intrusions cut the LRTF and are generally overlain by the basic tuffs and lavas of the BPF. On Clogwyn y Person, a rhyolite dyke that intrudes the BPF can be traced up into a dome overlying the main ash-flow tuff of the URTF, indicating late-stage activity. Typically pale-weathering, the rhyolites are strongly jointed, flow-banded and sparsely porphyritic; perlitic fracturing and autobrecciation are common.

Interpretation

The lower strata of the Cwm Eigiau Formation form part of the substrate onto which the 2nd phase of volcanic activity linked to the Snowdon Centre, here represented by the Pitts Head tuffs, was emplaced. Regional studies have inferred the presence of a NE-dipping palaeoslope with prograding alluvial fans in the south passing northwards into delta-front deposits (Reedman *et al.,* 1987; Howells *et al.,* 1991). In Cwm Llan, the presence of bands of heavy mineral concentrates indicates wave activity and the progradation of a wave-influenced beach. Into this environment, volcanic activity, within the evolving Snowdon caldera, commenced with the localized eruption of basaltic lavas and tuffs from a series of small vents which were probably controlled by deep-seated NE-trending fractures. The marked unconformity at the base of these basalts indicates uplift and erosion, and Howells *et al.* (1991) suggested that this, in part, reflects the upward propagation of pre-existing basement faults, probably triggered by the emplacement of magma into the cover sequence and the formation of a periclinal anticline within the sediments underlying the LRTF. This structure, termed the Beddgelert Pericline, is unique in the Caradoc strata of Snowdonia and heralds the main phase of ash-flow eruption; it later became the focus for volcanic activity, faulting and mineralization.

The LRTF represents a major period of ash-flow eruption and caldera collapse. From the evidence of facies and thickness variations, basal contacts and the distribution of associated rhyolite intrusions, Howells *et al.* (1986) inferred the presence of a caldera structure some 15 km in diameter. The section of tuffs within the Snowdon GCR site represents the infill to this caldera. Early eruptions, represented by the basal welded unit, are interpreted as reflecting a distinct eruptive event, possibly located on vents aligned along the NE-trending crest of the Beddgelert Pericline. In Cwm Tregalan, this unit rests conformably on reworked and subaque-ously erupted basalts, indicating emplacement in a marine environment. This contrasts with the predominantly subaerial emplacement far ther south.

The overlying main phase tuffs were ponded within the Snowdon caldera and, although uniform in appearance, geochemical data indicate that their accumulation involved at least two eruptive phases (Howells *et al.,* 1991). As the caldera progressively subsided, marine incursions began to rework the accumulating tuff pile. Sections through the upper part of the LRTF represent a progressively shallowing marine environment with rapidly fluctuating water depths and local topographical highs within the caldera. Sedimentation in a tidally influenced beach environment is indicated by the herringbone cross-beds, re-activation surfaces and bioturbation (Fritz *et al.,* 1990).

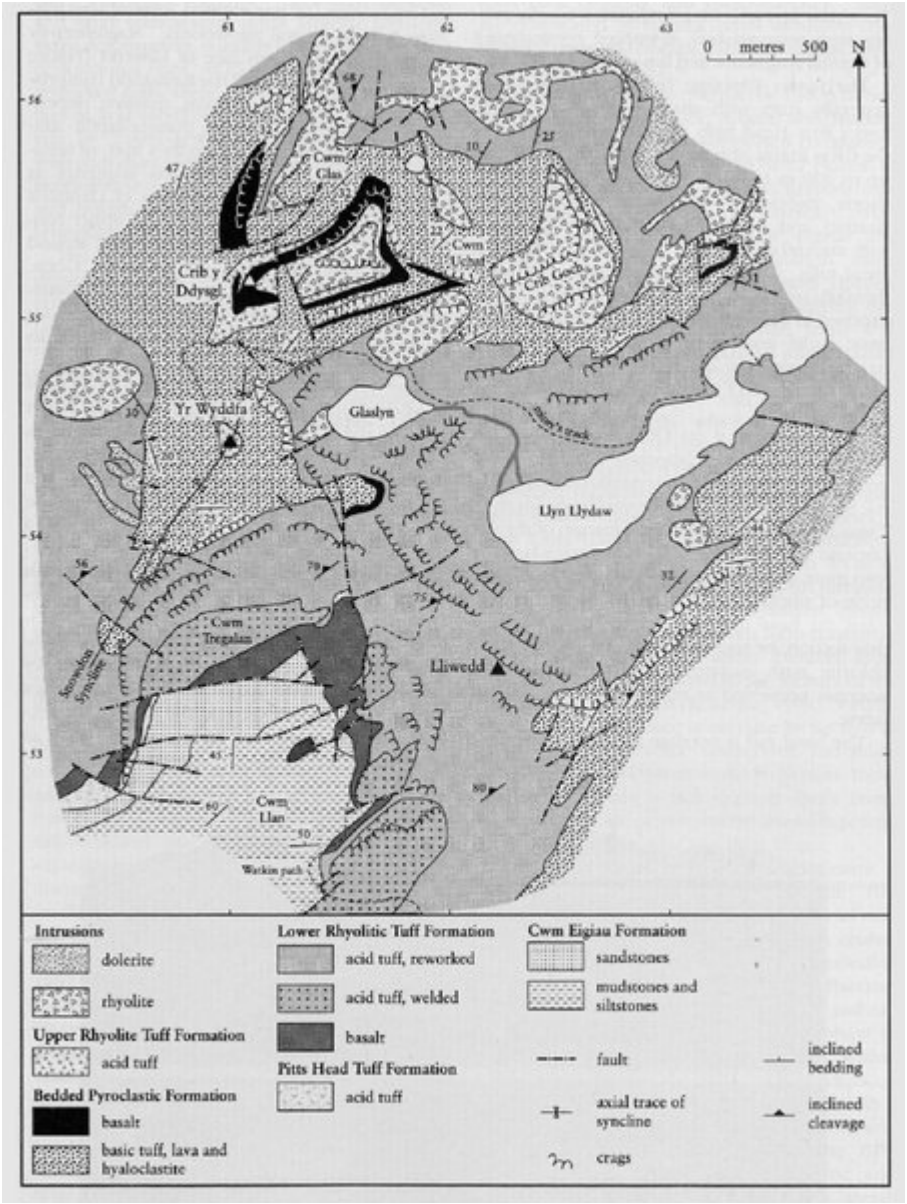
Although the subsidence is greatest in the northern part of the LRTF caldera, as indicated by the thick pile of intracaldera tuffs, on the evidence of the extrusion of rhyolite domes, and the subsequent complex interplay between basaltic magmatism and water depth, it is considered that the general subsidence was interrupted by resurgent uplift. This uplift has been attributed to the emplacement of acid magma at depth and is represented by the intrusion of a series of rhyolites both along NE-trending fractures and along the caldera margins (Campbell *et al.,* 1987; Howells *et al.,* 1991). Following resurgence and reworking, basic magmatism represented by the BPF occurred across Snowdonia. The detailed work of Kokelaar (1992) in the Snowdon Massif recognized a complex history with repeated uplift, emergence and subaerial erosion of a series of basalt island volcanoes. A total uplift of more than 336 m and subsidence of more than 500 m has been calculated by Kokelaar (1992.).

A return to acid volcanism is marked by the URTF, which is intimately associated with high-level rhyolite intrusion and final activity within the Snowdon caldera.

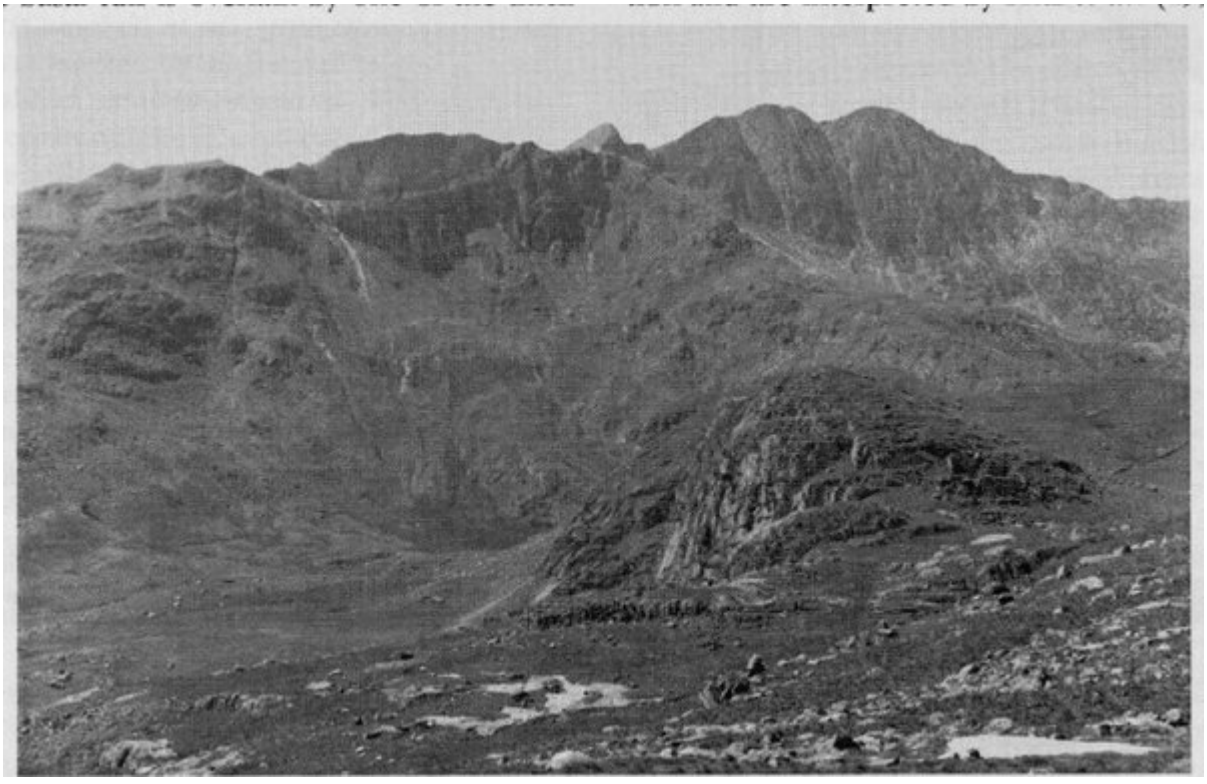
Conclusions

The Snowdon Massif GCR site provides important sections detailing the main phases of extrusive and intrusive volcanic activity related to the Snowdon Centre, a major caldera that developed in a predominantly marine setting. The spectacular ice-sculpted corms and hanging valleys of Snowdon offer an unrivalled opportunity to study the complex three-dimensional geological relationships within part of this caldera structure. Numerous studies have revealed the complex inter-relationships, through time, between alternating acid and basic magmatism, changing styles of volcanic activity and the background sedimentation. These relationships, most clearly expressed within the later stages of basaltic activity; represented by the Bedded Pyroclastic Formation, provide valuable insights into the ancient environments of Snowdonia during Caradoc times.

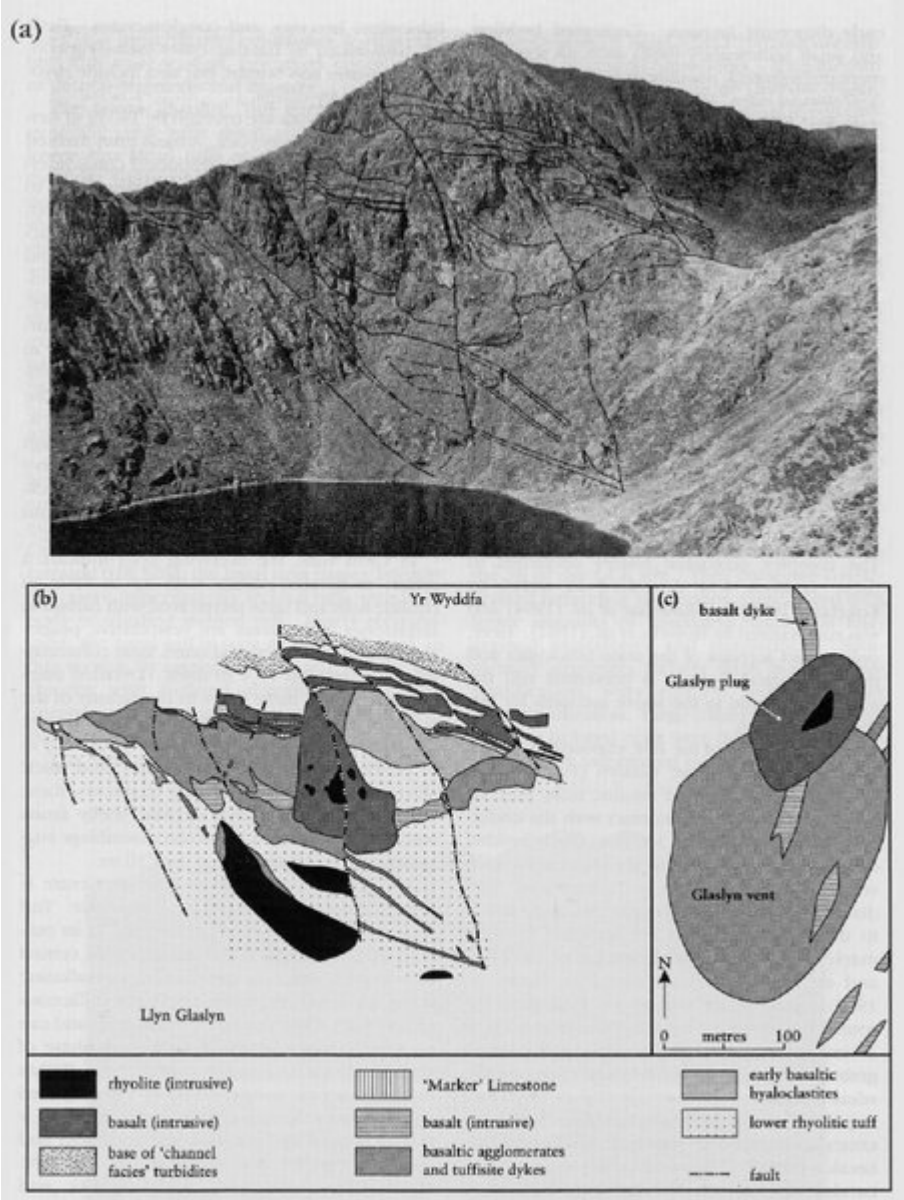
References



(Figure 6.44) Map of the Snowdon massif, modified after BUS 1:25 000 sheets 64/65 (1989) and 65/66 (1985).



(Figure 6.45) Lliwedd from Miner's Track showing the contact between the Lower Rhyolitic Tuff Formation and the Bedded Pyroclastic Formation near the centre of the ridge. (Photo: BGS no. A14391.)



(Figure 6.46) Details of the Bedded Pyroclastic Formation cropping out on the NE face of Yr Wyddfa, Snowdon above Llyn Glaslyn. (a) Photograph of NE face with geological boundaries added. (b) Key to the geological units exposed in a. (c) Sketch map of the Glaslyn Vent Complex. Reproduced from Howells et al. (1991).

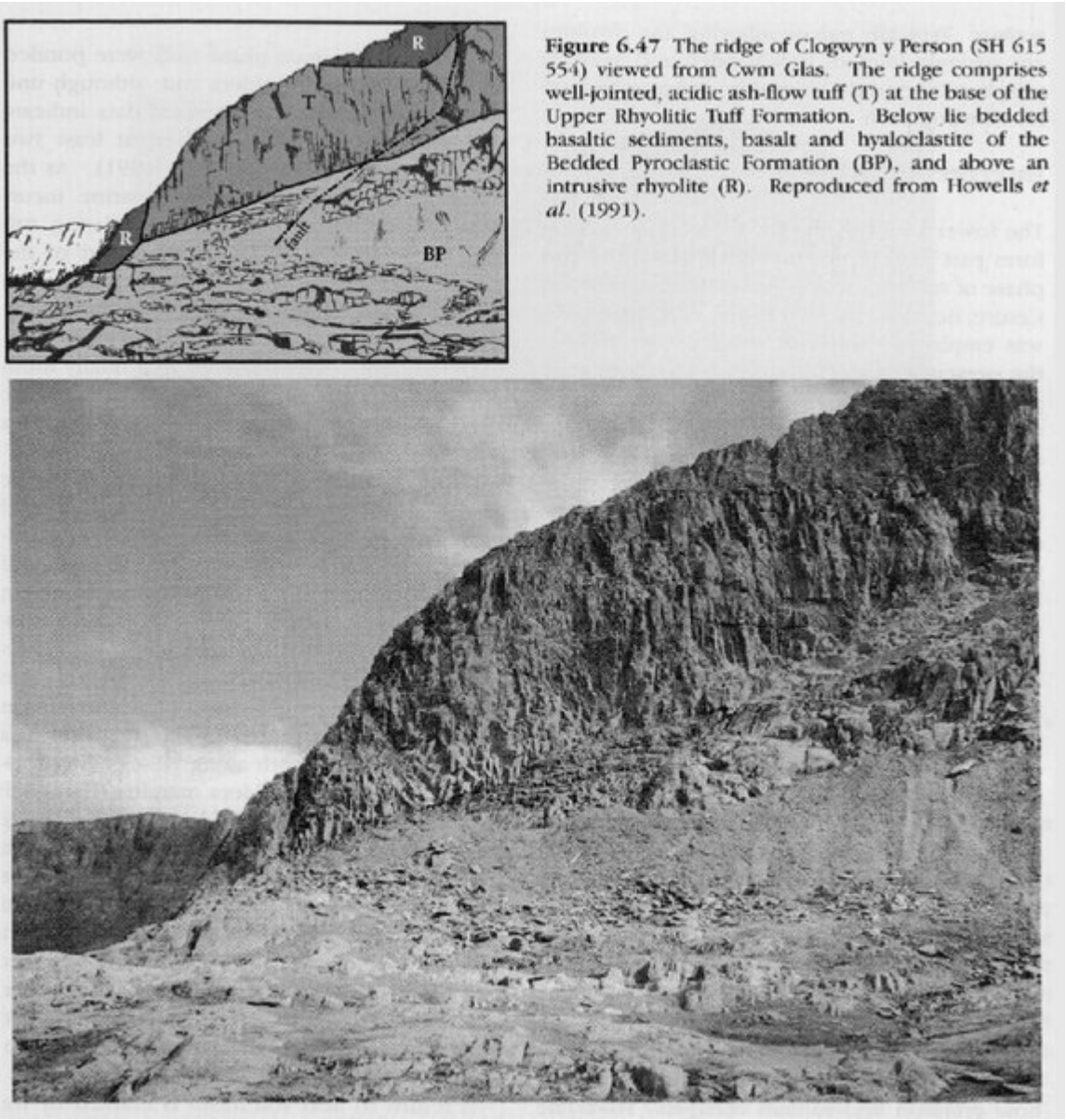


Figure 6.47 The ridge of Clogwyn y Person (SH 615 554) viewed from Cwm Glas. The ridge comprises well-jointed, acidic ash-flow tuff (T) at the base of the Upper Rhyolitic Tuff Formation. Below lie bedded basaltic sediments, basalt and hyaloclastite of the Bedded Pyroclastic Formation (BP), and above an intrusive rhyolite (R). Reproduced from Howells *et al.* (1991).

(Figure 6.47) The ridge of Clogwyn y Person [SH 615 554] viewed from Cwm Glas. The ridge comprises well-jointed, acidic ash-flow tuff (1) at the base of the Upper Rhyolitic Tuff Formation. Below lie bedded basaltic sediments, basalt and hyaloclastite of the Bedded Pyroclastic Formation (BP), and above an intrusive rhyolite (R). Reproduced from Howells et al. (1991).