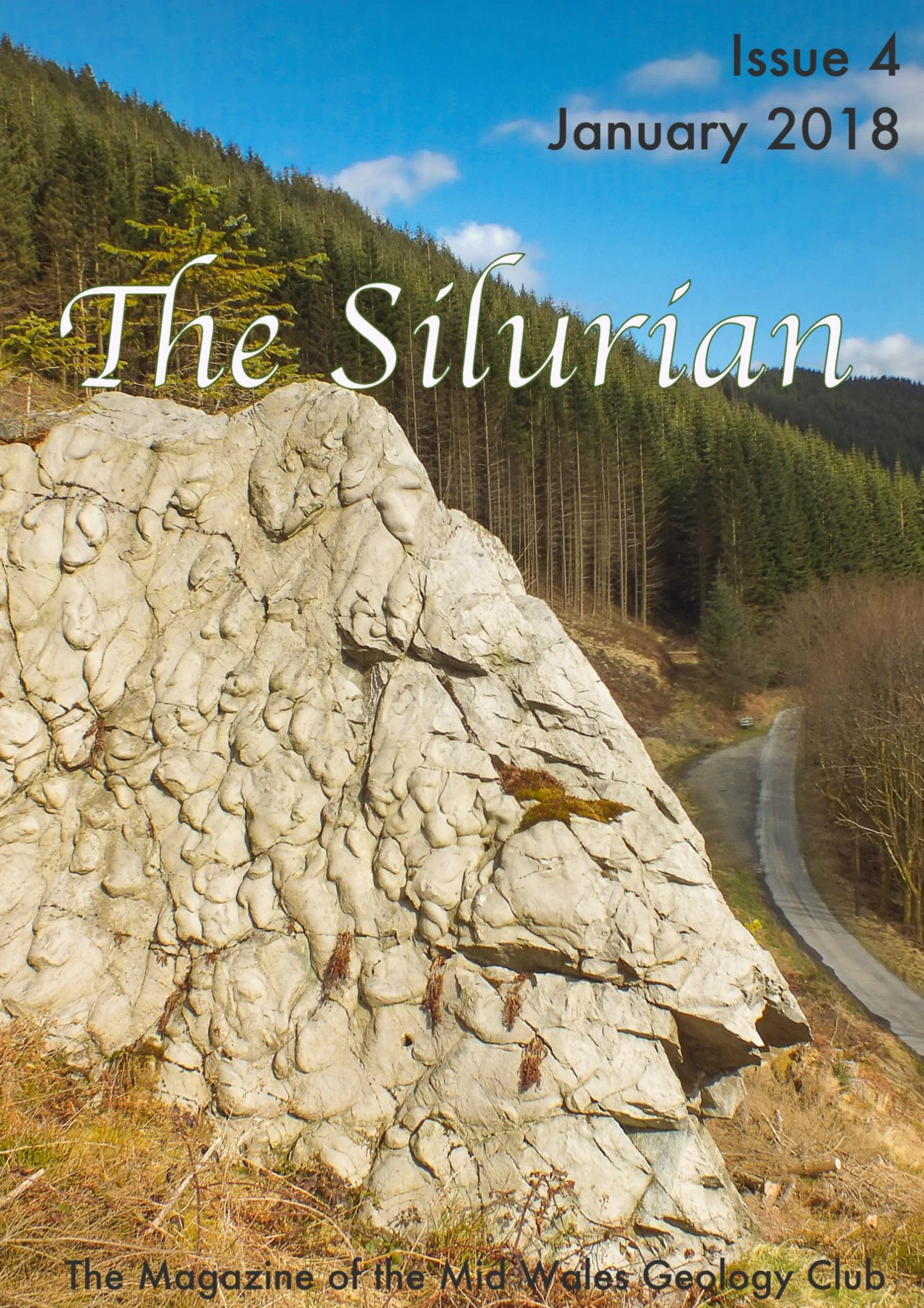
Issue 4

January 2018

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: The Drinking Stone in the Hafren Forest ©Bill Bagley

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There are some in the scientific field whose work lays the foundations on which others will follow. Henry Clifton Sorby was one of these remarkable individuals and his story is the first article in this issue.

In the scientific method a question is posed, observations and accurate measurements made, results obtained, and a conclusion formed based upon the findings. The “Drinking Stone” posed questions that required answers and a tentative conclusion can be found in the article by Colin Humphrey.

Michele Becker

Submissions

Please read this before sending in an article.

Submissions for the next issue by the beginning of November 2018 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.

'Members Photographs' and cover photos are also wanted. Cover photos need to be in 'portrait' format and a minimum of 3000X2000 pixels.

Henry Clifton Sorby:
His scientific journey and the making of a great experimentalist.

Henry Clifton Sorby (Wikipedia Commons)

Abstract
Sheffield is a technology based city and Henry Clifton Sorby was by far the greatest scientist it ever produced. Unlike most Victorian scientists, he was neither aristocrat nor academic, but came from a family of cutlers and toolmakers. His family background, education and lifetime scientific achievements are summarised with a view to establishing the unique circumstances giving rise to such an exceptional talent. His scientific work covered vastly differing disciplines, from meteorites to marine biology, but there is a connecting thread which can be summarised as a "journey through the sciences with a microscope."

(Sorby).. was a truly great man, whose physical insight and experimental ingenuity enabled him to found two important, though specialised, branches of science, but his geographical and his intellectual location were both such as to preclude his drawing admiration from more than a few. …..it was Sorby who first established the methods of observation and the framework of modern understanding of the real structure of inorganic matter above the scale of the atom – that all-pervasive polycrystallinity on which the properties of most useful substances depend. **Cyril Stanley Smith's forward to the only biographical book on Sorby.**

Early life and family
Henry Clifton Sorby was born near Sheffield in 1826. It was an insular community and the Sorbys had, for generations, been closely related to other similar Sheffield families, where the culture was one of application and the building up of their several small businesses. There was little appetite for leisure or scientific activities and any such would be directed to the improvement of product or profit. Sorby was the only son of the owner of the firm "John Sorby and Sons", cutlers and toolmakers, who also had a coal mine on his estate. He never married, but the descendants of an uncle still trade as "Robert Sorby", manufacturing woodturning tools in Sheffield.
His parents were first cousins, and his mother, later described as a "somewhat remarkable woman", was the daughter of a merchant and had been born and brought up in London, where the sciences would have been part of the social scene. She was probably the inspiration behind Sorby's interest in science as a boy. Throughout his life he was devoted to her.
His father died when he was 21 and he inherited the estate. He had little time for the business, but set himself up with a workshop and laboratory where he could indulge in research without the necessity of justifying the expense whether or not it was productive in the short or long term.

Education
Sorby's early education was typical of the children of his more well-to-do contemporaries. He went to a private school in Harrogate and then the Sheffield Collegiate School where, notably, he won a book, entitled *"Readings in Science"* published by the Society for Promoting Christian Knowledge (SPCK). This book provided an introduction to physical sciences, including chapters on light, optics and the microscope and influenced his later decision to take up scientific research.
Although Sorby's parents were interested in his education, at no time was it considered that he should go to university. The prevailing attitude was that he would inherit the family business and, unless entering the church or looking to an aristocratic lifestyle, university would be a waste of time. At that time, no university awarded degrees in science.
As it was, Sorby left school aged 15 and his parents engaged a full-time tutor, the Rev. Walter Mitchell, to complete his education. Mitchell was the recently installed curate of a local church and was a competent chemist, biochemist and crystallographer. This remarkable man's early tuition allowed Sorby

to pursue his education, as he later put it, "...not to pass an exam, but to qualify for a career in original investigation." Although a revolutionary in science, Sorby remained a pillar of the church throughout his life.

First researches

His earliest research was conducted under Mitchell's supervision and followed on from earlier researches of Baron von Liebig.

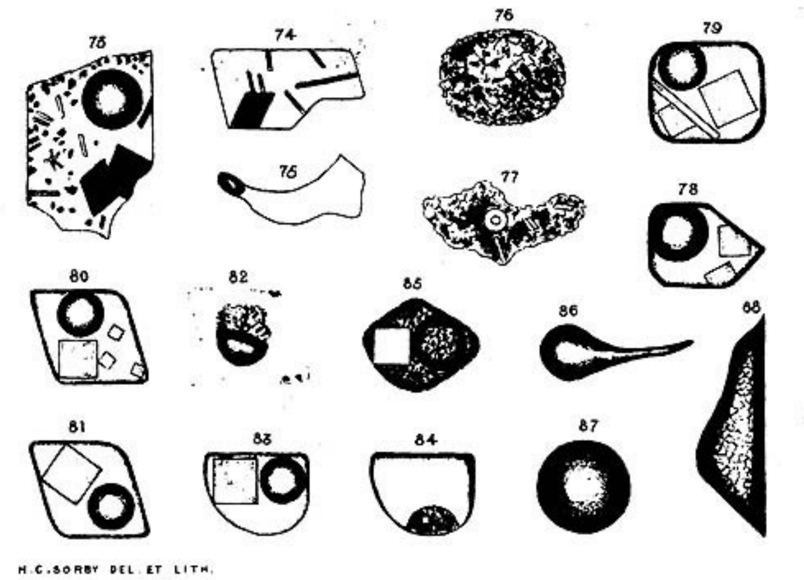
Liebig, often referred to as the founder of the fertiliser industry, studied the uptake and replenishment of inorganic elements by plants. Fundamental to this is the elemental analysis of plants, which Liebig determined by burning them and analysing their ash. Sorby thought that material was lost with the volatiles released in this method and developed an alternative method for sulphur and phosphorous, involving wet chemical analysis. In essence, his method for sulphur involved drying, weighing and extracting with hot nitric acid, before diluting, filtering and adding barium nitrate to precipitate sulphur as barium sulphate.

To estimate phosphorus, lead acetate was added to the filtered solution followed by ammonia solution, the precipitate being dried and calcined over low heat to convert it into a mixture of lead, lead oxide and phosphate of lead. This was dissolved in nitric acid and ammonia added until a precipitate of subnitrate was formed. When on adding acetic acid, the whole of the phosphate alone was left insoluble. This was filtered, washed, dried, ignited, weighed and the phosphorus calculated. He published a table representing the quantities removed from an acre by various crops, that being the amount which must be replaced to maintain fertility.

This was his only foray into agrochemistry, probably inspired by Mitchell, after which he was caught up in the excitement of the time as professional and amateur scientists, together with lay people, took up the fashionable science of geology. This may have been encouraged by the gift from a family member, Clement Sorby, of Playfair's *"Illustrations of the Huttonian Theory Of the Earth*" in 1846.

Boom times for geology

Although Britain had been exploiting more mineral resources than the rest of Europe, 18th century geological development was centred on the famous old mining school at Freiburg, where Werner had posited the first comprehensive theory of the origin of rocks, based on observation. His "Neptunian" theory was, loosely, that the earth originated with a completely watery surface and that rocks crystallised out and were deposited in rough layers, or strata. Firstly primitive rocks like granites, gneisses and schists, and then alluvial deposits, and so on.



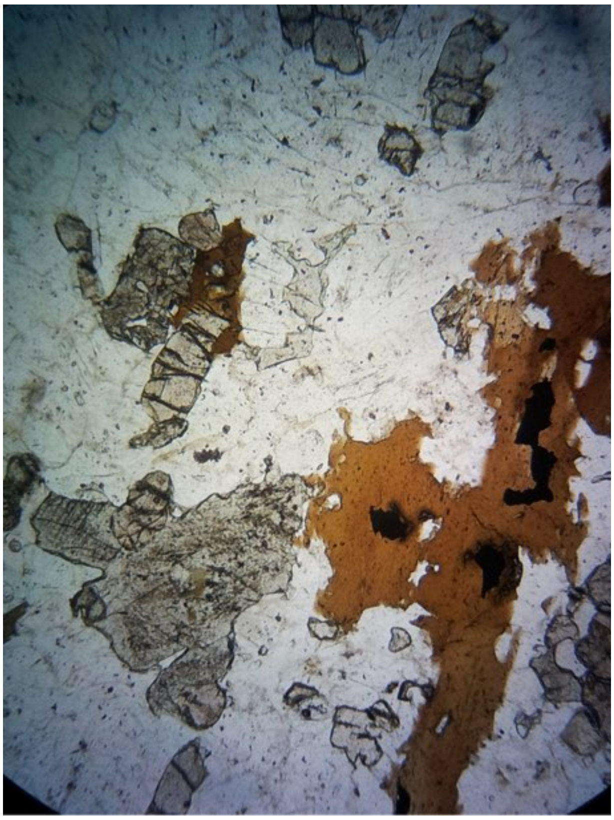
Fluid inclusions sketch by H.C. Sorby. Various cavities are filled with fluid with gas bubbles. (Wikipedia Commons)

At the turn of the century, Edinburgh was a great centre of scientific thought and John Playfair, Professor of Natural Philosophy, had published his "Illustrations of the Huttonian theory of the Earth" which explained in lucid style James Hutton's theories, which posited that granites at least were produced by igneous processes. Hutton's theory, dubbed "Plutonist" was that the interior of the earth was hot and this heat was the engine that drove the creation of new rock and that water and atmosphere eroded rocks, which were then deposited at the bottom of the sea as particles where they were cooked and formed into stone, in layers. Over long periods of time rocks were uplifted and the cycle repeated by the same slow processes as are going on at the present time, with "No sign of a beginning ….and no prospect of an end." This idea is often termed "uniformitarianism", as opposed to "catastrophism", often posited as conforming to a series of catastrophic occurrences such as in the biblical Noah's Flood.

In Sorby's time, most scientists had accepted the Huttonian theory; but many lay-people and the church were still arguing that such was atheistic and contrary to biblical teaching. Then, as now, geology exerts a certain fascination for the religious and creationists.

Early geological work

Sorby's first geological study was typical. Unlike many contemporary amateurs, he did not confine himself to collecting specimens for his collection, but carried out a research program. It started when he was walking back to his Orgreave estate and, during a shower, sheltered in a quarry and noticed "current structures", being the structures produced by the currents present during their original deposition.



Diorite plain polarisation. Transparent crystals are feldspars, brown is biotite and high relief pyroxenes.

He went on to produce maps of the valleys of the Don and the Rother, showing the character of the alluvial tract and the evidence for the meandering of the rivers in earlier times; but he did not stop there. He rigged up apparatus in the river itself, for measuring the flow and the rate of deposition of silt. He was the first geologist to follow the Huttonian principle that present-day processes are the clue to the past and to actually measure these.

The microscope and microscopic petrography

Into the maelstrom of public debate another technology was coming of age. Microscopes had been around for decades, but in the mid 19th century, British microscope makers became preeminent, producing instruments approaching the theoretical limits of performance. Like telescopes, expensive instruments graced the libraries of many aristocrats. Again, in Edinburgh, boundaries were being pushed by David Brewster and William Nicol who had taken up a technique, said to be based on that used by an Edinburgh lapidary, G. Sanderson, of making thin sections such that they could be examined by transmitted light. These they were using to examine wood, bones and teeth. This technique was also being used by William Wilkinson, who had been a student at University College, London, and was using it to examine bones and teeth when he was a physician in Manchester.

At the time, Sorby was starting to study the calcareous rocks of the Bridlington crag on the Yorkshire coast and was probably using the then current method of crushing and examining them with a lens. By coincidence, travelling from Scarborough to York, Sorby shared a railway carriage with Williamson and learned about making thin sections. Sorby then visited Williamson who taught him the technique. Sorby soon became proficient and later commented;

> "….*It occurred to me, as early as 1849, that a great deal might be learned by applying a similar method to the structure of rocks*."

Thus, Sorby was not the first to make thin sections, but he was the first to make them of hard rocks. He went on to apply the technique to the geology of the Malvern Hills in 1849 and read a paper on the subject to the Literary & Philosophical Society that year.

This was the birth of Microscopic Petrography and Sorby was rightly dubbed "The Father of Microscopic Petrography" The new discipline took off slowly as Sorby moved onto other topics but, fortuitously, in 1861, on the continent, Sorby met a student, Ferdinand Zirkel, to whom he explained the techniques he used and Zirkel took them up enthusiastically and in 1866 published "*Lehrbuch der Petrographie*" which was the standard work for many years. Whatever the science, microscopy was a connecting thread which ran through all Sorby's research projects. He worked extensively with R & J.

Beck, some of whose instruments were branded “Sorby – Beck” He was nominated for the presidency of the Royal Microscopy Society in 1874.

Slaty cleavage

In 1853, Inspired by a visit to Wales in 1851, Sorby studied a longstanding problem which had interested geologists for some time. Slates exhibit “Slaty Cleavage”, forming cleavage planes which do not correspond to the the way they were originally deposited and various chemical, mechanical and even electrical causes had been suggested. He investigated this phenomenon by making thin sections and examining them microscopically and showed conclusively that the cleavage is due to anisotropic pressure causing regrowth and reorientation of particles of mica into a plane perpendicular to the direction of greatest stress. His findings were first published in a paper “*On the nature of slaty cleavage”* in the Proceedings of the Yorkshire Geological Society in 1853.

Anecdotally, when De la Beche, the Director-General of the Geological Survey heard about it he commented that Sorby had no business studying that as it had already been settled. Fortunately Sorby took no notice and continued his studies. In 1857, largely on the basis of this work, aged 31, he was elected a Fellow of the Royal Society.

Granites

In 1855 Sorby met an Edinburgh watchmaker, Alexander Bryson, who had a collection of William Nicol’s specimens, including a number with fluid inclusions. These are small cavities within a crystal, formed while the crystal was growing and trapping some fluid material from which it was crystallising.

These had been studied for many years, but not in a geological context. Bryson had a number of granite specimens with inclusions in quartz crystals. Sorby made a special study of these and was able to make deductions about the depth and temperature at which they were formed. Many inclusions included aqueous solution plus a bubble of vapour. At the temperature when they were formed, they would have been filled with solution. If, on a heated microscope stage one is reheated so that the solution fills the cavity, that must be the temperature at which it crystallised originally.

Spectrum microscope

In the 1860s Bunsen and Kirchhoff’s work in spectrum analysis was inspiring the scientific community. Most were making use of emission spectra, but absorption spectra were becoming of interest mainly to organic chemists, but Sorby thought a spectroscope could be combined with a microscope and used to identify coloured minerals in thin sections. However he quickly moved on to the detection of small quantities of blood. In 1865 he submitted a paper “*On the application of spectrum analysis to microscopical investigations and especially to the detection of bloodstains.”* to the Quarterly Journal of Science.

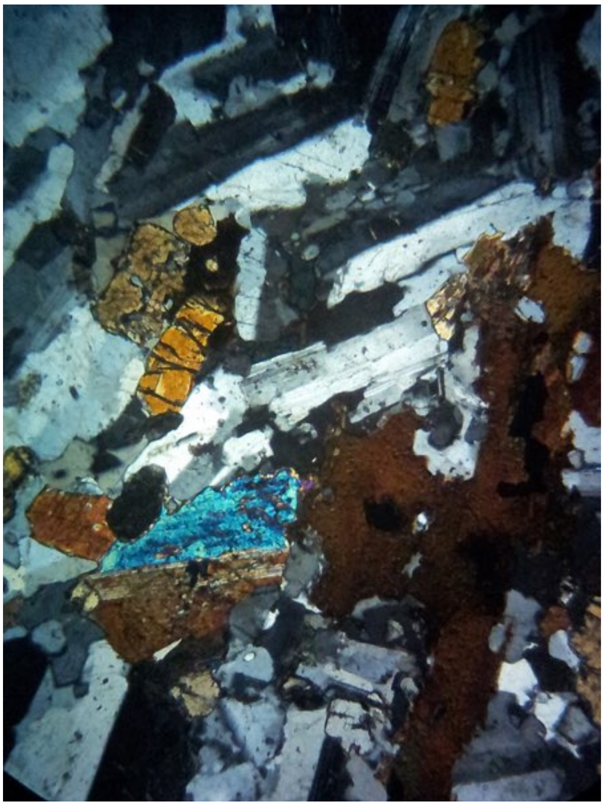
He developed this instrument and others in conjunction with R and J Beck and a “Spectrum Microscope” consisting of a direct vision spectroscope which was interchangeable with the ocular of a microscope was marketed as the “Beck-Sorby Micro-spectroscope”.

The Beck-Sorby Micro-spectroscope. Reproduced with permission.

Applied to meteorites and steel
Sorby's geological researches naturally led onto his study of meteorites, a field he actively researched from about 1861 when, after a British Association meeting in Manchester, he started collaborating with an astronomer, R. P. Greg who had published an atlas of meteorites.
Iron meteorites presented a problem, being largely opaque. However thin, transmitted light could not be used, so Sorby had to use incident or reflected light. The best Victorian microscopes were very versatile and came with a variety of incident light accessories. Sorby used an R and J Beck microscope and developed techniques for examining polished metallic specimens. As well as these, he prepared specimens which had been etched with dilute nitric acid.
To aid his understanding, he also prepared specimens of manufactured iron and steel, these being metals he would have been very familiar with. Aware of its practical importance, he was to spend the next twenty years sporadically studying their microscopic structure. In an autobiographical address in 1887 he stated "*It is now more than twenty years since I first commenced to carefully study the microscopic structure of iron and steel, in order, if possible, to throw light on the origin of meteoric iron, but soon found that the results were of even more value in connection with practical metallurgy."* Although it was slow to adopt Sorby's techniques, he is regarded as "The father of microscopic metallurgy."
Sorby had a longtime interest in the Sheffield Literary and Philosophical Society (Lit & Phil), being elected many times as president or secretary. This greatly facilitated the cross fertilisation of ideas and, while national London-based societies were becoming more specialised, the local Lit & Phil enabled Sorby to network with opticians, steelmakers, photographers and others. In particular his metallurgical work was assisted and encouraged by discussions with William Baker, a consultant chemist to iron and steel manufacturers, unfortunately more famous for his freak death, due to his sliding down the bannisters and falling three stories.

Marine biology
From 1878 Sorby embarked on an apparently new research avenue, marine biology. The connection was probably his involvement in the examination of the mineral specimens brought back by HMS Challenger after four years in the Pacific and Atlantic.
So enthused was he that he bought "Glimpse", a yawl with a crew of five, equipped with a laboratory. For the next 25 years, in the summers, he cruised the east coast studying marine biology and movements of silt and sewage.

Awards, illness and legacy
Sorby spent his life in Sheffield and joined and supported the Sheffield Literary and Philosophical Society, being elected president many times, however he was also nationally recognised and received three gold medals, the Wollaston of the Geological Society, the Gold Medal of the Dutch Society of Sciences and the Gold Medal of the Royal Society. He was president multiple times of the Royal Microscopical Society, the Mineralogical Society and the Geological branch of the British Association. He is regarded both as the "Father of microscopical petrology" and of "microscopical metallurgy."



Diorite cross-polarisation.
In crossed polars, feldspars are grey interference colours, biotite brown and pyroxenes higher colours.

From 1902, he was crippled and worked on his notes, producing his magnum opus "*On the application of quantitative methods to the structure and history of rocks."*
He was active in the furtherance of education in Sheffield and became President of Firth College and strove to establish a university, which was achieved in 1905.

Conclusions

What enabled Sheffield to produce such a unique great scientist? He was neither academic nor aristocrat. His family background equipped him with a work ethic and manual dexterity. Genetically there was intelligence and individuality. He would never go with the flow and was happy to plough his own furrow irrespective of scientific opinion.

His mother's influence probably enabled him to throw off pressure to continue the family business, no doubt to the great disappointment of the family. His inheritance enabled him to avoid having to justify a salary and to tackle projects with no prospect of short term reward. Perhaps it was his mother also who influenced the choice of Mitchell, the curate with an unusually intense scientific bent whose tuition inspired his pupil to spurn the family business and follow his vocation. It was, however, the microscope which was the connecting thread which makes sense of this journey through so many different scientific disciplines.

Tony Thorp

Further reading:

HIGHAM N. 1963. *A very scientific gentleman: the major achievements of Henry Clifton Sorby.* Oxford: Pergamon.
(The only biographical book on Sorby and a good starting point.)

CARPENTER W.B. 1881. *The Microscope 6th Ed.* London.
(Lots of microscopic techniques. Fluid inclusions pages 835 & 836. The Beck-Sorby micro-spectrometer page 105. Other microscope attachments and techniques of the times.)

Members Photograph

Apatite on calcite from Yates Mine, Otter Lake, Quebec. Janey Haselden

Bill's Rocks and Minerals

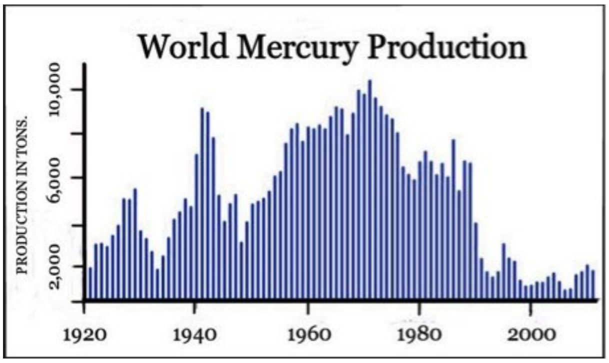
Mercury (Hg): It's Properties and Hazards.

Mercury is a mineral and native element which most of us recognise. Who hasn't seen a mercury thermometer or barometer or heard about mercury poisoning ? More later.

Mercury is the only mineral that exists as a liquid at room temperature. It freezes and adopts a solid structure at a temperature of minus 38.83ºC, and converts to a gas at it's boiling point of 356.73ºC. Both freezing and boiling point temperatures are the lowest of any mineral. When mercury is solid it is malleable, and can be cut with a knife. In it's natural liquid state it is noticeable that it adopts pronounced globules, which are the result of a very high surface tension. This is because of intermetallic bonding in which the mercury molecules have a very strong attraction to each other. Many liquids form globules, but none as extreme as mercury, for instance water globules are flatter and not so pronounced because of the weaker bonding of hydrogen.

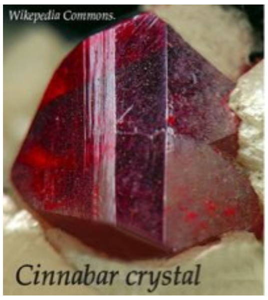
Mercury is not very common in it's natural liquid state, only being found as small globules on the surface of mercury ores, and for this reason liquid mercury is not a major contributor to global production. There are very few ores of mercury, the major one being cinnabar (HgS). Less productive ores are montroydite (HgO), tiemannite (HgSe), and calomel (Hg_2Cl_2). Cinnabar is, or was the major ore of mercury, but since about 2010 most countries have ceased to mine cinnabar for the production of mercury, regarding mercury as being a health hazard. Most countries have also restricted details of what they have produced, and data is very difficult to obtain. China, however is an exception, and is producing about 150,000 tonnes per annum.

Most countries are supporting their greatly reduced need by recycling. The bulk of recycled mercury is recovered from the rapid decline, and shut down of chlorine-alkali facilities, which had been using the mercury process, but now have large unwanted stocks. Specialist companies also recover mercury

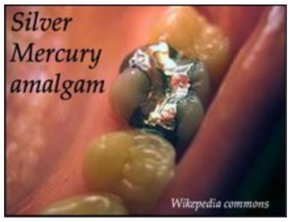


from the scrapping of float switches, thermometers, barometers, and particularly fluorescent light tubes and compact fluorescent lamps (C.F.Ls.) Historically mercury was also a key component of batteries, but the U.S.A. banned their sale in 1996, followed by a European ban in 1998.

Mercury Amalgams
Mercury readily forms amalgams with a number of minerals, including zinc, potassium, sodium, gold, silver, tin, and aluminium. In the process of forming an amalgam, mercury dissolves these minerals and incorporates them into an amalgam. Importantly it will not form an amalgam with iron, making iron flasks the preferred method of containment.



Dental amalgam is about 50% mercury, combined with mainly silver, and smaller amounts of tin and copper. There is a very lively ongoing argument about the use of dental amalgam. There are some who believe that the mercury in the amalgam can give rise to neurological and mental problems, while others consider it to be perfectly safe. An internet search will find hundreds of articles on the controversy, mostly against it's use.



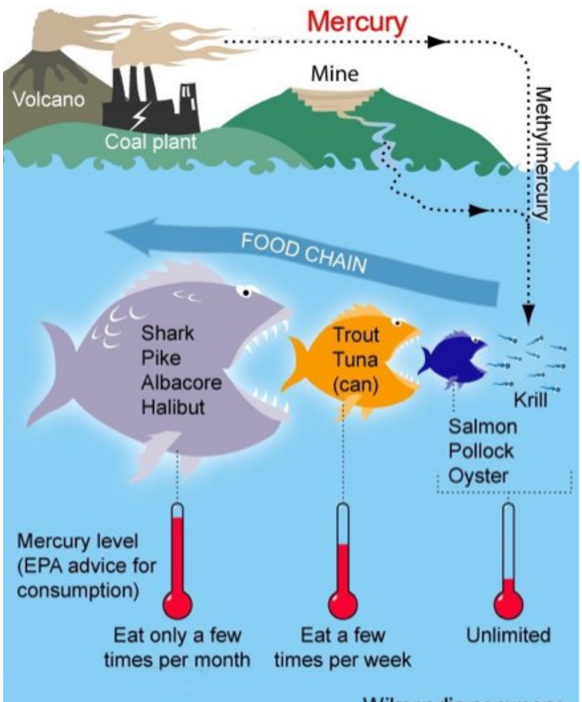
Airlines have banned the carriage of mercury, because of the ease with which it amalgamates with aluminium. Aircraft bodies are mainly aluminium, and any contact with mercury could be disastrous.

Today, we often hear about the use of mercury in gold recovery by impoverished miners in third world countries. This is achieved by the amalgam process in which small particles of gold are absorbed by the mercury, to be later recovered by boiling off the mercury.

Mercury gold amalgam

The boiling releases atmospheric mercury, which is very toxic and dangerous for the tens of thousand small scale miners who are using this method. Major gold mining companies have been pressured into using alternative methods, other than mercury for gold recovery, and now hardly use it at all.

Mercury is finding it's way into the ocean and eventually the food chain from three major sources: volcanic activity, mining sites, even those that are now closed, but mostly from coal fired power station emissions. The latter emit about 50% of the mercury which finds it's way into the ocean. In the U.S.A. there are about six hundred coal fired power stations. Once in the ocean, mercury is assimilated in the bodies of fish and shellfish. Mercury in smaller fish is concentrated even more as they are eaten by larger fish, until the very largest fish such as tuna, and sharks have considerable levels of mercury, They eventually end up in fish markets, and the human food supply. It is estimated that in the U.S.A. one in six women of child bearing age have blood mercury levels that are above the safe recommended limits. The worst occurrence of mercury poisoning from food occurred in 1956 in Japan. Minamata disease, was one of Japan's worst environmental disasters and was the result of mercury poisoning from eating fish and shellfish. Thousands of people were sickened or crippled by neurological disorders from the mercury leaks into Minamata Bay and nearby waters by chemical company Chisso Corp., which continued for more than a decade. Affected babies were born with severe deformities.



Wikepedia commons

In conclusion, mercury is a very interesting and useful mineral, but because of the knowledge gained over the years about it's harmful effects, it is now being used less and less in all it's applications. There is concern about the amount that has found it's way into the food chain, particularly into large fish. Mercury levels in tissue are cumulative and can not be removed. Symptoms of mercury poisoning include vision, hearing, and speech problems, lack of co-ordination, muscle weakness, and neurological problems.

Mercury is definitely both beauty and the beast.

Bill Bagley

Geological Excursions

Sites to visit :
Excursion Number 6

Tonfanau Beach: A Geological Walk in the Quaternary

Grid ref. SH 564038
Maps:
Topography: ***O.S. Landranger 23 Cadair Idris & Bala Lake.***
Geology: ***BGS 1:50,000 Sheet 149 Cadair Idris Solid and Drift.***
The walk is about 4km total, along a bouldery and sandy beach below low cliffs. High tides should be avoided. The beach is exposed and surprisingly unpleasant in bad weather, so appropriate clothing is necessary.
Access is convenient by rail to Tonfanau Railway Station. Car drivers can park opposite the station without obstructing gates.

Walk across the railway line and follow the tarmac road towards the beach, from the end of which, head for a gate onto the beach. The interesting cliff section is the next 2 kilometres, going north from the mouth of the Dysynni river.

The cliffs are low, only up to some three to four metres, but some are unstable and hard hats should be worn if you want to examine closely. All the major features are visible from a distance. The entire cliff section is in Quaternary deposits of what geologists term diamicton or, more descriptively, “boulder clay”, till, or drift. (Technically, diamicton indicates nothing about its derivation, but describes a deposit of unsorted particles, from clay to boulders, within a muddy or sandy matrix. Till or drift is specifically glacier derived.) Most of us who live inland rarely see clean vertical sections through till because it rapidly degrades and becomes vegetated. As Tonfanau cliff is being rapidly eroded, it gives us a fresh section through a library of till types.

A nearby borehole has shown that, below the visible section, there is some 36 metres of till, so we can see only the most recent of the glacial deposits. We do not see any contact between the till and bedrock.

The cliff immediately to the north is typical beige coloured till and contains clasts up to boulder size. It is interesting to take some and rub it between the fingers with a bit of spit. This gives an idea of how clayey the fine matrix is (some put it in their mouths, but you may not like to.) This till is quite sandy. The clasts also repay examination. What rocks are they and where from? What signs of their glacial origin are there? They may have striations or facets caused by being rubbed against the rocky bed of the glacier.

If it is possible to identify the origins of clasts, it enables geologists to tell whence the ice came. The obvious source of this till would be the Welsh hills immediately to the east, but the consensus now is that this till is derived from the Irish Sea Glacier, from the north or northwest as it contains clasts from the Irish Sea, Anglesey and the Lleyn Peninsula.

After the retreat of the glaciers, the deposit was subject to periglacial conditions and it is worth looking for any signs of this. We can only see what is visible in section, but can look for any cryoturbation structures or frost wedges. Ice freeze and thaw can open cracks which fill with more sandy or more gravelly material. Freeze-thaw can also move particles vertically, causing distortion of layers.

As we progress up the beach, we can look at what different boulders are around us. These could be erratics transported by ice (or could be ballast transported by people!) You will find several limestones. It is worth looking for fossils in them, are they Carboniferous or Jurassic?

Looking left, going straight out to sea, there is a field of rocks at near low tide level, which is part of the Sarn-y-Bwch; one of three sarnau which are ridges projecting into Cardigan Bay. The others are Sarn Badrig, south of Harlech and Sarn Cynfelyn, at Wallog. They are not of Roman construction, nor built by giants, but most probably the remains of median moraines between piedmont glaciers flowing west off the Welsh ice sheet.

Going further north, the cliffs get higher and there is some slumping. Keep an eye on the lowest part of the cliff. Not always exposed, there is less than a metre of a different coloured till. It is not beige, but a dark grey with a more clayey matrix (test with spit) and is well consolidated (it has resisted erosion better than the beds immediately above it.). It contains clasts derived from the east, near Cadair Idris, so is indeed Welsh till **(see Patton 2009)**.

Further on we start to get gravel beds of pebble to cobble-sized clasts with little matrix. These must have been transported by very fast flowing water as outwash or esker discharges from a melting glacier. (**Figure 1)**.

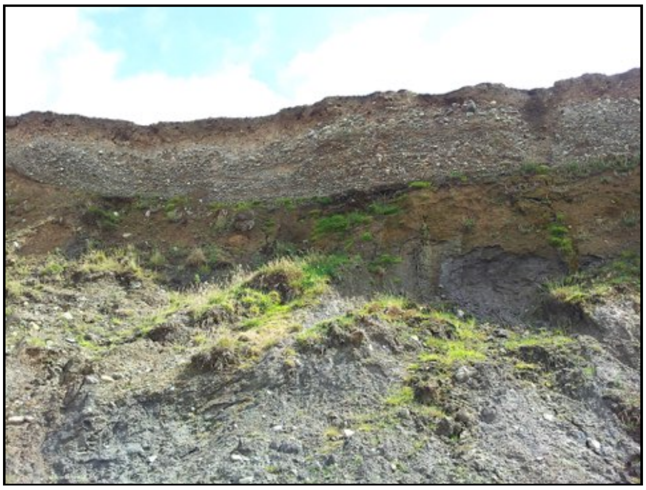


Figure 1. Gravel bed formed by fast flowing water.

Many of these have been broken up either by the repositioning of outwash channels or by ice push. **(Figure 2)**.

Figure 2. Gravel beds massively broken up.

Another structure you will find is alternating sandy and muddy beds indicating a fluvial environment **(Figure 3)** where outwash waters have repeatedly produced influxes of sand and mud.

Further on towards the end of the section, there are some surprisingly steeply humped gravel beds. **(Figure 4)** Could these have

Figure 3. Alternating sandy and muddy beds indicate a fluvial environment.

Figure 4. Beds "bulldozed" and over-steepened by a prograding glacier snout.

been "bulldozed" and over-steepened by a prograding glacier snout?

The cliffs begin to tell a story of the late Devensian ice movements. At one time Welsh ice from the east was predominant and deposited the dark grey till often exposed at the foot of the cliff. As it retreated, Irish Sea ice from the north impinged on Tonfanau forming an ice-dammed lake and discharged meltwater carrying sand and gravels to form the main part of the cliffs exposed at present.

The section ends where the cliff is obscured by the gabions used to shore up the railway when it was repaired a few years ago. If there is spare time on the way back, the examination of erratic boulders on the beach can prove most rewarding.

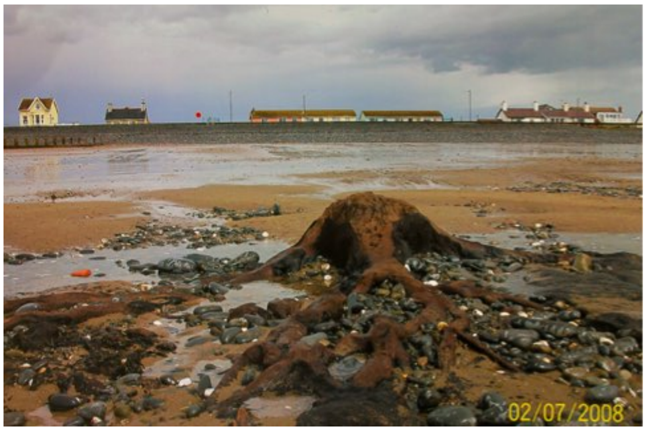
Tony Thorp

References: (Note: This is a rapidly eroding cliff. All references are out of date!)

GA Guide No. 54 (1995) *The Aberystwyth District* pp59-63 . (Dated, but gives a brief overall view)

Patton, H., Hamprey, M.J., 2009. *Ice-Marginal-marginal sedimentation associated with the Late Devensian Welsh Ice Cap and the Irish Sea Ice Stream: Tonfanau,* West Wales Proc. G.A. 120, pp256-274. (More recent with masses of detail and analysis, but data is about 10 years old)

Members Photographs



Submerged forest at Borth, Ceredigion.

According to Dyfed Archaeology (dyfedarchaeology.org.uk) the tree stumps are rooted in peat levels lying below the marine sands and have been preserved by the continuous waterlogged conditions. The radiocarbon dates suggest the trees died about 3500 years ago which is 2000 years after trees died at Ynyslas, indicating repeated inundations due to sea level rise.

Topsy Evans.

The Flora of Metalliferous Sites

The waste from metal mining and processing often still has levels of minerals present that are toxic to almost all life forms. Even such a toxic environment is an opportunity for those plants that can evolve and adapt to cope.

Mid Wales has many metalliferous mines that were principally worked during the 19th and early 20th centuries. The main mineral was galena (PbS) which also contained some silver, but zinc (ZnS) was produced from the 1880's and copper as chalcopyrite ($CuFeS_2$), was worked at a few mines e.g. Dylife Mine, Machynlleth **(Hall 2014)**. Heavy metal accumulation in soils can be the result of natural mineralisation due to ore bodies near the surface, although these primary sites are now rare, due to human extraction of the ores which is thought to have commenced in the Bronze Age. Mining and ore processing led to the destruction of many natural sites but created many secondary metalliferous sites in the form of spoil and waste heaps, deserted mine buildings and lagoons. Tertiary sites, can be subdivided into those whose genesis is a result of atmospheric deposition in the vicinity of metal smelters or alluvial deposition of metal-enriched substrates by sedimentation in river floodplains and on raised river banks **(Baumbach 2012)**. In addition metals can be added to the environment from agricultural, industrial and domestic outputs. Not only do metalliferous sites contain a richness of minerals but also some biologically important flora, these species and ecotypes have developed many morphological and physiological adaptations to survive in this extremely hostile environment. Known as metallophytes, they have evolved not only to withstand very high levels of heavy metals but also scarcity of nutrients and water. In addition to the flowering plants these sites often contain rare bryophytes, lichens and insects.

Mine spoil heaps. Dylife Mine, Machynlleth. Photo Richard Becker.

*Coral lichen **Stereocaulon vesuvianum** growing on mine waste at Dylife. Photo Richard Becker*

Plants, like humans, require a number of elements in order to function effectively, these essential elements are divided into macro and micronutrients based on the relative concentrations required. Macronutrients being required in amounts greater than for the micronutrients. The macronutrients are mainly involved in the structure of molecules, nitrogen, for example, is a constituent of many important molecules including proteins and chlorophyll. Micronutrients are involved in regulatory and catalytic roles, copper as an example functions as a cofactor for a variety of oxidative enzymes. The uptake of nutrients by a plant involves a complex interaction between the plant roots and the soil. Present in the soil are clay particles and humus which form the colloidal component. Due to charges present on the colloidal surfaces ions become adsorbed which forms a reservoir for nutrients, so that as the plant takes up nutrient ions via the root they are replaced by exchangeable ions from the colloidal reservoir. Mechanisms of uptake into the plant consists of simple diffusion, facilitated transport and active transport mechanisms. The uptake of nutrients, by most plants, is enhanced by association of the roots with soil microorganisms especially fungi. These fungal-root associations, or mycorrhizae, benefit the plant by significantly increasing the volume of soil accessible to the plant. Although essential to proper functioning of a plant, at higher concentrations these elements become toxic. In addition there are those elements that are not necessary for normal function and prove detrimental whenever they

Macronutrients	Micronutrients
Hydrogen (H)	Chlorine (Cl)
Carbon (C)	Boron (B)
Oxygen (O)	Iron (Fe)
Nitrogen (N)	Manganese (Mn)
Potassium (K)	Zinc (Zn)
Calcium (Ca)	Copper (Cu)
Magnesium (Mg)	Nickel (Ni)
Phosphorus (P)	Molybdenum (Mo)
Sulphur (S)	

are present in the substrate. Lead, silver aluminium, mercury, cobalt and chromium fall into this category. Metal toxicity is responsible for many visual symptoms in plants. Root growth is often reduced, and leaves may change colour. Competition with nutrient ions for uptake by roots can cause deficiency symptoms for example manganese competes with both iron and magnesium for uptake and inhibits calcium translocation into the shoot apex. Thus the dominant symptoms of manganese toxicity may actually be the symptoms of iron, magnesium or calcium deficiency.

As early as the 16th century Agricola understood that the signs of both toxicity and tolerance of plants,could be used in prospecting. The first comprehensive book on prospecting and mining, Agricola's *De Re Metalica (1556)* stated that:

"*... there are trees whose foliage in spring-time has a bluish or leaden tint, the upper branches more especially being tinged with black or with any other unnatural colour, the trunks cleft in two, and the branches black or discoloured... Therefore, in a place where there is a multitude of trees, if a long row of them at an unusual time lose their verdure and become black or discoloured, and frequently fall by the violence of the wind, beneath this spot there is a vein. Likewise along a course where a vein extends, there grows a certain herb or fungus which is absent from the adjacent space, or sometimes even from the neighbourhood of the veins*."

Writing only a few years later, Thalius **(1588 from Baker et al 2010)** was the first to recognise a relationship between the plant *Minuartia verna* (spring sandwort) and heavy-metal-enriched soils in the Harz Mountains, Germany. Subsequently, the association of the plant with lead-mine wastes in the Pennine orefield, gave rise to its local name 'leadwort'.

Metallophytes can be classified as follows: **(Baker et al 2010- adapted from Lambinon and Auquier (1963))**. The obligate metallophytes or those that can only survive on metal-contaminated sites, e.g. *Viola guestphalica* (zinc pansy), *V. lutea subsp.calaminaria* (yellow zinc violet), *Alyssum pintodasilvae.* Some of these plants are also metal "hyperaccumulators" accumulating very high levels of metals in their tissues. Facultative metallophytes are those genotypes or ecotypes/subspecies of common species which have a specific tolerance to metals. They also occur in non-metal enriched areas.The highly specialised ecotype, sub-species or genotype is dependent on the occurrence of specific metals in the soil, e.g. *Armeria maritima* (thrift), *Minuartia verna, Silene vulgaris* (bladder campion),and *Thlaspi caerulescens* (alpine pennycress). In addition, metal-tolerant species or pseudo-metallophytes. are moderately tolerant of heavy metals in the soil, but not dependent on their presence, e.g. *Achillea millefolium* (common yarrow), *Campanula rotundifolia* (harebell), *Ranunculus acris* (meadow buttercup), *Rumex*

*Metallophyte **Armeria maritima** (thrift). Photo Richard Becker.*

acetosella (sheep's sorrel). Finally there are the associated non-metal-tolerant species with little or no metal tolerance, the so-called 'indifferent' or 'accidental' species. These are often weedy species and often annuals which do not show any signs of vigour at the site and soon disappear.

The majority of species that tolerate heavy metal concentrations use exclusion as a mechanism. They retain and detoxify most of the heavy metals in the root tissues, with a minimized translocation to the leaves whose cells remain sensitive to the phytotoxic effects. One means of achieving this is by exuding organic acids which entrap the metals, mycorrhizae play an important role here. At the other end of the scale there are the "hyperaccumulators" which can accumulate levels of metals in their tissues, mainly leaves, up to 1000 times that in non-hyperaccumulating plants, without signs of toxicity. This ability is dependant on, a much greater capability of taking up heavy metals from the soil; a faster and effective root-to-shoot translocation of metals; and a much greater ability to detoxify and sequester huge amounts of heavy metals in the leaves **(Rascio and Navari-Izzo 2011)**. The hyper-accumulators have attracted a great amount of attention due to the possibility of exploiting their accumulation traits for practical applications, in particular to develop technologies for phytoremediation of heavy metal contaminated soils or for mining valuable metals from mineralised sites.

Metalliferous sites and the flora that they contain are unique but are under constant threat from agricultural reclamation, application of herbicides, and application of fertilisers and lime, causing eutrophication in the nutrient-poor metallophyte communities; vegetation succession due to lack of active ecological management; soil remediation enforced by regulatory agencies and site destruction due to mining, gravel extraction, landscape development or tree-planting **(Baker et al 2010).** These problems arise as these sites are seen as derelict, or classed as brownfield sites for development. They are often seen as "eyesores" on the local landscape or potentially dangerous. They are, therefore often cleared, levelled or made suitable for agriculture or for gravel and aggregate production. It is hoped that the sites that remain will be protected along with the unique flora that they contain.

Michele Becker

Pseudo-metallophyte ***Campanula rotundifolia*** *(harebell) growing on mine waste. Snailbeach, Shropshire. Photo Richard Becker.*

References:

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Hall, G. W. (2014): *Metal Mining in mid Wales 1822-1921.* Welsh Mines Society.

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The Drinking Stone and the Pencerrigtewion Member

This is an account of an unusual rock formation, the Pencerrigtewion Member, and of the Drinking Stone, a boulder of this unusual rock which is found perched on a roadside slope in the Hafren Forest, one kilometre east of the car park, just north of the public road (**SN 8674 8683**). The sediments which formed the Pencerrigtewion Member (PtM) were deposited at a critical time in the geological history of the area, when the global sea level was exceptionally low, consequently producing a mass extinction – the second most severe in the geological record. The word 'Member' signifies it is part of a larger geological Formation. Sediments of the PtM were probably widely distributed, but it was a thin deposit and, following the folding of the district, is now exposed in only a few places.

Geological history of the Drinking Stone

The Drinking Stone is frequently wet in the early morning. Legend has it that this boulder descends in the night to drink from the River Severn in the valley below (although non-believers say it is just the night-time dew which has settled on it!). Bill Bagley first brought this stone to the attention of Mid-Wales Geology Club members, and we began to puzzle over its unusually complicated markings. Situated on the steep slope above the road, the site was difficult to access until, during 2017, Natural Resources Wales created a large layby on the road and a path up to the Drinking Stone (**Figure 1**). They are considering placing an interpretation board nearby and club members are endeavouring to explain the environmental and depositional conditions which have led to this remarkable geological feature. Weighing over 50 tonnes, the stone has fractured from the bedrock, probably only a few tens of metres up the hill and a little to the west, and it has slid to rest here. We have been unable so far the find in the mature forestry the place where it broke away. Similar rock is exposed in other places in the forest but this boulder is unusual because of the large area of flute casting which it reveals. Perhaps one day, after the area has been clear felled, further investigation will be possible.

Figure 1. Path to the Drinking Stone.

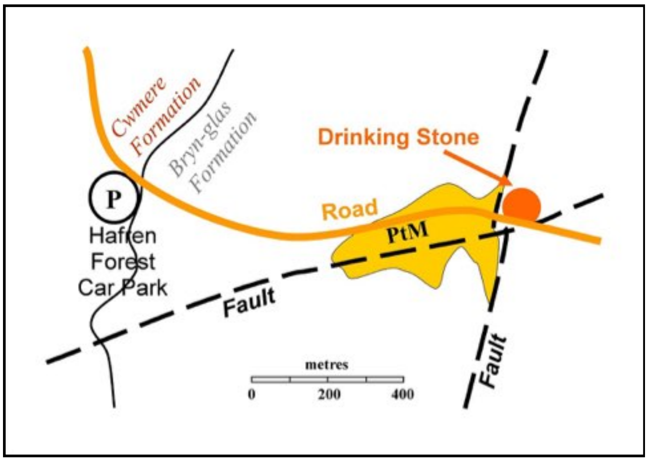


Figure 2. Location of Drinking Stone.

Two large and important faults – cracks in the Earth's crust – cross each other near here and are recorded on the BGS map. One runs north-south where the stone has probably broken away from bedrock. This is a southerly extension of the Dylife Fault and a feature of the Central Wales Lineament, a major north-south fault band. The stone lies just above the road near the edge of a vegetated outcrop of Pencerrigtewion rock (PtM) shown in yellow on **Figure 2.** The other fault runs east-west just below the road, where the River Severn has chosen to flow, and is a westward extension of the highly mineralised Van Fault. The stone has only been perched in its present position for a few hundred, or at the most a few thousand years. Perhaps it initially loosened from the bedrock when the faults moved as the weight of the thick ice age layer melted away more than ten thousand years ago.

The sediment from which the stone formed was deposited 445 million years ago in the Welsh Basin, when England and Wales was near to where Australia is now. The basin was an ancient sea which once covered most of Wales, as shown in **Figure 3**. It achieved depths up to 600 metres in places, continuing to subside as Wales was being stretched at that time. Rivers flowing from a mountainous English Midlands deposited muddy alluvium onto a coastal plain and thence into the eastern side of the Welsh Basin. Sediment accumulated in the shallow water until, periodically disturbed by earthquakes or fierce storms, it flowed down the long gentle slope onto the sea floor. Such flows were infrequent, often with hundreds of years between such events, but the accumulated sediment eventually formed rocks in places more than five miles thick.

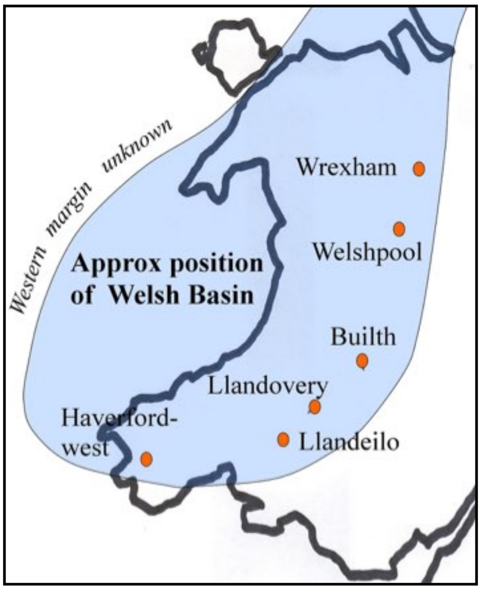


Figure 3. The Welsh Basin.

At that time Wales was part of a continent called Gondwana, which included Africa and South America. Gondwana was then situated over the South Pole so vast ice sheets lay across it. These ice sheets lowered the world's oceans by at least 100 metres, exposing the shallow shelf of the Welsh Basin. With the shelf exposed the shoreline receded to the edge of the basin slope. Rivers flowing into the basin then incised channels into the exposed sandy, rocky shelf floor, and delivered sand and small clasts directly onto the basin slope, producing a sudden change in the lithology of the sediment deposited on the basin floor below. We know that this clastic sediment arose only from within the basin because the rock contains no clasts identifiable as extrabasinal rock type.

The typical pattern of sedimentation of the Welsh Basin slope and sea floor before and after the PtM is described as a slope apron. The basin shelf prograded slowly, moving basinward along a front around 100 kms wide. Over millions of years, hundreds of cubic kms of mud slid from the shallows into deeper water. When the shelf became emergent this pattern of deposition changed. With rivers discharging close to the shelf edge, or even directly onto the slope, there was more localised build up of sediment. When these accumulations were disturbed the flows onto the basin slope then became sandstone lobes which flowed across the mudstone slope apron and debouched onto the sea floor as the channel margins failed. **Figure 4** shows how a sandstone lobe flows across the mud slope apron from the now-exposed shelf edge.

The rock which forms the Drinking Stone is called the Pencerrigtewion Member. Pencerrigtewion is a farm 1.5 km NE of Plynlimon. In Hafren Forest the PtM is typically 80 metres thick but it varies from place to place. When Gondwana passed away from the South Pole the ice melted and the sea level rose again, once more inundating the Welsh Basin shelf so that it ceased to be eroded, and muddy sediment from the basin margins was again carried to the shelf edge and deposited as a slope apron onto the basin slope.

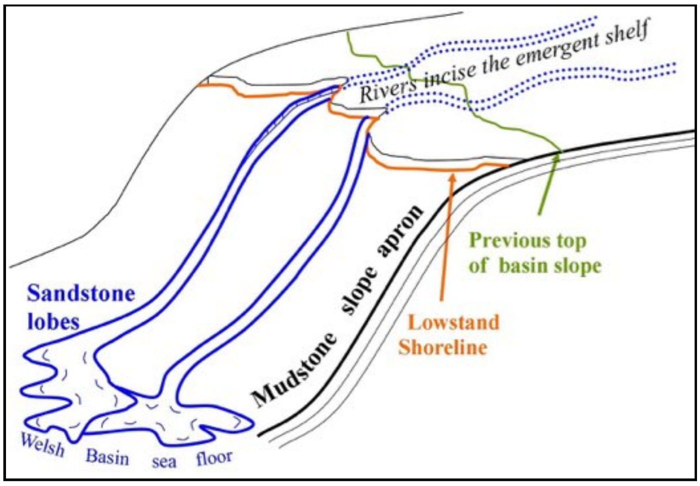


Figure 4. Slope Apron Formation.

The layer of Pencerrigtewion sandstone is harder than the mudstones above and below it in the geological succession, and where it is exposed today it forms many of the eminences seen in the district: in the north of Hafren Forest, on Plynlimon, and around Clywedog dam. It is intermittently exposed mainly in the four Central Wales Ordovician inliers, each of which is a pericline; from east to west: Van, Mynydd y Groes, Plinlimon and Machynlleth. In Hafren Forest the PtM was deposited close to the bottom of the slope but Plymlimon then lay further into the basin, and Machynlleth further still. A small exposure, one km across, is found beyond these inliers, 3½ km north of Aberdyfi, well out into what was the Welsh Basin, in Ordovician rock lying around Cadair Idris and the Harlech Dome. **Figure 5** shows these areas of Ordovician rock, with the PtM marked in yellow (the width of the narrow PtM outcrops has been widened in the illustration, otherwise they would not show at this scale).

The PtM signals an important change in the geological history of the area, a fact only fully understood in recent years. It represents a sequence boundary. The rocks of the district of course were laid down in the sea, and the record of sea level change can now be read in the rocks. This sequence boundary represents a sea level lowstand which followed a long period of falling global sea level and preceded a long period of sea level rise. The precise point in time where this sea level lowstand began is the place where the PtM begins. This can be seen in Quarry 8 (**SN 832 891**). The precise point where the lowstand ends is the place where the PtM also ends, and is seen in Quarry 9 (**SN 827 879**). The Drinking Stone has fractured from bedrock formed during the middle part of the PtM sedimentation.

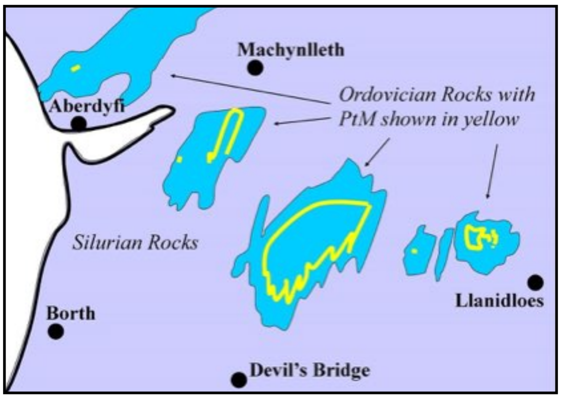


Figure 5. Distribution of the PtM.

Stratigraphically the PtM is the upper part of the Drosgol Formation, the whole formation being up to 450 metres thickness of massively bedded mudstone, extensively slumped and destratified. **Figure 6** shows a simplified stratigraphy around Ordovician-Silurian boundary, together with a rough indication of sea level movements at the time. Above the PtM lies the Bryn-glâs Formation, several hundred metres of mudstone, also slumped and destratified. The bottom of the Bryn-glâs is sometimes represented by the Lluast-y-Graig Member, in which the thick sandstone of the PtM quickly gives way to undisturbed, finely laminated mudstone with thin sandstone beds which are soon replaced by the monotonous disturbed mudstone.

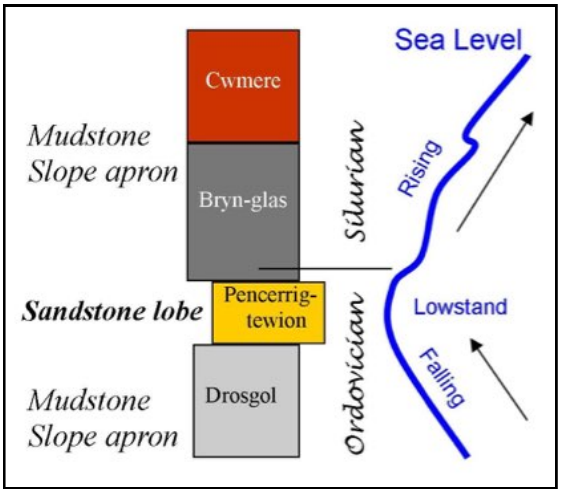
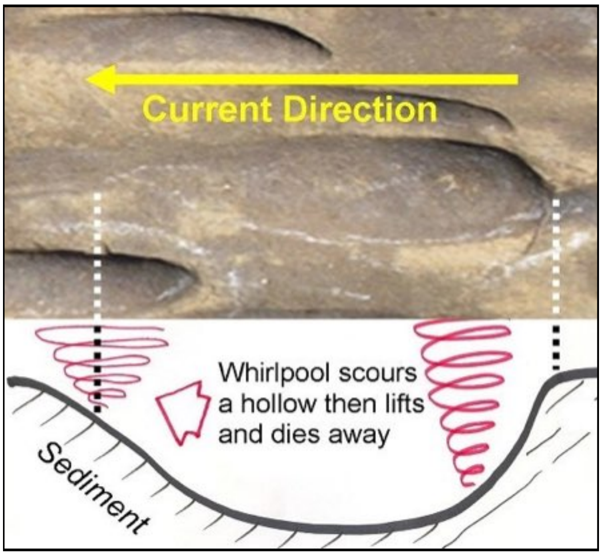


Figure 6. Stratigraphy and sea level.

Figure 7. Flute cast face.

Features of the Drinking Stone

One side of the Drinking Stone, originally the underside of a sediment bed, exhibits a splendid example of flute casting, as shown in **Figure 7.** Flute casts are sometimes caused when turbidity currents sweep across the sea floor. When the accumulated sediment on the edge of the basin shelf was disturbed it could slide down the basin slope as a debris mass flow, a saturated mass of mud and sand, or it could become entrained with water and flow as a turbidity current, a churning mass of water and sediment which, due to its higher density than sea water, surged downslope gathering speed and spreading out on the bottom of the slope until its energy dissipated and the sand and mud sank to the sea floor. The sediment deposited from a turbidity current is called a turbidite. As the energy of the current waned the sediment was deposited in order of coarseness: pebbly debris first, then sand a little further out, and finally mud and silt. The process of forming a flute cast is shown in **Figure 8.** Deposition of the Pencerrigtewion Member is regarded as as being often borderline between a turbidite and a debrite, i.e. between a turbidity current flow (sediments entrained in water) and a mass flow of sliding sediment on the sea bed. The PtM is also unusual in being very heterolithic – it covers a wide range of lithologies from mud through to conglomerates, depending on what was being eroded from the basin shelf.



Small vortices or eddies in the turbidity current eroded hollows in the underlying partially compacted muds. These were quickly infilled by coarse sediment dropping from the turbidity current, leaving the characteristic shape called a flute cast. In **Figure 9** a broken flute cast on the Drinking Stone reveals a medium-to-coarse grain size sandstone in the base of the trough, also with 1 mm grains of feldspar. Flute casts usually indicate the palaeocurrent direction, beginning with a relatively deep vigorous scour followed by a widening and shallowing of the scour as the vortex lifts away and dissipates. In bedrock, flute casts can be used to indicate the direction of flow. A general directionality of flow can be seen on the Drinking Stone, from bottom left to top right but some areas of flute casting, as in **Figure 10**, are unusually chaotic and show the current direction less obviously. The vortices can interact with each other and some are deflected. Sometimes one flute cuts into another as successive scours passed over the sea floor within the same turbidite, as shown in **Figure 11.**

Figure 9. Grain size of flute casts.

Figure 10b. Chaotic flute casting.

Figure 10a. Chaotic flute casting.

Figure 11. Successive scours.

Not all the flute casts exhibit the characteristic circular start to the erosive scour. **Figure 12** shows a smaller fragment of Pencerrigtewion rock beside the path and close to the Drinking Stone, and a flute cast with an unusually deep 'bullnose' scour. We have to speculate on how this formed by erosive action; perhaps by a circular scour rolling across the sea bed with its axis parallel to the sea floor. Sometimes, wrapped around the deeper part of a flute cast is a series of parallel small-scale steps or terraces. When these are contoured around the flute cast and parallel to the bedding surface, as in **Figure 13** it has been suggested (e.g. JL Roberts, The Macmillan Field Guide to Geological Structures, 1989, p 42) that these may be imprints of the bedding of the underlying sediments, caused by differential erosion of the different layers. If this is so it proves the feature is erosive rather than foundering of the overlying bed. Not all these surface markings on the flutes are contoured: some appear to be around the circular cross-section of the flute cast, as in the earlier **Figure 10**, so there must also be other causes as well.

The sole (i.e. the underside) of the Drinking Stone, in addition to its abundant flute casts, also shows bulging on a larger scale than the flute casting. The bulges are more symmetrical and exhibit no directionality. This is load casting, shown in **Figure 14.** The stationary, freshly deposited thick layer of sandstone, perhaps being being denser than the saturated underlying bed, as it certainly would be if it were a mudstone, has in places bulged downwards as it sinks and expresses water from the partially lithified sediment below. The Drinking Stone shows no bedding in the 2 to 3 metres of thickness above the flute cast face. It may have been a single very heavy turbidite flow, in which case the bed would have been exceedingly heavy and some load casting is to be expected. **Figure 15** shows this apparently massive bedding through the thickness of the stone.

In a few places laminated flow-like features can be seen between the various load casts and bulging flutes cast areas. They are unlike the main body of rock. The laminations look like cleavage but cannot be so because the direction of the laminations is inconsistent. Moreover, the laminated rock is not a

Figure 12. Bullnose flute cast.

Figure 13. Surface markings on flute casts.

Figure 14. Load casting.

Figure 15. Massive bedding of the Drinking Stone.

mudstone but is medium grain sandstone. These laminated structures appear to be dewatering flows, where the heavy overlying bed has begun to founder into the underlying bed, expelling saturated and partly lithified sediment upwards into the overlying bed, see **Figure 16**, and in earlier figures: **Figure 10b** (traces of lamination in several places) and **Figure 14** (right side has a markedly laminated area).

The side of the Drinking Stone opposite to the flute casts is the upper side, and is seen when approaching on the path. This appears to have fractured, and is too irregular to be a bedding surface. **Figure 17** shows a ball-like structure at ground level, as if an isolated mass of overlying sediment has sunk into the underlying bed. It might be another example of a large load cast. It could even be ball-and-pillow deformation, which is an extreme case of load casting where a ball-shaped or pillow-shaped mass of denser sediment sinks completely into the underlying uncompacted sediment. Such a feature can also occur as a result of sediment agitation and liquifaction during an earthquake. Much of the Bryn-glâs Formation which lies above the PtM was severely disturbed by earthquakes, as was the Drosgol Formation which lies below the PtM. A wider angle view of this feature in **Figure 18** also shows another possible circular shape, but smaller, above and to the right of the apparent 'ball'. We cannot be sure if these are load casts or ball & pillow structures (or nothing at all!) because part of the feature is missing, and we are not looking at a cross-section. The Drinking Stone is a geological curiosity which provokes much discussion.

Colin Humphrey

Acknowledgements
Mid Wales Geology Club is grateful to have been accompanied on site at times by Prof Jerry Davies, and Dr Bill Fitches. Assoc. Prof Geraint Owen has commented on some of the photos. The interpretations in this article remain the responsibility of club members. NRW kindly provided club members with vehicular access permits to the forest.

Much work has been done in recent years on the district geology, and this has guided the above commentary on the Pencerrigtewion Member. Particularly useful have been the following publications;

Wilson et. al. 2016. *Geology of the Llanidloes District: a Sheet Explanation to Sheet 164.* BGS.

BGS 2010. *1:50000 Sheet 164***,** Llanidloes.

Figure 16a. Dewatering sediment flows.

Figure 17. Possible Ball Structure from foundering.

Figure 16b. Dewatering sediment flows.

Figure 18. Wider angle view of drinking stone.