Geology of the Llanidloes district

British Geological Survey Sheet 164

These pages form a category providing a summary of the geology of the Llanidloes district (British Geological Survey Sheet 164).

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This Sheet Explanation was written and compiled by D Wilson, based on contributions by co-surveyors. The district was largely surveyed during 2006 by J A Aspden, C E Burt, J R Davies, M Hall, N S Jones, A B Leslie, T H Sheppard, P R Wilby and D Wilson as part of the Geocymru Project, supported by a grant from the Welsh Assembly Government. The southern and eastern margins were mostly surveyed by R Cave, J R Davies, C J N Fletcher, A J Reedman and R A Waters during the mapping of the adjacent Montgomery and Rhayader districts between 1986 and 1989; areas along the western margin were surveyed by R Cave between 1965 and 1972 as overlap from the Aberystwyth district. Biostratigraphical determinations of Silurian rocks were provided by A Snelling and J A Zalasiewicz (Leicester University). P A J Lusty contributed to the section on mineral resources. The British Geological Survey gratefully acknowledges the co-operation of landowners and farmers in allowing access to their lands during the geological survey.

Notes

The word ‘district’ refers to the area of the geological 1:50 000 Series Sheet 164 (Llanidloes). National Grid References (NGR) are given in square brackets. The district lies within NGR 100 km squares SN and SO; grid references are prefixed by these letters. Symbols in round brackets after lithostratigraphical names are the same as those used on the geological map.

The grid, where it is used on figures, is the National Grid taken from Ordnance Survey mapping.

Geological succession

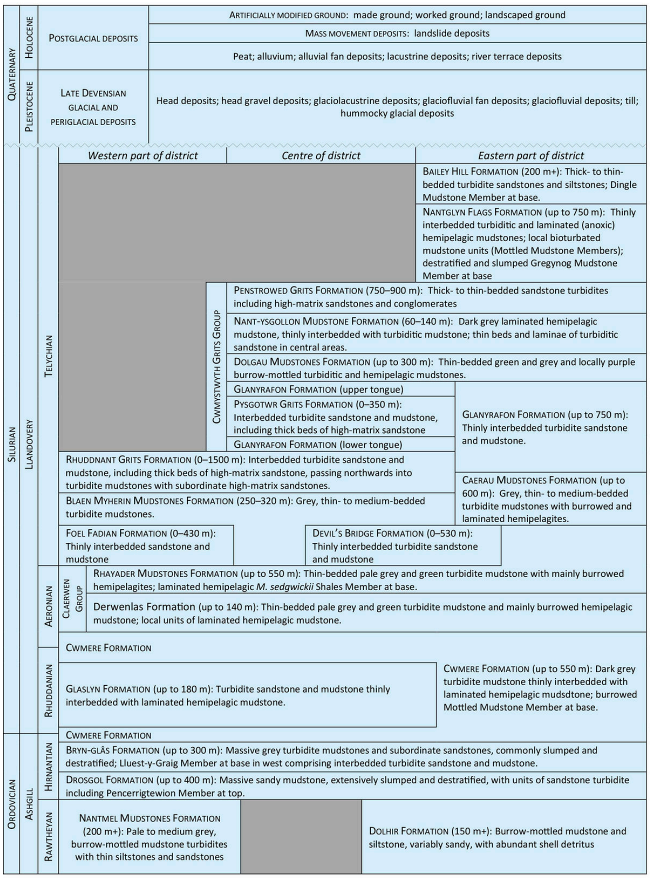

Figure P934394 Summary of the geological succession in the district.

Introduction

This Sheet Explanation provides a summary of the geology of the district covered by Geological 1:50 000 Series Map Sheet 164 (Llanidloes), published in 2010 as a Bedrock and Superficial Deposits edition. The district mostly lies within the county of Powys, but includes small parts of Ceredigion in the extreme west and south-west. Much of the western part of the district is occupied by the deeply dissected uplands of the Cambrian Mountains, a designated Area of Outstanding Natural Beauty. In this area the land rises to 740 m on the flanks of Plynlimon (Pumlumon Fawr), the highest summit in the range. It falls away towards the eastern part of the district into rolling countryside that includes the important catchment of the River Severn (Afon Hafren) and its tributaries, the largest of which are the rivers Carno, Trannon, Cerist, Clywedog and Dulas. A major reservoir (Llyn Clywedog) occupies the upper reaches of the Clywedog valley, its purpose being to regulate river discharge and groundwater levels within the catchment. The south-western part of the district is drained by the River Wye (Afon Gwy) and its tributaries, that flow south-eastwards via Llangurig. The sources of both the Severn and Wye are situated on the eastern flanks of Plynlimon within the western part of the district.

The town of Llanidloes is the main centre of population, with smaller settlements at Llangurig, Carno, Trefeglwys, Caersws and Staylittle; the Newtown conurbation impinges on the eastern part of the district. Much of the district is given over to beef and dairy farming, although sheep are reared in the remote upland areas in the west and extensive forestry plantations have been developed in places. The Ordovician and Silurian rocks of the district have been exploited locally, in the past, as a source of building material and, recently, commercial quantities of sandstone aggregate have been excavated at Penstrowed Quarry [SO 0680 9100]. The district includes part of the Central Wales Mining Field from which substantial volumes of lead and zinc ore were extracted during the 19th and early 20th centuries. A number of former mine sites are still visible, notably along the Van, Nant-y-ricket, Dylife, Dyfngwm and Llanerchyraur lodes (Jones, 1922[1]; IGS, 1974), and the historic Bryntail Mine, below the Clywedog Dam has been restored as a site of industrial archaeological interest.

The district is underlain by a succession of Late Ordovician (Ashgill) to Silurian sedimentary rocks, over 5 km thick, deposited between 450 and 420 million years ago in the Early Palaeozoic Welsh Basin (**Figure P930911**). The basin developed on a fragment of the ancient supercontinent of Gondwana, known as Eastern Avalonia (e.g. Pickering et al., 1988[2]), that drifted northwards to collide with the continents of Baltica and Laurentia during the Late Ordovician and Silurian (Soper and Hutton, 1984[3]; Soper and Woodcock, 1990[4]; Woodcock and Strachan, 2000[5]). To the east and the south of the basin lay the Midland Platform, a relatively stable shallow marine shelf that was subject to periodic emergence. The basinal sediments are predominantly deep marine turbiditic facies that were introduced into the district by density currents from southerly, south-easterly and north-westerly quadrants. Coeval shallower-water 'shelfal' sediments were deposited north and east of the district, and locally impinge on its northern margins. Thickness variations within the major sedimentary units suggest that, at times, syndepositional fault movements were an important control on their distribution. During late Silurian (Ludlow) times, shallowing of the basin occurred, and sandstones, variably interpreted as a turbiditic (Cave and Hains, 2001[6]) or storm-generated facies (Tyler and Woodcock, 1987[7]), were laid down over the eastern part of the district and adjacent areas. The shallowing was a result of tectonic reconfiguration of the basin, a precursor to the late Caledonian (Acadian) Orogeny that affected the region during the late Early Devonian, around 400 million years ago.

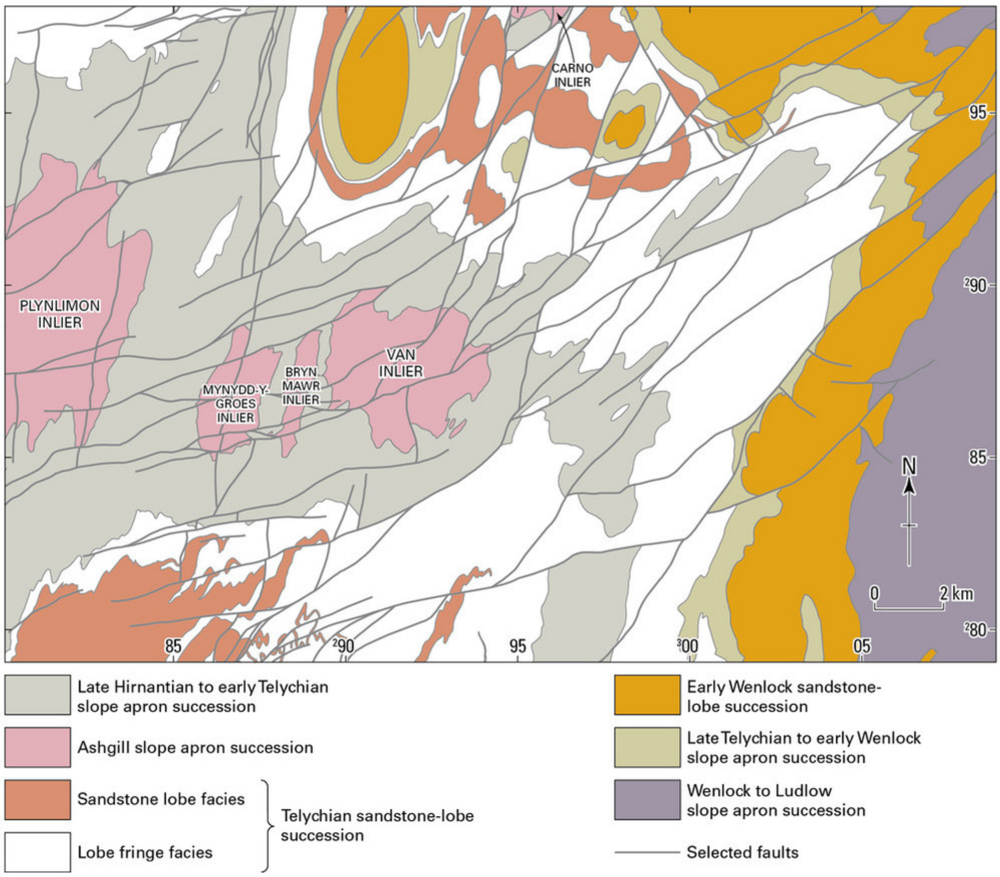

Figure P930911 Simplified bedrock geology of the district.

During the orogeny the basinal sediments were folded on a variety of scales, faulted and developed a regional cleavage. Many of the pre-existing syndepositional fault structures were reactivated at this time; they probably underwent further displacements during the subsequent Variscan and Alpine orogenic cycles. The array of east-north-easterly trending mineralised faults, along which many of the lead–zinc mines occur, appear to have been initiated during the early Carboniferous (Fletcher et al., 1993[8]).

The broad drainage pattern of the region was probably established during the early to mid Cenozoic (Brown, 1960[9]; Jones, 1951[10], 1955[11]), and modified during the Quaternary, when the British Isles were subject to a series of major glaciations. Quaternary superficial (drift) deposits mantle the solid formations over wide areas. They comprise Pleistocene sediments, deposited during the last major glaciation, and as periglacial materials that formed in the cold period immediately following ice retreat, and more recent alluvial deposits and peat. Any evidence of earlier ice advances is lacking, having been removed or obscured by the last glaciation (Late Devensian) around 20 000 years ago. At this time, ice sourced from the Welsh uplands covered the area, moulding the landscape to its present form. As the ice began to melt around 14 500 years ago, periglacial processes and meltwater reworked the previously deposited materials into a distinctive suite of landforms and deposits. Periglacial modification, under intense freeze-thaw conditions, continued until about 12 000 years ago when the climate began to ameliorate and peat started to form in upland areas. The glacial landforms were further modified during this period (the Holocene) as the present-day drainage pattern was superimposed on the remnants of the Tertiary system.

The first systematic investigations of the district by the Geological Survey were undertaken in the 19th Century; they were published as Old Series One-inch Sheets 56, 57, 59 and 60 Between 1848 and 1850. Since that date relatively little geological work has been undertaken. The structure and stratigraphy of the Tarannon area in the north of the district was broadly established by Wood (1906)[12], and that of the area around Llanidloes by W D V Jones (1944)[13]. The sedimentology of the late Silurian strata has been investigated by Dimberline (1987)[14], Dimberline and Woodcock (1987)[14], Smith (1987a)[15] and Tyler and Woodcock (1987)[7]. Detailed accounts of the geology of adjoining districts are given in Cave and Hains (1986[16], 2001[6]), and Davies et al. (1997)[17], and regional syntheses of the sedimentology and structure have been provided by Cherns et al. (2006)[18], Smith (1987b[19], 2004 [20]), (1990a, b, 2000), and Woodcock *et al*. (1988[21]; 1996[22]; 2000[5]).

The first detailed account of the lead mining and mineralisation within the district was given by O T Jones (1922)[1], and subsequent studies include those of Bick (1975[23]; 1977[24]) and Ball and Nutt (1976)[25]; recent work includes that of James (2006)[26]. The Quaternary deposits of the district have not been studied in detail, but the Pleistocene evolution of mid-Wales has been described in several regional syntheses (Bowen, 1973[27], 1974[28], 1999[29]; Lewis and Richards, 2005[30]), and a number of studies have concentrated on the geology, hydrology and geochemistry of rivers within the Severn catchment (Jones et al., 2006[31]; Leeks et al., 1988[32]; Neal et al., 1986[33]; 1990[34]; 1997[35]; Newson, 1976[36]).

Bedrock facies and sedimentation

The majority of the Ordovician and Silurian rocks of the district are re-sedimented, having been deposited by a range of mass-flow processes, resulting from submarine slope failure and avalanching along the margins of the Welsh Basin (Davies et al. 1997[17]). They include massive, dewatered units in which fluid escape and liquefaction has destroyed any original sedimentary structure, and slumps in which the original bedding fabric is highly deformed but still visible. Such units, collectively termed **'disturbed beds'**, are often tens of metres thick and have undergone in situ disruption or moved in a relatively intact manner for variable distances downslope. They are commonly interbedded with **debrites**, comprising massive, pebbly mudstones, conglomerates and matrix-supported sandstones, locally several metres thick, that are regarded as the products of fluid, but relatively cohesive (i.e. non-turbulent), debris-flows (Lowe, 1982[37]; Pickering et al., 1986[38]). Disturbed beds and debrites are both major components of the upper part of the Ordovician succession of the Welsh Basin, and occur at intervals within Silurian strata. However, large parts of the Silurian succession are composed of thinner and more regularly bedded mudstones and sandstones which record deposition from successive sediment-laden density flows that carried material, often for considerable distances, into the basin. The flows comprised turbulent mixtures of sediment and water, and deposited their sediment load as they decelerated and fanned out across the floor of the basin; thus, the coarser material (pebbles and sand) was deposited first followed, at a distance, by the finer (silt and mud). Each of these 'classic' **turbidite** units (Bouma, 1962[39]) exhibits a characteristic fining-upward sequence of sand into mud with a range of internal sedimentary structures indicative of a progressively waning flow velocity. They are commonly stacked in repetitive successions, hundreds of metres thick. Although individual flows may have been deposited in a matter of hours or days, successive flows may be separated by intervals ranging from months to tens or even hundreds of years. Many variations of the model Bouma turbidite are represented within the Welsh Basin succession (summarised by Davies *et al*., 1997[17]), including both coarse- and fine-grained turbidites that were emplaced by flows of a very different nature (Lowe, 1982[37]; Stow and Piper, 1984[40]).

Late Ordovician and Silurian chronostratigraphy and UK graptolite biozones (after Zalasiewicz et al., 2009[41]). * included together in the *turriculatus* Biozone (sensu lato) of earlier literature (see Davies et al., 1997[17]; 2013[42]).

Period	Global Series	British Regional Stages	British graptolite biozones/subzones	
Silurian	Pridoli			
	Ludlow	Ludfordian	*No younger biozones in UK*	
			Bohemograptus proliferation'	
			leintwardinensis	
		Gorstian	*incipiens*	
			scanicus	
			nilssoni	
	Wenlock	Homerian	*ludensis*	
			nassa	
			lundgreni	
		Sheinwoodian	*rigidus*	
			dubius	
			riccartonensis	
			firmus	
			murchisoni	
			centrifugus	
	Llandovery	Telychian	*insectus*	
			lapworthi	
			spiralis	
			crenulata	
			griestoniensis	
			sartorius (formerly included in the *crispus* Biozone)	
			crispus	*loydelli*
				galaensis
			*turriculatus**	*carnicus*
				proteus
				johnsonae
				utilis
			guerichi *	*renaudi*
				gemmatus
				runcinatus

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<tr><td rowspan="10"></td><td rowspan="10"></td><td colspan="2" rowspan="6">Aeronian</td><td colspan="2">halli</td></tr>
<tr><td colspan="2">sedgwickii</td></tr>
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<tr><td colspan="2">leptotheca</td></tr>
<tr><td colspan="2">magnus</td></tr>
<tr><td colspan="2">triangulatus</td></tr>
<tr><td colspan="2" rowspan="4">Rhuddanian</td><td colspan="2">cyphus</td></tr>
<tr><td colspan="2">acinaces</td></tr>
<tr><td colspan="2">atavus</td></tr>
<tr><td colspan="2">ascensus-acuminatus</td></tr>
<tr><td rowspan="4">Ordovician (part)</td><td rowspan="2">Hirnantian</td><td rowspan="4">Ashgill (part)</td><td rowspan="2">Hirnantian</td><td colspan="2">persculptus</td></tr>
<tr><td colspan="2">extraordinarius</td></tr>
<tr><td rowspan="2">Katian (part)</td><td rowspan="2">Rawtheyan</td><td rowspan="2">anceps</td><td>pacificus</td></tr>
<tr><td>complexus</td></tr>
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At the same time as the turbidites, debrites and disturbed beds were accumulating on the floor of the basin a constant fall-out of terrigenous sediment from suspension was taking place through the water column. These fine-grained **hemipelagic** mudstones commonly cap individual turbidite beds, and are interbedded with the various mass-flow units. Unlike the resedimented deposits, the hemipelagic material records more closely the environmental conditions that prevailed in the bottom waters of the basin at the time of deposition. Two distinct types of hemipelagite are present within the Welsh Basin. The first is a generally homogenous, pale greenish grey mudstone with darker burrow mottles that record deposition beneath oxygenated (**oxic**) bottom waters, when benthonic (bottom-dwelling) organisms were able to colonise the sediment successfully (**Plate P775110**). The second type is a dark grey, very thinly laminated, pyritic and graptolitic mudstone that lacks any evidence of burrowing, having been deposited under oxygen-depleted (**anoxic**) bottom conditions. The distribution of oxic and anoxic hemipelagite within the succession is one of the criteria by which the formational subdivision of strata in the Welsh Basin is achieved. Considerable thicknesses of strata contain one or the other type of mudstone, suggesting that either oxic or anoxic conditions were sustained across the basin floor for prolonged periods of time; at other times such periods were relatively brief, as indicated by rapid alternations of oxic and anoxic hemipelagic mudstone within the succession. The preservation of the fossilised remains of **graptolites** within the anoxic hemipelagite (**Plate P775109**) is critical in correlating the geological succession, and establishing the history of deposition within the Welsh Basin. The rapid evolutionary change of these planktonic colonial organisms during the Ordovician and Silurian allows the rocks in which they occur to be accurately dated, according to the established succession of UK graptolite biozones (see table; Zalasiewicz et al., 2009[41]).

Plate P775109 Mottled Mudstone Member (late Hirnantian) of the Cwmere Formation, Hafren Forest [SN 8416 8992]. Persculptus Biozone graptolites from the '*persculptus* Band'.

Plate P775110 Chondrites burrow-mottling in Mottled Mudstone Member above the '*persculptus* Band'; locality as Plate P775109.

The effects of global (eustatic) sea-level fluctuation competed with tectonism in controlling the type and distribution of sedimentary facies within the Welsh Basin during the Ordovician and Silurian. Two distinct types of turbidite system occur within the basin (Davies et al., 1997). Slope-apron systems, mostly of mudstone, characterise the Ashgill (Ordovician) to early Telychian (Silurian) basinal successions, when eustacy was the dominant control. In contrast, mid to late Telychian and early Wenlock sedimentation was strongly influenced by tectonism that resulted from plate collision, when voluminous amounts of sand were deposited in the basin as a series of major turbidite lobe systems. Palaeocurrent data, together with geochemical and heavy mineral studies, indicate that the sediment supplied to these different systems was also of different provenance (Ball et al., 1992[43]; Morton et al., 1992[44]). Slope-apron systems are generally composed of material derived from the east, whereas the sandstone-lobe turbidite systems contain material derived from southerly sources.

The slope-apron facies mainly comprise wedge-shaped accumulations of turbiditic and hemipelagic mudstone, ranging from tens to hundreds of metres in thickness, which typically thin towards the centre of the basin. In general, the distribution of anoxic hemipelagite within these facies closely correlates with periods of global sea-level high-stand (Johnson et al., 1991[45]; Johnson et al., 1998[46]; Davies et al. 2016[47]), when marine transgression resulted in high phytoplankton productivity and an outflow of warm surface waters from expanded shelf areas. Oxidation of the organic material, and the creation of a thermally stratified water column which inhibited the transfer of oxygen from surface waters, led to oxygen-depleted bottom conditions that were unfavourable for burrowing organisms (Curtis, 1980[48]; Leggett, 1980[49]). During periods of regression, the effects of thermal stratification were reduced and bottom waters were replenished with oxygen from surface levels, allowing burrowing animals to colonise the sediment. A contemporaneous increase of silt content within the turbidite mudstones reflects rejuvenation of the hinterland and basinward migration of facies. Each major anoxic/oxic couplet therefore represents a transgressive/regressive sequence, forming a slope-apron system which, in adjacent shelf areas, equates with a coeval sequence bounded by major discontinuities (Davies et al., 1997; Davies et al. 2016).

The introduction of large-scale, sand-dominated turbidite systems to the Welsh Basin during the Telychian and early Wenlock effectively masked the effects of a widespread eustatic transgression. The tectonic controls on the geometry of these turbidite lobe systems has been previously documented (Davies et al., 1997; James and James, 1969[50]; Smith, 1987a[15], 2004[20]; Wilson et al., 1992[51]). Major syndepositional faults were important in confining the path on successive turbidite flows (**Figure P930912**), and the eastward-migrating focus of deposition thoughout the late Llandovery and Wenlock reflects the successive eastward reactivation of such structures (Davies et al., 1997). The reasons for this are unclear, but may be related to the nature of plate collision and lithospheric stretching as Avalonia was progressively subducted beneath Laurentia (King, 1994[52]; Woodcock and Strachan, 2000[5]).

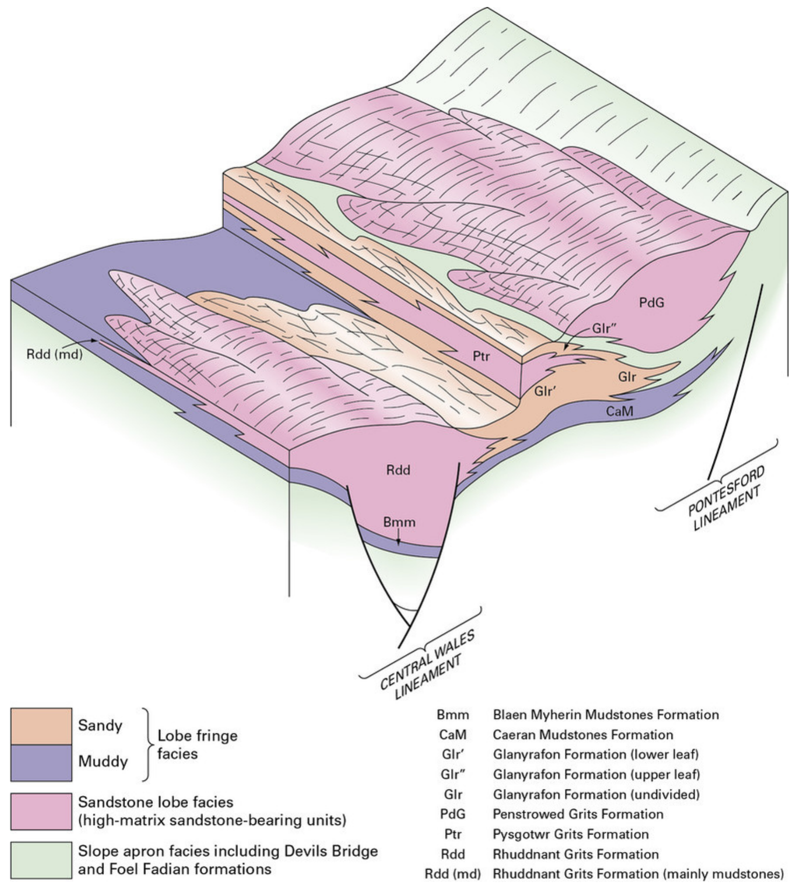

Figure P930912 Depositional model for the southerly derived sandstone lobe systems (after Davies et al. 2006).

Abbreviations: BMM Blaen Myherin Mudstones Formation; CaM Caerau Mudstones Formation; Rdd Rhuddnant Grits Formation; Rdd (md) Rhuddnant Grits Formation (mainly mudstones); Glr Glanyrafon Formation (undivided); Glr` Glanyrafon formation (lower tongue); Glr`` Glanyrafon Formation (upper tongue); Ptr Pysgotwr Grits Formation; PdG Penstrowed Grits Formation.

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Geological description

Ordovician

Ashgill slope-apron succession

The Ordovician rocks of the Llanidloes district are entirely of Ashgill age, and crop out within a series of named inliers in the central, western and northern parts of the district (**Figure P930911**). The inliers form a series of second-order periclinal folds ('domes') within the larger Teifi Anticlinorium and Central Wales Syncline (Jones, 1912[1]), two of the dominant structural features of mid Wales. The oldest Ashgill strata are a succession of predominantly turbiditic slope-apron sediments at least 200 m thick, represented by the **Nant-y-Môch Formation (NF)** and **Dolhir Formation (Dolh)**. The Nant-y-Môch Formation is composed of thinly interbedded bioturbated mudstone, siltstone and sandstone, with units of hemipelagic mudstone, exposed within the Plynlimon Inlier in the westernmost part of the district. The corresponding Dolhir Formation, which crops out within the Carno Inlier in the north, is a more proximal slope facies comprising sandy, burrow-mottled mudstones with locally abundant shelly detritus. Although the boundary between the two formations is thought to be transitional, it is obscured by later strata and its nature cannot be determined with certainty.

For the succeeding stratigraphy, the term 'Yr Allt Formation', widely used on BGS maps throughout central Wales, has been abandoned and the equivalent rocks included in the Drosgol and Brynglas formations (see Davies et al., 2009[2]; Cave and Hains, 1986[3]). The Nant-y-Môch and Dolhir formations are both succeeded by the **Drosgol Formation (DF)**, a thick unit (up to 450 m) of slumped and destratified mudstone and sandstone ('disturbed beds'), generated by multiple slope failures due to the rapid build-up and concomitant oversteepening of a prograding sediment pile. The high rates of sedimentation that accompanied slope progradation were a result of glacioeustatic regression during the late Ashgill Hirnantian stage (Brenchley et al., 2006[4]; Davies et al., 1997[5]). The uppermost part of the Drosgol Formation is represented by the **Pencerrigtewion Member (PtM)**, a series of amalgamated submarine channel-fill deposits and turbidite lobes (Cave and Hains, 1986; James, 1983[6]), comprising up to 180 m of thick-bedded, medium- to coarse-grained, locally conglomeratic sandstone, massive high-matrix sandstone and subordinate mudstone with much evidence of slumping and dewatering. The Pencerrigtewion Member crops out mainly in the Plynlimon and Van inliers, and represents the maximum glacial lowstand when the shelf and slope were effectively bypassed, and coarse sediment was delivered directly to the basin floor (Davies et al., 2009[2]).

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Late Ordovician and Silurian

Late Hirnantian to early Telychian slope-apron succession

The marked, rapid rise in sea level that followed the Late Ordovician glacial maximum is recognised across the Welsh Basin. It began during the late Hirnantian and continued into the Silurian, leading to the widespread re-establishment of mudstone-dominated slope-apron facies. The onset of this Hirnantian postglacial deepening is recorded by the **Bryn-glâs Formation (BGF)**, a mudstone succession up to 300 m thick that sharply overlies the Pencerrigtewion Member and is unfossiliferous and commonly thinly laminated, but contains units of slumped mudstone (Cave and Hains, 1986[1]; Davies et al., 2009[2]). Locally, in the westernmost inliers, the Pencerrigtewion Member is overlain by the **Lluest-y-Graig Member (LyG),** a sequence of thinly interbedded turbiditic mudstone and sandstone up to 50 m thick, which represents a basal division of the Bryn-glâs Formation.

The Bryn-glâs Formation is succeeded by the late Hirnantian to Aeronian **Cwmere Formation (CeF)**, which crops out in a complex pattern of folds around the flanks of the Ordovician inliers. It consists of 220 m to 550 m principally of thinly interbedded turbiditic and anoxic hemipelagic mudstones, generally in units about 5 cm thick, with thin beds and laminae of turbiditic siltstone and sandstone at intervals throughout. At its base is the **Mottled Mudstone Member (MMb)**, comprising up to 25 m of pale grey burrow-mottled mudstone (**Plate P775110**) that, in its lowest part, includes units of laminated hemipelagite containing latest Hirnantian *persculptus* Biozone graptolites (**Plate P775109**). The Mottled Mudstone Member sharply overlies the Bryn-glâs Formation and records the subsequent, postglacial recolonisation of the basin prior to the creation of a deep thermally stratified water column and the widespread deposition of the anoxic facies (Davies et al., 2009).

In the west of the district, around the Bryn Mawr, Mynydd-y-groes and Plynlimon inliers, the Cwmere Formation is largely replaced by the **Glaslyn Formation (Gly)**, a succession of abundant, thin, parallel- and cross-laminated turbiditic sandstone arranged in characteristic Bouma-type units, interbedded with turbiditic and hemipelagic mudstone. The sandstones form up to 50 per cent of the succession and are typically 1 to 3 cm thick, although they may locally reach thicknesses of 30 cm. The formation thins eastwards, splitting into two leaves that interdigitate with the Cwmere Formation around the flanks of the Van Inlier. The lower leaf crops out around the eastern side of the inlier, where it replaces the lower 30 to 60 m of the Cwmere Formation, including the uppermost part of the Mottled Mudstone Member; the upper leaf thins eastwards and passes into the Cwmere Formation north and south of the inlier. The Glaslyn Formation records deposition from mixed sand and mud turbidity currents, and was probably deposited as a number of small turbidite lobes that amalgamated on the margin of the Rhuddanian slope apron.

Marine regression during the Aeronian introduced the **Claerwen Group** (Davies et al., 1997[3]), which sharply overlies the the Cwmere Formation (**Plate P775111**). It comprises a slope-apron facies of predominantly oxic, pale grey-green, colour-banded turbiditic and hemipelagic mudstone, thinly interbedded on a scale of 2 to 3 cm, with subordinate thin siltstones and sandstones. The turbiditic and hemipelagic mudstones are mostly burrow-mottled, and there are horizons of diagenetic phosphate nodules at intervals. Individual turbidite units commonly display thin (1 mm or less) silt laminae at their bases, and were generally deposited from low-density, fine-grained turbidity currents. Thin units of anoxic mudstone, which occur in places throughout the succession, are thought to record brief transgressive pulses in response to fluctuations of the Gondwanan ice sheet (Page et al., 2007[4]). The Claerwen Group envelops earlier formations around the margins of the Ordovician inliers and crops out over much of the area around Llanidloes. It is comprises the **Derwenlas Formation** (**DlF**; up to 140 m thick) and the overlying **Rhayader Mudstones Formation** (**Rhs**; up to 550 m thick) separated by a widespread anoxic unit, the **Monograptus Sedgwickii Shales Member (lh^{s})**, at the base of the latter formation (**Plate P775112**). This anoxic level correlates with a major sequence boundary in shelfal areas bordering the Welsh Basin, and equates with a well-documented global marine transgression (Davies et al., 2013[5]and 2016[6]; Johnson, 2010[7]) which probably began during the late Aeronian *convolutus* graptolite Biozone; graptolites of the latter have been recorded in anoxic units within the upper part of the Derwenlas Formation.

Plate P775111 Rusty weathering anoxic mudstones of the Cwmere Formation overlain in the upper part of the scarp by more resistant bioturbated mudstones of the Derwenlas Formation, Uwch-y-coed [SN 8300 9502].

Plate P775112 Feature (slack) formed by Monograptus Sedgwickii Shales Member at the base of Rhayader Mudstones Formation (right of picture), with the underlying Derwenlas Formation exposed in left foreground, Uwch-y-coed [SN 8300 9513].

The Rhayader Mudstones Formation is succeeded diachronously by the **Devil's Bridge Formation (DBF)** and **Foel Fadian Formation (FoF)**, two broadly comparable early Telychian divisions of thinly interbedded, Bouma-type, turbidite sandstones and mudstones (**Plate P775113**), which crop out in the south-west and north-west of the district respectively. The sandstones are parallel and cross-laminated, between 1 and 5 cm thick, and form up to 30 per cent of the succession; widely scattered thicker sandstone beds range up to 30 cm. The interbedded turbidite mudstones are generally pale green-grey, colour banded and somewhat thicker. They are commonly capped by a thin burrow-mottled hemipelagic mudstone, although parts of each succession include laminated hemipelagites containing graptolites indicative of the *turriculatus* (s.l.) Biozone. Deposition of both the Devil's Bridge and Foel Fadian formations is thought to result from the overall increase in sediment supplied to the basin in response to tectonic uplift of the source areas during the Telychian (Davies et al., 1997; Soper and Woodcock, 1990[8]). Palaeocurrent indicators suggest that the Devil's Bridge Formation was derived from south-easterly quadrants whereas those of the Foel Fadian Formation are indicative of a north-westerly source. Both source areas lay outside the Llanidloes district. The Devil's Bridge Formation thickens to over 500 m in the extreme south-west, coincident with the basinward thinning of the underlying Rhayader Mudstones Formation. At its maximum development within the district the Foel Fadian Formation is 430 m thick, and it appears to thin in a general eastward direction. The reason for these thickness variations is equivocal, although the distribution of both formations was influenced by a sea-floor topography that may have been affected by contemporaneous movement on component structures of the Central Wales Lineament which runs through the western part of the district (Davies et al., 1997; see below).

Plate P775113 Thinly interbedded turbidite sandstones and mudstones of the Foel Fadian Formation, Foel Fadian [SN 8236 9554].

Telychian sandstone-lobe succession

The deposition of slope apron mudstones mostly ended during the early Telychian when a series of large-scale, sand-dominated turbidite-lobe systems (*sensu* Mutti and Normark, 1987[9]) entered the Welsh Basin from the south. This marked increase in the grade and volume of sediment supplied to the basin has been linked to plate collision and uplift of the sediment source areas (Soper and Woodcock, 1990; Woodcock et al., 1996[10]). The distribution of the sandstone-lobe systems within the southern Welsh Basin reveals a pattern of eastwards migration, which is related to the successive reactivation of intrabasinal faults (**Figure P930912**). These deposits are represented by formations that comprise the **Cwmystwyth Grits Group**. The first appearance of this southerly sourced sediment within the district is recorded by the **Blaen Myherin Mudstones Formation (BMM)** and **Caerau Mudstones Formation (CaM)**. These partly contemporaneous formations represent muddy fringing facies to the main sandstone-lobe systems, and are characterised by alternations of thin- to medium-bedded, dark grey turbidite mudstones and either laminated or bioturbated hemipelagites. The Blaen Myherin Mudstone Formation is up to 350 m thick and crops out in the west of the district, where it gradationally overlies the Devil's Bridge and Foel Fadian formations, west of the Central Wales Lineament. The Caerau Mudstones Formation, up to 600 m thick, crops out in the central parts of the district, east of the Central Wales Lineament, and generally overlies the Rhayader Mudstones Formation.

The Blaen Myherin and Caerau mudstones formations are indistinguishable and can only be differentiated where they are separated by the sandstone-lobe facies of the **Rhuddnant Grits Formation (Rdd)** or its fringing facies, the Glanyrafon Formation (see below). The Rhuddnant Grits Formation crops out in the south-west and north-west of the district, and comprises up to 1500 m of abundant, medium to very thick (up to 1 m), commonly amalgamated beds of coarse-grained, feldspathic, mud-rich sandstone ('high-matrix sandstone'), interbedded with subordinate thin-bedded, Bouma-type turbidite sandstone–mudstone couplets and packets of mudstone. The high-matrix sandstones range from very muddy types that grade into sandy mudstones and in which the regional cleavage is typically well developed, to harder, less muddy, normally graded beds. They commonly contain a variety of larger clasts including granules, small pebbles and rip-up clasts of sandstone and mudstone. Northward-directed flute and groove casts on the bases of certain beds indicate derivation from the southerly source. These sandstones have been interpreted as the products of high density sediment gravity flows, varying from slurry-like debris flows to highly concentrated turbidity currents. They were probably fast-moving and deposited their entrained sediment suddenly when flow velocity waned; contorted rip-up clasts, convolute lamination and dish structures are evidence of the rapid dewatering that occurred as the flows 'froze' in situ. The high-density turbidites were able to travel considerable distances beyond the limits of the Bouma-type flows, and into the mudstone belt that formed the distal fringing facies of the turbidite system (Davies et al., 1997; Lowe, 1982[11]); thus, feature-forming packets with high-matrix sandstone and commonly sandy mudstone beds occur locally within a succession predominantly of turbiditic mudstones in the north-west of the district (**Rdd(md)**). Regional studies (Clayton, 1992[12]; Davies et al., 1997; 2006[13]; Smith, 2004[14]) have shown that the Central Wales Lineament was an intrabasinal structure, which was active during deposition of the Rhuddnant Grits and largely confined them to its western side, where the thickest part of the succession crops out. The grits appear to sidelap against the structure and the youngest strata, of early *crispus* Biozone age, lie immediately to the east where they interdigitate in a complex manner with the succeeding **Glanyrafon Formation (Glr)**. The latter crops out widely in the south of the district around Llangurig, and in the north between Staylittle, Carno, Trefeglwys and Llandinam; further outcrops lie along Nant Feinion, south of Llandinam. It comprises a succession, in places up to 750 m thick, of thinly interbedded Bouma-type turbidite sandstone–mudstone couplets. The sandstones are both parallel and cross-laminated, and form 10 to 50 per cent of the succession, generally in beds about 5 cm thick, but locally up to 30 cm. The interbedded mudstones include both oxic and anoxic types, in which the hemipelagite is respectively either burrowed or laminated. In contrast to the Rhuddnant Grits, the Glanyrafon Formation was deposited from relatively slow-moving, low-concentration turbidity currents that were less confined by basin topography and therefore able to spread laterally, beyond the limits of the higher density flows, to form a sandy fringing facies of the turbidite system. The formation gradationally overlies and locally interfingers with the system's muddy fringing facies (Blaen Myherin Mudstones and Caerau Mudstones formations) and intervenes between the sandstone lobe facies of the Rhuddnant Grits and younger Pysgotwr Grits formations (see below).

The **Pysgotwr Grits Formation (Ptr)** crops out in both the north and south of the district, where it separates two units of the Glanyrafon Formation (distinguished as **Glr'** and **Glr''** respectively). It consists of bundles of high-matrix sandstone, comparable to those of the Rhuddnant Grits, but with noticeably coarser-grained, thicker (up to 2 m) and more massive beds, which alternate with packets of thin-bedded sandstones and mudstones (**Plate P775114** and **Plate P775115**). East of the Central Wales Lineament, where the Rhuddnant Grits are largely absent, the Pysgotwr Grits lie about 350 m to 400 m above the base of the Glanyrafon Formation. However, the formation thins eastwards and is absent to the east of the Tylwch Anticline; in this area, the Glanyrafon Formation is undivided. The eastwards disappearance of the Pysgotwr Grits Formation has been interpreted as evidence of sidelap against an active Tywi Lineament and the contiguous Tylwch Anticline (Davies et al., 1997).

Plate P775114 Thick-bedded high-matrix sandstones interbedded with thin turbidite sandstones and mudstones, Pysgotwr Grits Formation, Trannon [SN 8914 9576].

Plate P775115 Flute casts on base of turbidite sandstone, fallen block, Pysgotwr Ggrits Formation, Trannon [SN 8919 9578].

Late Telychian to early Wenlock slope-apron succession

A period of tectonic quiescence in the late Telychian led to the re-establishment of oxic slope-apron sedimentation within the basin, characterised by deposition of the **Dolgau Mudstones Formation (Dgu)** (the Tarannon Pale Shales of earlier workers e.g. Wood, 1906[15]). This distinctive olive-green and purplish red mudstone facies (**Plate P775116**) is up to 300 m thick, commonly silt-laminated and mostly bioturbated, but in places contains subordinate thin beds of laminated hemipelagic mudstone, recording brief episodes of anoxicity that were a precursor to a period of sustained anoxic deposition associated with the early Wenlock Ireviken Event (Gelsthorpe, 2004[16]; Jeppsson, 1997[17]; Munnecke et al., 2003[18]). The formation mainly crops out in the northern and eastern parts of the district. In the Trannon area, in the north, packets of thin-bedded turbidite sandstone and siltstone appear in the highest parts of the formation.

Plate P775116 Purple and green banded and mottled (oxic) turbidite mudstones, Dolgau Formation, Trannon [SN 8955 9565].

The earliest Wenlock strata are represented by the predominantly anoxic **Nant-ysgollon Mudstone Formation (Nyg)**, which sharply overlies the Dolgau Mudstones. Most of the formation has been assigned to the *centrifugus* Biozone (Davies et al., 1997), with the base of the Wenlock located within the lowest few metres of anoxic mudstone. The formation comprises a succession of dark grey, graptolitic, laminated hemipelagic mudstones, with subordinate colour-banded and burrow-mottled turbiditic mudstones and local slumped units. It is about 60 m thick on the flanks of the Pegwyn Hills in the south-east of the district, but thickens north-westwards to at least 140 m in the area around the Trannon Syncline, where it contains abundant thin beds and laminae of turbidite sandstone and siltstone (**Nyg(sa)**; **Plate P775117**). The distribution of this sand- and silt-rich facies was possibly controlled by intrabasinal topography and structure, as it appears to be confined within a north–south belt that extends onto the adjacent Dinas Mawddwy district. It represents a precursor to the major influx of turbiditic sandstone that is associated with the onset of Wenlock tectonism within the Welsh Basin (Davies et al., 1997).

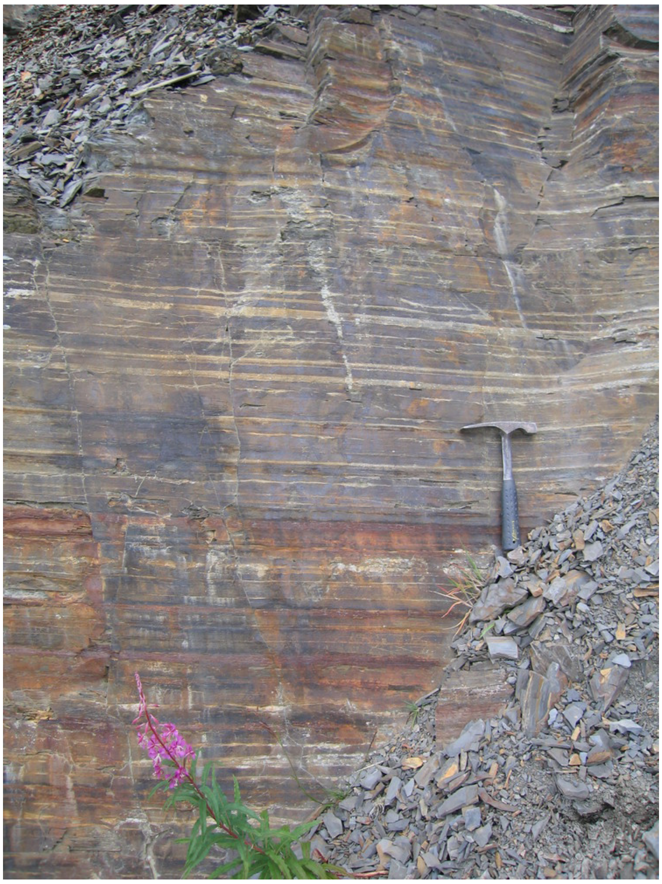

Plate P775117 Rusty weathering, laminated (anoxic) hemipelagic mudstones interbedded with thin turbidite sandstones and siltstones, Nant-ysgollon Mudstone Formation, Esgair Hir Forest [SN 9002 9362].

Early Wenlock sandstone-lobe succession

The renewal of tectonism in the early Wenlock coincided with the deposition of the **Penstrowed Grits Formation (PdG)**, which has its type locality at Penstrowed Quarry [SO 0680 9100] in the east of the district. The formation crops out mostly in the east, and as outliers within synclinal cores in the north of the district. It is up to 900 m thick and comprises thick beds of high-matrix sandstone, interbedded with thinner Bouma-type turbidite sandstones and mudstones in which the hemipelagic component is generally laminated (**Plate P775118**). The high-matrix sandstones are feldspathic, micaceous, and commonly contain variable amounts of bioclastic material; flute and groove casts on their bases indicate derivation from southerly source areas. On a regional scale, the Penstrowed Grits Formation thins eastward against a contemporary palaeoslope which lay to the east of the district, probably along the line of the Pontesford Lineament (Dimberline and Woodcock, 1987[19]); supporting evidence for this is obtained from slumped units at certain levels within the formation, with folds that are overturned westwards. However, biostratigraphical evidence (Davies et al., 1997) suggests that the formation also sidelaps in a westerly direction, and the idea has developed of a fault-controlled depression (the ‘Montgomery Trough’) within which the Penstrowed Grits turbidite lobe system expanded laterally (Cave and Hains, 2001[20]; Cave, 2008[21]; Cummins, 1959[22]; Davies et al., 1997).

Plate P775118 Massive, basal sandstone of the Penstrowed Grits Formation overlying Nant-ysgollon Mudstones Formation, north-east of Carno [SN 9850 9784].

Wenlock to Ludlow slope-apron succession

The **Nantglyn Flags Formation (NgF)** overlies the Penstrowed Grits Formation in the east of the district, and marks the gradual re-establishment of slope-apron sedimentation during a tectonically quiescent period that extended from the mid to late Wenlock (*riccartonensis* Biozone) into the Ludlow. It comprises up to 750 m of dark grey turbidite mudstones with subordinate siltstones and thin sandstones, thinly interbedded with laminated hemipelagic mudstones; thin units of slumped mudstone occur sporadically throughout. In the north-east of the district the **Gregynog Mudstone Member (GyM)**, a thick succession (up to 180 m) of slumped and otherwise disturbed anoxic mudstones and sandstone-mudstone turbidites, represents the lowermost division of the Nantglyn Flags Formation, although it incorporates lithological elements of both this and the underlying Penstrowed Grits Formation (Cave, 2008). Slumping was probably initiated by instability along the Pontesford Lineament which, at this time, formed the eastern margin of the Montgomery Trough. In the vicinity of Aberhafesp, the Gregynog Mudstone Member passes laterally into undisturbed Nantglyn Flags. Late Wenlock (Homerian) marine regression is recorded by the widespread deposition of bioturbated, oxic slope-apron mudstones that comprise the **Mottled Mudstone Member (MMu)** of the Nantglyn Flags Formation. Two discrete oxic units (**MMu**' and **MMu''**), separated by an anoxic interval 60 to 70 m thick, have been recorded within the district which suggests that regression was a more complex event than has been previously thought. These poorly bedded oxic mudstones, which appear about 200 to 300 m above the base of the formation, are generally calcareous, pale greenish grey and colour-banded with grey dark burrow mottles and a sparse, indigenous fauna of brachiopods, trilobites and bivalves.

Deposition of the anoxic Nantglyn Flags resumed in the late Homerian, and continued until early Ludlow times when they were succeeded by sandstone-rich facies of the **Bailey Hill Formation (Bai)**, which appears to have accumulated in a north–south orientated intrashelf trough or corridor that expanded laterally as the supply of resedimented sand increased throughout the Gorstian (Cave and Hains, 2001[23]). Over 200 m of the formation is present at outcrop in the extreme east of the district. It comprises a succession of buff-coloured, thin- to thick-bedded, fine-grained sandstones and siltstones, locally rich in bioclastic material, interbedded with thin laminated hemipelagic mudstones; slumped units occur at certain levels. A local basal division, the **Dingle Mudstone Member (DiM)**, consists of up to 40 m of homogenous grey mudstone with subordinate beds and lenses of fine-grained sandstone and siltstone. The Bailey Hill Formation has long been regarded as a basinal facies (Bailey, 1969[24]; e.g. Cummins, 1959[22]), its turbiditic origin having been re-emphasised by Cave and Hains (2001)[25]. However, sedimentary structures, bedforms and concentrations of shell detritus within the sandstones led Tyler and Woodcock (1987)[26] to argue that the formation was partly emplaced as a series storm sheet deposits below a strongly stratified water column.

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Structure and metamorphism

The main structural elements within the district are shown in **Figure P930913**. The tectonic history of the Welsh Basin records the sequence of events associated with the separation of the Neoproterozoic basement of Avalonia from Gondwana during the Early Ordovician, and the subduction of oceanic crust (the Iapetus Ocean) beneath the Avalonian palaeoplate as it converged with Baltica and Laurentia (e.g. Howells, 2007[1]). The eventual closure of Iapetus and the collision of Avalonia with Baltica, and then Laurentia, formed part of the Caledonian orogenic cycle (Cambrian to early Mid Devonian), and occurred from the mid to late Silurian onwards. The structural features of the Llanidloes district are largely the result of tectonic movements that occurred within these later stages of the orogenic cycle, during an episode widely known as the Acadian Orogeny (McKerrow et al., 2000[2]; Soper and Woodcock, 2003[3]; Woodcock et al., 1988[4]). Although the orogeny is traditionally thought to have resulted from the impact of Avalonia with the more northern Laurentian supercontinent (part of modern-day North America), recent studies suggest instead that a collision to the south may have been responsible (Woodcock et al., 2007[5]).

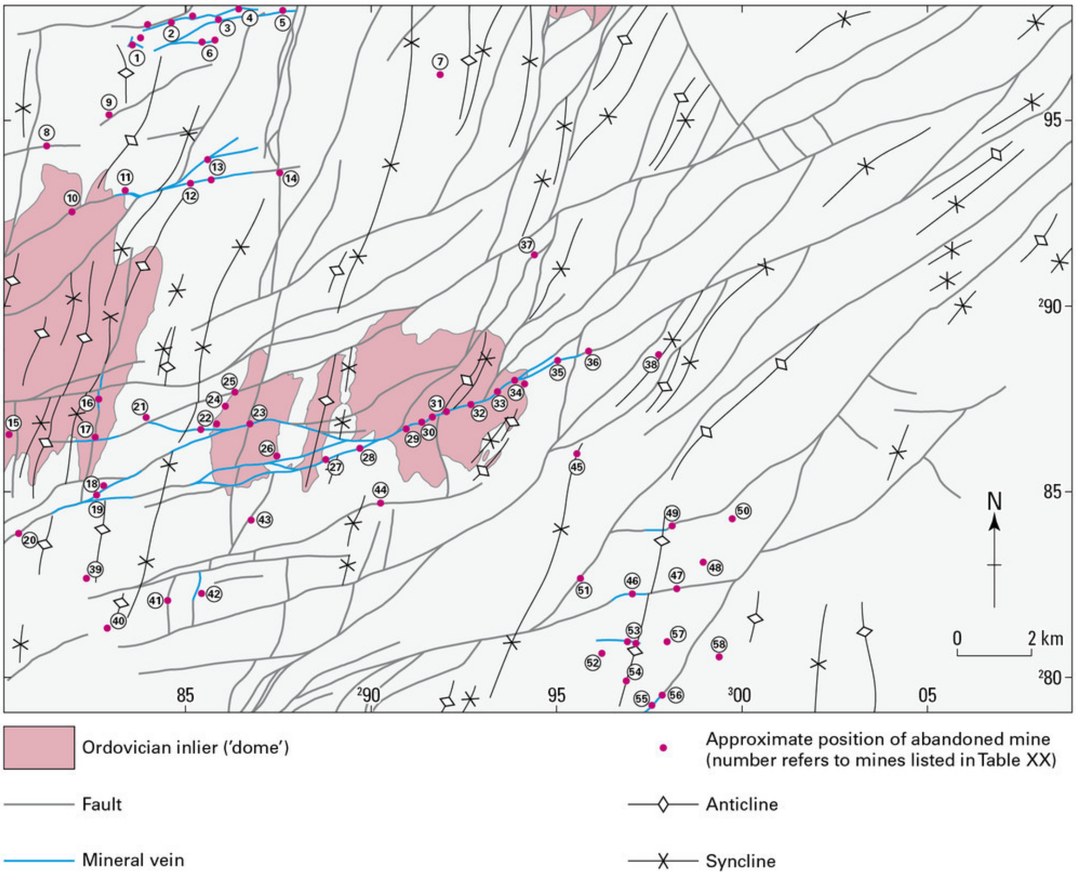

Figure P930913 Main geological structures of the district, including the principal mineral veins and mine sites. The numbers given refer to the mine sites listed in Table 1.

The Acadian Orogeny largely overprinted evidence of previous tectonism. Synsedimentary movements deduced from profound thickness and facies variations within the Telychian turbidite lobe systems (see above) occurred across structures which were reactivated during the orogeny. Within the district these include the **Central Wales Lineament**, an important structure which extends northwards from the River Wye valley west of Llangurig [SN 9104 7982] to Pennant [SN 8788 9783], and is marked by a complex zone of later folding and faulting that continues into adjacent districts (**Figure P930913**). The Acadian deformation of the **Tywi** and **Pontesford** lineaments, structures viewed as influential during Wenlock and Ludlow deposition in the east of the district, are well seen in the adjacent Rhayader and Montgomery districts (Davies et al., 1997[6]; Cave and Hains, 2001[7]).

The Acadian Orogeny ended sedimentation and resulted in uplift of the entire Welsh Basin. The basinal succession was folded by several orders of magnitude and faulted; a cleavage was widely developed as the rocks underwent low-grade (anchizone to epizone) metamorphism (Merriman, 2006[8]). One of the largest regional folds is the **Central Wales Syncline**, a first-order structure in the western part of the district that developed above or adjacent to the Central Wales Lineament (Davies et al., 1997; Smith, 1987b[9]). The complementary **Teifi Anticlinorium** (Davies et al., 2006[10]; Jones, 1912[11]) lies to the west of the syncline, its trace coincident with the core of the second-order **Plynlimon Inlier**; additional second-order periclinal structures which expose Ordovician strata include the **Mynydd-y-groes**, **Bryn Mawr** and **Van** inliers, in the central part of the district, and the **Carno Inlier** in the extreme north. Further second-order folds include the **Llanidloes Syncline** and **Tylwch Anticline** south-east of the Van Inlier, and the **Trannon Syncline** to the north. The broad disposition of Ordovician and Silurian strata is largely controlled by the second-order structures and, to a lesser extent, by lower-order folds (**Plate P775119**). The majority of second-order folds are open structures with axial planes that dip at steep angles to the west or north-west; lower-order structures are open to tight, their profiles usually controlled by the host lithology, particularly in the thinly interbedded turbidites.

Plate P775119 North-facing monocline in Rhuddanian and Aeronian rocks — well featured unit forming the high point on the left is the Derwenlas Formation, Tarren Bwlch-gwyn [SN 8030 9412] as viewed from the vicinity of Cefnwyrygrug.

A closely spaced cleavage is apparent in the muddier lithologies across much of the district, but it becomes weaker and patchily developed eastwards and is mostly absent in the extreme east; it is generally inclined at steep angles towards the west-north-west. Cleavage is commonly axial planar to the folds or transects their axial traces in a clockwise sense by a few degrees, and there is little evidence of the strong cleavage transection that has been reported from elsewhere within the basin (Woodcock et al., 1988[4], and references therein). It has been suggested that the clockwise transected folds reflect a noncoaxial (sinistral) transpressive strain history that resulted from oblique plate collision, although the reasons for this remain unclear (Soper, 1986[12]; Soper et al., 1987[13]; Woodcock et al., 1988[4]).

Acadian faults include a number of north–south aligned structures along the Central Wales Lineament that can be traced, as individual faults or anastomosing splays (such as the **Dylife Fault Zone**), from Pennant in the north of the district to the Wye Valley in the south. They are associated with a belt of tight folding and probably record displacements forced above a deep basement fault or shear zone during the orogeny. Comparable north to north-north-east-trending faults and tight folds also occur within the Plynlimon and Van inliers, and define the Carno Inlier in the north of the district.

The dominant fault trend was imposed across the district during a late to post-Acadian event as a series of predominantly north-east to east-north-east structures along which mineralisation has occurred in places (Davies et al., 1997[6]; Fletcher et al., 1993[14], **Figure P930913**). They typically show variable vertical offsets, which may be interpreted in terms of oblique or strike-slip displacements, and possibly involving the reactivation of pre-existing structures. They include the **Llanerchyraur** fault plexus in the north of the district, and the **Dylife-Esgairgaled-Llechwedd** and **Dyfyngwm** structures which may represent splays of the Camdwr Fault of the adjacent Aberystwyth district. In the central part of the Llanidloes district, a plexus of faults along which the **Van**, **Nantyricket** and **Nantygwrdy** lodes are situated, may be an eastward continuation of the Castell Fault which is recognised as a single structure to the west. Major fractures to the south and east of the Van Inlier include the **Clywedog**, **Cefn Carnedd** and the contiguous **Bryn Posteg** and **Wenallt-Highgate** structures, the latter locally defining the base of the Penstrowed Grits escarpment. It is likely that some faults within the district were reactivated during the subsequent Variscan (late Carboniferous) and Alpine (Cainozoic) orogenic cycles. Although there is no direct evidence for this, there are indications elsewhere that some mineral veins were active as late as the early Carboniferous (Fletcher et al., 1993[14]).

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Geophysics

The Bouguer gravity anomaly map (**Figure P930914**). reveals a more-or-less steady increase in gradient towards the north-west of the district. This pattern, which is apparent on a regional scale, reflects the main structural trend within the basin and is consistent with the presence of dense Lower Palaeozoic or basement rocks at a shallower crustal level in the coastal tract to the west. Euler deconvolution analyses of the regional gravity data (McDonald et al., 1992[1]) suggests that the juxtaposition of rocks of different densities took place across long-lived basement structures such as the Glandyfi Lineament (Cave and Hains, 1986[2]) and Bronnant Fault (Davies et al., 1997[3]; Wilson et al., 1992[4]).

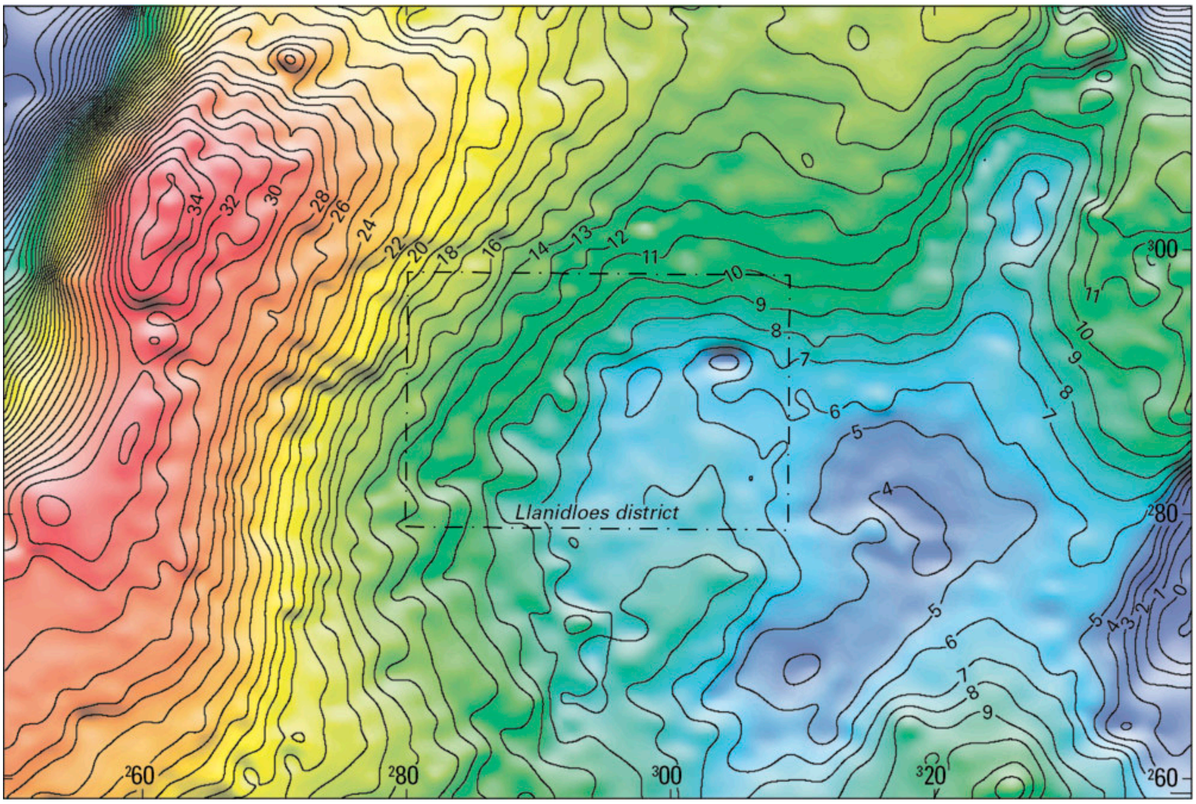

Figure P930914 Bouguer gravity anomaly map (scale 1:750 000). Bouguer gravity anomalies in milligals (mGal) calculated against the Geodetic Reference System 1967, referred to the National Gravity Reference Net, 1973. Variable Bouguer reduction density. The anomalies are shown as a colour-shaded relief presentation using the BGS COLMAP Package. The shaded topographical effect has been created using an imaginary light source, located to the north. Contour interval 1mGal (1mGal = 1 x 10-5 m/s^2). Based on data in the BGS National Gravity Databank. Station distribution approximately 1 per 1.3 km^2. The inset frame indicates the extent of the Llanidloes district.

The regional aeromagnetic anomaly map (**Figure P930915**) shows a weak magnetic high in the south-eastern part of the district. The reasons for this anomaly are unclear but reflect the presence of magnetic basement or a concealed igneous complex at a relatively shallow crustal depth. The feature is one of a series of weak anomalies that broadly lie along the Pontesford Lineament, one of the component structures of the Welsh Borderland Fault System (Woodcock and Gibbons, 1988[5]).

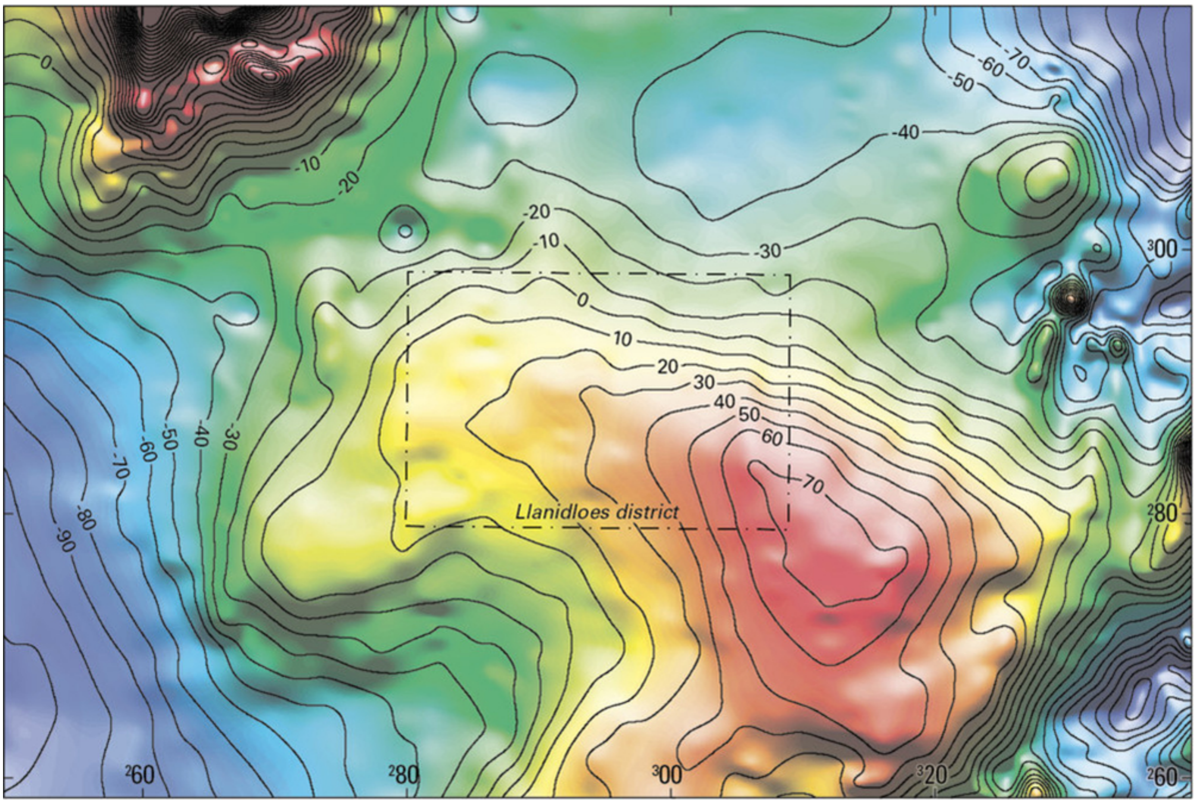

Figure P930915 Aeromagnetic anomaly map (scale 1:750 000).Total field magnetic anomalies in nanotesla (nT) relative to a local variant of IGRF90. The anomalies are shown as a colour-shaded relief presentation using the BGS COLMAP Package. The shaded topographical effect has been created using an imaginary light source, located to the north. Contour interval 10nT. Based on data in the BGS National Aeromagnetic Databank. Flown at a mean terrain clearance of 305 m on north–south flight lines 2 km apart with east–west tie lines 10 km apart. The inset frame indicates the extent of the Llanidloes district.

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Cenozoic

Palaeogene to Neogene

The uplift that affected the British Isles and established the broad drainage pattern of the region probably began during the early Cenozoic (Eocene) and culminated in the mid Cenozoic (Miocene). The reasons for this uplift are contentious (summarised in King, 2006[1]); theories include rifting and mantle upwelling in the north Atlantic that elevated the north-western margin of the European plate or uplift of the foreland ahead of, and as a result of, lithospheric loading by the Alpine mountain belt. It is likely that both processes were influential at different periods during the early to mid Cenozoic, as the present-day global plate tectonic configuration became established. Progressive denudation of Wales created a series of peneplaned surfaces (Brown, 1960[2]; Jones, 1951[3], 1955[4]; Walsh et al., 1999[5]) on which the modern river system became established (Dobson and Whittington, 1987[6]); remnants of these surfaces are preserved within the Cambrian Mountains today.

Quaternary

Plate tectonic reconfiguration and changing ocean circulation patterns led to an overall global cooling from the Early Eocene onwards, bringing about a succession of ice ages that affected much of the British Isles during the Pleistocene. The main agents of erosion and deposition during these periods were ice sheets, valley glaciers and their meltwaters which, together with periglacial processes, modified the landscape by changing drainage patterns, oversteepening and overdeepening valleys and depositing a range of superficial materials. Although the Llanidloes district was probably covered by ice on more than one occasion, the landforms and glacial deposits preserved there are considered to result wholly from the last major glacial event, which occurred from about 26 000 to 14 500 BP. During this episode, known as the Late Devensian Glaciation, a Central Wales Ice Sheet accumulated in the Cambrian Mountains and spread outwards into the river valley systems until, at its greatest extent, ice probably covered the whole of the district.

The material eroded and carried by the ice, including that formed during earlier periglacial processes (and possibly earlier glaciations), was deposited as a veneer of **till** (diamicton) over the bedrock during both advance and retreat of the ice sheet. Till deposits range from blue-grey, brown and orange-yellow gravelly, sandy and silty clay to clayey gravel with a variable proportion of cobbles and boulders, mostly of Lower Palaeozoic rocks (**Plate P775120**). They have been extensively modified by periglacial processes including solifluction, which has locally imparted a crude slope-parallel fabric to the clasts and has created a series of high-level terrace-like features, particularly in the north of the district.

Plate P775120 Poorly sorted, blue-grey till, weathering brown in upper part of section, containing subrounded to angular clasts, mainly of sandstone, Cwm Cledan, west of Carno [SN 9243 9650].

The **hummocky glacial deposits** that lie within the Severn Valley near Penstrowed [SO 0706 9124], on the flanks of Afon Carno at Caersws [SO 0344 9290] and around Cerist Bridge [SN 9643 8808] are interpreted as remnants of moraines, which accumulated during pauses in the retreat of ice along the valleys during deglaciation of the region. These heterolithic deposits comprise irregular mounds and ridges of clayey gravel, locally with beds and lenses of sand and gravel, laminated clay and till. Although the modern fluvial system has breached the moraines, in places they appear to represent constructional landforms that formerly extended across the valley floor and impounded glacial meltwater. Boreholes in the Severn valley near Caersws penetrated a succession of blue-grey laminated silts and clays, probably representing **glaciolacustrine deposits** that accumulated in ephemeral lakes behind the morainic dams; comparable clays were encountered in boreholes near Llandinam.

The undifferentiated **glaciofluvial deposits** that occupy parts of the valleys of the Afon Carno and Afon Trannon are mainly composed of gravel, sand and silt, which was carried by meltwater and deposited downstream from the retreating ice. They display an irregular surface morphology, possibly resulting from the in situ melting of bodies of stagnant ice and, thus, represent a late glacial period of aggradation that has been incised by the present-day river system. The most extensive deposit, along the Carno valley in the north of the district, is probably the remnant of a valley sandur; a comparable deposit occurs in the Trannon valley near Trefeglwys, although its morphology is suggestive of a fan or delta, which built out into the glacial lake occupying the Severn valley to the east. Well-defined **glaciofluvial fan deposits** of sand and gravel, contiguous and gradational into the undifferentiated glaciofluvial deposits, occur in places along the Trannon and Carno valleys.

In the tundra-like periglacial conditions that followed the retreat of the ice, intense seasonal freeze-thaw shattered rock and weakened previously deposited glacial materials. Downslope mass movement by a variety of processes including creep and saturated flow formed the range of **head** deposits that blanket most of the valley slopes and infill topographical hollows. They comprise highly variable gravelly, sandy or silty clay, locally stratified and with a preferred downslope clast orientation. Head deposits within the district have only been recorded where their morphology allows them to be mapped; elsewhere they are not distinguished from their parent materials. Distinctive, localised deposits of stratified gravel, usually consisting of angular mudstone fragments in a silty clay matrix, are separately recorded as **head gravel** and, for the most part, represent accumulations of frost-shattered bedrock (nivation scree).

The modern drainage pattern was largely established throughout the district during the Holocene (beginning about 11 700 years BP; Walker et al., 2009[7]) when, with a few exceptions (Jones, 1951), the rivers Wye, Severn and their tributaries re-established their previous courses. Incision of the rivers into the previously deposited materials was a response to isostatic readjustment and changing base level, and it produced a series of elevated **river terrace deposits**, composed of stratified sands and gravels. Gently sloping spreads of **alluvial fan deposits**, usually of less well-ordered sand and gravel, accumulated where tributaries emerged into the main valleys; they also show evidence of river incision and dissection. The **alluvium** that forms the floodplain of many valleys is the deposit of the modern river system, typically comprising silt and clay with localised organic clay, and beds and lenses of sand and gravel.

As vegetation was re-established under the more temperate climatic conditions of the Holocene, **peat** deposits began to accumulate in enclosed hollows and the poorly drained upland areas became sites of self-supporting (ombrogenous) bog (**Plate P775121**); peat has also built up in the abandoned meanders of the main river valleys. Small lakes, pools and poorly drained hollows within the previously glaciated landscape have become sites for the deposition of organic-rich silts and clays that constitute **lacustrine alluvium**.

Plate P775121 Thick accumulations of hill peat blanket much of the upland area around Plynlimon and Trannon [SN 8280 8940].

The generally wetter conditions of the Holocene have promoted the development of **landslides**, particularly in superficial deposits on oversteepened slopes that have been undercut by rivers and streams. It is likely that some landslides originated in the immediate postglacial (paraglacial) period, and many remain intermittently active to the present day.

The influence of man on the landscape during the Holocene has been significant. Mining activities and quarrying have left the district with excavated areas of **worked ground** and a variety of spoil of varying thickness. Much of the spoil is mine waste, but refuse tips, embankments, archaeological sites and all other areas where the ground has been raised above its natural level are grouped as **made ground**. Much of the waste and overburden has been subsequently moved and regraded to the point where the original extent of cut and fill or worked-out ground cannot be determined with any certainty; such areas are classified as **landscaped ground**.

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Applied geology

Geological knowledge is essential for efficient planning and development on both a regional and site-specific scale. Consideration of earth science issues early in the planning process can help ensure that site and development are compatible and that appropriate mitigation measures are taken prior to development. Exploitation of natural geological resources often conflicts with agricultural land use, pre-existing development and the environment. Potential geological hazards may present a risk to public health and require costly remediation. Engineering ground conditions and designated sites of geological conservation strongly influence the location and design of any new development.

Mineral resources

Mineral resources are natural concentrations of minerals or bodies of rock that are of potential economic interest. The Llanidloes district lies within the north-eastern part of the Central Wales Mining Field (Jones, 1922; Nutt, 1974[1]), an area of historic importance for the exploitation of **metalliferous minerals**, notably **lead** (galena) and **zinc** (mainly sphalerite) but also **barytes** and **copper** (chalcopyrite) locally. **Silver** was also found in association with the lead-zinc ore, in concentrations which, in places, made extraction of the ore economically viable. Mining within the district dates back certainly to Tudor, and probably pre-Roman times, but most took place during the mid 19th century. The peak period of production occurred between 1840 and 1880, but ended abruptly when the price of lead dropped sharply thereafter. There was a short-lived renewal of interest in the ore field during the 1914, 18 war, and sporadic exploitation continued until the early 1930s when mining activity ceased altogether.

The majority of recorded mineral occurrences within the district are of lead; a list of the principal mine sites is given in the table below. The lead-zinc mineralisation mainly occurs along a number of veins ('lodes') in the central and north-western part of the district, with some minor vein development to the south of Llanidloes (**P930913**). The eastern part is largely devoid of mining, with the exception of two small sites near Aberhafesp. The principal lodes are mostly located along the east-north-east-trending faults and connecting relay structures (James, 2006[2]; Jones, 1922[1]), and the mineralisation tends to be developed where the faults intersect the hinges of second- and third-order folds (Hughes, 1959[3]). The main productive lodes are found in close association with the Ordovician inliers and surrounding early Silurian (Rhuddanian to Aeronian) rocks, whereas the orefield in the north of the district lies within an area of later Silurian (Telychian) strata.

List of lead-zinc and other mines within the Llanidloes district

1	Bacheiddon	31	Bryntail
2	Rhoswydol	32	Glyn
3	Ceulan	33	Penyclun
4	Llanerchyraur	34	Van
5	Cae Conroy	35	East Van
6	Brynfedwen	36	Glan Gwden
7	Rhydymwyn	37	North Van
8	Glaslyn	38	Wheal Van

9	Moel Fadian	39	Nant Gwernos
10	Bugeilyn	40	Unnamed trials
11	Nantddu	41	Glan Severn
12	Dyfngwm	42	Nanty
13	Dylife	43	Siglenlas
14	Hirnant	44	South Van
15	East Plynlimon	45	Penrallt
16	Snowbrook	46	Brynposteg
17	Nantiago	47	New Brynposteg
18	Nantygwrdy	48	Newchapel
19	Dolminers	49	Gorn
20	Unnamed trials	50	Dolwen
21	Maesnant	51	Unnamed trials
22	Cwmricket	52	Unnamed trials
23	Nantyricket	53	Cwmfron
24	Rhydybenwch	54	West Nantycreiau
25	Nantmelyn	55	West Fedw
26	Van United	56	Fedw
27	Geufron	57	East Cwmfron
28	Gwestyn	58	Tynewydd
29	Aberdaunant	59	Unnamed mine
30	Crowlwm		

Although the ore within the Central Wales Mining Field was of high grade, it was largely confined to the zone of fracturing, and therefore limited in its extent and tonnage. Only in a few places was it worked from ‘flats’ extending beyond the vein and, even here it occurs in fissures and other lines of weakness (Hughes, 1959); there is no evidence of extensive disseminated mineralisation. In terms of production, the most important vein within the Llanidloes district was the **Van Lode**, along which a number of mines were located (Jones, 1922; **Plate P775122**). The **Nantyricket** and **Nantygwydy** (or **Wye Valley**) lodes appear to be situated along relay faults that may link the Van Lode with the important Castell Lode of the adjacent Aberystwyth district. Second in importance to the Van were the **Dylife** and **Dyfngwm** lodes, which possibly represent an eastward continuation of the Camdwr Fault that crosses the Plynlimon range. The closely spaced **Cae Conroy**, **Llanerchyraur** and **Rhoswydol** lodes in the extreme north of the district were also significant economically, although less so than those further south.

Plate P775122 The historic Bryntail Mine, located on the Van Lode, now restored as a site of special archaeological interest, Clywedog Valley below the reservoir and dam (in background) [SN 9138 8682].

Lead isotope analyses from elsewhere in the Central Wales Mining Field suggest the mineralisation took place in two distinct periods (Fletcher et al., 1993[4]). A late Acadian event of 390 Ma was probably associated with the development of the dominant east-north-east faults, the fracturing producing a network of fissures allowing penetration of the mineralising fluids. These zones appear to have been exploited by a second phase of mineralisation in the early Carboniferous (360 to 330 Ma), when extension of the former Avalonian plate led to reactivation of Acadian structures during the early phases of the Variscan Orogeny.

The commercial extraction of **hard rock** for **aggregate** currently takes place at Penstrowed Quarry [SO 0680 9100], which works the thick sandstone of the Penstrowed Grits Formation. Many of the other sandstone divisions have been exploited in the past for a variety of purposes, notably as local sources of **building stone**, particularly in the remote areas. The mudstone formations in general are not sufficiently durable as building materials, and the presence of pyrite-bearing (anoxic) mudstones at intervals throughout the succession limits their use as a fill or bulk aggregate; on weathering such material may release sulphates that can attack concrete. For many settlements the predominant building material was **brick**, readily supplied via the Montgomery Canal to Newtown and by rail to the mining field; bricks were also manufactured locally, utilising the lacustrine clays around Caersws.

Sand and gravel has not been widely exploited within the district, although potential resources of glaciofluvial gravel may be present in the Afon Carno valley north-west of Caersws. However, there is limited information on the thickness of these deposits, and their heterogenous clast content together with their variable clay content may limit their commercial value; the more localised hummocky glacial deposits likewise represent a poor to intermediate quality resource due to their heterogeneity. Alluvial fans and river terrace deposits may offer some potential, but hitherto have only been worked on a small scale as a source of farm aggregate; the variable clast size and content of certain alluvial fans may further limit their quality as aggregate.

Water resources

The high annual rainfall of the Cambrian Mountains, in association with the relatively impermeable bedrock, results in significant **surface run-off** within the river catchments. In the upper reaches of the Afon Clywedog this is collected by the Clywedog Reservoir, whose function is to balance water supply to the River Severn and regulate flow during the summer months. The alluvial and glaciofluvial sand and gravel of the Severn (Afon Hafren) are the principal aquifer of the district, from which **groundwater** is currently abstracted by boreholes at Llandinam [SO 0212 8939]. It was previously thought that the Lower Palaeozoic rocks of mid Wales were not a significant aquifer, but studies have shown that modest amounts of groundwater can be abstracted from fractured and weathered rocks in the near-surface zone as well as from the permeable superficial deposits (Robins et al., 2000[5]). Outside the main settlements, many dwellings and farms rely on private supply from boreholes and springs, and in the extreme north-east of the district a mineral spring (chalybeate) has been recorded at Black Well [SO 0880 9403].

Potential geological hazards

Low-lying parts of the district may be prone to **flooding** during periods of high river flow. At particular risk are certain reaches of the Severn valley in the east of the district and parts of the Wye valley near Llangurig. An indication of those areas that are prone to flooding is given by the extent of the alluvial floodplain deposits; however, flooding may also affect the lowermost river terraces and some alluvial fans. Areas lying outside the mapped limits of the alluvial deposits may also be at risk during anomalously large floods or when flooding is caused by blocked drains and culverts. Maps of those areas regarded as at risk of flooding are maintained by the Environment Agency.

Migration of toxic leachate from underground workings of metalliferous mines, or from spoil associated with mining, presents a significant **pollution potential**, leading to contamination of local surface or groundwater resources. Poorly planned remediation or exploitation of mine waste may release soluble or atmospheric contaminants to the surrounding area and watercourses. Moreover, alluvial deposits in proximity to mine sites may contain concentrations of ore from washings, dating back to the main period of mineral exploitation in the 19th century. The risk and consequences of disturbing these contaminated layers should also be considered when undertaking remedial work, or planning excavations for gravel extraction or construction. Contamination of groundwater by leachate may also occur from sources such as poorly engineered landfill sites, agricultural waste and active or former industrial sites including sewage works, gravel pits or quarries.

Natural gas emissions are a hazard associated with the accumulation of methane or radon. Both are capable of migrating through permeable strata and accumulating in poorly ventilated spaces such as basements, foundations or excavations where they may present a health risk. **Methane**, which is both an asphyxiant and explosive in high concentrations, is likely to be generated by the decomposition of organic material in landfill sites and unconsolidated organic-rich deposits such as peat. Methane emissions are not thought to pose a significant hazard; currently, Bryn Posteg [SN 972 822] south-east of Llanidloes is the only large operational landfill site within the district, and this is monitored by the Local Authority and Environment Agency. **Radon** is a naturally occurring ionising gas produced by the radioactive decay of uranium-bearing minerals. Although these are present in small quantities in all natural rocks and soils, they occur in higher concentrations in certain igneous rocks and black (anoxic) mudstones. Radon is a carcinogen, but does not normally present a hazard as it is normally dispersed within the atmosphere. However, high-level accumulations of radon are known to be associated with an elevated risk of cancers of the respiratory tract. Therefore, in areas at risk of radon accumulation, protective measures for new buildings (homes, workplaces etc) and remediation of existing buildings should be carried out. Advice about radon and its associated health risks may be obtained from the National Radiological Protection Board, Chilton, Didcot, Oxfordshire OX11 0RQ; further advice about radon levels within mid Wales is provided by Miles et al., (2007)[6]. **Slope instability** is typically revealed by the presence of landslip. About 78 landslips were identified during the present survey, most of which were located on drift deposits, particularly till. A number of landslips sited on steep valley slopes mapped as bedrock are shallow structures in undifferentiated head deposits; however, one of the larger slips, near Pontdolgoch [SO 0061

9388], appears to be located on steeply dipping bedrock. The principal influences for landslip within the district are a reduction in strength of the material, usually through high fluid pressures caused by an excess of water, and oversteepening of the slope commonly by erosion at the toe of the slip. Most of the landslips are located in rural areas although pressures on development for housing or infrastructure increase the possibility that building or engineering work will encounter them or create conditions under which instability may occur. The most effective strategy for dealing with landslip relies on the recognition of these problem areas in advance so that suitable remedial or preventative measures can be employed.

Subsidence due to the collapse of **shafts**, **adits** and **underground workings** is a feature of most mining areas. The Llanidloes district contains many underground workings and surface entries, mainly concentrated along the mineral veins. Although the sites of many shafts are known there may be other unrecorded mine entrances. This is particularly the case with trial shafts which did not work any quantity of ore. Many mine entries are recognisable by the spoil generated during their excavation, whereas others may have been obscured by mine waste. Careful site investigation, including a review of historical records, is necessary before any development takes place on previously mined areas.

Engineering ground conditions

Knowledge of ground conditions is a primary consideration in identifying land suitable for development, and underpins cost-effective design. Engineering ground conditions vary, depending on the physical and chemical properties of the local materials, the topography of the area, its hydrogeology (i.e. the behaviour of groundwater and surface water), and the nature of past and present human activity. The most significant development problems likely to be encountered in the district are due to the variability of the natural superficial deposits, weathering of the solid rocks and landslips. These can be effectively dealt with by first obtaining adequate information, including properly focussed site investigation to confirm the properties of individual sites.

Geotechnical details of the strength of materials within the district are sparse. Bedrock generally has high bearing capacities except in the weathered zone. The pyritic mudstones that are common in the Cwmere Formation, but occur also at intervals throughout the succession, may heave on weathering, and react to form sulphates that can chemically attack concrete. Glaciolacustrine deposits and peat have low bearing capacities that can give rise to moderate settlement. Till and hummocky glacial deposits generally have moderate bearing capacities but are highly variable by nature. Head deposits, alluvial fans and alluvium all have low to moderate bearing capacities. Glaciofluvial and river terrace deposits embrace a variety of foundation conditions, but generally have high bearing capacities. Artificial (made and landscaped) ground may be highly variable and can include contaminated land such as mine waste that would require remediation. It is important to note that the distribution of superficial deposits is complex, both in a vertical and lateral sense, and the geological map only depicts those at the surface where a thickness of more than a metre can be reasonably supposed; thus, deposits with moderate bearing capacities may conceal materials with low capacities that could pose problems during construction.

Geological conservation

The geological and mining heritage of the district forms a resource for tourism, education and scientific research, and is also a key issue in planning and development. Geological localities considered to be of national importance are protected as Sites of Special Scientific Interest (SSSIs). These are statutory designated conservation sites which have some protection under the Wildlife and Countryside Act (1981). Non-statutory conservation sites are designated as Regionally Important Geological Sites (RIGS), and listing of these is currently underway. Further information on the on the extent and designation of RIGS and SSSIs can be obtained from the Countryside Council for Wales, Plas Penrhos, Penrhos Road, Bangor, Gwynedd LL57 2LQ.

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Information sources

Further geological information held by the British Geological Survey relevant to the district and adjoining areas is listed below. Searches of indexes to some of the collections can be made on the Geoscience Data Index (GDI) system, available online at http://www.bgs.ac.uk. *BGS Catalogue of geological maps, books and data* is available on request or may be viewed on the website. Maps and other publications may be purchased online (www.geologyshop.com [1]) or through the BGS sales desks, and can be consulted at the BGS libraries.

Enquiries concerning geological data for the district should be addressed to the Manager, National Geological Records Centre (NGRC), BGS, Keyworth. Geological advice should be sought from Geology and Landscape Wales, British Geological Survey, Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE, Tel: +44 (0)2920 521962. The BGS hydrogeology enquiry service (wells, springs and water borehole records) can be contacted via the BGS website or at Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX0 8BB. Tel: +44 (0)1491 838800. Fax:+44 (0)1491 692345.

Publications

Original nineteenth century 1:63 360 scale geological maps are out of print, but can be provided as facsimiles or can be consulted at the BGS library, Keyworth. Unpublished 1:25 000 scale geological maps, listed below, are available on request. Groundwater vulnerability maps are published by the Environment Agency from data commissioned from BGS and The Soil Survey and Land Research Centre, and are available from BGS sales desks and The Stationary Office (020 7873 0011).

Many BGS products and data are available in digital form under licensing agreement, details of which are available from the Intellectual Property Rights Manager, BGS, Keyworth. Digital datasets include those covering geochemistry, geophysics, geohazards, hydrogeology, borehole logs and mapping and allow the information to be used in GIS applications.

Geological maps

The district was originally surveyed at the scale of 1:63 360 by W T Aveline, H W Bristow, A C Ramsay and A R Selwyn, and published as part of Old Series sheets 56, 57, 59 and 60 in 1848 and 1850. The Central Wales Mining Field was surveyed at the 1:10 560 scale by O T Jones of the University of Wales in 1917, 18, and part re-surveyed by D Williams in 1940. Small areas along the western and eastern margins of the sheet were surveyed at 1:10 560 scale by R Cave between 1965 and 1972. The southern margin of the sheet was surveyed at 1:10 000 scale By R Cave, J R Davies, C J N Fletcher, A J Reedman and R A Waters between 1986 and 1989 as part of the BGS Rapid Mapping Programme. The remaining area was surveyed at 1:20 000 scale in 2006 by J A Aspden, C E Burt, J R Davies, M Hall, N S Jones, A B Leslie, T H Sheppard, P R Wilby and D Wilson utilising previously published and unpublished data; the work was undertaken as part of the GeoCymru Project, supported by a grant from the Welsh Assembly Government.

1:1 500 000

Tectonic map of Britain, Ireland and adjacent areas, 1996.

1:625 000

Bedrock Geology of the UK: South Map, 2007.

Quaternary Geology: South Sheet, 1977.

1:250 000

52N 04W Mid Wales and Marches, Solid, 1990.

Geological Map of Wales (Solid Geology), 1994.

1:50 000

Sheet 164, Llanidloes, Bedrock and Superficial Deposits, England and Wales, 2009.

1:20 000, 1:10 000 and 1:10 560 The component BGS maps of the district at this scale are listed below, along with the surveyors' initials and the dates of survey.

Map number	**Surveyor**	**Dates**
SN 87	CJNF, AJR, JRD	1986–89
SN 88	RC, JRD	1965, 2006
SN 89	RC, JRD, JAA	1965, 2006
SN 97	JRD, RAW	1986–89
SN 98	DW, NSJ, ABL	2006
SN 99	JAA, THS, JRD	2006
SO 07	RC, JRD, MH, CEB	1986–89, 2006
SO 08	RC, MH, CEB,	1986–9, 2006
SO 09	RC, PRW	1988, 2006

Geophysical maps

1:1 500 000

Earthquakes 1980–2008, British Isles and adjacent areas, 2009.

1:1 000 000

Gravity Anomaly Map, 48ºN-54ºN, 6ºW-0ºE, Southern Britain, 1998.

Magnetic Anomaly Map, 48ºN-54ºN, 6ºW-0ºE, Southern Britain, 2004.

1:625 000

Gravity Anomaly Map of the UK: South Sheet, 2007.

Magnetic Anomaly Map of the UK: South Sheet, 2007.

Hydrogeological maps

1:625 000

Sheet 1: England and Wales, 1977.

Groundwater vulnerability maps

1:100 000

Sheet 27: Dyfed, 1990.

Sheet 28: Powys 1990.

Geochemical atlases

1:250 000

Stream waters in Wales, 2000.

Stream sediment and soil: Wales, 2000.

Books, reports and other publications

Books, reports and other select publications relevant to the district are listed in the References.

Documentary collections

Records of boreholes and site investigations pertaining to the district are available for consultation at NGRC in BGS, Keyworth. Index information, including site references, is held in digital format and can be viewed through the GDI, available on the BGS website.

Material collections

Material collections from the district are available for inspection at BGS, Keyworth, and include petrological hand specimens, thin sections and fossils. Index data for petrological specimens and for fossils is listed in the Britrocks and Palaeosaurus databases, respectively. These may be searched through the GDI on the BGS website.

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Article Sources and Contributors

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Geology of the Llanidloes area: Geological description - Cenozoic *Source*: http://earthwise.bgs.ac.uk/index.php?oldid=28853 *Contributors*: Dbk, Jeth1, Jrdav

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