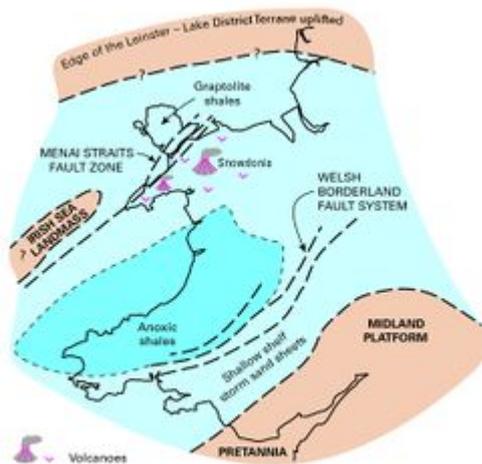


Caradoc Series, Ordovician, Wales

From Earthwise

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From: Howells, M F. 2007. [British regional geology: Wales](#). Keyworth, Nottingham: British Geological Survey.



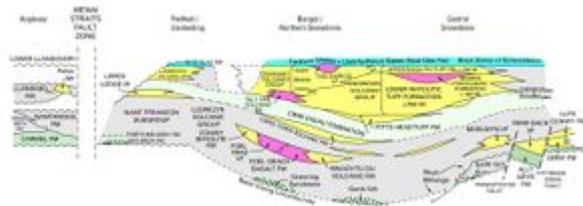
Palaeogeography of the Welsh Basin in Longvillian (mid-Caradoc) (adapted from Cope et al., 1992). P916159.

Global Series	Global Stages	Series	Stages/Substages	Graptolite biozones	Ma	
Lower	Hemantian	Hemantian	Hemantian	<i>Glyptograptus pectipitus</i> <i>Clasacograptus eubaccharum</i>	440	
			Ardvian	Leathryan		<i>Dicellograptus anceps</i>
				Caulleyan		<i>Dicellograptus complanatus</i>
				Fungillian		<i>Nemagraptus linearis</i>
	Katian	Katian	Oriskanyan	Oriskanyan	<i>Dicranograptus digram</i>	
				Actonian		
			Chazyan	Marathbaocikian		
				Woolstonian		
				Longvillian		
				Soudleyan		
	Sandbian	Cleopoc	Sandbian	Hemagraptan	<i>Diplograptus foliaceus (versatilis)</i>	
				Costanian	<i>Nemagraptus gracilis</i>	
			Avalonian	Valleyan	461	
Middle	Darriwilian	Darriwilian	Sandvillian	<i>Huaidograptus tenuicaulis</i>	c. 400	
			Aberystwythian	<i>Didymograptus meridiensis</i> <i>Didymograptus arcticus</i>		
	Stage 3	Avalonian	Fennian	<i>Eupanograptus frons</i> <i>Sagorites cadocensis gibberulus</i>		
			Whitlandian	<i>Didymograptus similans</i>		
Lower	Tremadocian	Tremadocian	Mordunian	<i>Didymograptus varians</i> <i>Sagorites phyllograptoides</i>	475 ±	
			Chewagran	<i>Clasograptus tenellus</i> <i>Robidmapora fabeliforme</i>		488

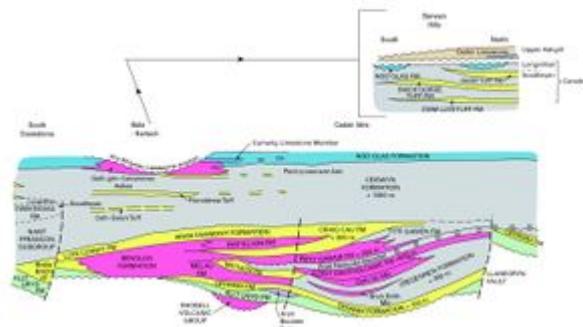
Ordovician series. P916227.



Cadair Idris scarp viewed across the Mawddach estuary. Middle to Upper Cambrian in the lowermost slopes pass up into the Ordovician Aran Volcanic Group in the ridges across Bryn Brith, to the left of centre. Acidic and basic volcanic rocks with intercalated sedimentary rocks and associated intrusions crop out in the main scarp. P662403 C D R Evans.



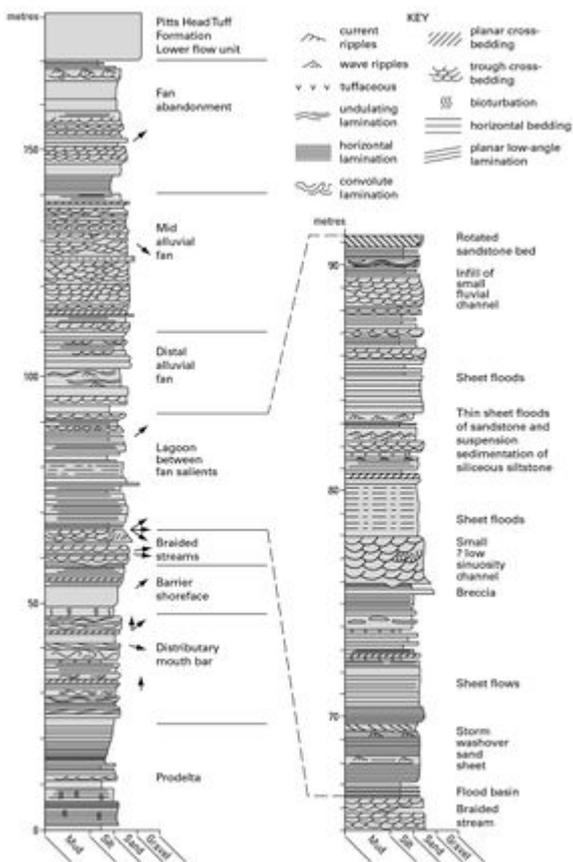
Cartoon (not to scale) illustrating a generalised vertical sequence of the Ogwen Group and equivalents (Arenig—Caradoc) across northern Snowdonia, Llŷn and Anglesey (adapted from Rushton and Howells, 1999). P916154.



Cartoon (not to scale) illustrating a generalised vertical sequence of the Ogwen Group and equivalents (Arenig—Caradoc) across southern Snowdonia and the Berwyn Hills (inset) (adapted from Rushton and Howells, 1999). P916155.



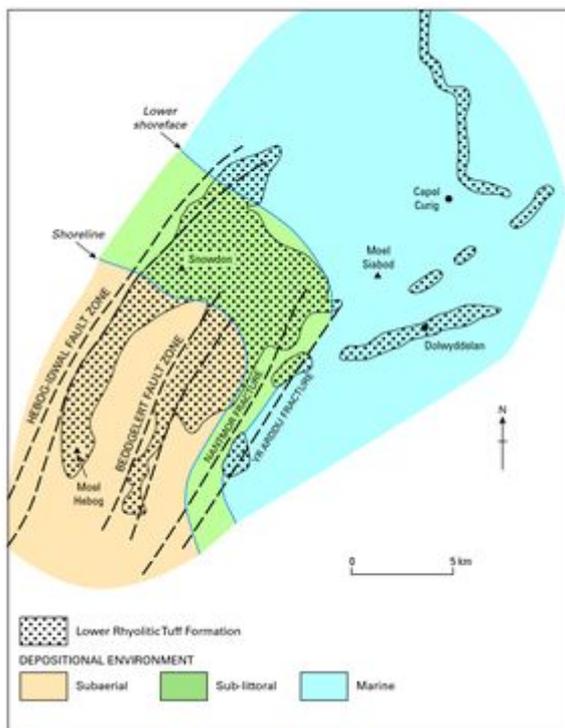
Wave ripple marks in coarse-grained sandstones, Capel Curig Volcanic Formation, near Cwm Clorad Isaf, west of Capel Curig. P662408.



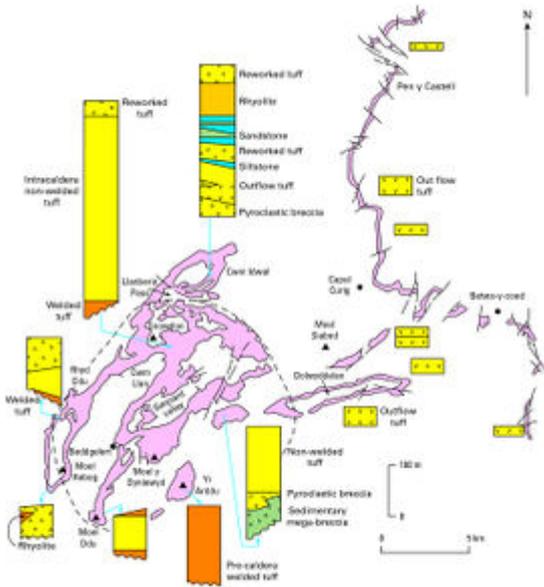
Graphic logs and environmental interpretation of the Pitts Head Tuff, Moel Hebog (adapted from Orton, 1988 reproduced in Howells et al., 1991). P916160.



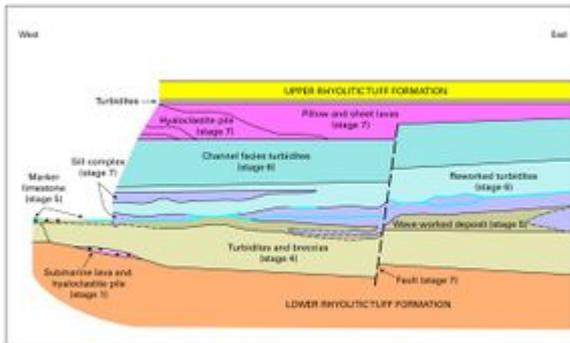
Siliceous nodules, acidic ash flow tuffs, Yr Arddu. P662409.



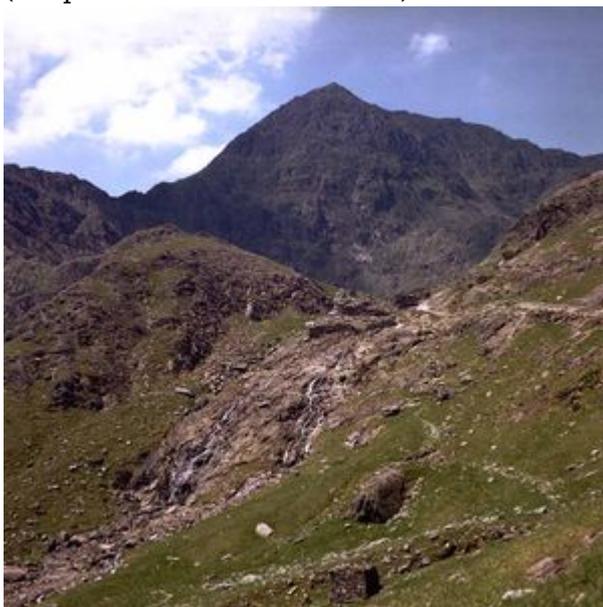
Depositional environment prior to the deposition of the Lower Rhyolitic Tuff (adapted from Howells et al., 1991). P916161.



Outcrop and measured sections of the Lower Rhyolitic Tuff Formation (adapted from Howells et al., 1991). P916162.



Bedded Pyroclastic Formation, a generalised section of the south face of Crib y Ddysgl (adapted from Kokelaar 1992). P916163.



Yr Wyddfa, summit of Snowdon from the Miner's Track below Glaslyn. Acidic ash-flow tuffs of the Lower Rhyolitic Tuff Formation

crop out in the foreground with basaltic volcanoclastic rocks and intrusions of the Bedded Pyroclastic Formation in the cliff face. P213255.



Bedded Pyroclastic Formation, basaltic volcanoclastic sedimentary rocks resting on the reworked top of the Lower Rhyolitic Tuff Formation, Cwm Glas (MFH P662410).



Clogwyn y Person, Upper Rhyolitic Tuff Formation and rhyolite intrusion, overlying Bedded Pyroclastic Formation. P662411.



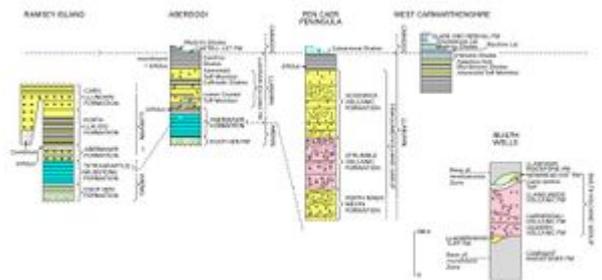
Parys Mountain, Amlwch, Anglesey, the main opencast excavation. Copper, lead and zinc have been worked as well as other rarer metals. There is evidence of Bronze Age mining at this site (MFH P662412).



Yr Eifl, Llŷn, viewed from near Llithfaen to the south-west. On the left is the Caer Gribin granophyre and on the right the Garnfor microgranodiorite intrusions (MFH P662413).



Cliffs south-west of Cemaes Head, Pembrokeshire. Folded and faulted, turbiditic sandstones and siltstones of the Dinas Island Formation (Caradoc). P662414.



Generalised vertical sections of the Ordovician strata of north Pembrokeshire, west Carmarthenshire and Builth Wells (adapted from several sources). P916156.

In early Caradoc times, the south-eastern margin of the Welsh Basin continued to be clearly defined by the Welsh Borderland fault system at the edge of the Midland Platform. Subsequently the platform was progressively transgressed (P916159), and by late Caradoc times it was totally submerged. At the north-west margin of the basin, the Irish Sea Landmass was probably submerged or subdued in relief for most of Caradoc times. The probable absence of Llandeilian strata over most of north-west Wales suggests that the deposition of the Caradoc sequence was preceded by uplift and erosion but, over most of the outcrop, there is little lithostratigraphical evidence in support of this break. The only evidence for a major discordance occurs on Anglesey, where a coarse basal

conglomerate with Monian Supergroup pebbles overlies Precambrian strata and, less graphically, in southern Snowdonia.

Caradoc strata occur within most of the Ordovician outcrops through Wales. In the northern part of the basin, shallow water sands were commonly deposited, whereas in the southern parts, deep water basinal muds persisted, although locally, as in south Cardiganshire, there were incursions of coarse-grained turbidites. In Snowdonia, the strata are the main component of the Ordovician outcrop and the sequence is dominated by volcanic rocks, which reflect an intense, but restricted, period of volcanic activity. The subdivision of the Caradoc into nine substages ([P916227](#)) was established, on the basis of the rich brachiopod and trilobite faunas, in the Welsh Borderland. There have been some tentative correlations between these stages and the graptolite biozones determined locally in the Welsh Basin and together with the shelly fauna of Snowdonia it has been possible to constrain the volcanic stratigraphy, with some confidence, into two stages, Soudleyan and Longvillian.

In southern Snowdonia, on the northern slopes of Cadair Idris ([P662403](#)) and Aran Fawddwy, the Llanvirn basaltic sequence (Llyn y Gafr Volcanic Formation) is overlain by a thick succession of silty mudstone with tuffaceous beds and a few thin sandstones (Ty'r Gawen Mudstone Formation) ([P916155](#)). Parts of the formation are laterally equivalent to two thick volcanic sequences (Pen y Gadair Volcanic Formation; Benglog Formation), which wedge out westwards towards the Llanegryn Fault. East of the fault, the base of the Ty'r Gawen Formation is marked by pyritic mudstone with phosphate nodules and scattered ooids (Fron Newydd Member); west of the fault, it is markedly unconformable. An impersistent ooidal and pisoidal ironstone, generally 1 to 2 m thick but up to 10 m near Cross Foxes, lies close to the base and has been worked for low-grade iron ore in small pits and levels that clearly mark its outcrop. The ironstone is mainly a massive bed of grain-supported chamosite ooids with rare pisoids. A poor graptolite fauna suggests the *Nemagraptus gracilis* Biozone.

On Cadair Idris, the Pen y gadair Volcanic Formation consists predominantly of pillowed, massive and autobrecciated basalt lavas with crystal tuffs and a few acidic ash-flow tuffs. The basalts are spectacularly exposed about the summit of Cadair Idris. The formation indicates a renewal of effusive and explosive basaltic volcanism in southern Snowdonia, and its distribution is similar to that of the Llyn y Gafr Formation. The acidic ash-flow tuffs, some welded, indicate contemporaneous explosive acid volcanism, but its source is no longer discernible. Towards the north, a sequence of pillowed basalts, primary and reworked basaltic tuffs and hyaloclastites (Benglog Volcanic Formation), with intercalations of graptolitic mudstone of *gracilis* or early *multidens* Biozone age, successively oversteps older formations to rest on Arenig rocks near Bala. On the south-east side of the Harlech Dome, there was local contemporaneous emplacement of acid ash-flow tuffs and rhyolites (Craig y Ffynnon Formation) and, slightly later, a restricted accumulation of andesitic lavas, crystal tuffs and breccias with intercalated mudstones (Pistyllion Formation).

The final episode of volcanism of the Aran Volcanic Group was probably the most explosive and widespread. On Cadair Idris, the Craig Cau Formation comprises tuffs, tuffites and volcanoclastic debris flow deposits with interbedded unfossiliferous mudstones, overlain by acidic ash-flow tuffs. The tuffs and tuffites contain a variable proportion of mud components and mudstone clasts. The contorted shape of some of the clasts indicate that they were incorporated while still unlithified, and suggests that the acid pyroclastic debris was erupted through unlithified mud. Emplacement was probably from a number of centres, and intrusion of the late stage Cadair Idris microgranite into one centre remains a possibility. The upper (welded) tuff can be traced eastwards through Aran Fawddwy and northwards to Arenig as the Aran Fawddwy Formation. It is overlain by silty mudstone of possible Costonian-Harnagian age.

The volcanic sequence throughout southern Snowdonia shows no evidence of significant reworking,

suggesting that its eruption and emplacement was largely contained within the marine environment. It is overlain by a thick sequence of mainly thinly bedded turbiditic silty mudstone and siltstone with interbedded laminated dark grey to black mudstone (hemipelagite) (Ceiswyn Formation). The proportion of mudstone increases up-sequence, which probably reflects gradual drowning of the shelf. The graptolite and trilobite faunas indicate that the formation is of early Soudleyan and *multidens* Biozone age. At its top, a thin bed of black, intensely cleaved, pyritic and graptolitic mudstone, the Nod Glas Formation, marks the top of the Caradoc (Onnian Substage). The mudstone is poorly exposed, but its outcrop can be mapped by the feature that it forms, a depression between Towyn and Dinas Mawddwy.

In the vicinity of Bala, the dominantly mudstone strata of the Caradoc pass laterally into a more silty and fine sandy sequence with three prominent, but thin tuff beds — the Cefn Gwyn Tuff, at the base of the Soudleyan Substage, and the Frondderw and Pont y Ceunant tuffs, within the Soudleyan. Also in this direction the lower part of the Nod Glas Formation has been reported to pass laterally into a calcareous and phosphatic facies (Cymerig Limestone Member, Woolstonian Substage), which overlies thin calcareous tuffs (Gelli Grin Calcareous Ashes, Longvillian Substage) ([P916155](#)).

The thick sequence of Caradoc rocks in the Berwyn Hills shows broadly similar sedimentary characters to the sequence farther west. It is dominated by silty mudstone and fine-grained sandstone, with local evidence of a volcanoclastic component, and three prominent tuff horizons — the Cwm Clwyd, Swch Gorge and Pandy Tuff formations. The sequence accumulated in shallow marine to intertidal environments, of generally low energy but with periodic storm events and intermittent local emergence. Faunas are relatively well preserved and provide valuable indices to depth, turbulence and rates of sedimentation. In the Vale of Ffestiniog, between Rhyd and Tremadog, pre-tectonic gravity sliding has disrupted the sequence close to the base of the Caradoc and the lower part of the Ordovician sequence is missing. A sedimentary *mélange*, the Rhyd *Mélange*, oversteps down to Tremadoc strata ([P916154](#)). The *mélange* is most easily recognised where there is a marked lithological contrast between the component clasts and matrix. The scale of the disruption ranges from rafts of Tremadoc and Ffestiniog Flags Formation strata, up to 300 m across, down to grain-to-grain sediment disruption. The top of the deposit grades up into disturbed and folded mudstone, and it is conformably overlain by two volcanoclastic debris-flow deposits, derived from the collapse and subaqueous reworking of associated rhyolite intrusions-extrusions (Moelwyn Volcanic Formation), of probable Costonian age. To the east of Ffestiniog, patches of similar *mélange* deposits have been determined in the poorly exposed ground on the northern edge of the Migneint.

In northern Snowdonia, slumped beds at the top of the Nant Ffrancon Subgroup reflect seismic activity prior to the first of two major cycles of Caradoc volcanism. The products of this volcanism comprise the Llewelyn Volcanic Group and the Snowdon Volcanic Group ([P916154](#)), which dominate both the Caradoc succession and the topography through central and north Snowdonia. The 1st Eruptive Cycle, expressed in the Llewelyn Volcanic Group, is distributed between Conwy in the north, through the Carneddau to the vicinity of Nant Peris in the south. The earliest activity developed from a number of centres, which were broadly contemporaneous. The Conwy Rhyolite Formation comprises intrusive and extrusive rhyolites and acidic ash-flow tuffs about a centre in the vicinity of Conwy Mountain. In the Anafon valley, these acid extrusive volcanic rocks abut and interdigitate with trachyandesite lavas and intrusions of the Foel Fras Volcanic Complex. Farther south, the early phase of the 1st Eruptive cycle comprises extrusive basaltic lavas, the Foel Grach Basalt Formation, and rhyolite lavas and acidic ash-flow tuffs, the Braich tu du Volcanic Formation, exposed high on the flank of Pen yr Ole Wen on the north side of Nant Ffrancon. The sedimentary association throughout this contrasting volcanic sequence is consistently of marine mudstone, and the dearth of volcanoclastic debris suggests the suppression of any significant volcanic edifices.

Along the outcrop, the interdigitations, juxtaposition and thickness of the various components are complex and were commonly influenced by active faults.

A number of subvolcanic intrusions are spatially associated with the extrusive volcanic rocks. These are mainly of intermediate, andesite-dacite composition with fewer rhyolites and microgranites. They occur from Penmaenmawr in the north, to Talgau in the Pass of Llanberis, in the south.

This early phase of intense volcanic activity was followed by a prolonged period of sedimentation which, in the area of the Carneddau, indicated progressive shallowing of the marine environment. Late in the interval, conglomeratic alluvial fan and braid-plain facies developed from a source in the north. Locally, these beds were reddened by oxidation during temporary emergence. It was upon this gentle, southerly dipping surface that the first major expression of acidic ash-flow tuff volcanism in Snowdonia (Capel Curig Volcanic Formation) was emplaced. This volcanism began with the eruption of a major ash flow from a centre that was possibly sited in the vicinity of the north Wales coast. From the relationship of the acidic tuff to its substrate, the ash flow is interpreted as having been transported sub-aerially southwards across the site of the Carneddau to a shoreline in the vicinity of the Ogwen valley; thence, it travelled subaqueously ([P662408](#)). To the north of the Ogwen valley, in the subaerial setting, the base of the ash-flow tuff is generally planar. However, to the south, on Gallt yr Ogorf, where it was deposited in water, the base of the tuff is intruded by 'flames' of sediment up to 25 m high, and in the Capel Curig Anticline, about Llynnau Mymbyr, large bodies of tuff within the underlying strata are detached from the main sheet. These relationships reflect the thixotropic yielding of the water-saturated substrate by the rapid emplacement of the ash-flow tuff sheet; the process was facilitated by fluidisation at the contact between the hot tuff and wet sediment. Farther south, in the Lledr valley, similar pods of tuff that were detached from the flow front are the sole representatives of the tuff sheet. The tuffs are welded in both the subaerial and subaqueous environments. The extremely limited reworking of the top of the tuff indicates rapid subsidence and re-establishment of the marine environment. Subsequent ash-flow volcanism developed from the northern centre, and a centre was initiated simultaneously in the vicinity of the Glyders, which is now marked by rhyolite intrusions that were emplaced during the late stages of the volcanic activity. This centre developed a temporarily subaerial edifice, with repeated emplacement of blocky ashflow and slumped tuffs that incorporate a significant amount of epiclastic debris. Dust-rich eruptions during the later stages resulted in accumulations of accretionary lapilli tuffs, and their distribution in the associated marine sedimentary sequence corroborates the site of the eruption centre.

Following the 1st Eruptive Cycle, there was a prolonged period of sedimentation (Cwm Eigiau Formation) prior to the initiation of the second cycle and the emplacement of the Snowdon Volcanic Group. The distribution of the sedimentary facies indicate that marine conditions prevailed over part of the area, but in the south-west, around Moel Hebog, fluvial and deltaic deposition occurred on a palaeoslope that dipped generally towards the north-east. Cross-bedded sandstones and debris flow deposits, interpreted as alluvial plain and fan deltas, pass north-eastwards into shoreface deposits interleaved with the marine sediments ([P916160](#)). Oxidation of the sediments indicate local emergence and the sediments record the changing position of a shoreline ([P916161](#)). It was on to this surface that the earliest deposits of the second cycle, the Pitts Head Tuff Formation, were emplaced.

The development of the 2nd Eruptive Cycle, represented by the Snowdon Volcanic Group, was influenced by north-east-orientated, basement-controlled fractures, which defined the Snowdon Graben, and a central Beddgelert Fault Zone. The fractures influenced both the volcanic centres and the distribution of the deposits. Broadly contemporaneous eruptions from a centre in the Crafnant country, in north-east Snowdonia, probably developed along an extension of the same lineaments. The earliest eruptions formed two subaerially erupted ashflow tuffs of the Pitts Head Tuff Formation,

which overlies the oxidised alluvial deposits on Moel Hebog. The eruptive centre lay about Llwyd Mawr, where a sequence of compositionally similar tuffs was ponded in a volcanotectonic depression and juxtaposed against Llanvirn mudstone. The lowest outflow tuff can be traced along the west side of the Snowdon massif; it crossed the shoreline into the sea to the north of Cwm Caregog, and continued under water through to the Ogwen Cottage area. Throughout this distance the tuff is essentially complete, with a well defined basal zone that shows a concentration of feldspar crystals, and a massive welded central zone with local rheomorphism, which grades up into a finer grained, nonwelded, locally reworked top. Siliceous nodules are common, generally in patches, although the spectacular examples on Moel Hebog at the base of the central unit, are lithologically controlled. The tuff horizon lies just below the Soudleyan-Longvillian stage boundary, which is the most tightly constrained stage boundary within the Caradoc of central and northern Snowdonia. Thin, fine-grained tuffs at about this level along Y Braich, on the north side of Ogwen valley, and on Curig Hill, east of Capel Curig, may be the distal air fall from this eruption.

Following this early eruption, the north-east-directed palaeoslope was maintained, and the strata deposited in the interval before the next significant eruption thicken in that direction. North of the Pass of Llanberis, these strata comprise a thick succession of coarse- to medium-grained, cross-bedded sandstones with intercalations of siltstone and fine-grained siliceous tuffs that probably represent distal air-fall and water-settled vitric dust. In Cwm Idwal, the narrow quarry excavation south of Ogwen Cottage indicates their past importance as 'honestones'. Late in the interval, basaltic volcanism was extensive, and is indicated by basalt lavas (and intrusions), hyaloclastites and tuffs, which are well developed from Cwm Cneifion to the Pass of Llanberis and farther into Cwm Llan, on the south side of Snowdon, where they are the sole element. The basalts form a coherent geochemical group, distinct from those erupted later in the cycle.

The emplacement of the Lower Rhyolitic Tuff Formation was concentrated about the Snowdon Centre. Magma movement prior to the first eruption domed and disrupted the partly unlithified sediments in an area about the Beddgelert Fracture Zone, and the earliest, acidic ash-flow tuff activity developed at a centre close to Yr Arddu (Yr Arddu Tuffs) ([P662409](#)) and the Nantmor Fracture. The ash-flow tuffs, with a patchy concentration of blocks, accumulated close to their eruptive centre, which was later intruded by a rhyolite. Subsequently, the main caldera-forming activity within the Lower Rhyolitic Tuff Formation ([P916162](#)) developed progressively along the Beddgelert Fracture Zone. Early fissure eruptions, probably along the line of the Gwynant valley, produced welded ash-flow tuffs with large rafts of the the earlier Pitts Head Tuff, south-west of Cwm Tregalan and between Beddgelert and Moel Ddu. To the east of the fracture zone, thick wedges of sedimentary and volcanic breccias, such as those on the south-east side of Llyn Dinas, developed as a result of instability caused by enhanced tectonism in the vicinity of the fracture zone. The activity progressed into the main eruptive phase and the emplacement of more than 500 m of homogeneous, nonwelded acidic ash-flow tuff about the Snowdon massif. The distribution of these tuffs, the associated facies and thickness variations, allowed the caldera structure to be clearly defined. The thickest intracaldera sequence, at Lliwedd, lay close to the eruptive centre and to the north margin of the caldera, along the line of the Llanberis Pass. There the base of the tuffs, marked by a coarse breccia, is exposed in Dinas Mot and Dinas Gromlech. The primary intracaldera tuffs thin south-westwards to Moel Hebog, where they include large rafts of the Pitts Head Tuff, close to the south-western margin of the caldera.

From the north of Llanberis Pass to Cwm Idwal, a nonwelded ash flow tuff outside the caldera margin, the sole primary representative of the caldera-forming activity, is overlain by tuffs and volcanoclastic sediments reworked from the caldera margin. The base of the outflow tuff includes numerous blocks in irregular patches and entrained in layers, and the overlying reworked tuffs display a progressive increase in the sedimentary component. A thick rhyolite near the top of the

sequence in the core of the syncline at Cwm Idwal forms a prominent feature along the east limb to Esgair Felen, high above Llanberis Pass; the fine-grained, columnar jointed, devitrified rhyolite is autobrecciated at its top contact, and is overlain by cross-bedded coarse-grained sandstones crowded with rhyolitic debris.

To the east, the outflow tuff, a single primary, nonwelded, ash-flow tuff, about 40 m thick, was transported into deeper water, and forms a persistent outcrop from Betws y Coed and Capel Curig in the south to Conwy in the north. Subsequently the Crafnant Centre (Crafnant Volcanic Group) developed in north-east Snowdonia in a basin dominated by mud deposition. The influence of the Snowdon Centre was minimal. The main activity was of acidic ashflow tuff volcanism, with much slumping and soft-sediment disruption, but to the north, at Tal y Fan, a contemporaneous basic centre is marked by a restricted sequence of basaltic lavas and tuffs with a coeval dolerite sill (Tal y Fan Volcanic Formation). At the Snowdon Centre, the form of the caldera established from the distribution of the tuff facies is corroborated by the distribution of five geochemically distinct groups of rhyolites, which were successively emplaced along specific annular and linear patterns within the structure. The earliest rhyolites were related to a resurgent phase within the caldera, which initiated a period of shallow marine reworking of the intracaldera tuffs, prior to an episode of basaltic volcanic activity (Bedded Pyroclastic Formation) ([P916163](#)). In Cwm Glas, rhyolitic pebble and cobble conglomerates that lie on the reworked top of the intracaldera tuffs are overlain by a rhyolite lava, which was itself eroded into small stacks. The contemporaneous emplacement of a large rhyolite intrusion, exposed in the face of Cyrn Las, deformed the intracaldera tuffs into a well-defined syncline.

The Bedded Pyroclastic Formation forms extensive outcrops about the Snowdon massif and in the cores of the Cwm Idwal, Moel Hebog and Dolwyddelan synclines. Its base is variably conformable to unconformable on the Lower Rhyolitic Tuff Formation. It is dominated by basaltic volcanoclastic sedimentary rocks, with high level intrusive and extrusive basalts, hyaloclastites and basic tuffites. The formation is well exposed in the outcrops between Cwm Glas and the north-east face of Snowdon ([P213255](#)); ([P662410](#)). The succession records the complex interplay between uplift, subsidence, volcanism and sedimentation in a shallow- marine environment, and developed from the shoreline reworking of small Strombolian-type island volcanoes. Shoreline cliffs formed and debris was reworked into offshore fan deltas and distal turbidite aprons.

At Cwm Idwal, in the core of the syncline, a sequence of cross-laminated basaltic tuffites with ripple-marked bedding planes and a late Longvillian fauna overlie the acidic debris flow tuffites at the top of the Lower Rhyolitic Tuff Formation. The overlying pillowed basalt and basaltic breccias, which form the cliffs about Twll Du, are most easily examined in the blocks within the landslip in the slope below. The syncline at Moel yr Ogof, south-west of Snowdon, also has pillowed basalts, pillow breccias and hyaloclastites in the core, which are overlain by bedded basaltic tuffites with two relatively massive basalt flows. At Dolwyddelan, the sequence, predominantly of basaltic tuffites with volcanoclastic turbiditic sandstones and siltstones, thins to the south across the axis of the syncline, reflecting its accumulation in deeper water at some distance from the eruptive centre. The final expression of volcanism at the Snowdon Centre was of acidic activity (Upper Rhyolitic Tuff Formation), which is represented in restricted outcrops high on Crib y Ddysgl ridge, in small synclinal outliers on the ridge east of Lliwedd and in the Dolwyddelan Syncline. The most spectacular outcrop is at Clogwyn y Person ([P662411](#)) where a thick, acidic ash-flow tuff in the main cliff oversteps bedded acidic tuffs and tuffaceous siltstones to rest directly on the basaltic volcanoclastic sequence. Locally there is evidence for emergence and littoral erosion with basal unconformities, intrusion of rhyolites into wet sediment and dykes feeding rhyolite domes. At the base of the sequence, rounded rhyolite pebbles lie on a slightly undulose unconformity and indicate local emergence and littoral erosion. Along Crib Goch, an intrusive rhyolite, of probably similar age,

forms one of the most spectacular outcrops in Wales.

In eastern Snowdonia, at Dolwyddelan, most of the sequence consists of poorly bedded, heterogeneous and ill sorted mixtures of pyroclastic and epiclastic debris. Similarly, at the Crafnant Centre, the last major acidic event was the emplacement of a massive tuff, with little evidence of internal sorting or bedding, as exposed in the high scarps of the Gwydir Forest, west of Llanrwst. It is a heterogeneous mixture of acidic shards, pumice clasts and feldspar crystals in a dominantly mudstone matrix. The mixture is considered to have resulted from an explosive eruption through unlithified mud. However, near Dolgarrog, a final expression of basic volcanism resulted in a restricted accumulation of basaltic lava, pillowed breccia and hyaloclastite associated with black graptolitic mudstone (Dolgarrog Volcanic Formation) ([P916154](#)). In central and south-west Snowdonia the strata overlying the volcanic sequence have been removed by erosion, but in the core of the Dolwyddelan syncline black pyritic and graptolitic mudstone overlies the volcanic sequence. Similar mudstone occurs throughout north-east Snowdonia (Llanrhychwyn Slates, Cadnant Shales), and the absence of any significant reworking of the underlying volcanic sequence indicates both its containment in a marine environment and rapid subsidence. In the vicinity of the small basic centre at Dolgarrog, a stratified pyrite deposit (Cae Coch) occurs at the basal contact of the black mudstone; the ore deposit formed by hydrothermal exhalation on to the sea floor.

Graptolites in the black mudstone indicate a *D. clingani* Biozone age and possibly part of the underlying *D. multidentis* Biozone. The accumulation of black mud, which reflects an euxinic environment, was widespread throughout north Wales at this time (Nod Glas Formation). The mudstone is thickest, up to 450 m, in north-east Snowdonia where there is no evidence of significant reworking in spite of the close association with the thick volcanic sequences. The relationships suggest extensive and rapid postvolcanic subsidence within the Snowdon graben.

During the evolution of volcanism at the Snowdon centre both acidic and basic magma bodies were emplaced within the accumulated sequence, but with little surface expression. The intrusions can be broadly subdivided into acidic and basic with only a single intermediate, andesitic intrusion (Llyn Teyrn) exposed. The major acidic plutons include the Tan y Grisiau Granite and the Mynydd Mawr and Ogwen microgranites. The basic intrusions are of dolerite and basalt. The dolerites are a persistent feature of the Caradoc outcrop, but only in association with the extrusive volcanic sequence within the Snowdon Graben.

Emplacement of many of the intrusions stimulated hydrothermal solutions, which pervaded the centre and profoundly altered the sequence in places. The hydrothermal alteration included all mineralogical, chemical and textural changes in rocks resulting from interaction with hot water of varying chemistry. The processes were complex, in many instances changing the bulk chemistry of the volcanic rocks, and elsewhere Cu/Pb/Zn mineralisation was a distinctive feature. Devitrification of the volcanic glass, the dominant element of both the acid and basic volcanic rocks, was intense. Volcanogenic control of Cu, Pb and Zn sulphide deposition is most evident about the Snowdon centre ([P916164](#)). The extensive small workings for metalliferous sulphides, evident from both excavations and waste tips that occur across the Snowdon massif, date largely from the 19th century. The sulphides occur both in thin veins and in disseminations about lithological contacts. Only in a few cases, as at Britannia Mine in Cwm Glaslyn, have individual veins been worked for more than 200 m along strike. The main metallic minerals, pyrite, chalcopyrite, sphalerite and galena, are associated with calcite and quartz. Most are fracture-fill veins, probably the result of hydraulic fracturing, with a variety of ore textures and, in places, clasts of wall rock. The distribution pattern of old workings indicates a marked concentration along the Beddgelert Fault Zone and particularly within the basic lithologies of the Bedded Pyroclastic Formation, close to its basal contact with the Lower Rhyolitic Tuff Formation. Because of the close relationship between mineralisation and the caldera structure, it is suggested that the metals were derived by leaching of the volcanic rocks by a convecting

hydrothermal cell that incorporated meteoric (sea) water and was driven by a residual, subcaldera, magmatic heat source.

On Anglesey, basal Caradoc breccias overstep on to the Monian Supergroup at Carmel Head, and in the south coarse sandstones with interbedded mudstones transgress older Ordovician rocks; the strata have yielded Costonian brachiopod faunas and *gracilis* Biozone graptolites. At Parys Mountain, a complex association of acidic ash-flow tuff, rhyolite and breccia with some carbonated basalt, probably of Caradoc age, is juxtaposed against mudstone. The volcanic rocks are host to a massive sulphide deposit, which has been worked possibly since the Bronze Age ([P662412](#)) and is still a subject of intense exploration. Elsewhere, shales with a *clingani* Biozone fauna, which overlie basal Caradoc sandstones and siltstones, reflect progressive deepening during continued transgression.

On Llŷn, Caradoc strata overlie Arenig to lower Llanvirn strata. Near Pwllheli, acidic ashflow tuffs have been correlated with the Pitts Head Tuff Formation, but the main volcanic sequence of trachyandesite and acidic ash-flow tuffs (Upper Lodge Volcanic Formation) was derived from a local centre ([P916154](#)). The Llanbedrog Volcanic Group comprises similar lithologies, but is associated with reworked, locally derived volcanoclastic conglomerate, sandstone and siltstone. Coeval intrusions form a prominent feature ([P662413](#)), as in the stock-like granodiorite intrusions at Bwlch Mawr and Caer Gribbin on the north coast and the gabbroic dolerite sill at Mynydd Penarfynydd. The sequence is overlain by black mudstone of the Nod Glas Formation.

In south-west Wales, extensive dark grey, silty, graptolitic, pyritous mudstone is Caradoc in age, and indicates that relatively deep water and low energy conditions had persisted since late Arenig times. However, in north Pembrokeshire and south Cardiganshire, the sedimentation was influenced by movement on the Newport Sands Fault. South of the fault, sedimentation was mainly of mud, which now comprises the Pen yr Aber and Cwm yr Eglwys mudstone formations. North of the fault, the upper part of the Cwm yr Eglwys Mudstone Formation interdigitates with and is overlain by turbiditic sandstone, mudstone, slumped beds and conglomerate of the Dinas Island Formation ([P662414](#)), which is well exposed in the cliff sections between Dinas Head and Poppit Sands. In Carmarthenshire, the deposition of mud graded into more lime-rich beds (Mydrim Limestone) at about the *gracilis-multidens* Biozone boundary ([P916156](#)). At Llandeilo, the intertidal to subtidal siltstone and mudstone persisted into early Caradoc times, and grade up into deep-water black shales (Dicranograptus Shales). Along the Tywi Anticline, faulted inliers of blue-grey and black mudstone (St Cynllo's Church Formation) with a few thin sandstone and bentonite bands are of *multidens* and *clingani* Biozone age.

In the northern part of the Builth Wells inlier, coarse basaltic breccias of the Trelowgoed Volcanic Formation are of probable Caradoc age, and are possible correlatives of agglomeratic tuffs, rhyolitic breccias and spilitic basalts interbedded with mudstone and siltstone of *gracilis* Biozone age, near Llanwrtyd. Localised slump deposits may indicate contemporaneous fault activity at the basin margin. In the inlier and along the Tywi Anticline, impersistent sheets of dolerite intrude Caradoc mudstone, and the irregular peperitic contacts indicate that the sediment was unlithified at the time of emplacement.

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