# Llyn Padarn

[SH 550 630]–[SH 590 610]

Potential GCR site

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## Introduction

Llyn Padarn is situated within an area of spectacular scenery on the fringes of Snowdonia. It has been selected for the GCR independently for its Cambrian stratigraphy and is proposed as a Precambrian site because of its particularly good exposures of the Arfon Group, and also because of its accessibility (Howells *et al.,* 1985; Reedman *et al.,* 1984). These rocks crop out extensively on the south-eastern side of the Menai Strait between Caernarfon and Bangor, as shown in (Figure 6.1). Llyn Padarn (Figure 6.5) includes the eastern part of the Arfon Group, which here is particularly well exposed in large crags and ice-moulded rocky knolls on the shores and nearby hills surrounding the northwestern half of the lake. The lower part of the group comprises the Padarn Tuff Formation, dominated by acidic ash-flow tuffs (ignimbrites) and probably exceeding 1500 m in thickness. This is overlain by a further several hundred metres of clastic sedimentary rocks, the Fachwen Formation (Reedman *et al.,* 1984; Howells *et al.,* 1985).

Outcrops of the Arfon Group are restricted to North Wales in the vicinity of the Menai Strait and both geophysical and outcrop evidence suggest that the group thins rapidly to the southeast, where it is covered by the Lower Palaeozoic sequences of Snowdonia. Little therefore is known of its original lateral extent beneath these younger rocks towards central Wales. The Bryn-teg borehole (Allen and Jackson, 1978), however, penetrated through the Cambrian cover strata in the Harlech Dome region (Figure 6.1), and proved approximately 140 m of volcanic and sedimentary rocks beneath. These, named the Bryn-teg Volcanic Formation, occupy an appar ently similar stratigraphical position and are correlated with the Arfon Group. The Bryn-teg sequence contains lithologies that include: andesite, dacite, tuffites, interbedded volcaniclastic mudstones, siltstones and sandstones and intrusive basalt. Allen and Jackson (1978) drew attention to the abundance of volcanic clasts in the basal conglomerates of the overlying, Cambrian-age Dolwen Formation. No evidence for an angular difference across the junction was found in the borehole, but Allen and Jackson (1978) nevertheless concluded that such an abrupt change in lithology meant that the Bryn-teg Formation and Dolwen Formation were unconformable and separated by an erosional interval. According to G. Hornung and A. Gray (in Allen and Jackson, 1978), the chemistry of the volcanic clasts in the Dolwen conglomerates is not of 'Bryn-teg'-type, but more in keeping with their derivation from Precambrian volcanic sequences such as that at Llyn Padarn.

Little geochemical detail is available for the Arfon Group, but data were presented by G. Hornung and A. Gray (in Allen and Jackson, 1978) for the equivalent Bryn-teg Volcanic Formation. Using a selection of the less alteration-prone trace elements, they showed that these rocks were part of a 'calc-alkaline island arc succession' that can be correlated with similar rocks in the Avalonian sequences of Newfoundland.

The late Precambrian age of the Padarn Tuff Formation was confirmed by a U-Pb determination of 614 Ma ± 2 Ma on rocks collected from an exposure near the outlet of Llyn Padarn, south of Bryn yr efail village (Figure 6.5). As remarked earlier in the introduction to this chapter, such an age is also close to that of the St David's Granophyre and reinforces the correlation between the Arfon and Pebidian Precambrian divisions within the Cymru Terrane (Figure 1.1), (Figure 1.2).

## Description

The Padarn Tuff Formation crops out extensively in numerous ice-moulded hillocks on the slopes rising to the north-east and south-west from the shores of Llyn Padarn (Figure 6.6). The white-weathering tuffs typically consist of phenocrysts of quartz and sodic plagioclase in a matrix of devitrified and recrystallized, eutaxitically welded shards and vitric dust The

phenocrysts, generally up to 2 mm in length and forming *c.* 25 per cent of the rock, show euhedral, rounded, embayed or angular fragmental forms. Quartz phenocrysts commonly occur as resorbed or hollow crystals and the feldspars are commonly sericitized or sieved by chlorite and carbonate. Locally the tuffs contain clasts of welded tuff, tubular pumice and chloritized fiamme, drawn out into the welding fabric. The main variants from the typical welded tuff are thin layers of non-welded vitroclastic tuff and vitric dust-tuff, which may locally define the tops of major flows. There are no intercalated sedimentary beds within the tuffs; thin beds of reworked, crystal-rich tuff debris, displaying small-scale cross bedding, are impersistent and rarely extend along strike for more than a few tens of metres.

The welding foliation is clearly visible in many of the outcrops around Llyn Padarn and generally dips at between 40° and 60° to the northwest, though the dip decreases and becomes more variable at the north-western end of the lake. A particularly good locality to view the welding foliation is in an old road cutting on the south-western shore of the lake, close to its north-western end (Figure 6.7); [SH 560 622].

The most striking impression gained from an examination of the many outcrops of the Padarn Tuff Formation around Llyn Padarn is of its great uniformity of composition and texture. Furthermore, the overall north-westward dip of the welding foliation indicates that these tuffs accumulated to a great thickness, estimated to be at least 800 m in the vicinity of Llyn Padarn.

The Fachwen Formation occurs to the east of the Padarn Tuff Formation, its crop crossing the central part of Llyn Padarn. Locally its basal beds are seen overlying the Padarn Tuff Formation, either disconformably or unconformably, but commonly it is in faulted contact with the welded tuffs of the Padarn Tuff Formation. The basal strata are normally clast-supported conglomerates of angular to subrounded pebbles, cobbles and blocks of welded and non-welded acidic tuff and felsite. These are enclosed in a matrix of resorbed and hollow quartz and feldspar crystals, fine lithic grains and recrystallized vitric debris. Rounded clasts of basalt, jasper, quartzite, granite, siltstone and quartzose schist are rare near the base of the conglomerates, but become increasingly abundant in the upper part.

Near Llyn Padarn the conglomerates form wedges up to 150 m thick which grade, both laterally and vertically, into coarse-grained, cross-bedded sandstones composed predominantly of quartz and feldspar crystals and grains of acidic tuff. At several localities a thin, welded, acidic ash-flow tuff is intercalated within the basal part of the formation.

Fine- to coarse-grained clastic sedimentary rocks, containing much reworked volcanic debris, make up the bulk of the rest of the formation. Lateral and vertical variation is rapid, but generally near Llyn Padarn, above the sandstones and conglomerates, the middle part of the sequence is dominated by laminated tuffaceous siltstones and tuffites, with sandstones becoming more abundant in the upper part.

The formation thickens markedly from east to west north of Llanberis; on Gant y Foel [SH 585 620] it is represented by a single sandstone unit *c.* 40 m thick, whereas around Fachwen [SH 575 618] it is *c.* 450 m thick and increases to over 600 m near Moel-i-Ci [SH 590 661]. Outcrops can conveniently be examined around Fachwen [SH 574 618] and along footpaths between Bigil [SH 579 623] and Deiniolen [SH 579 633].

## Interpretation

The great thickness and the homogeneity of the Padarn Tuff Formation indicates rapid accumulation from pyroclastic flows restricted in a topographical depression. The current geometry of the formation suggests that the depression was a NE-trending graben, or half-graben, bounded on the west by the Dinorwic Fault. The voluminous eruption of ash-flow tuffs and the collapse of the fault-bounded depression were probably genetically linked.

A pronounced Bouguer gravity anomaly low, approximately coincident with the outcrop of the Padarn Tuff Formation, was originally described by Powell (1955) and subsequently modelled by Reedman *et al.* (1984). It provides additional evidence for the previous existence of an extensive topographical depression in which up to 2 km thickness of acid tuffs accumulated. This depression, some 15 km wide and possibly as much as 60 km long, can be compared to the Toba volcano-tectonic depression in Sumatra, Indonesia, a collapse structure associated with the voluminous eruption and accumulation of acidic ash-flow tuffs.

Following the accumulation of the ash-flow tuffs of the Padarn Tuff Formation, continued differential subsidence and uplift, accompanied by sporadic volcanism, erosion and the accumulation of a thick sequence of volcaniclastic sediments, characterized the further development of the Arfon Basin (Reedman *et al.,* 1984). In the east, lenses of conglomerate and coarse sandstone at the base of the Fachwen Formation represent alluvial fans and fluvial deposits that probably accumulated close to the fault system at the eastern margin of the structure, which restricted the Padarn Tuffs. Although acid tuff clasts predominate in these basal beds, rounded clasts of more distant provenance are also present. The Fachwen Formation conglomerates rest either disconformably or unconformably upon eroded ash-flow tuffs of the Padarn Tuff Formation. Around Llyn Padarn, variations in the angular relationships at these contacts take place abruptly across faults, suggesting rotation of the fault blocks prior to, and perhaps during, sedimentation.

To the west of Llyn Padarn, between Bangor and Caernarfon, there are extensive outcrops of the Arfon Group separated from the Llyn Padarn outcrops by the Aber-Dinlle Fault and an intervening tract of Ordovician strata (Bangor Sheet, 106). Here, in ascending order, the Arfon Group comprises: the Padarn Tuff the Bangor and the Minffordd formations (Reedman *et al.,* 1984; Howells *et al.,* 1985). Around Bangor, the Minffordd Formation comprises conglomerates, sandstones, acid tuffs and tuffites, and rare basic tuffites. The higher beds in the formation display a westward overlap on to the Padarn Tuff Formation adjacent to the Dinorwic Fault, indicating continued fault activity which was accompanied by erosion of the Padarn Tuff Formation. As in the Padarn area, the polymict, ill-sorted, massive conglomerates are interpreted as small fans that accumulated adjacent to contemporaneous fault scarps. The Bangor Formation, restricted to a small area near Bangor (Reedman *et al.,* 1984), comprises similar lithologies to the Minffordd and Fachwen formations.

The distribution and composition of epiclasts in the conglomerates and sandstones of the Minffordd, Fachwen and Bangor formations reflect uplift and progressive stripping of the volcanic cover in the region adjacent to the basin. Initially, volcaniclastic debris of the Fachwen Formation was mainly derived from the irregularly faulted surface of the Padarn Tuff Formation within the basin, though in the east clasts of both metamorphic rocks and of basalt are found. The former are possibly derived from the pre-Arfon basement in the east and the latter from basalts locally erupted onto the Padarn Formation surface as at Coed Glanyrafon [SH 502 596], west of Betws Garmon. The Minffordd Formation shows a progressive increase in the ratio of basic to acidic detrital material during its accumulation. The acidic debris was probably derived mainly from the erosion of outflow deposits from the early Arfon Basin, and the basaltic material from lavas of undetermined provenance, which were progressively unroofed by uplift outside the basin. Further uplift and erosion of the basin margins in the west resulted in the supply of clasts of the pre-volcanic basement, including Penmynydd schists, to the proximal fan facies of the basal conglomerates of the Bangor Formation. Acidic volcanic debris continued to be supplied, but a sedimentary hiatus is suggested by the unconformity at the base of the Bangor Formation. This non-sequence could reflect uplift and erosion, removing the source of basaltic debris, or a change in topography, which prevented its incorporation in the Bangor Formation sediments.

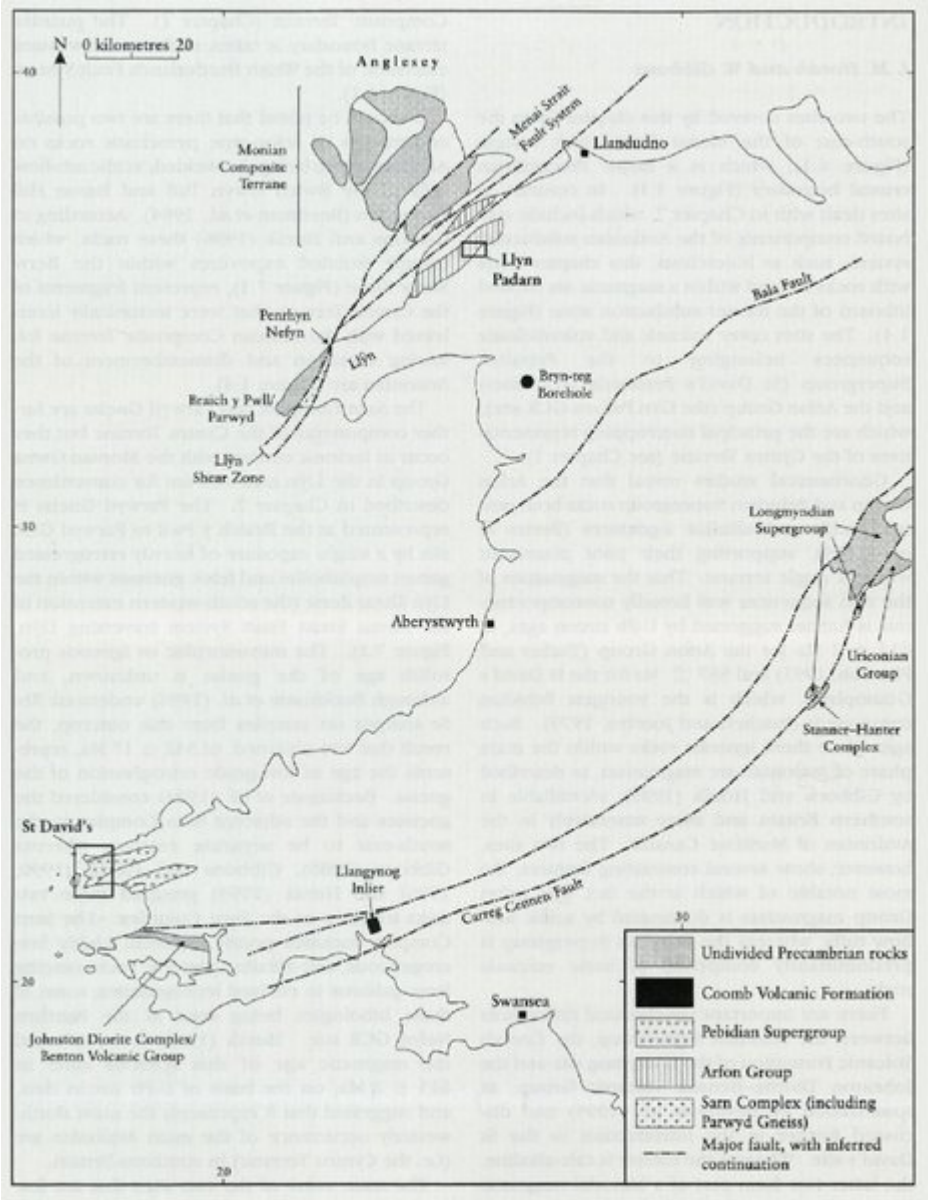
In contrast to the Arfon Group, the Precambrian rocks in the Bryn-teg borehole show a style of magmatism that gave rise to basic and intermediate volcanic products, most of the pyroclastic rocks being of basic composition. The depositional environment is believed to have been subaqueous (Allen and Jackson, 1978). Nothing is known of their lateral extent, but it is possible that both the Arfon Group and Bryn-teg Formation represent the broadly synchronous expression of volcanism and sedimentation dominated by contrasting volcanic centres within an extensive late Precambrian volcanic province.

## Conclusions

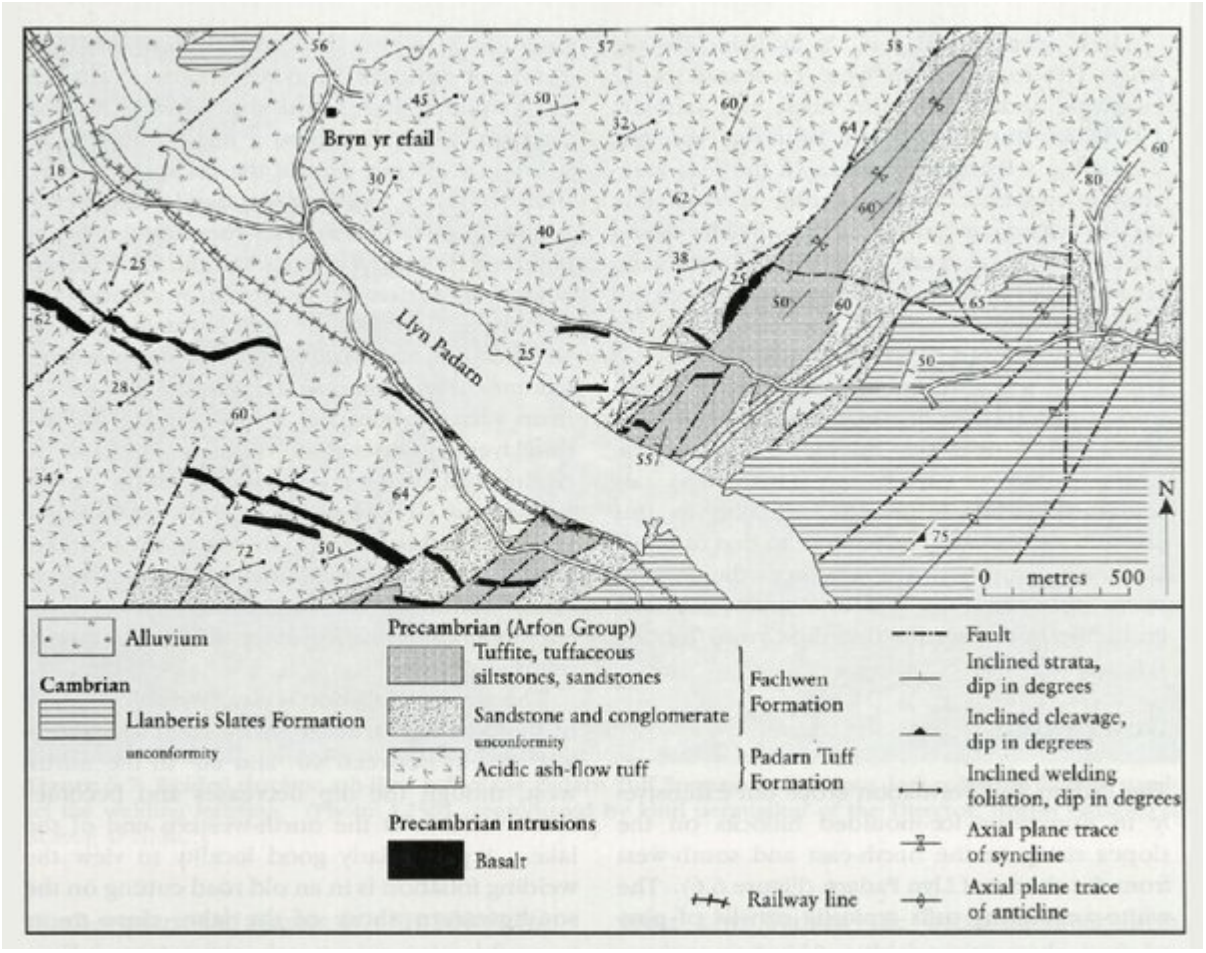
The extensive outcrops of the Arfon Group are important for illustrating the development of a voluminous late Precambrian volcanic episode in the Cymru Terrane (Figure 1.1). The oldest rocks, of the Padarn Tuff Formation, represent perhaps as much as 500 $km^3$ of rhyolitic ash-flow tuff that was erupted explosively from volcanoes located within a region characterized by fault-controlled subsidence. The volcanism was succeeded by erosion, with the accumulation of conglomerates, sandstones, siltstones and tuffites making up the overlying Fachwen Formation. Initially its detritus was largely derived from the local volcanic terrain, but subsequently material was eroded from older sequences farther afield, at the margins of the Padarn Tuff depression. This progression indicates that the area

continued to subside through repeated extension of the crust along major NW-trending faults.

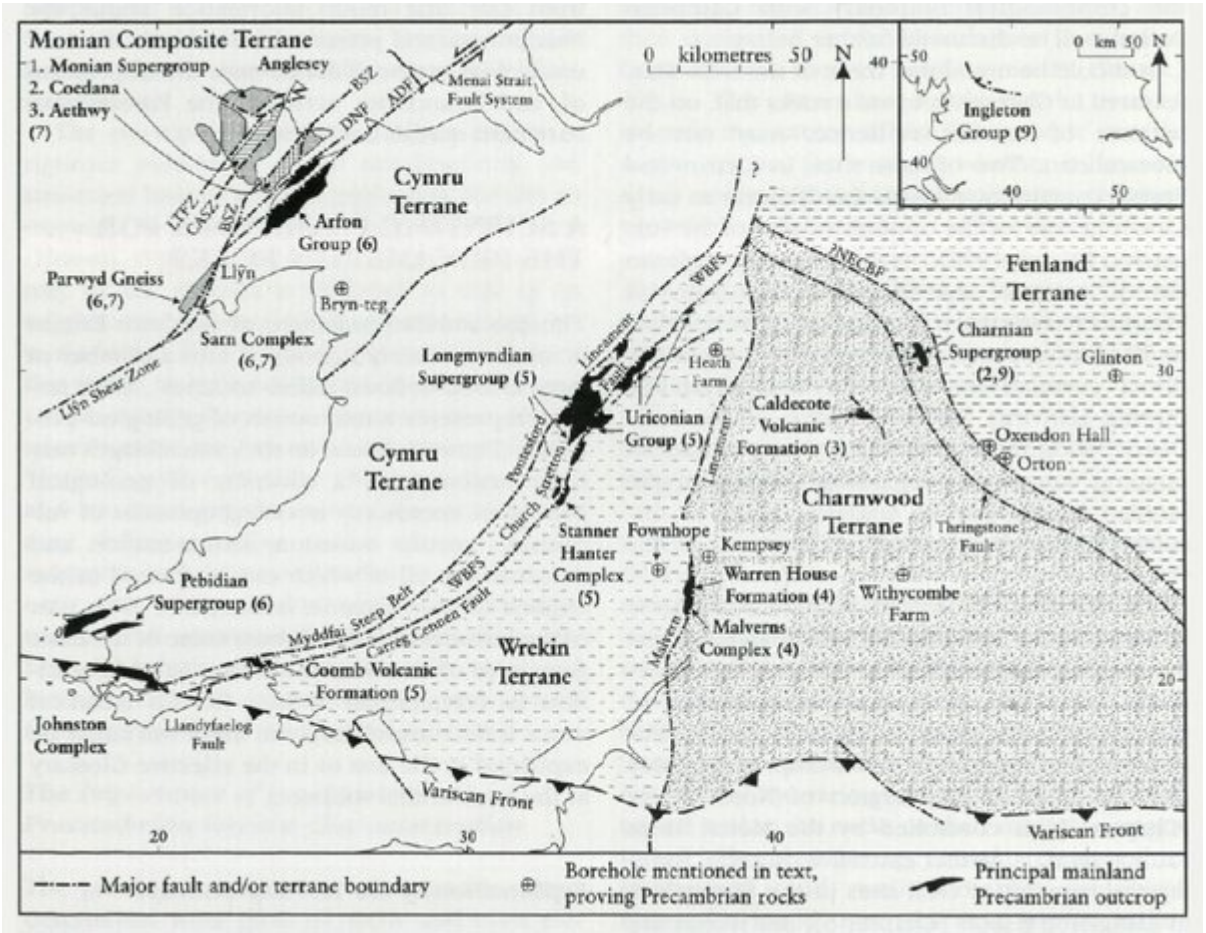
## References



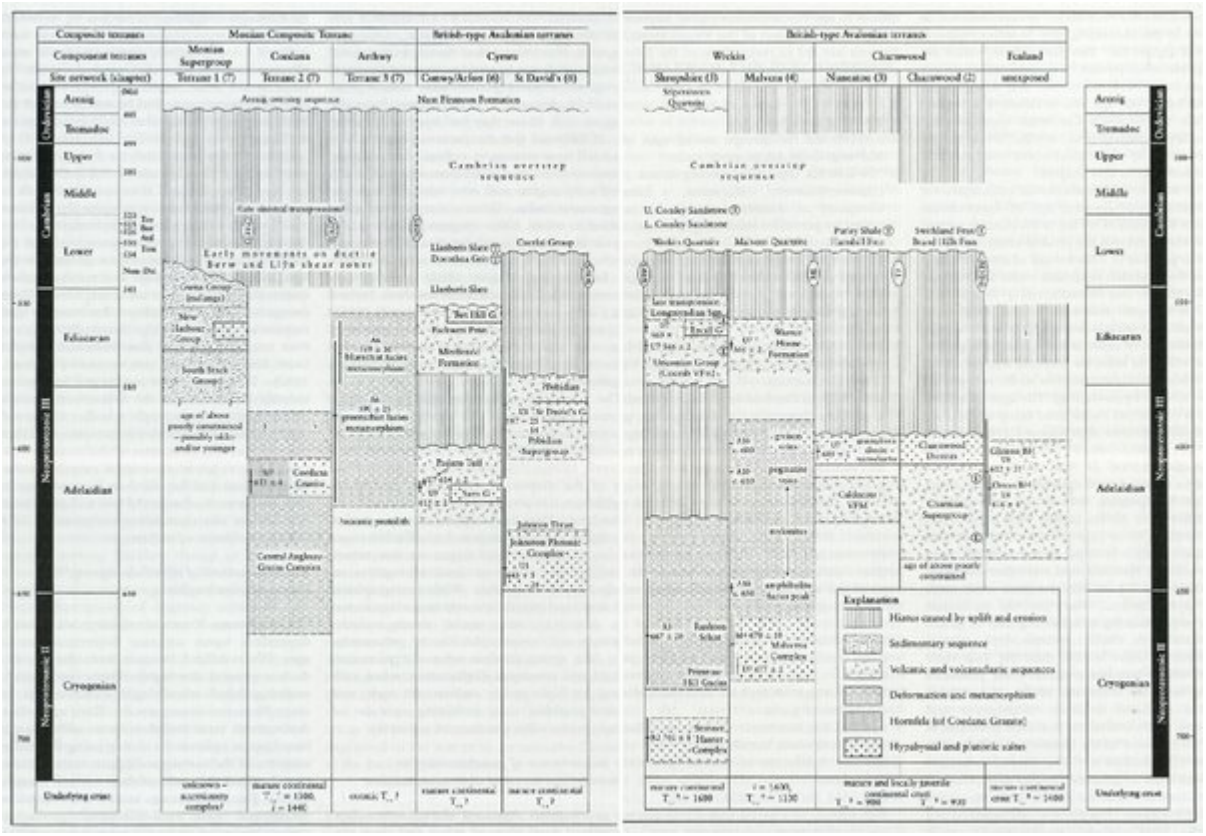

*(Figure 6.1) Geological map showing the relationship of the St David's and Llyn Padarn sites to other Precambrian outcrops.*



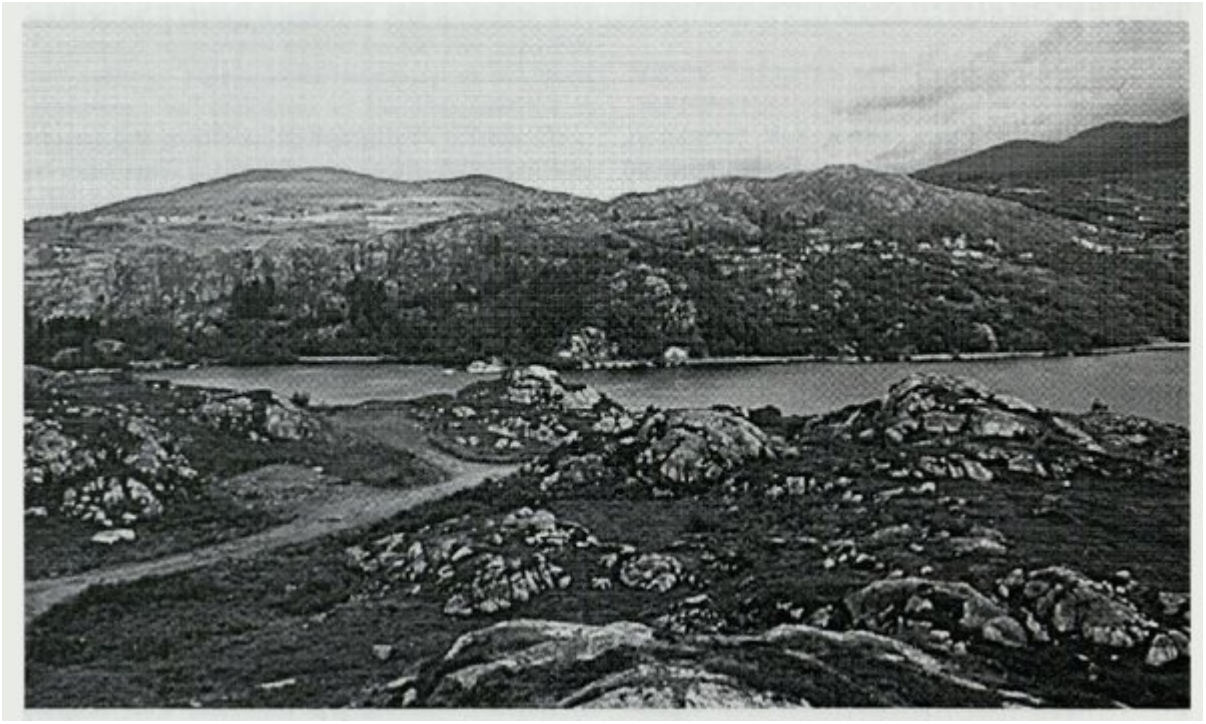

*(Figure 6.5) Simplified geological map of the Llyn Padarn site (based on BGS 1: 25 000 maps for parts of Sheets SH55 and SH56)*



*(Figure 1.1) Sketch map showing the distribution of Precambrian outcrop, and boreholes proving Precambrian rocks, in southern Britain. Note that the outcrops are labelled with the names of the principal geological units, followed by numbers (in brackets) of the chapters for the relevant GCR sites. Terrane boundaries are slightly modified after British Geological Survey (1996); Myddfai Steep Belt after Woodcock (1984a); Monian Composite Terrane after Gibbons and Horák (1990). Key: ADF, Aber-Dinlle Fault; BSZ, Berw Shear Zone; CASZ, Central Anglesey Shear Zone; DNF, Dinorwic Fault; LTFZ, Llyn Traffwll Fault Zone; ?NECBF, postulated NE Charnwood Boundary Fault. The boundary of the Midlands Microcraton basement domain is outlined by the NECBF and Pontesford-Myddfai lineament systems; WBFS, Welsh Borderland Fault System.*



*(Figure 1.2) Correlation chart for the late Neoproterozoic history of southern Britain. Key: A, $^{40}Ar$–$^{39}Ar$ age; M, U-Pb monazite age; R, Rb-Sr whole-rock isochron age; U, U-Pb zircon age; $T_{DM}$, Depleted mantle Sm-Nd age; i, inherited zircons. Key to faunas; (E) Ediacaran fossils; (T) Teichichnus trace fossils. Key to horizontal boundaries; continuous line, conformable stratigraphy; wavy line, unconformity; dashed T line, tectonic contact; dashed line, nature of contact uncertain. Terrane boundaries: BSZ, Berw Shear Zone; CASZ, Central Anglesey Shear Zone; LTFZ, Llyn Traffwll Fault Zone; ML, Malvern Lineament; MSFS, Menai Strait Fault System; ?NECBF, postulated NE Charnwood Boundary Fault; TF, Thringstone Fault;WBFS, Pontesford Lineament of Welsh Borderland Fault System. Literature sources: 1, Patchett and Jocelyn (1979); 2, Patchett et al., (1980); 3, Beckinsale et al., (1984); 4, Thorpe et al., (1984); 5, Davies et al., (1985); 6, Dallmeyer and Gibbons (1987); 7, Tucker and Pharaoh (1991); 8, Noble et al., (1993); 9, Horák et al., (1996); 10, Strachan et al., (1996). Stratigraphical data for Lower Cambrian sequence, and fossil occurrences after McIlroy et al., (1998): nem-Dal, Nemakit-Daldynian; Tom, Tommotian; Atd, Atdabanian; Bot, Botomian; Toy, Toyonian.*



*(Figure 6.6) View to the north-east across Llyn Padarn with numerous outcrops of the Padarn Tuff Formation in the foreground. (Photo: L2244, reproduced by kind permission of the Director, British Geological Survey, © NERC.)*

*(Figure 6.7) Welded rhyolitic ash-flow tuff of the Padarn Tuff Formation. Elongate dark-coloured fiamme parallel the welding foliation. (Photo: L2501, reproduced by kind permission of the Director, British Geological Survey, © NERC.)*