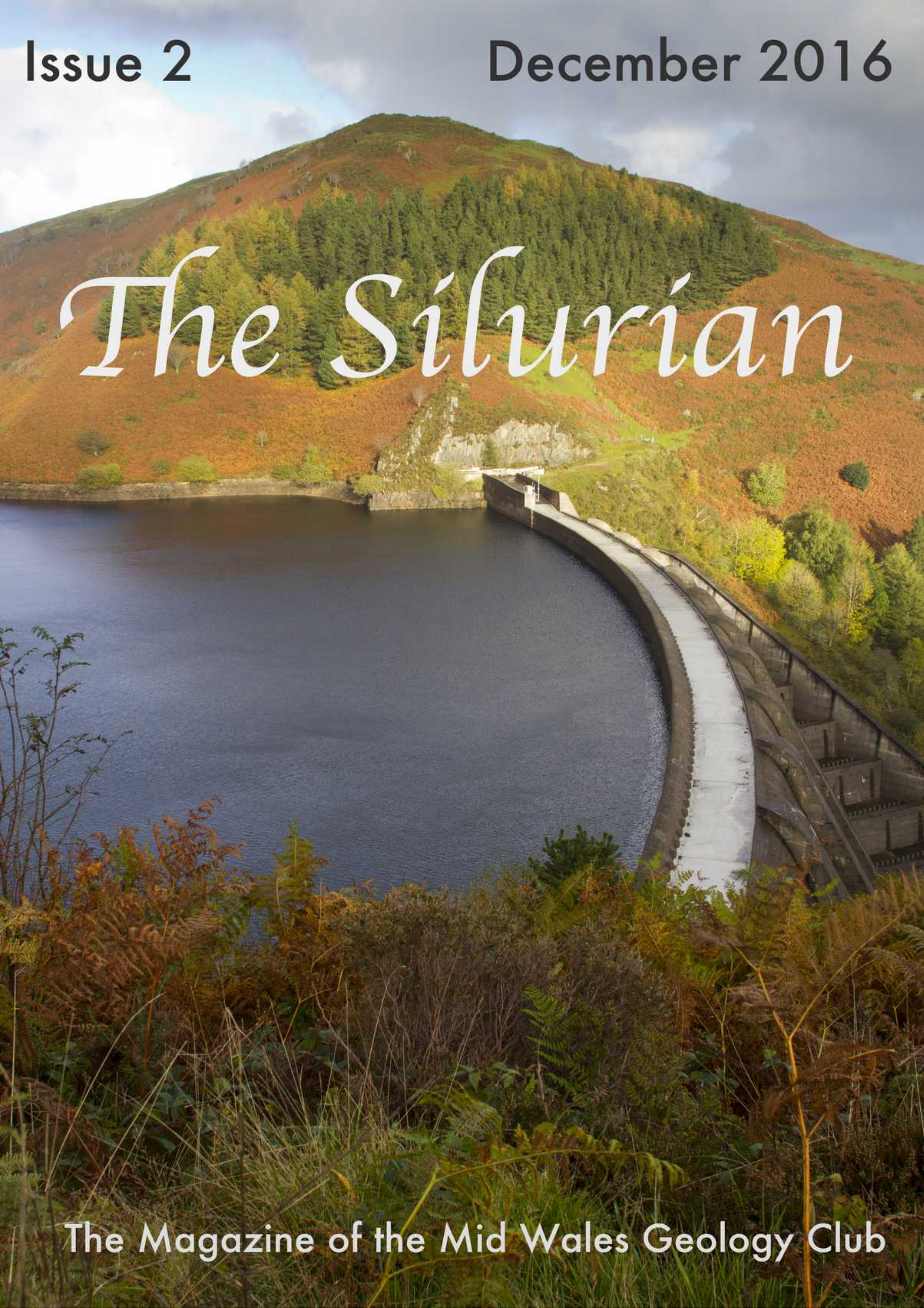
Issue 2 December 2016

# The Silurian



The Magazine of the Mid Wales Geology Club

# Contents



## The Magazine of the Mid Wales Geology Club

**www.midwalesgeology.org.uk**

*Cover Photo: Clywedog Dam ©Richard Becker*

All photographs and other illustrations are by the author unless otherwise stated.



In this issue we report a talk given to the club earlier in the year by Prof. Jerry Davies, a former Chief Geologist for Wales with the British Geological Survey. He and his colleagues considered the way rocks near Llandovery could be interpreted to reveal the cycles of sea level change 440 million years ago, and how a signal of global change caused by periodic collapse of the Antarctic ice sheets could be distinguished from changes wrought by local factors.

In the last article of this issue we have endeavoured to explain how this changing sea level is reflected in rocks of some of the quarries in Hafren Forest. It is a sobering thought that global sea level changes we think were abrupt all those years ago were actually slow compared to the 3.4 +/- 0.4mm per year that NASA tells us is happening now.

Elsewhere in this issue Tony Thorp discusses diamonds (are they really forever?); and one of our members recalls his experience as a junior site engineer as Clywedog dam was beginning to rise from the ground. There is also a short and rather tragic biography of Victorian local geologist Joseph Bickerton Morgan.

All this and more, along with regular pieces from Sara and Bill..

**Michele Becker**

*Hunstanton - base for the club's 2017 Field Weekend. Photo ©Richard Becker*

**Submissions**

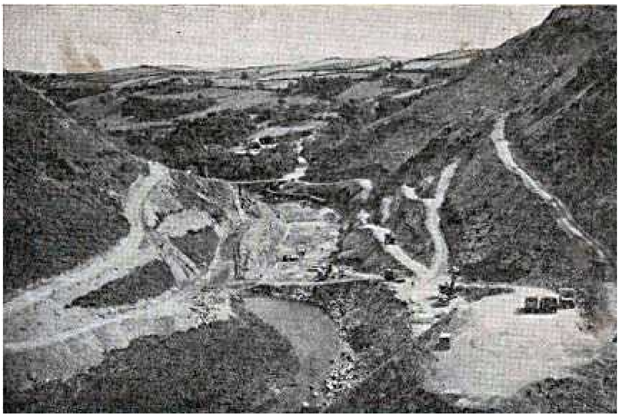
Submissions for the next issue by the beginning of May 2017 please.

Please send articles for the magazine digitally as either plain text (.txt) or generic Word format (.doc), and keep formatting to a minimum. **Do not include photographs or illustrations in the document.** These should be sent as separate files saved as uncompressed JPEG files and sized to a **minimum size of 1200 pixels** on the long side. List captions for the photographs at the end of the text, or in a separate file.

# Learning from Experience:
## my involvement with the construction of Clywedog Dam

My formal studies were over, as was an apprenticeship with Vickers Armstrong. Work in a factory seemed so restrictive and the inverse of the country life I was used to. Civil engineering seemed more attractive than electrical engineering. So in the autumn of 1963 I headed into the hills of Mid Wales, full of excitement, and with some anxiety, to cut my teeth on my first major project.

We had to walk a couple of miles from the start of the access road construction to the V- shaped valley of the Clywedog, with it's rocky river bed and steep sides covered with rough grass and rocky outcrops. I soon learned that my studies did not have much use in this very practical environment. Surveying and setting out gave some insight into the shape of things to come. An experienced practitioner guided us into the intricacies of the theodolite, and other techniques. There was no satellite geodetic assistance in those days. All calculations were done by triangulation with log tables.



*The excavations have started.*

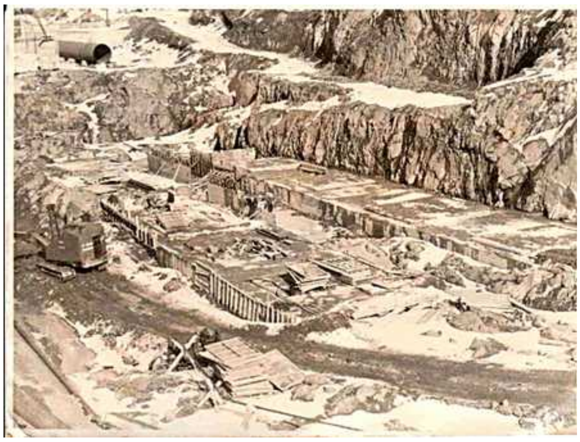
The dam was designed as a double curvature concrete buttress structure, the buttresses fanning out from a radial point upstream of the dam and on the side of the valley as it curved around to the north. The central buttresses would be the most structurally significant with foundations deep into the rock of the valley floor. The dam was to be 72 metres high from the valley floor.

Over the early weeks, local tracks were converted into haul roads, fields were levelled, foundations were laid for offices and other people started to arrive. I was soon involved in the planning of preparatory works for the overhead cableway, the concrete batching plant, a bailey bridge across the river, the quarry and crushing plant, and then pipework for the river diversion to allow foundation construction in the dry. Access roads were cut into the hillside to give access to the buttress foundation at different levels on the hillside, to the concrete batching plant platform and the radial cableway runway and pivot point. As the work progressed, I was discovering another world of Welsh farms and villages and people and girls, mixed with beer and dancing, a controlled and ordered workplace and a wild and unfettered social life. Our presence impinged on the local community, but we didn’t notice and didn’t really care. There were four of us lads, carefree bachelors, living in caravans and squats, all straight out of university. We bought a sailing dinghy between us and raced and sailed in extreme conditions. Our bolthole was Newquay where we camped and drank into the night. Worked hard and played hard!

*Excavations on the south bank.*

But memory plays tricks. The general run of activities is forgotten but a few incidents achieve a longevity beyond their importance or relevance. They are exaggerated and differentiated due to personal involvement and become the jewels in the memories. And, so it is, that certain events became part of the life experiences that make me what I am. So to the anecdotes.

It started with arriving at “the coal face”, the world of logistics, the supply of human resources, of schedules to be met, of programmes to be accessed. As new recruits, we were involved in the peripheral discussions but not involved in the decision making. The start was getting into the ground, “cutting the first sod”. There was little topsoil to remove and the top rock layers were weathered and friable. Below this, the rock had to be blasted with care to prevent disturbing the lower levels of rock foundation. It was done in two stages,first a general blast to outwith 2ft above the foundation levels, (we were still using Imperial units then). This remaining rock, known as “the Popped”, was used to obtain a general foundation



*The first foundations coming out of the ground.*

which was then cleaned and levelled by hand using sand cement mortar to fill the cracks and crevices. Blanket grouting of the sub foundation rock was carried out on a 10ft grid pattern and some 10 to 20ft into the rock ensuring most of the cracks and fissures were filled with mortar. Later, a grout curtain was drilled and grouted 50ft and more into the rock at the up stream toe of the dam to limit underseepage due to the high working water pressure in the valley floor. At the same time, a 10ft diameter steel pipe was installed at the side of the lower foundations in order to carry the river flow during the dam construction. An upstream cofferdam guided the river flow through the pipe and disgorged below the location of the stilling basin (where flow velocity was reduced). The original design had two pipes but a decision to install just one would be rued later.

*The Bailey Bridge access to the north bank.*

The overhead cableway spanned the valley to deliver concrete, plant and equipment to most areas of dam construction. Three derricks were installed, one at the upstream face and at each flank downstream of the dam to cover areas not within reach of the cableway. A rock cutting was made above the south location of the south abutment, above the batching plant and was on a radial curve with its centre at the mast on the north flank. Later, this was the target of some Welsh nationalists who considered the construction of the dam as an English invasion Their explosives delayed but did not stop the works.

*The 'Blondin' carriage on the south bank.*

A rock cutting was created for the concrete batching plant and the access to it, which eventually became the access road to the control house. A 4 cubic yard capacity, split drum mixing plant was elevated on a structural steel frame with a chute to the side that could fill a 4 cubic yard bottom opening skip. This skip would then be in the coverage of the overhead cableway (or blondin as it was called, after the French tightrope walker) and concrete could be delivered to almost every area of the dam.

The quarry was surveyed and the sandstone approved for use as aggregate in the concrete mixes. A large jaw crusher was erected away from the proposed rock face. Conveyors raised the general mixed stone to the screens which separated the different sizes of stone into bins and storage areas. Concreting sand was imported by road from Ellesmere. The quality and gradings of these ingredients was checked by the laboratory set up for the purpose of quality control. The other major ingredient of concrete was a special coarse ground cement produced at Aberthaw in South Wales, brought to Llanidloes station by rail and then in road tankers to be air blown into 50 ton silos above the batching plant.

For me, a great many new experiences were absorbed and stored for future reference; a fast moving and ever changing scene which challenged my previous views and added excitement to life.

Nick Platt

# Member's Photo

***Torquirhynchia inconstans***

This is an Upper Jurassic rhynchonellid brachiopod, approx. 165 million years old, from the Lower Kimmeridge Clays, and was found in Weymouth, Dorset. Like all brachiopods it has an asymmetric commissure, thought to be an adaptation to life in tidal environments.

Janey Haselden

# Sea Level Change in the Geological Past

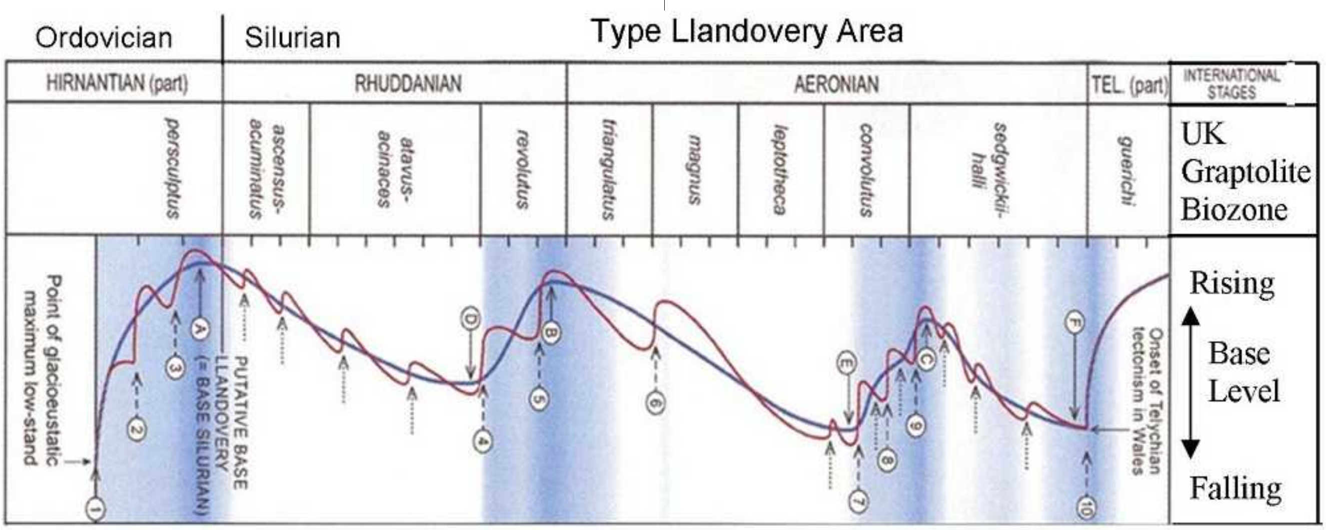
**A talk by Professor Jerry Davies**

Professor Jerry Davies, former chief geologist for Wales with the British Geological Survey, and now honorary professor at Aberystwyth University, gave the February 2016 evening lecture to the club. Titled 'Sea level change in the geological past', the speaker examined the influence of glacioeustasy (effect of polar ice and glaciers on global sea level changes) during the early Silurian in Mid Wales. The rocks surveyed lie in a band some 20 km north-east to south-west, close to the town of Llandovery and are the international type section for the Llandovery, and one of the best studied early Silurian sequences in the world. The Type Llandovery area lay on the south-east margin of the Lower Palaeozoic Welsh Basin, close to the Welsh Basin Fault Zone which controlled the subsidence of the basin at that time, and thus influenced its sedimentation. Plate movement, and therefore tectonism, was ongoing through the Llandovery associated with the closure of the northern section of the Iapetus Ocean.

A new architectural model for the Type Llandovery sedimentary succession was determined, based on fifteen traverses across the area. It takes the form of a cross-section containing the different rock formations. This was then developed into a chronostratigraphical model, a cross-section in which the different rock formations and facies (recognisably different bodies of rock) could be presented with time on the x axis, not in years but in graptolite biozones. This work was based heavily on stratigraphical logging of the lithology and sedimentary structures of the district, and on extensive biostratigraphy. All this formed the basis for inferring the way in which sea level, or more precisely the local drainage datum, called base level, was changing through the time interval. Interpreting the geology to identify changes in the sea level or base level is called sequence stratigraphy.

Deposition during the latest Hirnantian stage (end-Ordovician period) to early Telychian stage (early Silurian period, Llandovery epoch) can be grouped into three major cycles, called simply 'sequences', each of which comprises a period of prograding, when the shoreline advanced seaward by substantial sedimentation during a time of falling sea level, culminating in a sea level lowstand; plus a period of progressive flooding during rising global sea level, culminating in a sea level highstand. In the former, an unconformity can be detected proximal to the shoreline and inferred in the deeper basin, and in the latter a maximum flooding surface can be identified. The low frequency, large amplitude sequences are inferred to be glacioeustatic in origin. Around 20 parasequences (lower order fluctuations) are superimposed on the base level sequences, as shown in the diagram. The parasequences may have their origin in regional forcing factors. Smaller fluctuations (not shown) may sometimes be detected superimposed on the parasequences.

Determination of the extent and timing of these base level changes in the Llandovery Type area is based on biostratigraphy, including graptolites in deeper water and other fossils in shelf and slope areas, where different species of brachiopods in particular are useful depth indicators. This work was reported in Davies et. al. (2013) in Geological Magazine*. It also highlighted a number of changes to the accepted geological architecture of the Type Llandovery area, including prograde sequences not previously identified in the record. Comparison of Type Llandovery area marine base level changes with those in other districts of the UK with Llandovery rocks, including North Wales, the Lake District and the Southern Uplands of Scotland, showed a similar pattern of sequences. This begins to suggest a glacioeustatic cause.




Shaded areas indicate eustasy dominant Extract from Davies et. al. (2016) p102 cropped & annotated

The next step was to take the new Type Llandovery area model global, and see the extent of correspondence with marine base level curves around the world, where 62 datasets were obtained from the literature. These included both global and regional base level curves interpreted from the rock record, in a variety of tectonic settings, together with records of glacial activity, isotope data, changing patterns of facies and fauna, and climate models. The results have now been published by Prof Davies and his colleagues**.

All the datasets have been adjusted to fit into the twelve recognised UK graptolite biozones for the time period, with each biozone being divided into three, giving 36 time slices where available data on base level change from widely different sources could be compared. Where there is a high correspondence of data from different datasets around the world it is likely that eustasy was an important factor in shaping the local events. Conversely, where there is a lower correspondence of sources it is likely that regional influences were dominant, and glacioeustasy less important. Prof Davies adopts a 'eustasy index' to quantify the relative importance of eustasy in base level change, though he stresses that a low eustasy index does not mean that eustasy was unimportant, merely that it was less important than regional factors which may have caused local base level movements to diverge from global trends.

The striking result of this analysis is the proof that the major deepening events in the Llandovery Type area, do indeed correspond with major deepening events elsewhere, with south polar ice sheet disintegration being the dominant forcing factor. But during major progradation sequences in the Llandovery, which occurred during falling base level, regional forcing factors were more important than eustasy. Prof Davies suggested that each time the South Polar ice sheet disintegrated, it did so quickly, with the rise in eustatic sea level being clearly recorded in regional base level changes. However, the advances of South Polar ice and consequent falls in global sea level may have occurred more slowly, and as sediment source areas were exposed and eroded, the epeirogenic response (subsidence of sedimented basins and progressive uplift of eroded areas) quickly outstripped eustasy as the dominant forcing factor. Moreover, the record of regressive events (falling base levels) was less well preserved because of continuing erosion.

Colin Humphrey

** Davies, J.R., et. al., 2013. A revised sedimentary and biostratigraphical architecture for the Type Llandovery area, central Wales, UK. Geol. Mag. 150, 300-332.*

*** Davies, J.R., et. al., 2016. Gauging the impact of glacioeustasy on a mid-latitude early Silurian basin margin, mid Wales, UK. Earth-Science Reviews 156 2016 82-107.*

# Bill's Rocks and Minerals
## Halite (Common salt).

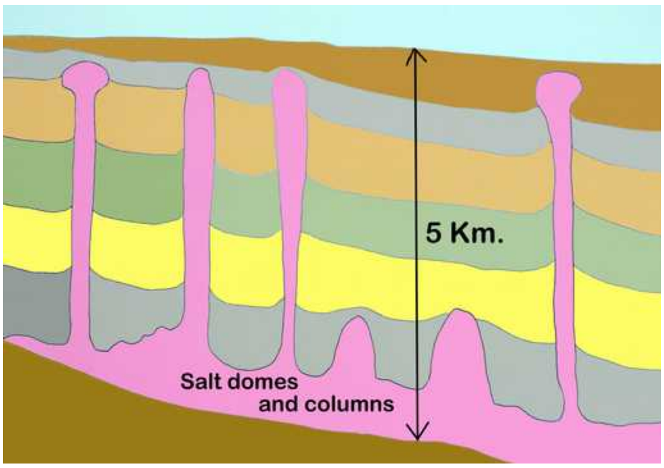
Halite, or common salt is only one of a number of evaporite minerals, some of which are well known to us, for instance, calcite, gypsum, dolomite, borax, anhydrite and magnesite. Perhaps not so well known are, sylvite, kainite, langbeinite, and several more.

**Evaporite minerals**

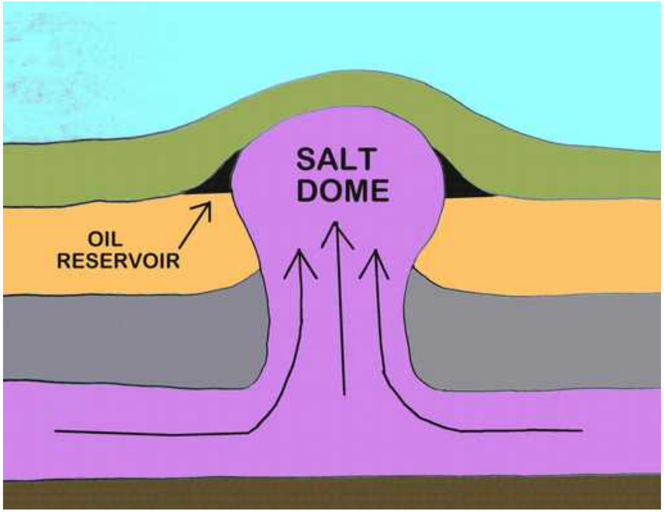
| Mineral class | Mineral name | Chemical composition |
|---|---|---|
| Chlorides | Halite | $NaCl$ |
| | Sylvite | $KCl$ |
| | Carnalite | $KMgCl_3 * 6H_2O$ |
| | Kainite | $KMg(SO_4)Cl * 3H_2O$ |
| Sulphates | Anhydrite | $CaSO_4$ |
| | Gypsum | $CaSO_4 * 2H_2O$ |
| | Kieserite | $MgSO_4 * H_2O$ |
| | Langbeinite | $K_2Mg_2(SO_4)_3$ |
| | Polyhalite | $K_2Ca_2Mg(SO_4)_6 * H_2O$ |
| Carbonates | Dolomite | $CaMg(CO_3)_2$ |
| | Calcite | $CaCO_3$ |
| | Magnesite | $MgCO_3$ |

The first thing to establish is the occurrence of evaporite mineral deposits, in other words, how and where they are formed. They are formed as the result of the evaporation of salt rich bodies of water, and there are two types of depositional environments, marine and non-marine.

Dealing first with marine environments. Typically sea water carries about 3.5% by weight of salts, but the salts won't start precipitating until the water has evaporated to about half it's original volume. For this to happen the sea must be closed off, either by tectonic activity or by lowering sea levels due to glaciation. As the body of water evaporates, the salts or minerals in suspension become more and more concentrated until they are forced to precipitate and form crystalline structures. The first and better known minerals to precipitate from the shrinking body of water are the carbonates calcite and dolomite, followed by the sulphates gypsum and anhydrite, then the



chlorides sylvite and halite. Once the sea has completely dried and the sedimentary layers of salts are deposited the lowered sea basin creates conditions which allows coverage by other sediments such as mudstone and sandstone.




Much of the salt mined from the completed sedimentary layers is from salt domes which may be as large as five miles in diameter. The mechanism that creates salt domes is quite simple. Pressure exerted by overlying sediments on the comparatively fluid salt layer forces it to migrate upwards through those mud and sandstone sedimentary layers, deforming them as it does so, creating salt domes and salt columns, and also creating conditions for oil reservoirs. Most salt domes and columns do not reach the surface, but when they do salt glaciers can be formed. A recommended site to learn more about salt domes is to be found at http://geology.com/stories/13/salt-domes/

*Salt pans at Gozo. Creative Commons by Paul Stephenson.*

Today about 25% of salt production is from the forced evaporation of sea water in very large salt pans. The other 75% of production is from historic deposits, both marine and non marine.

Many non marine deposits of salts are in the form of playas or salt flats, and they are the result of falling water levels in shallow inland basins which periodically fall by evaporation, resulting in the precipitation of their salt content. Usually found in desert areas, and often in close proximity to coastal regions, these basins or playas derive their salt content from ground water, and can cover vast areas. Although the basins are very shallow, often only a few metres deep, they hold vast amounts of salt simply because they are so large. The largest salt flats in the world are at Salar de Uyuni in Bolivia, covering an area of 4000 square miles. Not so large, but still quite substantial are the probably better known salt flats at Bonneville, Death Valley, and Salt Lake in the U.S.A.

*Death Valley salt flats. Creative Commons by Vadim Kurland.*

There are three main types of salt extraction, deep shaft mining, solution mining, and solar evaporation.

In deep shaft mining, the salt from ancient buried deposits and salt domes is found in a compact form as rock salt, with crystals rarely observed, and usually quite discoloured as the result of mineral impurities. Untreated, it is mixed with sand and used as a road treatment in winter conditions. It can also be refined and used as a food additive.


In solution mining, halite is extracted from salt beds by erecting wells which inject water to dissolve the salt, making a brine solution which is then pumped away to the refinery plant for evaporation. This type of salt production is the main source of salt for food additives and industrial processes.

Solar evaporation is a natural process which creates seasonal opportunities for salt harvesting. Salt gathering usually happens once a year when the evaporated salt beds reach a specific thickness. This type of salt production can only occur in areas with low rainfall and a lot of sun, for instance, Australia and some Mediterranean countries.

Halite crystals, although rare in deep mined deposits, are plentiful in playas and salt beds because they are open to air, allowing unrestricted growth. Although halite is typically colourless or clear it is not uncommon for it to have a light pink colour because of the presence of the organism Halobacterium ssp. which live in the brine. On the Mohs scale halite has a hardness of 2.5 which is about the same as your finger nail, and the crystals are cubic with perfect cleavage, and a conchoidal fracture.

Halite crystals have an interesting habit of sometimes displaying " hopper growth", a habit which is also known


*Hopper crystals. Creative Commons R. Weller/Cochise College.*

in several other minerals. Hopper is a descriptive term of the appearance of dished faces in the crystal which happen because of a combination of fast growth, and preferential growth on the corners and edges of the crystal.

For an informative site on salt production and salt evaporates a visit to the website below is recommended.
www.slideshare.net/hzharraz/topic-6-evaporite-salt-deposits

Bill Bagley

To see more of Bill's minerals visit
http://midwalesgeology.org.uk/bagley-collection.php

# Joseph Bickerton Morgan – Aspiring Geologist and Networker.

***The "tradesman" from Welshpool who achieved success in the late Victorian world of the "Gentleman Scientist".***

Joseph Bickerton Morgan came from a very ordinary background. He was born on 26th June 1859 at Rose Cottage, Daywell, near Oswestry. His father, Arthur Joseph Morgan, was from Llansantfraidd, Montgomeryshire and at the time of his son's birth described himself as a farmer. Joseph's mother was Hannah White Bickerton who had been born in Liverpool. Joseph had an elder sister, Mary Jane. She worked at home as a mantle maker and remained unmarried. Sadly, Hannah Morgan died on the 5th April 1861, aged 35, as a result of Tuberculosis, the disease which would also claim the life of her son, just as his career as a geologist was burgeoning.

By 1871 the Morgan family had moved to Welshpool, where Arthur had set up shop as a grocer, living at 27 Severn Street. He also had a new wife, Ann, from Llanraeadr-ym-mochnant. The business was obviously successful. Ten years later they had moved to larger premises at number 30. Arthur now described himself as a confectioner and the census records the young Joseph as a baker. This situation appears to have caused Joseph considerable distress, as is very apparent in one of his letters to Professor Charles Lapworth, whose help Joseph managed to obtain in order to further his interest in the study of geology. By 1891, when we find evidence that Joseph was gaining significant recognition as a geologist, the census records him merely as a grocer's assistant! His achievements and a scientist's curiosity and enthusiasm are reflected in his letters to Lapworth. He surely found this description frustrating and a very bitter pill to swallow.

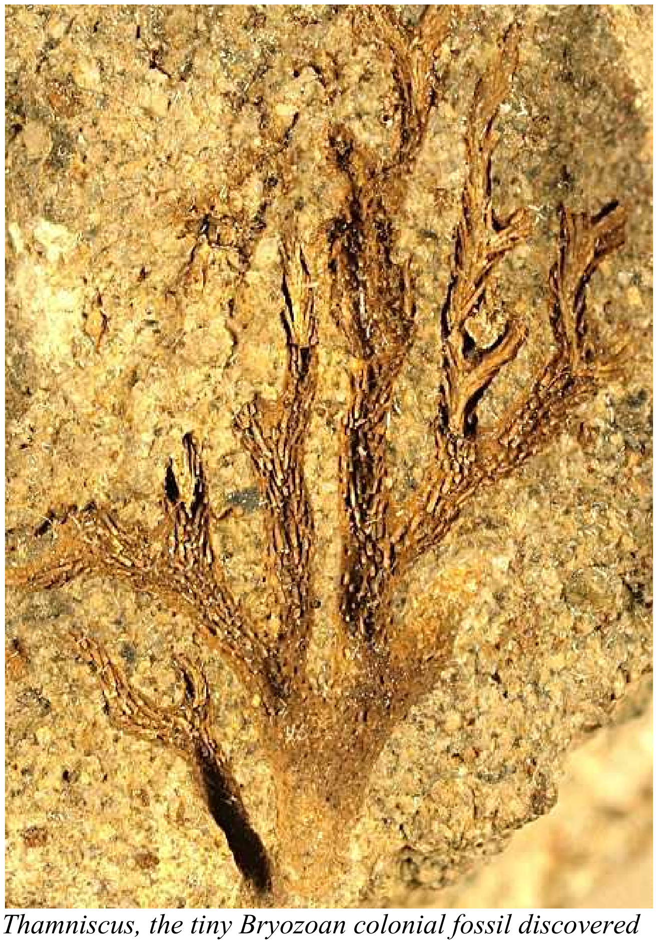
*30 Severn Street, Welshpool, where JBM lived and worked as a baker.*

It is difficult to determine exactly when Joseph began to show an interest in geology or, indeed, what stimulated it. His letters and handwriting reflect a good standard of education, a valuable asset in an age when rates of illiteracy were very high. He would have left school at the age of 13 and it appears that the demands of the shop left little time for self-improvement. The main amateur interests of the day were in 'living' natural history or in the field of archaeology. Geology as an academic study was still in its infancy, still the preserve of the enthusiastic few. Were there local factors which might have caught Joseph's attention? Did he meet anyone in Welshpool who inspired him and kindled a fire within him that was to become his consuming passion?

In researching the story of Joseph Bickerton Morgan, (shall we now just refer to him as JBM as those of us who have got to know him affectionately do?) documentary evidence is scant. However, I suggest the names of two influential local men. Firstly Morris Charles Jones and secondly the Rev. John Edward Vize, Vicar of Forden, the quintessential "Gentleman Scientist".

Morris Charles Jones was born in Welshpool, educated in London and went on to become a solicitor, practising successfully in Liverpool until he retired in 1880. He then served as a Justice of the Peace for Montgomeryshire. He was very interested in Archaeology and undertook an extensive excavation of the site of Strata Marcella Abbey. However, from the perspective of this article, his greatest contribution to mid-Wales came in 1867, when, together with T.O. Morgan of Aberystwyth, he was instrumental in founding the Powysland Club. The first annual meeting was held on 1st October 1868, with the Earl of Powis in the Chair. His wide-ranging interests were reflected in the club's annual publication, the Montgomery Collection, which he edited up to the time of his death. On the nomination of the Earl of Powis he was appointed a governor of Bangor College. Now here was a man with influence and connections!

Morris Charles Jones recognised JBM's ability and appointed him as an honorary assistant curator at the Powysland Museum in Welshpool, where he was given the task of re-organising the collections. The proceedings of the annual general meeting for 1889 record the expansion of the geological section which had been added to and arranged by JBM. In this regard, his work was highly praised and through Morris Charles Jones may have come to wider attention. JBM was also responsible for developing some of the courses which were run by the museum. These were seen as an important aspect of life in Victorian times for those who wished to improve themselves in days when education was valued as a way to progress out of poverty and when any form of further education for many was no more than a distant dream.



*Thamniscus, the tiny Bryozoan colonial fossil discovered by JBM near Welshpool. ©Cindy Howells, NMW.*

The Rev. John Edward Vize, Vicar of Forden for 40 years, was a member of the Powysland Club and so is likely to have had personal contact with JBM. He was a classic example of a Victorian English scientist, being an educated man with time to spare from his clerical duties to investigate the world around him. He is best known for his research on fungi. In his day he was regarded as one of the worlds leading mycologists. Vize was also very interested in the subject of conchology. He appears to have built up a very large collection of shells, a considerable number of which he donated to the Powysland museum. One of JBM's first tasks was to classify and arrange this collection. In doing this he is again likely to have had first-hand contact with Vize and would have received great encouragement from the clergyman, who was known to have a great enthusiasm for his subject.

The shell collection is no longer housed at the Powysland Museum. Investigations a few years ago revealed that some of the collection is now on display in the museum at Llanidloes. The museum also stores a quantity of material which is thought to be the rest of the collection. Sadly housing and storage conditions at some point over the years have degraded the collection.

JBM joined the Conchological Society of Great Britain and Ireland at a meeting held on the 6th May 1886. He maintained his membership until 1893. He did not publish any papers in the Journal of Conchology, neither is an obituary recorded.

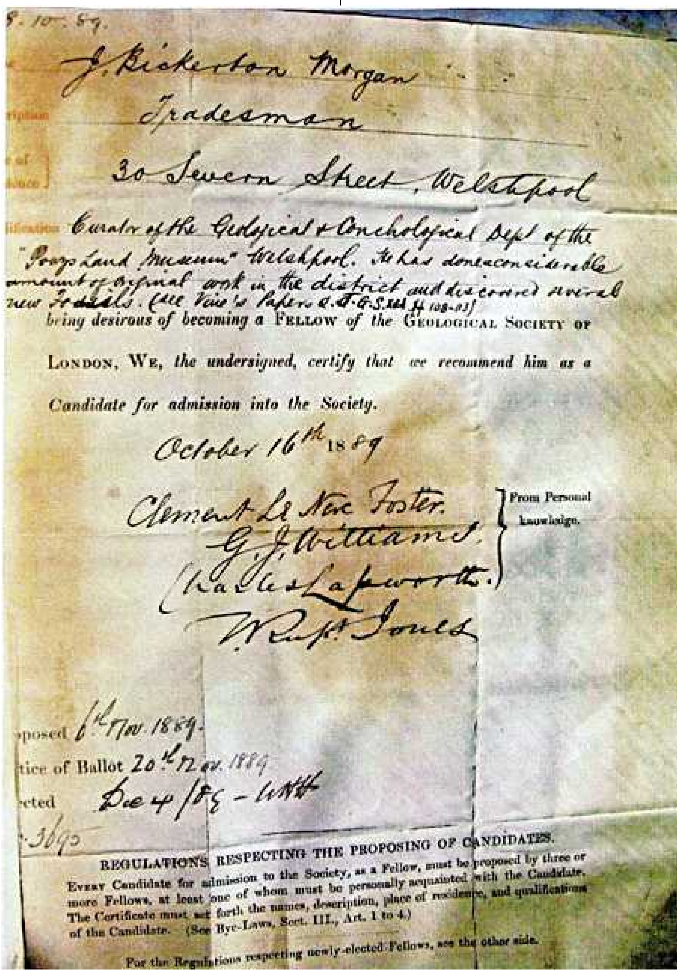
Exactly when JBM started to correspond with Professor Charles Lapworth is not known but evidence from archive material held at the University if Birmingham's Lapworth Museum shows that it was under way by October 1882. The archive contains ten letters from JBM to Lapworth in which he seeks help in identifying fossil specimens, advice on areas in which to research the Silurian and Ordovician strata, and on methodology. The general context suggests that a number of other letters were written to Lapworth but have not survived. Unfortunately all of JBM's papers have been lost, depriving us of the replies received.

Lapworth encouraged JBM to examine the rocks in the Chirbury and Shelve area which he and others were researching. From the letters we can conclude that JBM was a regular visitor to the area and would have contributed to the information shown on the Shelve map. The map is approximately six foot square, hand painted and lettered on linen. The Chirbury area is important in defining the geology of the Marches. The Chirbury series contains the Spywood Grit and the Aldress, Hagley and Whittery Shales noted by JBM. These beds are important in unravelling the geological sequence as they lie at the interface between the Ordovician and Silurian periods. Hence this area became the centre of attention, with visits in turn from Sedgwick, Murchison, Salter, Rupert Jones, Lapworth, Foster and Watts, as the sometimes acrimonious debate over exactly where the division lies was gradually resolved. Here our man from Welshpool was walking in the footsteps of, and rubbing shoulders with, the greatest names in British geology. Baking be blowed – this is progress towards academia!

JBM was obviously very encouraged by Lapworth and continued to map the strata of the region and search for new fossil specimens. The year 1885 saw another achievement for a developing geologist. George Robert Vine published a paper in the Quarterly Journal of the Geological Society which contained descriptions of a new species of *Phyllopora, P. tumida* from the Caradoc rocks of Llanfyllin and of *Thamniscus antiquus* from the Bala volcanic ash of Middletown Hill, both collected by JBM. Vine was a corset and stay maker in Sheffield who specialised in the study of Bryozoans. Between 1877 and 1893 he published about seventy five papers on Bryozoans. He is principally remembered as the author of the Order of Cryptostomata. However, Vine, a Chartist and Methodist preacher, was regarded as something of a firebrand, with rather subversive views who never became part of the geological establishment.

JBM continued his researches of the Ordovician and Silurian interface in the area around Powis Castle and the Montgomeryshire marches. He painstakingly assembled fossil evidence until he reached a point where he felt able to challenge the currently established thinking. His findings were gathered into a brief paper which was presented to a British Association meeting held in Leeds in 1890. Here he is actually challenging the great Sir Roderick Murchison. He was obviously very confident in himself and the quality of his researches. His paper argued the need to change the boundaries and the points at which this should be done. He finished by stating the need to redraw the map, something he would do in his leisure time. Remember, he was still at the bakery! In a Geological Society obituary attributed to William Whitehead Watts, the writer expresses the hope that the submission can be expanded using JBM's papers. Sadly for us there is no evidence that this came about, and as previously stated, the papers are now lost.

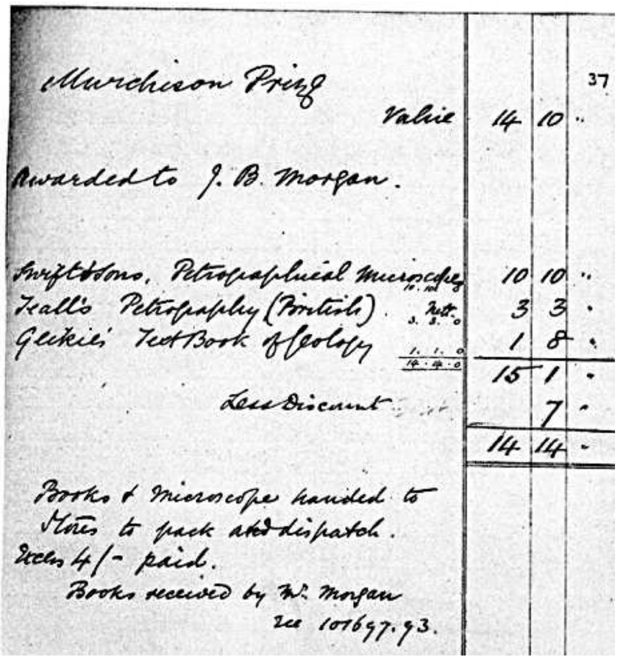
In the autumn of 1889 JBM applied for Fellowship of the Geological Society of London. Here again, on his application form, we see further evidence of JBM's ability to make contacts and network at the highest level. His nomination paper was signed by Clement Le Neve Foster, Charles Lapworth, T. Rupert Jones and Griffiths Williams, some of the foremost names in British geology. It is difficult to overstate the significance of this. It follows on from the establishment of JBM's relationship with Charles Lapworth which had blossomed over a number of years. Lapworth saw in JBM a prodigious talent which he nurtured and encouraged. He was a man of standing in the world of geology and must have had every confidence when introducing the young new-comer to his colleagues. The letters of JBM show that he visited the Wotherton area with Le Neve Foster in June 1889. At this time a new mine shaft had been sunk and time was spent examining some of the spoil. Intriguingly, JBM does not tell us which Le Neve Foster accompanied him. Was it Clement, who at the time was Inspector of Mines for the North Wales District, or was it his younger brother Ernest Le Neve Foster, who was a mining engineer? We shall never know. Joseph Bickerton Morgan was elected to Fellowship of the Geological Society of London on the 4th December 1889.


9. 10. 89.
J. Bickerton Morgan
Tradesman
30 Severn Street, Welshpool
Curator of the Geological & Conchological Dept of the "Powysland Museum" Welshpool. He has done a considerable amount of original work in the district and discovered several new fossils. (see Vine's Papers Q.J.G.S. ... 108-...)
being desirous of becoming a FELLOW of the GEOLOGICAL SOCIETY OF LONDON, WE, the undersigned, certify that we recommend him as a Candidate for admission into the Society.
October 16th 1889
Clement Le Neve Foster. } From Personal knowledge.
G. J. Williams.
Charles Lapworth.
T. Rupt. Jones
...posed 6th Nov 1889.
...tice of Ballot 20th Nov. 1889
...cted Dec 4/89
REGULATIONS RESPECTING THE PROPOSING OF CANDIDATES.
EVERY Candidate for admission to the Society, as a Fellow, must be proposed by three or more Fellows, at least one of whom must be personally acquainted with the Candidate. The Certificate must set forth the names, description, place of residence, and qualifications of the Candidate. (See Bye-Laws, Sect. III., Art. 1 to 4.)
For the Regulations respecting newly-elected Fellows, see the other side.

*JBM's application for Fellowship of the GSL.Image courtesy of the Geological Society*

The other signatories are also significant. Thomas Rupert Jones qualified as a doctor but schooling in Somerset had stimulated an interest in fossils and he soon turned his attention full-time to geology. By 1849 he was assistant secretary to the Geological Society of London and in 1862 became Professor of Geology at the Royal Military College, Sandhurst, where he was an authority on *foraminifera.* He was elected a Fellow of the Royal Society in 1872. He was also a winner of the Geological Society Lyell medal. Quite an endorsement.

Griffiths Williams started his career as a schoolmaster (as had Lapworth) and became Headmaster of the Higher Grade School in Blaenau Ffestiniog but soon became very well-known in North Wales as a geologist. In 1895 he was appointed Assistant Inspector of Mines for the North Wales District under Clement Le Neve Foster. Quite how he became a friend of JBM is not clear, possibly through the latter's decision to exhibit at the National Eisteddfod in Carnarvon. Their friendship was sufficiently strong for Williams to be executor to JBM's Will.



| | | |
|---|---|---|
| Murchison Prize | | 37 |
| Value | 14 | 10 - |
| Awarded to J. B. Morgan. | | |
| Swift & Sons, Petrographical Microscope | 10 | 10 - |
| Teall's Petrography (British) | 3 | 3 - |
| Geikie's Text Book of Geology | 1 | 8 - |
| | 15 | 1 - |
| Less Discount | | 7 - |
| | 14 | 14 - |

Books & Microscope handed to Stores to pack and dispatch.
Stores 4/- paid.
Books received by Mr Morgan

*The Murchison Prize. Image courtesy of Imperial College*

At last, it is all coming together for the young man from Welshpool. In 1892 JBM decided to devote himself entirely to science. Again with the friendship and support of Charles Lapworth, he obtained a free scholarship to the Royal College of Science, later to become Imperial College, London. He applied himself single-mindedly to his studies and in just one year succeeded so well that he obtained the first prize at the college, together with the Murchison Medal and a gift of instruments and books. Success at last as he began working as a Demonstrator, the first step in his new academic career. Now he really was Joseph Bickerton Morgan, Geologist.

However, his devotion to his studies and the years of toil in the bakery in Welshpool had taken their toll. He suffered a haemorrhage of the lung and an attack of pneumonia, from which recovery was very slow. He was admitted to the Royal National Hospital in Ventnor where he appeared to be making good progress towards a full recovery but another haemorrhage set in and he died peacefully on the 8th March 1894, taken by the tuberculosis which had ended his mother's life at almost the same age.

The obituaries were fulsome in their appreciation of his life and praised his achievements. He had demonstrated that wherever you started it was possible to dream dreams and with tenacity turn them into reality. It is safe to say that JBM would have become one of the giants of British geology.

Julian Lovell

*Next time: A real "Gentleman Scientist", John Edward Vize of Forden, Vicar and Mycologist.*

# Geological Excursions

## Sites to visit.

## Excursion Number 3

### The Ring Hole

Near Dolfor, landsliding in superficial deposit, slumping in the Montgomeryshire Trough

*Location: Grid ref. SO120837*
*On the north side of the B4355 road from Dolfor to Knighton, about three miles from Dolfor. There is a convenient lay-by just opposite and some "Danger landslip" signs nearby.*

*Fig. 1*

The Ring Hole itself is a deep semicircular declivity within a few yards of the road, formed by landslip within the great thickness of clayey till or boulder clay. Before exploring the Ring itself, it is worth looking at the surrounding landscape. You are on a bleak plateau at some 450m surrounded by a number of rounded hills, of about 500m height. This is held to be part of the Mid Wales "peneplain", a proposed pre-glacial erosion surface, established during Mesozoic times and since then uplifted, dissected and eroded by ice and water. The generally rounded nature of the topography results from the uniform sedimentary nature of the Silurian bedrock.

During the Devensian glaciation, this area would have been subject to a great thickness of ice sheet which deposited masses of boulder clay on its retreat. This plasters the surface to such an extent that it masks the topography of the bedrock beneath it.

The Ring is best descended by taking the path round the west (left) side, from which the whole structure can be seen. It is some 150m wide and over 50m deep. (Fig 1) The near side shows a near vertical face in boulder clay with scree slopes below. Visiting this site in winter I have seen well developed pipkrakes (ice needles) on the boulder clay faces.
Pipkrakes develop in wet clays if the interior is just above freezing and the surface is below. Capillary water moves towards the surface and freezes there, producing ice crystals which grow outwards as they are fed by water

from within the clay. This blows particles away from the surface. The crystals can be inches long, a bit like hoar frost; but the process is different as hoar grows from its ends, not its roots. Weathering is eroding these faces, producing loose scree slopes at their bases, sloping at about 28 degrees. The screes comprise the pebble/boulder component out of the boulder clay as the clay particles have been washed out. They remain bare as water is not retained.

Some 50 m along the face edge there is a good path down to the base of the cliffs, along which you can examine the till and scree. The scree is mainly composed of sandstone and siltstone, similar to the local rocks, sometimes showing the typical brownish weathering and fine lamination of the Bailey Hill Formation. It is not very rounded and has not travelled very far.

Nearer the brook (the infant River Teme) the Council have tried to stamp on the toe of the landslip by loading it with large imported blocks of a dolerite rock. (Fig 2) Is it from Criggion Quarry? Clay is exuding below them, so they are not particularly effective!

*Fig. 2*

The stream is now fairly innocuous, but as the ice melted at the end of the ice age, it must have been a raging torrent carrying rocks and boulders with it. It has carved a significant gorge into the sandstone of the Bailey Hill Formation. Crossing over the stream, one can examine the rocks exposed in the gorge. These comprise thinly bedded sands and siltstones of the Upper Bailey Hill Formation (Lower Ludlow) which contain a large proportion of "disturbed" or slumped beds. Locally, there are many such which can be seen along and near the A483. The degree of disturbance varies from little to completely homogenised with just the harder concretions distributed therein. The rocks exposed here are gently dipping, with the bedding more or less intact, but with some packets of beds contorted, waved and even rolled. There is one spectacular "sausage roll" fold near the toe of the landslip. (Fig 3). Some packets of beds are undisturbed (Fig 4) and others are coherent, but folded on a metre scale.

*Fig. 3*

The precise mechanism involved is obscure, but the movement must have occurred soon after deposition and be related to the rheology of the freshly deposited water/sand/silt slurry when subjected to disturbance, possibly of a seismic nature. (We are still struggling to model the behaviour of such complex fluids which show exotic visco-plasticity and history dependent behaviour!)

*Fig. 4*

By studying the vergence* of the folds in slumped beds it is possible to deduce in which direction movement occurred. It can be assumed that movement occurred in the direction of vergence and that it would have been downslope.

It is by this kind of study that the existence and position of the "Montgomery Trough" was determined. In the 1960s R.J.Bailey studied the palaeocurrents and slumping in this area and found that the slumping confirmed that there had been palaeoslopes forming a trough aligned NE-SW in this part of the Welsh Basin, while palaeocurrents were generally towards the NE. This sounds easy, but try to determine whether the folds here verge to the left or the right. You may have to ask several people and average! It is worth discussing whether such features could equally well be produced by tectonic means and what other evidence would be relevant.

From further downstream a series of terracettes can be seen which are held together by the strength of vegetation and have failed in a rotational mode. The gorge becomes more extreme and you may have to walk at a higher level, but the bedding becomes a bit thicker and shows typical brownish weathering of Bailey Hill. At this point one can return to the road or, if sufficiently energetic, climb Cilfaesty Hill, just to the east, which is a good viewpoint.

*Note on Vergence:
Vergence is the geological term for the direction of overturning of an asymmetrical fold in which one limb is shorter and steeper than the other. In the figure below for example the fold verges to the right.

Tony Thorp

# Geological Excursions

## Sites to visit.

## Excursion Number 4

## Tan Lan

### O. T. Jones's famous Ordovician shoreline.

*Location: Tan Lan Cottage SO 057 547 .*

**Permission from the owner is required for the visit.**

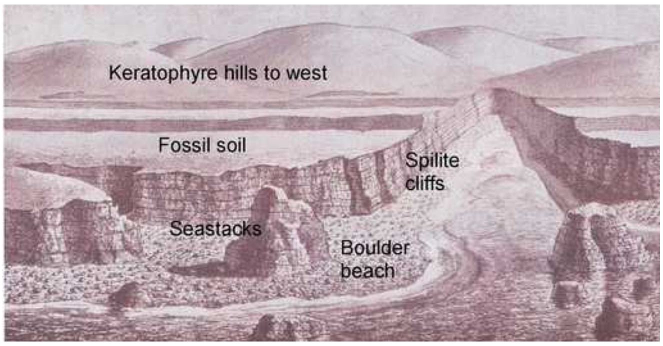
Relict early Ordovician shoreline in the Builth Inlier (based on a field trip September 2016 which was led by Tony Thorp)

This excursion visits the southern Builth Inlier, just west of Carneddau, to examine early Ordovician (Llanvirn) sites made famous by Jones and Pugh's 1949 paper *An Early Ordovician Shoreline in Radnorshire'*. Prof. OT Jones (d.1967) is still regarded as Wales's greatest geologist. The 1949 paper interprets the present rugged upland grass terrain as originally a high cliff face of altered submarine lava flows and pillow lavas, with a boulder bed beach, and with sea stacks. The paper even reports an early soil (which, on the visit ,we did not find!) on the clifftop. A sketch of this scene in the paper is important as one of the first detailed palaeogeographical reconstructions – a device now common in geological texts.

Park at Tan Lan Cottage adjacent to the large new quarry. A dolerite sill cuts the '*Glyptograptus teretiusculus* Shales' of the quarry. OT Jones had much to say about the dolerites but not this quarry; it has only just been opened. This was the furthest west site of the day; the rock dips west so this was above the relict beach and above the shallow water sandstone which enveloped it. By then the water had become deeper. These black shales provided biserial *G. teretiusculus* graptolites, a fine *Monobolina ramseyii* brachiopod, some other brachiopods and pyrolusite dendrites ($MnO_2$).
After visiting the quarry walk 500m south to Newmead Scar (SO 057 542). In thick woodland an old quarry face

*Vesicular lava flow, Newmead Scar.*

of relict cliffs of OTJ's Lower Spilite (today named Builth Volcanic Formation) is exposed. This is sea floor pillow lava and effusive lava flows which were metasomatically altered, and described in 1977 by BGS as spilitic andesites. The rock is highly vesicular, with the size of vesicles expanding towards the outer surface of the effusion. (We carefully edged west at the top of a steep tree-covered scree slope, holding on to the base of the outcrop.) The dip is c30ºW so we were walking up-succession – in effect up the spilite of the cliffs. Eventually Tony pointed out the contact with OTJ's Grey Feldspar Sands (now the Newmead Sandstone) which in gradually rising sea level eventually inundated all of the ancient shoreline and remaining cliffs.




*O T Jones's sketch of a shoreline near Tan Lan.*

Walk 150m SE up the hill (east is back down the succession) to an example of OT Jones's boulder beds (SO 0581 5464), where he conjectured (and sketched) a structure consisting of pebbles and boulders fallen from the cliffs and lying on a beach. There are large pebbles of spilite embedded in ferruginous, feldspathic sand (itself eroded from spilite). Further up the hill, 200 m east, is OT Jones's wave-cut platform (SO 0599 5468), which lay below his cliffs, and now appears in the field as mossy rough spilite exposures on the topographical slope. Tony pointed out a prominent crag on the hill 200m further east, another of OT Jones's sites, explaining it was still boulder beach there, but with spilite boulders over 1m diameter embedded in sand.

Roughly 1 km south from Tan Lan is the site of Jones's most iconic interpretation: a line of sea stacks now close to a long stone wall and scarcely identifiable on the ground (SO 0584 5400). The cliffs were said by OT Jones to face east to the sea and to the line of degraded sea stacks, with the intervening vegetated ground revealed by WW2 slit trenches to be Grey Feldspar Sand. However, this must have been a typo because the cliffs surely would have faced west to the sea and sea stacks; the main body of spilite, with the cliffs, lies east of the stacks. His diagrams and sketches are not consistent in that respect. It might be fun sometime to excavate and check whether the four 'sea stacks' meet the basic requirement, i.e. are they definitely spilite cliff material surrounded by the 'beach' of Newmead Sandstone.

Colin Humphrey

# Fossils in the News

Almost 30 years ago (not newsworthy, I know!) I arrived at Durham University to read Geology. I was extremely pleased and quite amazed to see that our cohort (1987-1990) was almost 50:50, male to female. Sadly, this gender equality in our fabulous science has not always been the case and, as a serving teacher, I know how hard it is to attract girls into any science, let alone 'rock bashing'!

However, all is not lost for the future, as I want to recommend to all Mid Wales geologists (and their relatives) a brilliant Christmas gift for the budding palaeontologist (girl or boy). Let me introduce "Lottie™ – Fossil Hunter"!


Lottie may be a little doll, but she won a mighty 'Positive Role Model' award in 2015. She was developed by British academics and she's made in Ireland (by Arklu Ltd.) to have a child-like 'age appropriate' body, wears normal, non-sexualised clothing and does things that little (and big) girls like to do – like fossil collecting!

Fossil Hunter Lottie™ comes with a backpack, hammer, chisels, sturdy footwear (Barbie™ never had shoes like these!), a whole array of plastic ammonites and a book on Mary Anning! She is utterly charming (Dave got me mine last Christmas and I use her as an ambassador for women in science at school).

Lottie follows on from the 2013 Lego female palaeontologist who was part of a set celebrating women in science: the palaeontologist is joined by an astronomer and chemist. The Lego sets sold out within weeks and now trade at high value on online auction sites to collectors! Lottie and her good friend Finn (a boy doll) are available on all good on-line selling sites and have their own page http://uk.lottie.com/.

Sorry to harp on about women palaeontologists, but another website that might be interesting to readers is the fantastic http://trowelblazers.com/ which has literally dozens of articles about women palaeontologists, archaeologists and geologists. Their latest feature is on Winifred Goldring, who was State Palaeontologist of New York from 1939 to the early 1950s. Winifred rode around with her pick axe in a motorcycle sidecar and in the 1920s redesigned the Hall of Palaeontology at New York State Museum. Trowel Blazers also have a Facebook page and in their words they serve to celebrate women "archaeologists, palaeontologists and geologists who have been doing awesome work for far longer, and in far greater numbers, than most people realise." Long may they continue!

Sara Metcalf

# Member's Photos

Sara accidentally dressed to match the Gwna Mélange sequence at Porth Twr Bach bay on Llanddwyn isle on Anglesey.

The rocks are an amazing mixture of colours and textures: dark green lavas, bright rose pink quartzites, purple manganese rich shales, blue-black intrusive dolerite dykes and honey coloured limestones. Her matching clothes are Berghaus, Craghoppers and Mountain Warehouse!!

David Hearn

# Diamonds and the Amateur Geologist

## Diamonds are forever!

Well, not so sure about that. Since the mid 1950s, the synthetic diamond industry has grown. Mainly this is for industrial purposes, but a profitable sideline is of course the jewelry trade, where they are sold on the basis of being environmentally preferable and not conflict related. As an extra, they can of course be made from you after cremation if you don't mind paying a premium!

The collapse in value benefits amateur geologists like us because rock cutting, grinding and lapping is now so easy, we can all cut, polish and make sections using the small tools found in most households. In the simplest case, the cheap diamond hones sold to sharpen your pocket knives are ideal to plane off flat rock surfaces to show structure. Otherwise, diamond discs for small angle grinders cost about £5 at Lidl or on e-bay. With this tool one can cut hand specimens down to size, with little risk of shattering the critical bits.For about £30 there is a water cooled machine sold as a "Tile cutter" which is preferable, but less convenient to use. I use mine out of doors, while wearing a waterproof jacket!

*Lapping the easy way*

With tools like these, your collection of rocks and fossils can be kept as compact specimens. Ideally the rocks are best displayed as hand size, with one face cut and polished and one fresh broken. Fossils can be on appropriately sized substrate, with little surplus material.

With rather more perseverance, thin sections can be produced. The "traditional" method was to produce the first surface by cutting and then grinding using carborundum powder of progressively finer and finer grades. Then the second surface was treated similarly and reduced in thickness by measurement, using a microscope and the birefringence of a convenient mineral like quartz for the final reduction to the standard 30 micron thickness.

Carborundum is very messy to use as each grade must be completely removed before the next is used. Bonded diamond is a revelation in this respect, as the abrasive remains attached. The best way to use diamond hones is to work in a "Kitty-litter" tray with half an inch of water.
Even easier grinding and lapping can be carried out with diamond lapping discs now available from China for only £7 each for a 6 inch disk, of anything from 100 grit to 3000 grit. It is a characteristic of amateur geologists' homes that their collections spiral out of control into outbuildings and gardens. Using very basic equipment amateurs can now cut to size, polish and section their collections, not only adding interest, but reducing the physical size to manageable proportions.

*Using a diamond hone.*

So, we are all benefitting from the collapse in the price of diamonds and, interestingly, in the collapse in the most successful cartel in the history of marketing. That is the control of the market by de Beers and Ayers, their advertising agency. Therein lies another story!

Tony Thorp

*Part 2 to follow next time.*

# Member's Photo

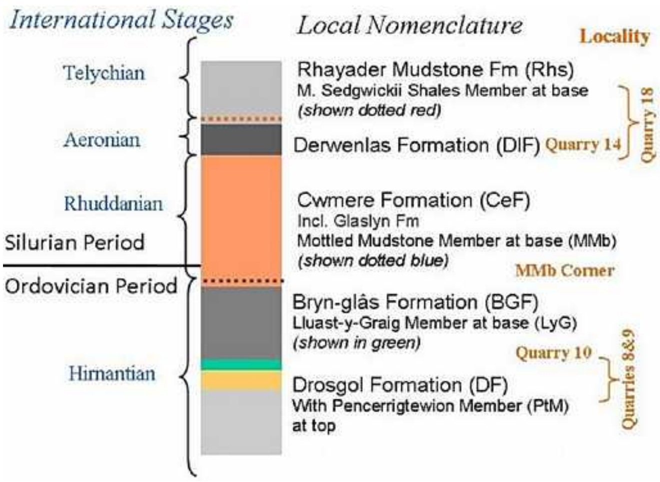
Fossil *Calamites* (Giant horsetail) internal cast of stem showing branch scars. Byrmbo fossil forest, Wrexham.

Richard Becker

# Geology in the Hafren Forest

Members of Mid Wales Geology Club have been examining the geology of Hafren Forest for three years. The numerous quarries there tell a detailed story of changing sea levels and depositional environments at the end of the Ordovician period and into the Lower Silurian. Most of the Forest roads are accessible to the public only on foot or bicycle, but Natural Resources Wales kindly gave permission for us to use vehicles for the duration of the study. We have been fortunate on occasions to enjoy the guidance of Professor JR Davies and of Professor WR Fitches. The Forest is situated between Clywedog reservoir to the east, and Plynlimon to the west, and covers 40 square kms. First planted in 1937, on land acquired as twelve upland farms, around 100kms of forest road had to be built, requiring the opening of some 34 quarries, and numerous road cuttings, providing a splendid opportunity to study the geology of the area.

All the rock was deposited in the Lower Palaeozoic Welsh Basin from the late Ordovician, Hirnantian stage, to early Silurian, Telychian stage, in the time period 446 – 433 Ma. Sediment flowed into the basin from the Midland Platform to the east and from Pretannia to the south. Before the Acadian Orogeny the area lay at the bottom of a prograding slope which formed near the the south-east margin of the basin. A combination of glacioeustasy (global sea level changes due to ice sheets) and regional tectonics, caused large and frequent fluctuations in local sea level, which are well recorded in the rock exposures. The area lies across the NNE aligned Central Wales Lineament, which was important in the fault controlled subsidence of the Lower Palaeozoic Welsh Basin, and its subsequent inversion.

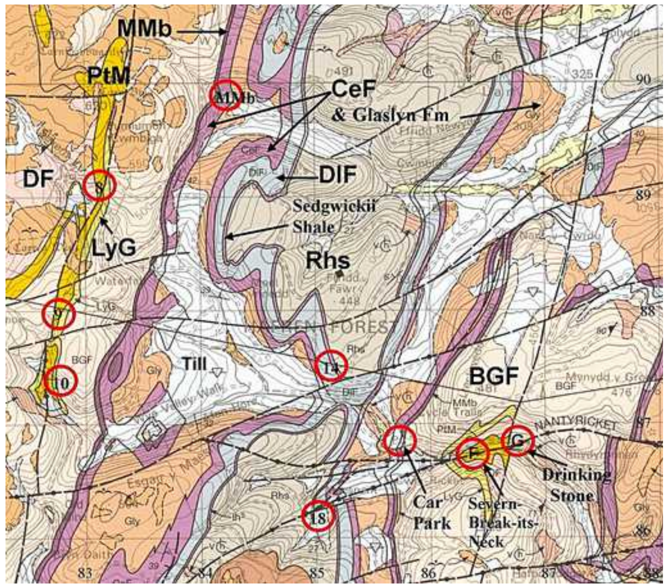



*Stratigraphic column, based on the sequence in the BGS sheet 164 (Llanidloes) showing selected localities.*

The stratigraphy is detailed in BGS Sheet 164 (Llanidloes) published for the first time in 2010. It comprises: the Upper Ordovician Drosgol and Bryn-Glas formations of the late Hirnantian stage, overlain in the Lower Silurian by the Cwmere, Derwenlas and Rhayader Mudstone Formations of the internationally recognised Rhuddanian, Aeronian and Telychian stages (small differences exist between boundaries of local and international stages). The main part of Hafren Forest includes around 1km of vertical succession of rock (small separate outlying areas of the Forest expose Upper Silurian rock and are not considered here). The Central Wales Syncline runs nearly north-south through the Forest, so the youngest rock (Rhayader Mudstone) lies along this line. The strata then rise onto the Plynlimon Dome to the west and onto the Clywedog dome (outside the Forest) to the east, with older and harder rocks exposed as inliers on both domes.

**Interpretation of sea level change and depositional environment**

The most interesting parts of the succession are those where the latest sequence stratigraphy infers changing sea level, often in detail, and sometimes abruptly. The technique of sequence stratigraphy has allowed, during the last two decades, new insights to be gained into the changing depositional environments of this part of the southern Welsh Basin. During the late Ordovician and early Silurian, eustasy (global changes in sea level) played an important part in local patterns of sediment sourcing and deposition. However, during the Telychian stage tectonics became important in Wales, and this obscured the eustatic signal in the local sedimentary successions which followed.




*Geological map of part of the forest. Copied from BGS sheet 164, annotated with rock types and with localities circled in red.*

Study of the Type Llandovery area (Davies 2012, 2016) some 30 miles south of Hafren Forest resulted in a new sequence stratigraphy for the Llandovery epoch of the Silurian in that district (see the article titled ‘Sea Level Change in the Geological Past’ in this edition of *The Silurian*). The correspondence of the sequences in the Type Llandovery area with those in many other parts of the world has provided new evidence of the effect of glacioeustasy, as southern polar ice sheets waxed and waned. The latest Ordovician and early Silurian sequence in Hafren Forest can now be confidently interpreted in the context of this new sequence stratigraphy of the nearby Type Llandovery area, because in Hafren Forest during this period, changing sea level was also strongly reflected in the geological record.

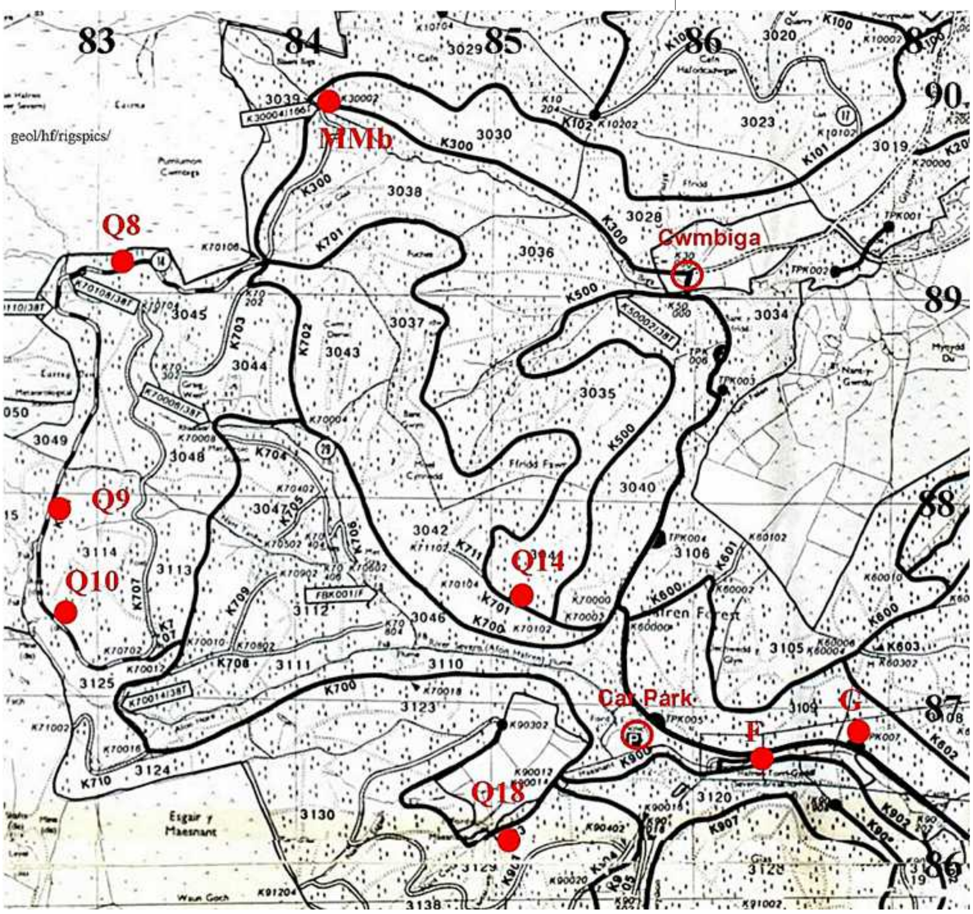
**Selection of sites, and access**

Rocks of the Rhuddanian and Aeronian stages of the Lower Silurian are widespread in the Forest, and exposed in numerous places. Rocks of the Hirnantian stage of the Upper Ordovician are less widely exposed in the forest. They include localities exposing the Pencerrigtewion, Lluest-y-Graig and Mottled Mudstone Members and their subjacent and overlying rocks.

Three parts of the succession are considered in this note. First is the Drosgol - Bryn-glâs boundary. At the top of the Drosgol Formation (DF) is the Pencerrigtewion Member (PtM), now interpreted as the acme of a glaciostatic sequence lowstand (the Hirnantian lowstand). Overlying this is the Bryn-glâs Formation (BGF), when sea level began to rise again, restoring mud deposition. The basal member of the Bryn-glâs Formation in this part of the district is the Lluest-y-Graig Member (LyG), a stratified mudstone interbedded with thin sandstones. This soon gives way to the more widely encountered slumped and destratified mudstone, the main part of the BGF. These rocks, including the upper and lower boundaries of the PtM, are exposed in Quarries 8, 9 & 10, three points along a stretch of track some 2km long running roughly N-S near the western edge of the Forest.


*Quarry 8 - DF/PtM boundary. Pencerrigtewion Member is a sandstone lobe appearing as topmost Drosgol Fm. It represents a sea level lowstand.*

Next is the Mottled Mudstone Member (MMb), the topmost part of the BGF. A second pulse of transgression near the end of the BGF was followed by a brief regression which triggered re-ventilation of the southern Welsh Basin and re-colonisation of the sea floor by benthic (sea floor) creatures, which left evidence of their burrows in the form of dark mottling now seen in the mudstone. This was quickly followed by a third pulse of transgression, re-establishing anoxicity and extinguishing benthic life, thus preserving graptolite remains. This is recorded in the earliest Cwmere Formation (CeF). The above localities are in the Ordovician.




*Road map of part of the forest. Selected geological sites shown as red dots with Q numbers being quarries. F is Severn-break-its-neck. G is the DrinkingStone. Vehicles may use the road to the car park and onto Cwmbiga.*

Finally, there are quarries which record the frequent sea level changes in the Lower Silurian, in particular in the Derwenlas Formation (DlF), where short term cycling of sea level caused basin bottom water to alternate repeatedly between dysoxia (partial anoxia), and partial re-


*Quarry 9 - Upper boundary of PtM. Sharp boundary between the Pencerrigtewion sandstone and the overlying Lluest-y-Graig mudstone.*

ventilation causing more oxic bottom water. Most of the DlF succession is exposed in one quarry. Another quarry exposes part of it, with the merit of also exposing, by faulting, the subjacent CeF, and the overlying Rhayader Mudstone (Rhs). All the localities described below are on or close to the Severn Way, a national trail which leads to the source of the river Severn.

**Upper Drosgol Formation (DF) and Lower Bryn-glâs Formation (BGF) - Quarries 8,9,10**

Quarry 8 extends 100m along the north side of the road at [SN 832 891]. A dip of 50º, younging to east, exposes the topmost DF dark mudstone at the western end of the quarry and, with a noticeable colour difference, the contact [SN 8300 8912] with the fine sandstone Ptm which forms the top of the DF. The contact between the PtM and the overlying LyG (bottom of the BGF) is seen 80 m east, dipping into the wet, vegetated quarry floor near the eastern end [SN8316 8917]. During the Drosgol Formation the depositional environment mostly led to muddy sediment being deposited but there were around eight sandstones, up to 10m each. Eventually global cooling and South Polar ice sheet formation during the late DF caused a sea level lowstand which ended the muddy phase of DF deposition and began in the PtM to strip away and remobilise sandy sediments deposited previously proximal to the basin. The PtM was deposited as a sandstone lobe, here around 60m true thickness, spreading across the mainly muddy slope apron of the DF.

*Quarry 8 - Lluest-y-Graig. Finely laminated mudstone with bedding picked out by weathering.*

It is heterolithic, including fine, medium and coarse sandstone, sometimes conglomerate; even occasionally mudstone; some large mudstone rip-up clasts also appear in the sandstone here. Fragments of LyG at the far eastern end of the quarry appear chaotically banded as the fractures break across the finely laminated mudstone, an effect enhanced by weather bleaching of alternate layers.

Quarry 9, a small roadside exposure at [SN 8277 8795], 1.1km south from Quarry 10, shows in cross-section the boundary between the top of the PtM and the bottom of the LyG – and hence between the DF and the BGF. Here the bedding is nearly horizontal. The base of the quarry is a 1m thick bed of immature, feldspathic, medium grain sandstone which is the top of the PtM. The lithology is the same as that seen at the bottom of the PtM in Quarry 8 (although the PtM is not the same throughout). Above this is up to 10cm of thin-bedded, colour-banded mudstone, the lowest LyG, recording the beginning of the first major pulse of transgression after the sequence lowstand, and therefore also the beginning of the BGF. Above these first mudstone beds is another sandstone bed c30cm thick, part of the LyG, which consists of thin mudstone turbidites interbedded with sandstone turbidites generally less than 20cm.

*Quarry 10 - The Bryn-glâs formation. Featureless, slumped, and destratified mudstone seen from the southern end.*

Quarry 10 [SN 8279 8738] is 600 m south along the road from Quarry 9. This is low in the BGF, just above the LyG. Sea level was rising during the BGF; it is slumped and destratified due to high deposition rates and oversteepening, as well as possible disturbance due to isostatic movement on faults. Some stratification is discernible as slight colour-banding of freshly broken rock at the foot of the face, but there is almost no evidence of bedding on the substantial brown weathered face. Iron staining in fallen stone shows Liesegang rings. This is a mudstone turbidite with irregular cleavage. The smooth, shiny surface on some fractures may be due to grain alignment during slumping.

*Part of the Drinking Stone. Classic example of soft sediment deformation on base of a detached block of Pencerrigtewion sandstone.*

Drinking Stone and Severn-Break-its-neck are also interesting exposures of the Ptm sandstone, and are passed very close to the Forest main access road. The Drinking Stone is clearly situated [SN 8675 8679] on the bank above the road just over 1km before the main car park. So called because legend says its morning wetness is due to nightly drinking in the river below! It is a 5 m boulder of Ptm sandstone detached and slid from bedrock uphill some 100m to the NW. Vegetation makes access difficult but the west facing side of this boulder is a bedding under-surface presenting an interesting large area of soft sediment load casting. Severn-Break-its-Neck [SN 8631 8674] is nearby, and is signed from the main access road. Here the river Severn has chosen a major fault as a west-east passage across this hard rock and onto the softer BGF mudstone. A waterfall occurs as the river flows off the erosion resistant Ptm cap rock onto the softer rock below. A small bridge allows the bed rock to be viewed both sides.

**Mottled Mudstone Member (uppermost BGF), and lowest CeF – 'Mottled Mudstone Corner'**

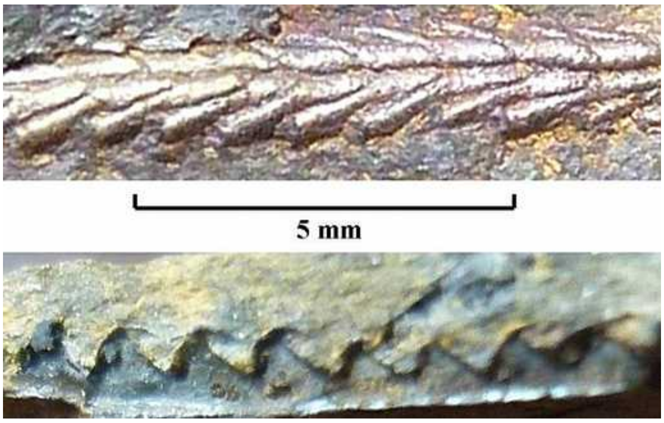
The Mottled Mudstone Member (MMb) occurs at the top of the BGF and is exposed in a cutting on the north side of the Forest road at [SN 841 899], which we have called 'Mottled Mudstone Corner'.

*Burrow-mottling in the MMb. Burrows show dark on wet surface. A sharp sea-level fall removed water column stratification, re-oxygenated bottom water, allowing re-colonisation.*

This can be accessed after parking roadside at Cwmbiga [SN 858 890] and walking 2km west along the road. It includes a 30m length up-sequence from the topmost BGF, through the Mottled Mudstone Member and into the Cwmere Formation. The MMb is widespread in the district but, being thin (here less than 10m), it is rarely well exposed. Natural Resources Wales kindly removed the overgrowth and, following a routine fire-hose drill using the nearby stream, a nearly pristine section of MMb has been revealed! The west (left) end, nearest the stream, strikes and dips 015/38E, and exposes BGF mudstone with a sub-vertical cleavage. Here, at the very top of the BGF, the normal destratified and slumped lithology disappears and the bedding reappears.


*Mottled mudstone road cutting looking North. MMb dips west. Topmost Ordovician. Bedded BGF, burrow-mottled MMb, and graptolitic CeF.*

The BGF was mostly a time of rising sea level, the second major pulse of transgression after the lowstand, interpreted as glacioeustasy, with southern polar ice sheets melting in response to global warming. But during the latest BGF a short sea level fall occurred, perhaps a few tens of metres, re-ventilating the basin bottom water, leading to re-colonisation of the sea bed, and burrowing. At first the organisms are small and the dark burrow mottles (seen most easily when wet) are only 1-3mm in diameter in the pale colour-banded rock, but quickly with increasing oxygenation, slightly larger organisms appeared, leaving burrows up to 10mm across. The boundary between unmottled BGF and definitely burrow-mottled MMb can be determined to less than 1 metre. Traces of burrow-mottling begin 10m from the bridge, and cease after 20m where the lithology changes to rusty weathering, graptolitic CeF. The final exposure of MMb shows burrows up to 10mm.




*Graptolites in MMb and Rhs. Above: biserial **Normalograptus persulptus** in the basalCeF at Mottled Mudstone Corner. Below: **Monograptus sedgwickii** from basal Rhs in Quarry 18.*

Burrow mottling, and the Mottled Mudstone Member itself, was ended by a third pulse of transgression which once again flooded the shelf, re-establishing anoxic conditions probably by a combination of stratification of warm top water flowing from the shelf, and upwelling at the shelf margin causing increased organic production which deoxygenated the water. As the global sea level rose this time, it reached a point at which the southern Welsh Basin, periodically isolated from the Iapetus Ocean, again became connected to it, resulting in an influx of ocean water and marine life. This event is termed the persculptus connectivity. It led to the finely laminated Cwmere Formation, rich in pyrite with consequent rusty weathering of exposed rock. Within 2m of the MMb the lithology is clearly anoxic and rusty weathering, with a regular fine cleavage and containing *Normalograptus persculptus* graptolites [SN 8414 8993], preserved because the sea floor had again become anoxic. The exposure reveals only a few metres of the CeF and is therefore the topmost Ordovician. The BGS map of the Llanidloes district (BGS 2010) shows the base of the Llandovery, which is therefore the Ordovician-Silurian boundary, as just above the base of the CeF. In the early 1990s the base of the Llandovery was taken as first appearance of the graptolite *N. persculptus,* but now it is taken as the first appearance of the later *A. acensus* and *P. acuminatus* graptolites. These have not been found in the lowest Cwmere in the district and hence the lowest Cwmere is here assigned to the Ordovician.

**Lower Silurian rocks - Quarries 18 &14**

Quarry 18 is on the south side of the road [SN8506 8633], 800m on foot SW of the public car park; a right of way crosses the river. Faulting and the angle of cut of the quarry juxtaposes Cwmere, Derwenlas and Rhayader Mudstone Formations side by side. Looking south into the quarry the CeF lies to the left (north-east), DlF is in the centre and Rhs at the right (south-west). The CeF is identified by its pale and extensive rusty weathering, and extremely friable nature: where the rock is well weathered it can be rubbed to a mud between the fingers. The DlF in the centre is mostly a pale grey and greenish, more oxic mudstone. The pale grey Rhs on the right shows its characteristically evident bedding, jointing and cleavage discontinuities. At ground level in the Rhs to the right of the fault cleft, is an interval of darker millimetre-laminated shale with sparse *Monograptus sedgwickii* graptolites, displaying their characteristically hooked thecae. This is the Sedwickii Shale, the appearance of which determines the base of the Rhayader Mudstone Formation in the district.

*Quarry 18 - Cavitation mineralisation in Rhs. Movement on the fault (direction arrows) causes cavitation and formation of white mineral bands, each consisting of numerous fine fibres parallel to the movement.*

The CeF records the third transgressional pulse after the eustatic lowstand which occurred during deposition of the Ptm. The basin shelf was flooded again, altering the mixing currents and stratifying the water column, leading to dysoxic or anoxic bottom water. The overlying DlF records mostly more oxic conditions, though with periodic lower order sea level movements which led to intervals of dysoxic bottom water, and some pyrite formation, with consequent rusty weathering. The overlying Rhs begins with an important transgression, anoxicity, and the Sedgwickii Shales, followed by mostly oxic bottom waters and bioturbation of the sediment. This eustatic surge is indicated in the earliest Telychian part of the sequence stratigraphy diagram.

The curious juxtaposition of CeF, DlF and Rhs is the same small quarry deserves a mention. It is due to faulting. A major transverse fault thirty miles long runs very close to this quarry and is extensively mineralised in the district. South-west it becomes the Castell Fault in Ceredigion, and to the east it passes through Severn-break-its-neck and on to the Van lode. A short splay on this fault runs approximately north-east, from the visible cleft at middle-right of the quarry, passing in front of the left side of the quarry face. The Rhs lies on the viewer's side of the fault, and the DlF and CeF lie on the other side, i.e. behind the fault. Normally the CeF-DlF boundary would lie stratigraphically some 45m below the basal Rhs but a heave south of the fault has lifted it to the level of the Rhs. Pronounced subvertical slickensides appear on the DlF at the back of the quarry face. Further evidence of tectonic movement is suggested by a prominent pattern of microcrystalline mineralisation in the Rhs, where sliding of joint faces caused slight cavitation, forming horizontal lines normal to the direction of movement. Under hand lens each of these lines is a short band of fibrous mineralisation (probably clay minerals like illite, smectite and chlorite) with the fibres parallel to the axis of movement.

Quarry 14 [SN 8514 8751] is 1.3km north-west of the public car park on foot. It provides an unusual continuous exposure of several alternations between oxic and dysoxic sediments during the Upper DlF, and is seen as parasequences in the *convolutus* biozone of the Aeronian stage of the sequence stratigraphy. Thinly interbedded mudstone turbidites dip c.20ºE and vary from pale grey to nearly black. The oxic horizons are grey and the dysoxic ones are faintly rusty weathering and sparsely graptolitic, except for the very rusty weathered exposure of the top of the succession at the right (east) side of the quarry which has abundant graptolites, which may be *M. triangulatus* or *M. convolutus*. This also contains bentonite horizons, one of 15mm, and much fine pyrite, where ferric compounds have been reduced to sulphide. The alternations result from minor regional fluctations in marine base level superimposed on a rising eustatic trend of sea level – alternations of perhaps 10m. This was more easily seen before the face was blasted in 2016. Now the face is very ragged and a large volume of loose rock lies against it. When this has been removed the feature may again become visible. At present study of the quarry remains difficult.

Three transgression-regression couplets can be seen in the above rocks, and in the sequence stratigraphy diagram of the the Type Llandovery area (previous article). Each rises to a maximum flooding surface and then falls to a lowstand: **1.** the rise during the late Ordovician (including the earliest CeF), followed by a fall in mid CeF (Hirnantian-Rhuddanian couplet); **2.** the rise during late CeF and fall in early DlF (Rhuddanian-Aeronian couplet); and **3**. the rise at earliest Rhs and subsequent fall (Aeronian-Telychian couplet). These sequences, and the parasequences superimposed on them, adjust the various, often differing and usually much simpler sequence stratigraphies proposed over the last twenty years or so, and provide valuable insights into the depositional environments of the southern Welsh Basin.

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*Clearing the Mottled Mudstone Member. 23rd June 2015.*

*Photo ©Richard Becker.*