What’s in the Welsh Basin?: insights into the evolution of Central Wales and the Welsh Borderlands during the Lower Palaeozoic

David Schofield


During the first half of the 20th century, geological studies in the region were led by Professor O.T. Jones. By 1912 he had proposed an overall structure for the region, within which sediments had been transported from an uplifted area underlying much of England into the deep water of the Welsh Basin. Together with his colleague and lifetime friend, W.J. Pugh, who subsequently became director general of the Geological Survey they identified extensive volcanic activity around Builth Wells.

The current phase of work by the BGS started in the mid 1980’s and has largely been driven by the requirement to complete 1:50,000 scale geological map coverage of Wales and the Welsh Borderlands. High quality academic studies have been conducted in the area and the results need to be integrated with the Survey’s mapping. This new phase commenced with a transect across the central part of the Welsh Basin in the Rhayader and Llanilar districts, aiming to establish a workable stratigraphy for the turbidite sequences within the basin informed by new concepts on deep marine sedimentology, sequence stratigraphy and the relationship between depositional facies, eustacy and tectonics.


The British Geological Survey (BGS) has a long history of geological study in the Welsh Basin starting in the mid 19th century under the directorship of Sir Henry Thomas de la Beche, founder of the Geological Survey of Great Britain, and subsequently under Sir Roderick Impey Murchison who had earlier undertaken pioneering stratigraphic studies in the area, at the same time as the Reverend Professor Adam Sedgwick.

During the first half of the 20th century, geological studies in the region were led by Professor O.T. Jones. By 1912 he had proposed an overall structure for the region, within which sediments had been transported from an uplifted area underlying much of England into the deep water of the Welsh Basin. Together with his colleague and lifetime friend, W.J. Pugh, who subsequently became director general of the Geological Survey they identified extensive volcanic activity around Builth Wells.

The current phase of work by the BGS started in the mid 1980’s and has largely been driven by the requirement to complete 1:50,000 scale geological map coverage of Wales and the Welsh Borderlands. High quality academic studies have been conducted in the area and the results need to be integrated with the Survey’s mapping. This new phase commenced with a transect across the central part of the Welsh Basin in the Rhayader and Llanilar districts, aiming to establish a workable stratigraphy for the turbidite sequences within the basin informed by new concepts on deep marine sedimentology, sequence stratigraphy and the relationship between depositional facies, eustacy and tectonics.

1British Geological Survey, Keyworth, Nottinghamshire, UK. E-mail: dis@bgs.ac.uk

BACKGROUND

It would take a book to describe the geology of the Welsh Basin, for which the recently published British Regional Geology for Wales serves admirably (Howells, 2007). The purpose of this paper is rather to focus on new developments, which primarily concern the Lower Palaeozoic Welsh Basin, illustrated in Figure 1 as much of the area underlain by Cambrian, Ordovician and Silurian rocks and is based on the presentation made by the author to the Society on 13th February 2008.

The Welsh Basin comprises a great thickness of Lower Palaeozoic sediment and represents a zone of enhanced, punctuated subsidence of the continental lithosphere throughout that period of geological time. Much of the dynamic change within the basin developed in response to plate tectonic forces generated by the creation and break-up of the Gondwana supercontinent. It was on the margins of this supercontinent that much of Southern Britain lay, on a microcontinental fragment known as Eastern Avalonia (Figure 2). Wales and surrounding parts of the British Isles lay on a segment of Eastern Avalonia, at the edge of the supercontinent.

Figure 1. Outline Bedrock Geology map of Wales and adjoining areas prepared by the British Geological Survey. © NERC, all rights reserved.
eventually leading to rifting, subsidence and creation of the Atlantic oceanic crust and subsequent foundering of the affected continental margins, such as the southern Irish Sea (Cope, 1994). The renewed erosion of the surrounding elevated rim, including central Wales, in the early Tertiary created the basic landscape seen today, modified by a series of Quaternary ice ages and their aggressive glacial and periglacial weathering regimes (Lewis & Richards, 2005).

**GEOLOGICAL STUDIES**

The study of the geology of the Welsh Basin has been as sporadic as the tectonics. Murchison and Sedgwick carried out pioneering stratigraphic studies in the eastern and northern regions respectively (e.g. Sedgwick & Murchison, 1836), defining the Silurian and Cambrian Systems but famously leading to an almost irreconcilable dispute due to the overlap in their stratigraphies, only resolved after their deaths by the conception of the Ordovician by Charles Lapworth (1879). The British Geological Survey (Geological Survey of Great Britain as it was then) conducted a systematic mapping programme across the region in the 1840’s and 1850’s but, by today’s standards, only at a reconnaissance level of detail.

It was almost a century before the area was mapped in detail, driven by academic studies based initially largely at the Universities of Birmingham, Cambridge and the University College of Wales at Aberystwyth, the latter under the guidance of Professor Owen ("O.T.") Jones, who was succeeded in 1919 by his student, colleague and lifetime friend (Sir) William Pugh when Jones moved to Manchester University. Jones was the first to publish a substantial area of mapping (1909), then jointly with Pugh (1916), followed by a number of their students, notably K.A. Davies (1926), former Director of the Uganda Geological Survey.

Their mapping of the Welsh Basin continued for the next three decades; greater detail was provided by Bassett (1969) within the benchmark volume edited by Alan Wood arising from the 1967 symposium held at the University College of Wales, Aberystwyth, in honour of Jones and Pugh (Wood, 1969). This symposium inspired further mapping studies (e.g. Kelling, 1968; Kelling & Woollands, 1969; Holland et al., 1979)
and the first applications of modern sedimentological concepts within the basin.

Specific areas were the subject of detailed studies by academics and their research students. One important group was based at Manchester under Jones’ direction, notably the mapping of the Builth Wells area by Stephen Straw, the inspirational supervisor of the founder members of the Ludlow Research Group (LRG) (Straw, 1937). The LRG was to subsequently undertake important mapping and stratigraphical studies across the central Welsh Basin and into the Welsh Marches during the second half of the century (Rosenbaum, 2008).

**APPLIED GEOLOGY**

Geology has a considerable impact on the lives of those who live in the area. Mineral extraction is still important to local development; groundwater resources are a major concern for both domestic consumption and commercial use; the landscape attracts tourism and its configuration determines the potential for sustainable development of the region. It is the responsibility of the BGS to maintain and develop the nation’s understanding of its geology to improve policymaking, enhance national wealth and reduce risk.

Throughout the 19th century geological surveying was driven by national strategic priorities such as securing primary resources, including coal and metalliferous minerals, and understanding aquifers in the light of increasing domestic and industrial water demand for the growing urban centres. Present day drivers of BGS activity include meeting the demand from local and regional authority planners and other public sector bodies for accurate geological information. This is largely to provide knowledge of ground conditions in support of regional planning, safeguarding mineral resources and mitigating natural and anthropogenic hazards including pollution, flooding, landsliding and environmental change. A long history of industrial activity within the Lower Palaeozoic Welsh Basin has provided a strong mandate for the recent phase of BGS activity and has informed the following account.

The central parts of the Welsh Basin, underlying the Cambrian Mountains, are host to extensive metalliferous mineralisation known as the Central Wales Mining Field. This has seen a long history of exploitation: copper was mined at Cwmystwyth in the Bronze Age (Bevins, 1994) (Figure 3) and gold mining is known from Roman times (e.g. Dolaucothi); lead, silver and zinc mining reached its peak in the mid 19th century but had all but ceased by the 1930’s. From time to time it has become economically feasible to re-work some spoil tips for minerals, or indeed necessary to reclaim individual mine sites. However, such activities require careful planning as disturbing mine waste could expose toxic materials or lead to enhanced solubility of sulphide minerals exposed to rainwater, resulting in possible surface and groundwater contamination.

The distribution of most of these mineral deposits is determined by stratigraphy (lithology) and structure (folding and cleavage formation in relation to topography). However, the metalliferous mineral deposits frequently occur where there is a relationship between fault movement and fluid migration. It is thought that these ores, mostly lead and zinc sulphides, were deposited in Ordovician and Silurian times as metals in ionic form, widely disseminated in the host sediments and scavenged by warm hydrothermal fluids accumulated in fracture systems where sudden depressurisation eventually led to precipitation in a concentrated form during Devonian and Carboniferous times (Davies et al., 1997).

An extensive network of dams and reservoirs linked by aqueducts for urban water supply
developed over one hundred years from the late 19th century; borrow pits and quarries for roadstone have accompanied the development of surfaced roads since Georgian times; and demand for construction materials (building stones, roofing slates, etc.) has created a large number of small workings scattered throughout the area.

**PALAEOGEOGRAPHY**

**Precambrian**
The fragments of crust (‘terranes’) underlying the Welsh Basin were formed towards the end of the Precambrian, largely in an island arc setting adjacent to the so-called Amazonia region of Gondwana, now part of South America (Samson et al., 2005). These migrated around the margins of Gondwana, but were reassembled by Cambrian times to form Avalonia (Pharaoh & Carney, 2000). Examples include:

- Wrekin Terrane (exposed in the borderlands e.g. Malverns; Wrekin; Primrose Hill; Rushton)
- Cymru Terrane (underlying much of Wales e.g. St Davids; Harlech Dome, proven in boreholes)
- Monian Composite Terrane (exposed on Anglesey and the Llyn Peninsula)

**Cambrian**
By the Early Cambrian the terranes were probably assembled into a coherent block, uplifted in the vicinity of Anglesey and the Welsh Borderland with a basin in between: now the Harlech Dome of Gwynedd and St. David’s succession in Pembrokeshire (Figure 4). The driving force for deposition at that time was probably related to Laurentia rifting away from Gondwana and the Iapetus Ocean opening up. However, little is known of the detailed geometry of the proto-Welsh Basin at that time. Hence, developing new Cambrian expertise and tackling this scientific issue will be one of the aims of BGS activity in NW Wales in the coming year.

**Ordovician**
In the Tremadoc (early Ordovician) Iapetus began contracting, and subduction zones developed on both Avalonian and Laurentian margins. Above retreating oceanic subduction zones (e.g. van Staal et al., 1998 and references therein).

In North Wales and Pembrokeshire volcanism typical of a volcanic arc setting provides evidence for the effects of subduction during the Tremadoc. At the end of this Stage, basin uplift and deformation occurred (as can be seen, for example, at St Tudwals on the Llyn Peninsula; Figure 5), accompanied by low grade metamorphism. Could this be due to a tectonic event? A similar scenario has been recorded in North America, where uplift is thought to coincide with island arcs colliding with the continental margin followed by renewed subduction (van Staal et al., 1998).

A renewed cycle of subsidence and marine transgression commenced during the next stage of the Ordovician, the Arenig. Deposits from the margins of this rejuvenated basin are preserved in the Llanvirn record of the Llandeilo area. These were carefully studied by Alwyn Williams (1952) who produced a detailed stratigraphy based on sections in Dinefwr Park (owned by the National Trust), railway cuttings at nearby Ffairfach and adjacent ground south of the River Tywi. The succession comprises massive coarse clastic sediments probably deposited from submarine debris flows overlain by shelfal fossiliferous limey sandstones and mudstones that record both the action of waves and periodic storm events that attest to their shallow marine setting (Figures 6, 7 and 8). Volcanic activity at this time attests to renewed subduction following Tremadoc plate readjustment.

Towards the Late Ordovician, during the Caradoc Stage, volcanic activity reached its peak, with volcanic centres developed in North Wales, Pembrokeshire and along the Welsh Borderlands Fault System (WBFS), including the Builth Wells, Llanwrtyd and Shelve volcanic inliers. Extruded rocks have compositions more akin to back arc setting that attest to the relative inboard position of the basin compared to that of the Tremadoc, possibly following accretion of a long excised, outboard terrane during that period of later Tremadoc deformation and uplift.
Figure 4. Possible Cambrian palaeogeography for Wales. At that time basin subsidence led to deposition of thick units of mature sandstones that either formed part of a contiguous basin or a series of separate rift basins. These developed as Avalonia split away and migrated along the continental margin of Gondwana. © NERC, all rights reserved.

Figure 5. During the early Ordovician, the effect of contraction of Iapetus became apparent from the extrusion of subduction-related magmas in North Wales and Pembrokeshire. This culminated in an episode of basin uplift and low grade metamorphism before renewed onset of subsidence in the Middle Ordovician (Arenig). The photograph shows an example of the resulting sub-Arenig unconformity from St Tudwals on the Llŷn Peninsula. © NERC, all rights reserved.

Widespread volcanism finished at the end of the Caradoc, implying that Iapetan oceanic crust had ceased to be subducted beneath this part of its continental margin. The end of the Caradoc was also marked by widespread deposition of carbonaceous material: the so called Caradoc Black Shales including the Nod Glas Formation of North Wales. This event may reflect elevated concentrations of atmospheric carbon dioxide released from the extensive late Caradoc volcanoes, or changes in oceanic circulation related to the onset of a significant period of global cooling (ie. onset of icehouse conditions) and forms the focus of ongoing research by BGS geologists and university collaborators. Deposition within the basin from Caradoc through to Late Silurian times is recognised to have been dominated by formation of a broad
continental slope apron where dilute, mud-dominated turbidity currents periodically sloughed off the continental shelf to form distinctive thin ‘event-beds’ (e.g. Davies et al., 1997). Intervening with these, normal background sedimentation comprised the slow rainout of mostly organic material from the water column to form delicately laminated hemipelagite beds. Key to understanding the evolution of the succession during this time is the recognition of contrasting sea-floor environments, preserved by the dominant turbidite mudstones:

1. Oxic facies mudstones were deposited where sufficient oxygen was present at the sediment-seawater interface to support a varied in-fauna, giving rise to burrow-mottled pale grey mudstones with infilled burrows and apatite (phosphatic) cement. These conditions appear to correlate with times of falling sea level, corresponding to a marine regression (Davies et al., 1997).

2. Conversely, anoxic facies mudstones were deposited where seawater was strongly stratified; the sediment was oxygen depleted, there was little life or bioturbation, and organic material was preserved. These conditions occur as sea level rises, corresponding to a marine transgression, or episodes where there is abundant carbon in the atmosphere.

3. Restricted areas of deposition of sand-dominated turbidite bodies entering into the mud-dominated slope apron, whose genesis was largely controlled by active tectonics, in particular uplift along the basin margins that distributed sandy detritus through turbidite channel and lobe systems into the slope apron.

This latter characteristic is illustrated in Caradoc rocks exposed in the south of Cardigan Bay. Here, interbedded sandstone and mudstone turbidites record local reactivation of subsidence by tectonic activity (Figure 9) resulting in large volumes of coarse clastic material being resedimented within a narrow, fault bounded tract within an otherwise mudstone-dominated continental-slope apron (Davies et al., 2003).

Investigating the distribution of the mudstone facies and coarse clastic deposits has enabled understanding of both eustatic (sea-level) changes and the influence of active tectonics on facies architecture during the evolution of the Welsh Basin. Throughout the Caradoc to Late Silurian development of the basin, it can be shown that there were a number of regressive-transgressive cycles that reflect both the far field eustatic and tectonic changes and more localised intra-basinal effects.

Late Ordovician, Ashgill Stage, deposition, along with the early Silurian, Llandovery Stage deposits, underlie much of the Central Wales region (Figure 1). In the light recent Lower Palaeozoic research, the evolution of this part of the succession is now interpreted in relation to two new concepts:

1. the influence of active fault displacement, and
2. the impact of global cooling and the onset of glaciation on the main continent of Gondwana (which at that time was centred over the South Pole).

A global drop in sea level during the Ashgill is reflected in the formation of strongly bioturbated turbidite mudstones in the lower part of the succession, possibly reflecting changes in ocean circulation accompanying the onset of global cooling; while rapid growth of the adjacent shelf areas in response to continued falling sea-level preserved in the upper part of the succession gave rise to instability of the basin slope and widespread slumping (Figures 10 and 11).

The acme of the glacio-eustatic regression during Hirnantian times is characterised by faunas adapted to cold water conditions and development of widespread emergence on the adjacent contemporary shelf area to the southeast (Figure 12; e.g. Davies et al., in press).

Intra-Ashgill tectonism is recorded on the basin margin in the Shelve Inlier. Here, uplift and folding may reflect larger-scale plate adjustments such as collision of the Baltica palaeo-plate (now underlying much of Scandinavia) with Avalonia. Within the basin itself, this event was marked by localised deposition of coarse clastic material, conglomeratic debris and sandy turbidites that spilled off the shelf as it was uplifted, punctuating the mud-dominated continental-slope apron (Figure 13). An example of this is preserved around Llanwrtyd Wells where deposits of the Bryn Nicol and Taliiars formations are interpreted to be confined by active faults (Figure 14; Schofield et al., 2004; Schofield et al., in press a).
Figure 7. Carn Goch, an ancient hill fort where the Ffâirfach Grit is most significantly exposed. © NERC, all rights reserved.

Figure 8. An interpretation of Middle Caradoc palæogeography. © NERC, all rights reserved.

Figure 9. An example of the Caradoc succession from the south of Cardigan Bay. Rhythmically interlayered turbidite sandstone and mudstone beds locate a former the infill an active submarine graben at this time. Davies et al. (2003). © NERC, all rights reserved.

Figure 10. The late Ashgill Yr Allt Formation is characterised by monotonous, locally poorly organised mudstone deposited during sea level, illustrated here in Cardigan Bay. Davies et al. (2006a). © NERC, all rights reserved.

Figure 11. Glacio-eustatic regression at the end of the Ashgill gave rise to rapid expansion of shelf areas and resulting instability of the adjacent slope apron. Hence the late Ashgill is marked by abundant slumped mudstone deposits such as these from the Yr Allt Formation. Davies et al. (2006a). © NERC, all rights reserved.

Figure 12 is located a few pages further on.
apron succession was punctuated by narrow, point sourced units of coarse clastic turbidites recording more localised tectonic events and the influence of higher frequency changes in sea level.

The general depositional model for the basinal Llandovery is one in which easterly-derived slope apron turbidites thin westward toward the basin floor. These are overlain by southerly-derived sandstone-rich turbidites of Telychian age. A schematic facies and system architecture diagram for the Rhayader and Llanilar district (Figure 16; after Davies et al., 1997) reveals the slope apron succession interleaved with sandstone-rich turbidites strongly localised by active faults within the basin. The mudstones themselves comprise a lower unit of anoxic facies deposited during post-glacial sea-level rise overlain by strongly bioturbated oxic facies mudstones deposited during the onset of renewed regression (Figures 17, 18 and 19).

Figure 13. The Shelvian Orogeny, a period of deformation within the WBFS, was marked by deposition of coarse clastic material; conglomeratic debris flows and sandy turbidites, that spilled off the shelf as it was uplifted, punctuating the mud-dominated continental slope apron. These are illustrated here from near Talgarth in the Llandovery district. Schofield et al. (in press a).

Figure 14. Distal effects of the Shelvian event can be interpreted in terms of sedimentation confined by active faults, for example the Llanwrtyd Fault of the Builth Wells district where coarse grained deposits of the Bryn Nicol Formation are confined in the hanging wall of the structure, as illustrated on this block diagram. Schofield et al. (2004. © NERC, all rights reserved.

Silurian

During the Llandovery, the lower division of the Silurian Period, the Welsh Basin was subdivided into northern and southern sub-basins along the axis of the uplifted Berwyn Dome and Derwen Horst, adjacent to the Bala Fault. A broad shelf area to the southeast was coincident with the WBFS, its edge located within the Tywi Anticline (Figure 15). Slope apron sedimentation was influenced by post-glacial sea level rise, giving way to a fluctuating regression culminating in a putative glacial readvance that reached its maximum at the start of the Wenlock. The slope

Figure 15. This proposed palaeogeographic reconstruction for the Llandovery reveals development of northern and southern sub-basins, separated by a system of highs: the Berwyn Dome and Derwen Horst, roughly coincident with the Bala Fault. There is also a broad shelf area to the southeast, coincident with the WBFS and parts of the Tywi Anticline. © NERC, all rights reserved.
The localisation of large southerly-derived sandstone bodies within fault systems of the Central Wales Syncline attests to an episode of Telychian tectonics which has not been satisfactorily related to more regional events, but may potentially record the onset of terminal continental collision between Laurentia and Avalonia. A schematic cross-section (Figure 20) shows how the Telychian sandstone facies might have been fault controlled. Careful dating of these units with graptolites has shown a succession of fault activation and deposit localisation from the centre of the basin, back towards the margin.

The best example of a narrow, early Llandovery (Rhuddanian to Aeronian), point-sourced coarse clastic depositional tract is preserved in the vicinity of Caban Coch reservoir. Here turbidity channel deposits contain enormous clasts (of Avalonian material) and feed a positive lobe feature built up on the contemporary slope apron (Figures 21 and 22). The chronostratigraphic architecture of the Llandovery basinal succession produced by Schofield et al. (in press a) reveals major cyclicity in sedimentation superimposed upon which are the effects of regional scale tectonic events and the influence of lower order changes in sea-level, reflected in a series of point-sourced turbidite channel-lobe systems that punctuate the basin (Figure 23). Sandy facies expansion as sea-level falls or the hinterland uplifts, and contraction as sea-level rises, so giving a good indicator of localised tectonics or changes in basin geometry. The contemporaneous Llandovery shelf, characterised by condensed sequences, with sandstone-rich and shelly sediments and local disconformities, also shows a response to the contemporary basinal events. The fossiliferous strata which make up this succession have a long history of study. Sections exposed around Crychan forest, near the town of Llandovery itself, were proposed by Robin Cocks and co-workers (Cocks et al., 1984) as the world stratotype reference section for the Llandovery Stage. Recent work by the BGS has refined both the biostratigraphic framework and understanding of facies architecture enabling better comparison with the adjacent basinal succession. In particular it has allowed correlation of periods of regression recorded in the basinal succession with expansion of the shallower water shelfal facies and emergence of the more proximal parts and conversely periods of transgression with contraction of the shelf and inundation with deeper water facies (Figure 13; Schofield et al., in press a). This reveals an Hirnantian regression, also a middle Aeronian progradation and, notably, the main Telychian uplift. This was followed by transgression and deposition of the basinal anoxic facies of the Builth Mudstones Formation in the succeeding early Wenlock.

Contrasting coeval basin and shelf successions has revealed considerable detail about fluctuating sea-level and, applying high resolution graptolite biostratigraphy, the timing of localised tectonic events. Together these form a powerful tool for correlation with other basins in the British Isles. The start of the Middle Silurian Wenlock Stage resulted in renewed deposition of anoxic turbidites in the basinal area, indicative of marine transgression that may have marked the end of another episode of ice advance across the Gondwana continental interior. These Early Wenlock anoxic facies turbidites were succeeded by another pulse of axially derived coarse clastic deposition (the Pennsrowed and Denbigh Grits formations) attesting to tectonic reactivation of intrabasinal faults at this time (Figure 24).

An architecture for the adjacent shelf area during Wenlock and Ludlow times was compiled by Holland and Lawson (1963), illustrating marine regression ultimately leading to progradation of terrestrial facies of the Old Red Sandstone across earlier nearshore and shelfal sediments (Figure 25), mirroring the original observations of Murchison in the area. This follows on from the work of Straw in the late 1920’s and 1930’s which was essentially used by Holland and Lawson. However this work was largely biostratigraphic and did not recognise the detailed lateral facies variation that reveal the dynamic evolution of the basin at that time. The recent BGS work (Schofield et al., 2004) presents a somewhat different architecture defined for the Mynydd Eppynt succession of the Builth Wells district (Figure 26).
**Figure 12.** Lithostratigraphic architecture for the Llandovery of the type area, including the Late Ashgill, contrasting older classification schemes with that proposed by Dr. J.R. Davies (Schofield et al., 2008). This diagram also shows that acme of the Ashgill glacio-eustatic regression led to emergence in the contemporary shelf area to the southeast. Schofield et al. (in press b). © NERC, all rights reserved.
Figure 16. Deposition in the central part of the basin during early Llandovery times was dominated by slope and deep marine deposits. This schematic architecture diagram reveals a slope apron of turbidite mudstone thinning toward the basin centre. Interleaved with the turbidites were sandstones strongly localised by active faults within the basin. The mudstones themselves comprise a lower anoxic facies deposited in an oxygen-poor environment (which favours preservation of organic fossil material, particularly graptolites) overlain by strongly bioturbated oxic facies mudstones. © NERC, all rights reserved.

Figure 20. A schematic cross-section to show how early Llandovery sandstone facies might have been fault controlled. Careful dating of these units with graptolites has shown a succession of fault activation and deposit localisation from the centre of the basin, back towards the margin. Davies et al. (2006b). © NERC, all rights reserved.
Figure 17. Example of an anoxic facies turbidite with preserved hemipelagite. © NERC, all rights reserved.

Figure 18. Typical rhythmitic, thinly layered sandstone-mudstone turbidite couplets. © NERC, all rights reserved.

Figure 19. Coarse clastic turbidites of Telychian age. Davies et al. (2006b). © NERC, all rights reserved.

Figure 21. Outcrop of localised, point sourced, coarse clastic turbidites at Caban Coch reservoir (part of the Elan Valley scheme). © NERC, all rights reserved.
Dramatic flooding of the extensive shelf during the earliest Wenlock transgression was followed by progradation of the shelf facies from the southwest during regression. The end of the Wenlock is marked by another marine transgression and return to deeper water sedimentation which gave way to another cycle of regression and progradation of shelf facies that ended in late Ludlow times (around the *leitwardinensis/bohemicus* biozone boundary) with a flooding surface marking renewed deepening followed by shallowing up from proximal shelf facies through to shoreface facies marked by the Tilestones Formation.

This Late Silurian shoreface was inundated by terrestrial deposits of the Old Red Sandstone (ORS) which prograded across the basin margin, effectively marking the end of the basinal record of the Lower Palaeozoic. It is worth noting that the base of the ORS is also diachronous and comes in earlier in the Silurian to the southwest, in Pembrokeshire suggesting that uplift may have progressed from the southern part of the basin, possible starting in Telychian (Middle Silurian) times.
Figure 23. Chronostratigraphic architecture of the Llandovery basin illustrating the expansion and contraction of point sourced turbidite sandstone channel-lobe bodies with time (Schofield et al., in press b). This reveals major cyclicity in sedimentation superimposed upon which are the effects of regional scale tectonic events and the influence of lower order changes in sea-level, reflected in a series of point-sourced turbidite channel-lobe systems that punctuate the basin. This diagram basically shows sandstone facies expansion as sea level falls or the hinterland uplifts, and contraction as sea level rises, so giving a good barometer to localised tectonics or changes in basin geometry. © NERC, all rights reserved.

Figure 26. Chronostratigraphic architecture of the Mynydd Epynt escarpment in the Builth Wells district, illustrating cycles of progradation of nearshore facies from the south. The final cycle of regression is marked by shallowing-up from proximal shelf through to shoreface marked by the Tilestones Formation before the incoming of continental facies of the Old Red Sandstone. After Schofield et al. (2004). © NERC, all rights reserved.
Devonian
A major episode of regional deformation, the Late Caledonian Acadian Orogeny, developed in Middle Devonian times, some 400 Ma. During this episode the basin was uplifted, reactivating existing faults and propagating new ones. Folding was widespread and the formation of a penetrative slatey cleavage imparted a pronounced southwest-northeast tectonic ‘grain’ within the Welsh Basin rocks.

THE FUTURE
The current phase of activity by the British Geological Survey (BGS) started in the mid 1980’s and has largely been driven by the requirement to improve provision of geoscience data and complete 1:50,000 scale geological map coverage of Central Wales and the Welsh Borderland. In this region the Survey mapping was over a century old, providing a level of detail considered insufficient for modern use (Figure 27).

Research commenced with a transect from the basin margin to its centre, across the Rhayader and Llanilar districts (Davies et al., 1997) led by Drs. R.A. Waters (now retired from BGS) and J.R. Davies who is now the BGS Chief Geologist for Wales. The initial studies were aimed at improving provision of baseline geological data, and understanding the facies architecture and the relationships between larger scale processes such as oceanographic and climatic changes and plate tectonics. The work integrated existing academic studies (summarised in Part 4 of volume 95 of the Proceedings of the Geologists’ Association, for 1984, e.g. the papers by Prof. M.G. Bassett and by Dr. N.H. Woodcock) and established a workable stratigraphy within the basinal turbidite succession informed by new concepts on deep marine sedimentology and basin dynamics (Figure 1; Davies et al., 1997).

Careful surveying at the 1:10,000 scale combined with detailed graptolite biostratigraphy and interpretation of remote sensing images has provided new insights into the controls on the development of the Welsh Basin. These include the influence of a Late Ordovician glaciation, centred on the palaeocontinent of Gondwana, that strongly affected sea-level and ocean circulation at that time, and the gradual progress of Caledonian plate collision that brought about changes in the geometry of the Welsh Basin seen through migration of clastic facies through time and space (e.g. Davies et al., 1997).

This approach was developed further during subsequent work in the Builth Wells (Schofield et al., 2004) and Llandovery districts (Schofield et al., in prep a) where important relationships between depositional processes in the basin and those of the adjacent shelf succession in the Welsh Borderlands were investigated.

This included some famous stratotypes such as Alwyn Williams’ type area of the Llandeilo (1952) and has led to substantial revision of stratigraphy in the type area of the Llandovery Stage and Straw’s Wenlock to Ludlow succession of Mynydd Eppynt and the Myddfai Steep Belt (1937). Future plans include utilising modern stratigraphic concepts to re-establish the linkages of the Wenlock to Ludlow succession between the Welsh Basin and the shallow water environments of the Welsh Borderlands, to the east.

Current work in the Dinas Mawddwy district aims to produce the first 1:50,000 scale geological map of this area and build on research into palaeoenvironmental controls on Ashgill and Llandovery sedimentation (Schofield, 2008). Parts of this district were originally surveyed by William Pugh (1928) and Douglas Bassett (1955) and include the contemporary northern margin of the southern Welsh Basin.
ACKNOWLEDGEMENTS

This paper was compiled from the lecture presented by the author in Shrewsbury on 13th February 2008 to the Shropshire Geological Society forming part of the 2008 Darwin Festival, and was edited by Michael Rosenbaum. David Schofield publishes with the permission of the Executive Director, British Geological Survey, NERC.

REFERENCES


Kelling, G. (1968). Submarine channel and fan deposits, Silurian of central Wales, United Kingdom. American Association of


Pugh, W.J. (1928). The geology of the district around Dinas Mawddwy (Merioneth). Quarterly Journal of the Geological Society, **84**, 345–381.


Copyright Shropshire Geological Society © 2009.

ISSN 1750-855x