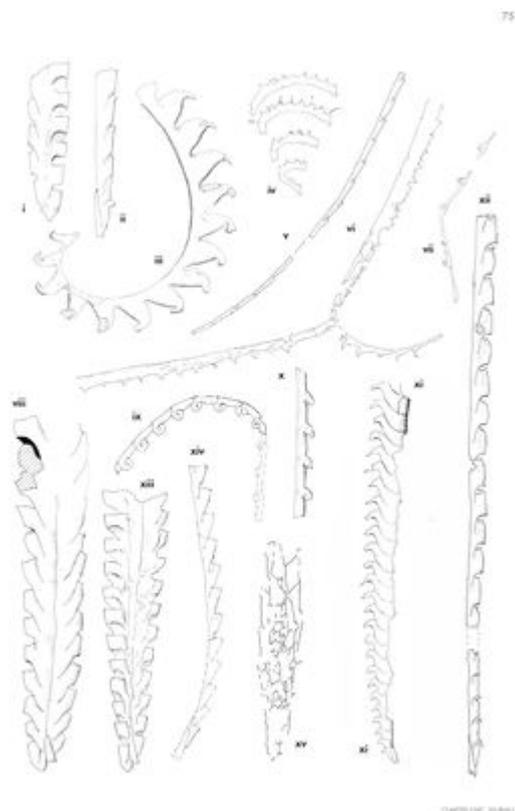


Llandovery Series, Silurian, Wales

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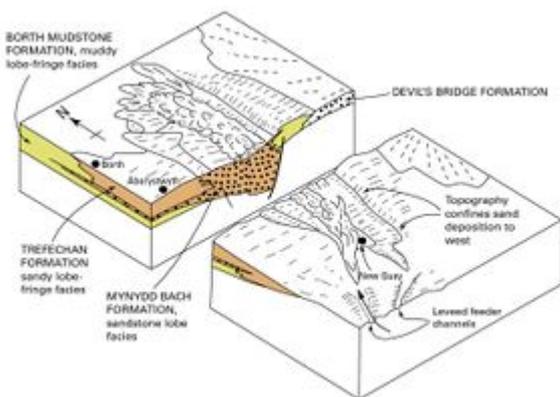
Ordovician (Ashgill) and Lower Silurian (Llandovery to Wenlock) graptolites from Wales. i *Normalograptus arvulus* (Lapworth) X10 ii *Monoclimacis* cf. *crenulata* sensu Elles and Wood X10 iii *Monograptus triangulatus fimbriatus* (Nicholson) X10 iv *Spirograptus turriculatus* (Barrande) X5 v *Atavograptus gracilis* Hutt X5 vi *Cyrtograptus rigidus cautleyensis* Rickards X5 vii *Monograptus gemmatus* (Barrande) X10 viii *Normalograptus persculptus* (Elles and Wood) X10 ix *Streptograptus exiguus* (Nicholson) X10 x *Paradiversograptus runcinatus* (Lapworth) X10 xi *Monograptus flemingii* (Salter) X5 xii *Monoclimacis* cf. *griestoniensis* sensu Elles and Wood X10 xiii *Normalograptus? magnus* (Lapworth) X10 xiv *Plectograptus? bouceki* Rickards X10 xv *Pristiograptus pseudodubius* (Boucek) X10. P916165.



Silurian (Wenlock and Ludlow) graptolites from Wales. i *Saetograptus varians* (Wood) X6 ii *Gothograptus nassa* (Holm) X6 iii *Monoclimacis micropoma* (Jaekel) X6 iv *Pristiograptus* cf. *deubeli* (Jaeger) X6 v *Saetograptus colonus compactus* (Wood) X6 vi *Lobograptus scanicus* X6 vii *Saetograptus clunensis* (Earp) X6 viii *Saetograptus leintwardinensis* (Lapworth) X6 ix *Bohemograptus* cf. *butovicensis* (Boucek) X2 x *Bohemograptus bohemicus tenuis* (Boucek) X6 xi *Spinograptus spinosus* (Wood) X6 xii *Monograptus uncinatus orbatus* Wood X6 xiii *Saetograptus leintwardinensis* (Lapworth) X6 xiv *Monograptus* aff. *unguliferus* Perner X6 xv *Pristiograptus jaegeri* Holland X6 xvi *Lobograptus scanicus* (Tullberg) X6. P916166.



Provenance of the Aberystwyth Grits (adapted from Cave and Loydell, 1997). P916170.



Depositional models for the Aberystwyth Grits (adapted from Davies et al., 1997). P916171.



Harp Rock (Craig y Delyn), Borth. The lowest of the three prominent turbiditic sandstones marks the base of the Aberystwyth Grits Group (Llandovery). P662417.

The type area of the Llandovery Series lies just to the east of Llandovery, in the Tywi valley, and it was here that O T Jones, in 1925, described three 'lithological stages', with 13 lithological subdivisions and specific faunas. Following additional work by A Williams and others, it has been these faunal assemblages that have been the basis of Llandovery correlation ([P916228](#)). For

example, the Rhuddanian Stage was defined at a section in the vicinity of Cefn Rhuddan Farm, the Aeronian Stage from a forestry road section north of Cwm coed Aeron Farm and the Telychian Stage from a section close to Pen lan Telych Farm.

Marine faunas, particularly shelly faunas that were sensitive to water depth, document the extent of the early Llandovery transgression. Nearshore areas were characterised by the *Lingula* brachiopod community and progressively deeper environments by the *Eocoelia*, *Pentamerus*, *Stricklandia* and *Clorinda* brachiopod assemblages. The deep-water basinal environments were characterised by benthic faunas known only from their trace fossils, such as the *Nereites* assemblage, or by planktonic organisms, particularly graptolites ([P916165](#)) ([P916166](#)), which litter the laminae of black and dark grey mudstones.

In early Llandovery times, the shelf formed a narrow zone between western Pembrokeshire and Llandovery, but broadened northwards to include the Berwyn Hills ([P916167](#)). Between Abbeycwmhir at the northern end of the Twyi Anticline and the west Berwyn Hills, Telychian strata overlie Ashgill strata; the unconformity is overlain by graptolitic mudstone and not the coarse clastic deposits that would be expected across a transgressive shoreline. The break represents either nondeposition or removal by slumping. The Llandovery succession is more complete both in the east Berwyn Hills and in the basin to the west. These spatial relationships suggest that the non-sequence indicates the position of the outer shelf and the adjacent upper part of the west-facing submarine slope of early to mid-Llandovery age.

To the south, near Welshpool, Llandovery strata overstep the Ashgill to rest upon strata of Caradoc age. The *Meifodia-Clorinda-Stricklandia* fauna of the basal conglomerate (Powis Castle Conglomerate) may be indicative of relatively deep water, which suggests that the shoreline in this vicinity was probably fault controlled ([P916168](#)). In the vicinity of Llandrindod Wells, the shelf facies, which outcrops east of the Garth Fault, comprises distal shelf-ramp mudstone similar to the slope-apron mudstone to the west ([P916169](#)). Its age ranges from Telychian (Cerig Formation) to early Wenlock (Builth Mudstones Formation), and in the Builth Wells district it rests unconformably on Ordovician strata. In spite of the thickness and facies changes related to penecontemporaneous fault movements, the main influences on sedimentation were changes in sea level. These mudstones (Telychian Stage) crop out around the closure of the Tywi Anticline, between Rhayader and Abbeycwmhir, but, on the eastern side of the anticline, the Telychian sequence rests with marked disconformity both on earlier Llandovery and Ordovician strata. However, slumped and disturbed beds and turbiditic pebbly sandstones (Henfryn Formation) overlie the disconformity, and have been interpreted as the result of coeval movement along the Tywi Lineament. This would confirm an erosional model for the dis-conformity rather than a non-depositional slope.

At Llandovery, the sequence is up to 1200 m thick with possibly one internal unconformity. It has been divided into eight formations comprising mudstone and fine-grained sandstone with parallel and cross-laminations, accompanied by a few thin, fine-grained, micaceous shelly sandstones and calcareous sandstones that are deeply weathered to rottenstones. However, the biofacies is distinctive, and L R M Cocks and co-workers have correlated the evolutionary lineages in brachiopod faunas to the graptolite and acritarch biozones. The mud-dominated deposition of the shelf sequences reflects relative stability, and the sandstone beds indicate periodic storm events.

A similar mudstone-dominated sequence can be traced south-westwards into the northern limb of a syncline in the vicinity of Haverfordwest, but in the inliers, on the south limb, the facies is more distinctly littoral. For example, at Rosemarket, conglomerates and sandstones (Rosemarket Beds) of Telychian age, with fossils representative of the *Pentamerus* and *Clorinda* Communities, unconformably overlie Precambrian rocks, and at Marloes similar strata overlie the Skomer Volcanic Group.

The Skomer Volcanic Group, up to 1000 m thick, is well exposed about Skomer Island, Midland Island and the Marloes peninsula. Because of the proximity of the group to the outcrops of lower Ordovician volcanic rocks, it had been regarded as Arenig in age. However, the volcanic rocks are interbedded with, and overlain by, sedimentary rocks that contain upper Llandovery faunas (Coralliferous Group) and particularly those of the nearshore *Lingula* and *Eocoelia* Communities. The conformable boundary with the Wenlock Series is contained within the Coralliferous Group. The most abundant rock type in the Skomer Volcanic Group is basaltic lava and some of the flows are pillowed, indicating subaqueous emplacement. However, other flows with distinctively reddened top surfaces suggest subaerial weathering during temporary emergence. Flow-banded rhyolites, such as that at Garland Stone, are thick, generally restricted in extent and, unlike the basalts, shed much clastic debris into the associated sedimentary environment. Finely laminated, acidic dust tuffs occur low in the sequence and much volcanoclastic material is incorporated into debris flow deposits. A thin acidic ash-flow tuff near the top of the sequence provides a clear datum plane eastwards between Mew Stone and The Neck, on the south and west of Skomer Island, to Midland Island, and just south of Jeffry's Haven on the mainland. The volcanic group is unconformably overlain by conglomerate and sandstone, which in turn are overlain by green siltstone with thin bentonite beds. Evidence of early Silurian volcanic activity of broadly similar chemical character was determined in a borehole near Maesteg, and farther east in the Tortworth inlier in Somerset. The chemical signature of some of the widespread bentonite bands in the Welsh borders and across the Midland Platform has facilitated correlation, but the source of the volcanic dust has not been identified; it is possible that the activity was sited on the southern edge of Laurentia.

West of Rhayader, a slope-apron facies, deposited within the basin, comprises thinly bedded mudstone turbidites (derived from the east) with interbedded hemipelagites. The mudstone turbidites are variably siltstone/mudstone couplets, structureless or graded mudstone, or silt-laminated mudstone capped by graded and/or structureless mudstone. The hemipelagites are laminated or burrowed; the laminated types display delicate, continuous alternations of dark grey carbonaceous laminae and pale grey silty laminae. The sparse bioturbation and the preservation of organic debris support accumulation in anoxic bottom water conditions. Where bioturbation does occur, the hemipelagites are pale grey and without discernible carbonaceous debris; they indicate relatively oxic bottom conditions and the pale colour reflects destruction of organic carbon by downward migrating oxidation fronts.

The character of the hemipelagites allowed discrimination of anoxic, oxic and mixed slope-apron facies to the west of Rhayader ([P916169](#)). During Rhuddanian (Cwmere Formation) and late Aeronian (*M. sedgwickii* Shales) times, the influx of terrigenous silt was reduced and anoxic facies sedimentation was established. With the mixing of the basin waters and a higher silt input, an oxic facies was established in Aeronian times (Derwenlas Formation) and early Telychian times (Rhayader Mudstones Formation). A mixed facies formed across parts of the proximal apron (Tycwtta Mudstones Formation), and at the same time there was anoxic facies deposition farther west. Within these dominantly mudstone sequences a complex of channels and lobes of turbiditic, coarse-grained and pebbly sandstones and conglomerates has been distinguished both on the eastern limb of the Central Wales Syncline (Caban Conglomerate Formation; [P662415](#)) and on the western limb (Ystrad Meurig Grits Formation). The determination of the distribution of the internal facies of both these formations, and their intricate relationship with the slope-apron facies envelope, has illuminated the details of the architecture of this ancient system ([P916169](#)).

As the sea transgressed eastwards across the Midland Platform in late Llandovery times, the amount of sediment delivered into the Welsh Basin from the east waned considerably. Simultaneously, there was a progressive increase in the influence of northerly directed channel systems from a landmass (Pretannia) to the south.

Reconstruction of the basal sequences in central Wales, in the Llanilar-Rhayader area, has shown that after the deposition of the Caban Conglomerate Formation there were three main events when sand was distributed widely in the mud-dominated sediments of the basin. The earliest, in early Telychian times (*turriculatus* Biozone s.l.), forms the striking sequences in the sea cliffs around Aberystwyth (Aberystwyth Grits Group) ([P662416](#)). The formation comprises turbiditic sandstone and mudstone in variable proportions; the sandstones rarely exceed 0.3 m in thickness. The sequence was one of the earliest to be ascribed to density current deposition, and was described, in a seminal paper, by A Wood and A J Smith. In addition, there are many folds and dislocations within these outcrops that have caused much debate as to whether they are the result of early soft-sediment deformation or later tectonic deformation.

The base of the Aberystwyth Grits Group is exposed at Harp Rock ([P662417](#)), near Borth, where it conformably overlies the Borth Mudstone Formation, and it crops out to the south, to beyond Newquay. The turbiditic sandstones are generally fine grained, and sedimentary structures such as flute casts, groove casts, bounce casts, grading and convolute lamination are abundant. In the northern part of the outcrop, where the turbidity currents were distal, dilute and non-erosive, thin, black, pyritous, graptolitic and carbonaceous mudstone beds are common. The mudstones indicate brief intervals of anoxic bottom conditions, which later became dominant.

The problems of the distribution of the Aberystwyth Grits Group facies ([P916170](#)), ([P916171](#)) and its lateral relationships are typical of all these diachronous Llandovery formations. The group shows marked changes from south to north with increasing distance from source, and from west to east towards the Bronant Fault. The Borth Mudstones Formation, which clearly underlies the group near Borth, is, at least in part, the lateral equivalent, and the graptolite faunas are closely comparable; the group lies entirely within the *turriculatus* Biozone s.l. In sharp contrast to the eastward derivation of the underlying formations, the turbiditic element of the Aberystwyth Grits Group was derived mainly from the south; the current outcrop represents part of a turbidite fan. This change in provenance is considered to reflect contemporaneous tectonic and volcanic activity in Pembrokeshire.

In Telychian times, the eastward margin of the southerly derived turbidite systems migrated progressively eastwards ([P916169](#)). Within the Central Wales Syncline, the Cwmystwyth Grits Group comprises thinly bedded turbiditic sandstone/mudstone couplets, with lesser hemipelagites. However, it includes abundant thick-bedded turbiditic sandstones, which have been given local names (Rhuddnant Grits and Pysgotwr Grits formations). The thickness of the group and its constituent formations vary considerably, and some of these changes are controlled by major faults. The high-matrix sandstones of the Rhuddnant Grits form beds up to 1.5 m thick, and occur in packages up to 50 m thick. A concentration of high-matrix sandstone at the base (Llyn Teifi Member) is well exposed in the crags about Llyn Teifi. There is no systematic distribution and the sandstone lithologies pass laterally into turbidite sequences that are dominated by thinly bedded sandstone/mudstone couplets (Glanyrafon Formation). However, the dominant transport directions are from the south. On the western limb of the syncline, the lower part of the Rhuddnant Grits Formation spans the late *turriculatus* Biozone while the top encompasses much of the *crispus* Biozone. In contrast, most of the formation on the eastern limb lies within the *crispus* Biozone ([P916228](#)).

Similar high-matrix sandstones are the dominant lithology of the Pysgotwr Grits Formation, which crops out about Llyn Cerrigllwydion and in the upper reaches of Afon Ystwyth. They were derived from the south, and the sequence spans the *crispus* and *griestoniensis* biozones. By comparison with modern turbidite systems, both the Rhuddnant and Pysgotwr Grits formations are mainly of the median sandstone-lobe facies, and the amalgamated beds of the Llyn Teifi Member are of proximal settings. The systems did not evolve by the free progradation of sandy fans but were tectonically

controlled — the sandy (proximal) facies are anchored by bounding faults and prevented from prograding over less sandy (median to distal) facies.

Into north Wales, Llandovery rocks form a narrow outcrop along the northern limb of the Derwen Anticline to the vicinity of Cerrig y Drudion, and a restricted outcrop, at Capel Garmon, on the west side of the Conwy Valley Fault. Farther north, a narrow outcrop of blue black shales (Gyffin Shales) between Conwy and Deganwy is where G L Elles began her pioneering studies on the stratigraphical importance of the graptolite faunas. The Bryn Dowski Mudstone Formation, which spans uppermost Ashgill to middle Llandovery, comprises dark grey hemipelagic mudstone that is graptolitic in places, turbiditic mudstone and pale burrow-mottled mudstone. Towards the top of the sequence (Telychian Stage), black graptolitic mudstone is overlain by pale, mottled grey-green, turbiditic and hemipelagic mudstone (Pale Slates). The strata are closely comparable with coeval sequences in mid Wales and suggest tectonic quiescence. Similar, but less complete deep water mudstones occur at Parys Mountain on Anglesey and close to Llanystumdwy on Llyn. At both localities, there is no indication of the influence or the proximity of the north-western edge of the basin. In south-east Wales, at the south-western edge of the Midlands Platform, borehole and geophysical data have proved thick basinal accumulations of early to mid Llandovery strata, unconformable on Tremadoc strata, in the Woolhope and probably Usk basins.

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