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The Silurian

The Magazine of the Mid Wales Geology Club

Contents

The Magazine of the Mid Wales Geology Club
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Cover Photo: Parys Mountain copper mine, Anglesey. ©Richard Becker

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I would like to use this section to say all the best for the future to club stalwart Colin Humphrey and his wife Mary. Colin joined the club in 2002 and has been a driving force behind its success ever since. He now moves on to pastures (or should we say rock formations) new.
We will give him a suitable period to learn the geology of his new home area of Hampshire before asking him to guide us around it for a club Summer weekend.

Michele Becker

Colin on a field trip. Photo Chris Simpson.

Submissions

Please read this before sending in an article.

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.

Anglesey's Complex Rocks

- assembled by plate tectonic processes.

The standard view of Anglesey geology, based on the detailed work of Edward Greenly in 1919, dates from long before plate tectonics was understood. There has been much controversy about the exact chronological order of the main units, and whether they might perhaps be "upside down".

Since 2007, some Japanese scientists, working with Brian Windley of Leicester University, have put forward a new view, where the Anglesey rocks are seen as a classic example of what happens when an ocean plate is subducted under a continental plate. The main components, including an accretionary complex, extensive mélange, an exhumed blueschist, an ophiolite sequence, and continental margin sediments, are exactly what one sees in other parts of the world where an ocean plate has been subducted. An example is the San Francisco region - as was well illustrated in Chris Simpson's recent talk to our group. As Chris pointed out, one of the key features of such a scenario is that the older units are on top, with the younger units thrust underneath - the opposite of the usual stratigraphic order!

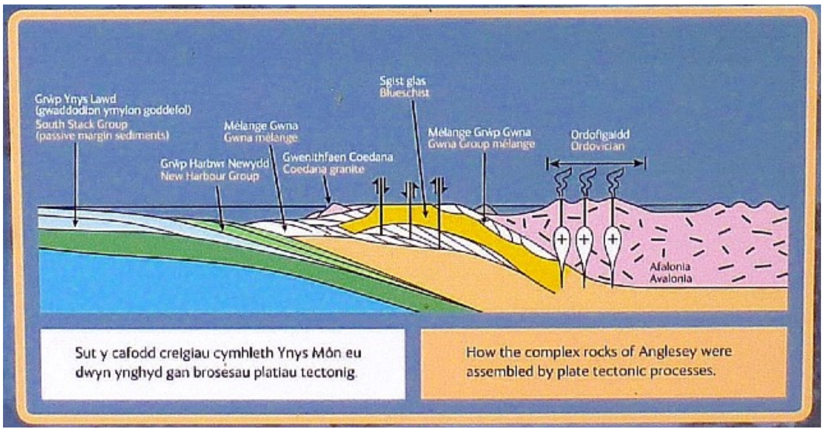

***Figure 1** Photo of the GeoMôn Geopark information board at Llanddwyn Island.*

The "Japanese" analysis is summarised in the diagram by Professor Shigenori Maruyama, taken from my photo of the GeoMôn geopark information board at Llanddwyn Island **(Fig. 1)**.

The analysis is explained more fully in papers from 2007 [1] and 2010 [2], with a useful overview on the GeoMôn website [3].

To summarise the story, around 680Ma, an oceanic plate was being subducted under Avalonia, leading amongst other things to the magmatism of the Malvern Hills. Subduction was building up an accretionary complex corresponding to the Gwna Group. The accretionary process continued over a long period of time until at least the early Cambrian.

The accretionary complex mainly consists of ocean plate sediments scraped off the descending plate by the overriding continental plate. It typically comprises a succession of small units thrust one under another in succession. Each unit, or "horse", represents a slice of seafloor. Each typically encapsulates, at the base some pillow basalt from a mid-ocean ridge, capped by bedded chert and sometimes limestone, with possibly mudstone and turbidites on top. The units are particularly well exposed over the entire Llanddwyn island, where the Japanese scientists have mapped out 23 "horses", which they believe represent over 7,800m of seafloor shunted into an accretionary deposit only about 300m thick.

At the core of the subduction's accretionary process is a deep oceanic trench, with a particularly steep slope on the continental side. In many situations, material tumbles down this slope, creating a chaotic mixture of various rock types, mostly derived from previously accreted seafloor, with components ranging from kilometre-scale chunks down to small pebbles. This is the famous Gwna Mélange. As I understand it, it's more likely to be the result of an ongoing process, rather than being produced by a single, huge, catastrophic event. The mélange can be seen on the north coast of Anglesey, and less dramatically at the southern tip of Llanddwyn island **(Fig. 2)**, as well as the famous example on the mainland at the southwestern tip of the Lleyn peninsula.

Returning to the detailed story of the subduction, it is thought that at around 620-600Ma or perhaps earlier, Avalonia advances to the point where a mid-ocean ridge

Fig. 2 *Gwna Mélange, Llanddwyn Island, Anglesey.*

gets subducted. Although the exact effect of such an event is unclear, it is suggested this led to the creation of the Coedana granite within the continental crust at the edge of Avalonia.

Around 575-550Ma, a ductile wedge of the accretionary complex, a few kilometres thick, gets subducted, recrystallised under blueschist conditions (high pressure but relatively low temperature), and then is squeezed back to a higher level, possibly assisted by a shallowing subduction angle. In this way, the Blueschist Unit is formed.

After the emplacement of the Blueschist Unit, the accretionary process continues, with conditions producing mélange becoming more prevalent.

During the final stages of the subduction, in the Cambrian, continental margin sediments corresponding to the New Harbour Group, and subsequently the South Stack Group, are underthrust more-or-less intact into the base of the accretionary complex. This underthrusting leads to doming of the already accreted complex, causing a fragment of the western margin of Avalonia containing the Coedana granite to become separated from the rest.

At some point after the New Harbour Group turbidites were emplaced, a deep slice of ocean crust was thrust within it - as a so-called "dismembered ophiolite".

After subduction had largely ceased, magmatism continued into the Ordovician, resulting in the igneous rocks of North Wales. And there the subduction story ends.

In a later paper from 2013 [4], Windley and others show that the Anglesey story is far from unique. For at least 3.8 billion years, the Earth has experienced a remarkably consistent process of sea floor spreading, subduction and accretion at continental margins. Other examples are to be found in Greenland, Central Asia, Japan, and the previously mentioned California coastal range. A further example is nearer at home in the southern uplands of Scotland, where an accretionary complex was formed on the margin of Laurentia as the Iapetus Ocean was being subducted. All of these examples show very similar rock types and structures. It appears that the overall process is a major factor in the creation of continental crust. It is even suggested it has played a part in plate tectonics being a major heat loss mechanism on Earth since the early Precambrian.

David Warren

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[4] Kusky TM, Windley BF, Safonova I, Wakita K, Wakabayashi J, Polata A & Santosh M, 2013. *Recognition of ocean plate stratigraphy in accretionary orogens through Earth history: A record of 3.8 billion years of sea floor spreading, subduction, and accretion.* Gondwana Research, 24.2, 501-547.
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Bill's Rocks and Minerals

Copper (Cu): An everyday mineral.

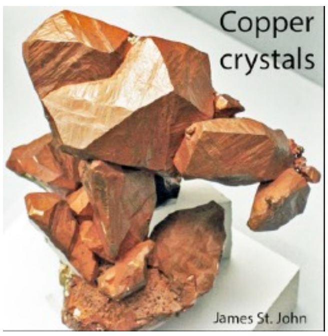
Copper is one of the most common and recognisable minerals, in fact it is so recognisable and well known that even most children know what it looks like. It can be seen around the home in the form of copper wiring, copper piping, and copper utensils.

Plumbing fittings.

Wikipedia commons

Copper is a transition metal. It has an atomic number of 29 and atomic weight of 63.546. It occurs in native form as a face centred cubic crystal. It also occurs as a polycrystal (minute crystals in a random arrangement). It is one of the few minerals that can occur in a directly usable form. A very comprehensive description of copper and its physical parameters can be found in an interactive version of the periodic table, at www.ptable.com

Copper is most commonly found as an ore in porphyry deposits, which account for about two-thirds of known global resources. Porphyry deposits are formed on the sea-bed by volcanogenic activity, usually as chalcopyrite, ($CuFeS_2$) or less commonly as chalcocite (Cu_2S) or bornite (Cu_5FeS_4). Porphyry deposits also occur as carbonates, such as azurite ($Cu_3(Co_3)_2(OH)_2$) or malachite ($Cu_2CO_3(OH)_2$). Parys mountain in Anglesey, recently visited by the club is a massive sulphide deposit formed in the late Ordovician period about 441 Ma. Most copper is found as an ore which requires crushing and separation from the ore body, with a good ore having a content of 10% copper.



Copper crystals

James St. John

Another major source of copper are sedimentary deposits, which account for about a quarter of the worlds known resources, for instance there are particularly large deposits in the African copper belt, and in the eastern European Zechstein basin. Copper is a native mineral, and is one of the few minerals that occur in a natural state, albeit, not in major deposits. There have been instances of small native deposits being found at Parys mountain, for instance, in 1800 there were reports of lumps of native copper being found with weights of about 30lbs (13.6kg). There have been exceptional discoveries of native copper in large amounts, one of the largest was found in the Keweenaw peninsula, Michigan, USA, and it weighed 420 tonnes.

Native copper Formation.

Wikipedia commons

Copper is one of the first minerals to be used by early man as long ago as 9000 B.C. It's low melting point of 1084^{o}C enabled it to be smelted in a wood fire, and this was exploited by the Mesopotamians around 5000 years B.C. The Romans mined copper in Cyprus, and it is from this era that copper derived its name, *aes cyprum* (metal of Cyprus). It was later corrupted to *cuprum*, and later still became copper in the English language. Ancient civilizations, including the Romans, used alloys of copper to make utensils, coinage, and ornaments.

Roman Copper coin British museum

Alloys were used because it was discovered that the addition of small amounts of other metals, up to 30% in the smelt, created a harder wearing metal than the original copper. Copper by itself is very soft, classed as only 3 on the Mohs scale and is easily deformed, making it unsuitable for making tools and some domestic items, whereas the addition of other metals creates a whole range of different copper alloys, used for different purposes, dependant on the additional metal content. The addition of 30% zinc creates brass, and 10% of tin creates phosphor bronze. There are many other copper alloys, each having been designed to fulfil a particular function. While


Copper kettle Sjohistoriska museet

not a copper alloy, but a gold alloy, copper is a constituent part of most gold jewellery, added to give both strength and colour, for instance 18ct. yellow gold has 10% copper content, 22 ct. yellow gold has 2% copper content, and 18 ct. rose gold has 22% copper content. Pure copper is used to make wrist bracelets, which are wrongfully supposed to help alleviate painful joint conditions.

During the 1770s and 1780s it became apparent that sheathing the wooden hulls of sailing ships with copper overcame the problem of wood rot due to shipworms, barnacles, and seaweed. The copper was impervious to worms and barnacles, and had the added advantage of acquiring a poisonous surface film on contact with sea water, which deterred weeds from attaching to the hull, and hindering the speed of the ship. The British were at the forefront of implementing this practice, first with merchant ships and then naval ships. The ships spent much less time in harbour being maintained, with the added bonus that they were faster in the water. The whole naval fleet, some 200+ vessels, were sheathed in copper, with each of larger naval ships requiring 15 tons of copper. The bulk of the copper came from Parys mountain in Anglesey, and was used not only on British ships, but used worldwide. Later years saw the development of copper based paint which was applied to hulls, and served the same purpose. Modern use of copper as sheathing continues today in the form of copper-nickel alloys which are used as cladding on oil rigs, sea based wind turbines, and other marine applications. Copper is also being used more regularly in architecture with some really large buildings having a copper façade.


Royal observatory Edinburgh. Wikipedia commons

Copper is a constituent component of naturally occurring minerals, for instance Azurite is a copper carbonate, Malachite is another carbonate, and Turquoise ($CuAl_6(PO_4)_4(OH)_8 \cdot 4(H_2O)$)is a hydrated phosphate of copper and aluminium, all of which are used to make items of jewellery. It is obvious that both manufactured, and naturally occurring alloys of copper illustrate the ease that copper bonds with other minerals in a process known as metallic bonding.

Copper is an essential trace mineral in the human body, and is a component in numerous intracellular metalloenzymes. These metalloenzymes are essential in the synthesis of haemoglobin, elastin, collagen, and norepinephrine. It is also involved in iron absorption, a deficiency of which results in iron deficiency anaemia. It is also vital in maintaining normal functioning of the thyroid gland, preserving the myelin sheath which protects nerves, and maintaining the health of bones. It is also crucial in the brain and the nervous system, playing a role in making neurotransmitters, which are the chemical messengers essential for communication between nerve cells. Considering the importance of copper in the human body, only a minute amount is needed, between 1.5 and 2.0 mg. per Kg. of body weight, thus someone with a weight of 60 Kg. would have approximately 0.1 gm. of copper. The body itself cannot produce copper, so it is gained from the food we eat, a balanced diet supplying an adequate amount.

Bill Bagley

Interesting facts about copper

Copper is biostatic, so bacteria will never grow on it’s surface.

The Statue of Liberty is made from over 80 tonnes of copper.

Copper is the most recycled mineral. 80% of the copper produced to date is still circulating through recycling.

Rocks Along the Monty

To the present generation it might appear that British canals exist for the purpose of enjoying the rural countryside by boat as your holiday cruise takes you slowly along between one waterside pub and the next, or as a preserved habitat for aquatic plants and animals! None has this image more than the Montgomery Canal (or Monty for short). But look back 250 years and you see that canals were constructed to play a vital role in the Industrial Revolution allowing mass carriage of heavy minerals such as coal, limestone, ironstone and clay, from places where they were extracted to places where they were used. This was at a time when the alternatives were pack-horse or horse-and-cart carriage along poorly maintained roads. Alternatively goods could be carried on a limited number of rivers, though such waterways were subject to flood and drought.

***Fig. 1** Portrait of the young Duke of Bridgewater.*

Canals provided a solution to these transport problems as is well illustrated (literally) in the engraving from Samuel Smiles' book, *James Brindley and the Early Engineers*, It shows the Duke of Bridgewater pointing proudly to the canal he commissioned (now called the Bridgewater Canal) in 1759 to convey coal from his mines at Worsley into the growing city of Manchester (**Fig. 1**). Along its eight mile course the canal crossed the River Irwell by the country's first canal aqueduct at Barton. Note that the canal boats are drawn by horses using a purpose-built towpath, whereas those on the river are pulled by gangs of men walking over rough grassland.

Within the mine special boats were used, known as "starvationers" because they were particularly narrow and could collect the coal directly from underground seams as they were worked. On emerging from the mine tunnels the coal was transferred to barges in which it was carried for 8 miles into Castlefields in the heart of Manchester.

Clearly there was a geological connection between the canal and its cargo, but also a geomorphological one in that the line of the canal was along the Irwell valley but kept above the river to avoid the seasonal fluctuations in rainfall. These two factors were the dominant influence on canal building over the next 60 years.

The actual cutting of canals revealed the otherwise hidden geological strata beneath the soil. It was this connection that struck William Smith so forcibly while he was employed as surveyor of the Somerset Coal Canal from 1793 to 1799. He followed it up later as he travelled all around the country as a land surveyor, sometimes asking the postillion of the horse-drawn coach to stop while he looked at the rocks in roadside quarries. (Try that today in a coach on a motorway!). By 1815 Smith's travels had been so extensive that he was able to create the first geological map of England and Wales. Though differing in detail and stratigraphic nomenclature, the overall

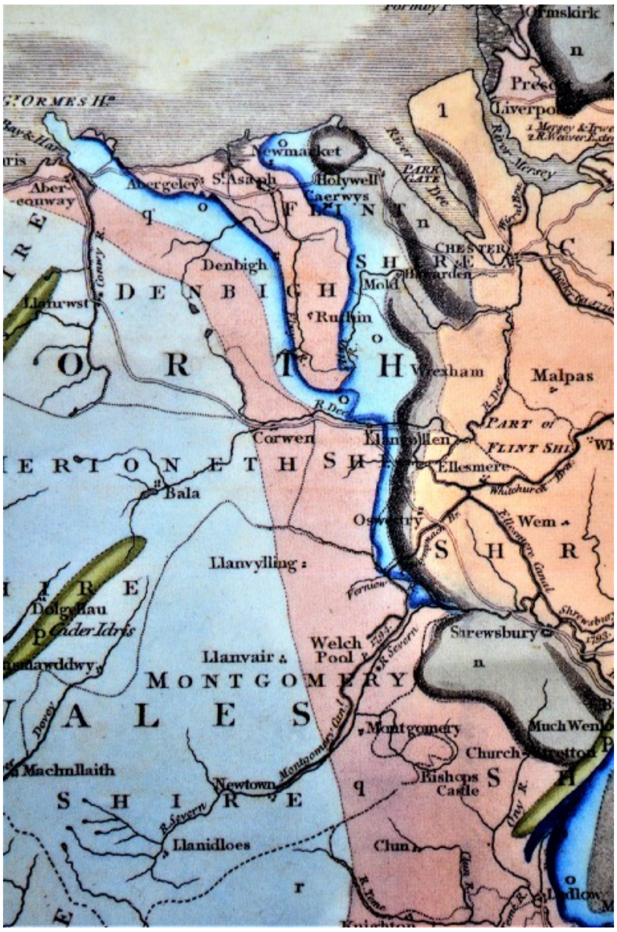


***Fig. 2** John Cary's amended Smith map of 1820.*

pattern of this map looks remarkably similar to those produced today by the British Geological Survey, except for the lack of detail in west and mid Wales where the largely unfossiliferous strata were described as greywacke.

The industrial value of the rocks carried by canals was emphasised even further when Smith's publisher, John Cary, published a slightly amended version of Smith's map in 1820 (see **Fig. 2** above) This map made more obvious the canals and navigable rivers and, in an additional key, it listed all canals, navigable rivers and (the few) railways of the time, giving for each the main mineral cargoes carried.

What we now call the Montgomery Canal was two separate undertakings at that time: a branch off the Ellesmere Canal heading south from Lower Frankton to Llanymynech, which made an end on connection with the Montgomeryshire Canal from Llanymynech to Newtown. Both were a product of the "canal mania" of the early 1790s. The Ellesmere Canal is shown on Cary's map as transporting "*Coal, Lime & its stone, Iron, Lead*", whilst the Montgomeryshire Canal carried "*Coal, Iron, Lead, Limestone*".

The limestone was initially that from the southern limit of the North Wales outcrop of the Carboniferous Limestone immediately above Llanymynech (see **Fig. 3**). Limestone was burnt extensively at this time to produce lime as a fertiliser for acid soils. Although the Severn Valley from Newtown to Pool Quay was quite wide and relatively flat and cultivable, its soil was somewhat acid, having been derived as sediment from the older deep water and volcanic rocks of Ordovician and Silurian age through which the river had cut its valley from Plynlimon north-eastwards. Across the North Shropshire plain east of Oswestry the countryside was much flatter, but the soil was equally acid, again derived from glacial sand or the protruding outcrops of the Triassic sandstone hills.

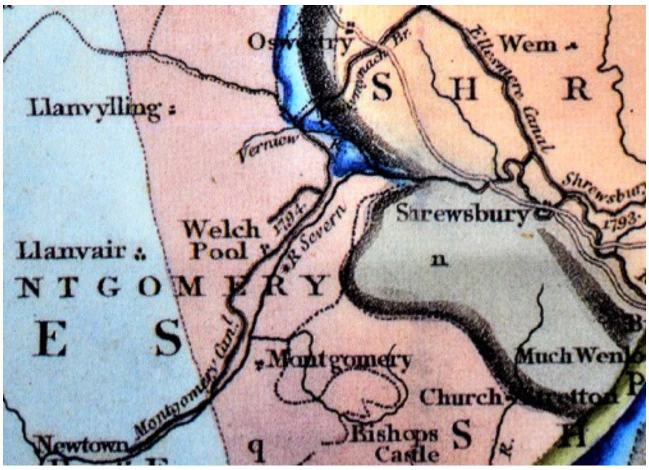


__Fig. 3__ Part of Cary's map showing the route of the Montgomery and Ellesmere canals.

The problem with providing lime (calcium hydroxide, $Ca(OH)_2$) for improving soil fertility is that the quick lime (calcium oxide, CaO) produced by burning the limestone (calcium carbonate ($CaCO_3$)), reacts vigorously on contact with water to produce dangerous levels of heat. Transport of quick lime from lime kilns to its point of use by boat was therefore a dangerous practice due to the possibility of water leakage into the boat. To overcome this, the quarried limestone was mostly carried by boat to be burnt in kilns as close to the point of use as possible. The result is that 92 lime kilns were constructed along the length of the Montgomery canal.

__Fig. 4__ Remains of Llanymynech wharf.

The ruins of a significant number of these remain, many in banks of three or more, as visible evidence of the extent of this trade. Most impressive are those on the north eastern edge of the village of Llanymynech. The quarry above the village had been in use since before the building of the canal. The arrival of the canal led to the construction of wharves, with canalside kilns fed by steep inclines from the quarry directly down to them. The remains of some of these are still clearly visible (see **Fig. 4**)

Wharves were cut into the northern side of the canal with kilns adjacent. But even more impressive is the partly restored Hoffman Kiln, (**Fig. 5** below) one of only four built in England in the early years of the 20th century. This type of kiln was designed to allow continuous burning of limestone through the provision of

Fig. 5 *Hoffman kiln, Llanymynech.*

16 separate kilns under one roof. Dominated by its single tall chimney the individual kilns could be fired in sequence, allowing for continuous production of burnt lime. But despite its proximity to the canal, it did not contribute to trade on the Monty because from the 1860s onwards a railway line from Oswestry to Welshpool had been built alongside the canal for much of its length, taking the carrying trade away from the waterways.

Lime burning required a further cargo for the canal: coal as the fuel for the kilns. It is far from obvious today that this mineral was also available fairly close to the canal, in particular from the Oswestry Coalfield. Coal seams were present in the Carboniferous rocks at no great depth to the south of Oswestry. Direct connection was made at several points north of Llanymynech between the mines of the Oswestry coalfield and canal wharves. This is most clearly seen at Gronwen wharf, (**Fig. 6**) a mile south west of Maesbury Marsh, where coal was brought down to the canal by tramway from Gronwen near Morda.

Fig. 6 *Gronwen wharf and colliery arm.*

Building Stones

Further south in Welshpool, and very conspicuous to the north side of the A458 as it enters the town at the western roundabout, rises the so called Standard Quarry. At first site this appears to be almost horizontally bedded rock; but closer examination reveals it as strongly jointed columns of trachyte, a very fine-grained Ordovician intrusive volcanic lava (a poor equivalent of the Giant's Causeway). This rock was quarried here for many of Welshpool's rows of 19th century cottages usually used in as random masonry (i.e. uncut blocks) of a rather dull grey-green colour. (See *The Building Stones of Welshpool: a geological trail* written and published by the Mid-Wales Geology Club, 2012)

The relationship between the Standard Quarry and the canal was short lived as a cargo. Initially the stone was taken down to Welshpool canal wharf along a tramway and then taken on by boat, but this, like the limestone trade, was soon taken over by the railway following the construction of the line through Welshpool in the 1860s.

A journey along the canal reveals in some detail other aspects of the geology that the route passes through with canal-side buildings, locks and bridges often making use of the nearest supply of stone. Most obviously in Llanymynech many of the older buildings are of Carboniferous Limestone. Take a look at the Cross Keys Hotel in particular, with its smart ashlar frontage but only rough uncut blocks of limestone behind.

Bricks became a significant cargo for a time. Today it is difficult to see, other than from shallow pits in the soil, the places where the local clay was satisfactory for brick building of the locks and bridges of the canal itself. More substantial were the brick works at Buttington using fine shale rather than pure clay as a main ingredient. There was briefly a tramway down to the Buttington Wharf, again with several lime kilns just north-west of what is now the north end of Welshpool by-pass. The canal traffic was soon superseded by the much closer line of the railways to Shrewsbury and Oswestry.

At The Wern, discussed below, clay was dug initially for puddling (i.e. making watertight) the canal bed, and brick making by the canal company for its own locks and bridges.

Water Supply

Water supply is crucial in determining the course of a canal since a boat uses at least one lock-full of water in its descent from or ascent to the summit level of a canal. Canals cannot therefore be built like roads, with frequent humps and hollows. Most canals were built as far as possible following the course of river valleys but, as with the Bridgewater Canal and almost all subsequent canals, at a level above the flood plain.

Ice Age geological evolution of the Welsh borders had resulted in an oddity for the builders of the Montgomery Canal. The pre-glacial route of the proto-River Severn had been from Plynlimon northwards past the west side of the Breiddens and continuing north towards the present day Dee estuary. When this route was blocked by glaciers during the last Ice Age, probably for the last time during the Devensian as little as 25,000 years ago, the Severn was diverted eastwards around the north side of the Breiddens and along the southern margin of the extensively till and alluvium covered North Shropshire plain, on through Shrewsbury and the over-flow channel of the Severn Gorge at Ironbridge. As a result the line of the canal mirrored the fall on the Severn Valley as far as the Bele Brook crossing, a minor west bank tributary of the Severn about 3 miles south of Ardleen, at Wern.

Fig. 7 *Frankton cottage and lock.*

From the north side of the Bele Brook valley the canal veered further north, up through two locks at Burgedin, across the Vyrnwy and rising through two further locks at Careghofa, just below Llanymynech. Here it made an end-on junction with the Llanymynech Branch of the Ellesmere Canal which rises steadily to Lower Frankton and its junction with what became the main line of the Ellesmere Canal, now well known as the Llangollen Canal.

This made the Montgomery Canal unusual in having a “sump level” along its course at Wern, rather than a summit level which was more typical of most canals as they crossed

Fig. 8 *Carreghofa top lock and inlet.*

watersheds. As a result, water for the operation of the locks had to be supplied from at least two sources: one at Newtown and the other at Lower Frankton.

At Newtown some water was pumped up into the highest pound, but most of the supply was secured by building the substantial curved double weir two miles further downstream at Penarth which holds the river at a level from which it is diverted into the Montgomery Canal below the nearby Freestone Lock. At the north end the main water supplied is off the Llangollen canal at Lower Frankton. This in turn gets its main water supply from the River Dee at the Horseshoe Falls two miles upstream of Llangollen town. What few people would realise is that the flow of the River Dee is itself controlled to a limited extent by a weir at the lower end of Bala Lake which was built to make the natural lake itself larger, explicitly for the supply of the canal water.

There is also a feeder serving the lowest level from the River Tanat to the west of Llanymynech hill, which enters the canal above the top lock at Carreghofa (**Fig. 8**). This was once intended to be a short branch canal around the south west side of the hill to quarries at Porth-y-waen, which seems to be a line shown on Cary’s map.

So the next time you are wandering along a peaceful section of the Monty, take a closer look at the state of the nearby River Severn or other rivers and streams, imagine the trade along it 200 years ago, and look at the surrounding countryside and settlements to ask yourself “I wonder how much that would have changed if William Smith had never discovered what was beneath the soil!”.

Andrew Jenkinson.

Geological Excursions

Sites to visit :
Excursion Number 7

Moel-y-Golfa
– An Ordovician Island Arc Volcano

Grid Reference SJ286125

Maps: Topography:
O.S. Landranger 126 Shrewsbury or
O.S. Explorer 240 Oswestry.
Geology:
BGS 1:50,000 Sheet 151 Welshpool Bedrock and Superficial

Fig. 1 *Romany Chell monument on the top of Moel-y-Golfa, looking to Breidden Hill and Criggion quarry. Photo ©Richard Becker*

The basic walk is about 3 km, following gentle forest paths, but if one decides to go up to the summit for the view, it is double that and is scrambly in places. The start is at a sizeable layby at SJ286125, on Shepherd's Lane, which is a narrow lane accessed by way of Garreg Bank off the A458, at Trewern,

The summit of Moel-y-Golfa is the highest of the Breidden Hills which, geologically, comprise an inlier of more resistant Ordovician rocks faulted or unconformably overlain by the surrounding younger ones. It comprises a series of shales and volcanics intruded by the much quarried Criggion dolerite forming the bulk of Breidden Hill in the north and by the Moel-y-Golfa andesite on the south east flank. There is some doubt as to the exact nature of the massive Criggion dolerite which could be a laccolith-like intrusion within an anticlinal fold or alternatively a more sill like structure. Whichever the case, on the south east flank which we are exploring, the strata are generally dipping steeply and younging to the south east.

The rocks here were laid down some 450 million years ago in Caradocian, Upper Ordovician times when Wales was off the northern shore of the microcontinent Avalonia, facing the Iapetus Ocean to its north. Iapetus was closing as its crust was being subducted beneath Avalonia. This was causing island arc volcanism, just as in Indonesia today. This walk explores the structure of an island arc volcano.

Fig. 2 *"Bomb rock" from the Bulthy Formation*

At the start point of the walk, at the north end of the layby, there is an opportunity to examine a fresh exposure of the country rock, which represents the background sediment into which or onto which the volcanics were deposited or intruded. This is the Stone House Shale formation, a fairly thin bedded grey marine mudstone, dipping steeply to the south east. You may be able to find a thin bentonite layer indicating that times were not completely geologically quiet (Bentonite is a volcanic ash which has degraded to a pale clay. It feels slippery if wetted and is the result of a distant eruption.).

Walk down Shepherd's Lane past Trinity Cottage, some 600m to a track on the left (SJ283119). Take the path into the wood, heading south east (not the main drive south to the house). Follow the path, going gently uphill, looking at the rocks you are walking on. At first they will be shaley, together with some from till (boulder clay) or head (from up the hill). After about 300m (SJ285117) just before the path starts going downhill and where a path joins from the left, you will start to find different rocky fragments of a conglomerate including fist sized rounded cobbles. This is the very distinctive "Bomb Rock" (**Fig. 2**) of the Bulthy Formation. At this point, go back a short distance and cast around just below the path and you will find a small quarry at SJ285117. This is not the “Bomb rock”, but is a pale rather flinty greenish buff rock containing angular fine to coarse grains. It is a volcanic ash or tuff, comprising particles ejected from an explosive eruption. It shows some bedding (**Fig. 3**) and has a rhyolitic composition. It is the Middletown Quarry Member of the Stone House Shale. Looking around, there is some disturbed ground above the path going up the crest of the spur and some further quarrying below. The old quarrymen had evidently extracted this rock from a thin sliver, lying between the shale and the “Bomb Rock”. They must have appreciated that its bedding and jointing produced handy brick-shaped stones. The path we follow must have been the track they used to sledge or cart the stone down to the village as, from this point, it contains a lot of their rejects, together with Bulthy or “Bomb Rock”.

Fig. 3 *Specimen from Middletown Quarry Member.*

Shortly, rounding a bend you enter the disused Moel-y-Golfa quarry, now overgrown with 50-60 year old trees, the main face is some 20m high in a massive medium grey andesite (**Fig. 4**). (Andesites are igneous rocks, intermediate between basalts and rhyolites and are characteristic of island arcs in subduction zones.)

According to the guide some columnar jointing is apparent on the north east face, but it is not very obvious now, however one can make out the odd ovoid “pillow” structure, indicating that the intrusion was subaqueous. Prominent fault-like features in the main north face are held to be syn-emplacement slides which occurred at or near the time of eruption. One can envisage magma pulses causing slumps in the still fresh previously intruded rocks.

The rock can be examined safely by looking at the blocks on the floor of the quarry (**Fig. 5** below). In some there are large andesitic clasts within a similar andesite matrix. These could be lumps of earlier erupted rock stripped off the walls of a conduit by molten magma, a vent agglomerate.

Return from the quarry the way you came, looking at the exposures just round the entrance. The rock here shows some bedding, with strange irregular fracture surfaces above, almost reminiscent of aa lava flows. Could one imagine fresh, but solid lava being bulldozed by newly intruding magma?

But, what of the strange “Bomb Rock”? This has the same composition as the andesite, but the cobbles within it are not volcanic bombs because their shape and crystal structure are wrong. Symmetrical nicely rounded cobbles are usually produced on beaches by wave action. Could one imagine an island arc volcano, its base sub-aqueous, rising out of the Ordovician sea, being eroded, with a beach covered in andesitic cobbles?

Near where you found the small Middletown Member quarry, there is a path on the right, heading uphill. This is one option to extend your walk to the summit, however the easiest and most direct way is to return to Shepherd’s Lane and go to a smaller layby 200m below

Fig. 4 *The main face in Moel-y-Golfa Quarry showing syn-emplacement slides. Joiner photo ©Richard Becker*

__Fig. 5__ A loose boulder on the floor of the quarry showing andesite clasts in an andesite matrix.

the first location at SJ 285123. A track heads south west uphill from here. About 150m along you will pass the rather disappointing Trinity Well, which is marked on the Explorer map at SJ287122. It consists of a hollow with some clean pebbles in it showing that water is sometimes there, but no structure. To find it, cast around above the track where there is a cut fallen tree and some dampness.

The path continues and joins one that contours along the 250m contour. Nearby a waymark sign points uphill (east) along a poor path, continue as it gets slightly scrambly until you reach the crest, then turn left and follow the path uphill. Towards the top there are a couple of rocky scrambles, then follow the path to the summit and monuments. Return the way you came, otherwise it is possible to further extend the walk by continuing to the north east and then contouring anticlockwise back to the layby at the start.

The whole enables us to envisage an Ordovician island arc volcanic environment with emergent andesitic volcanoes, submarine pulses, slumps and explosive eruptions, spewing ejecta which settles into the surrounding seas. Erosion would have been more rapid then as vegetation had not evolved, so imagine a grey, buff and brown volcanic landscape with boulder beaches and perhaps, in the distance, another island with plumes from an active volcano.

Tony Thorp

Reference and guide:

Cave, R. and Dixon, R.J. *The Ordovician and Silurian of the Welshpool Area* pp51-84 **in Woodcock N.H. and Bassett, M.G. (eds) 1993** *Geological Excursions in Powys, Central Wales*. University. of Wales Press, Cardiff.

Members Photographs

"Thunder Egg"

"Thunder eggs are spherical objects which form in some types of silica-rich volcanic rocks. As the lava cools, trapped steam and other gases form an expanding bubble. Silica and feldspar minerals often crystallise around the bubble or grow crystal fibres which radiate outwards from the centre (spherulites). Internal gas pressure forces the spherulite apart to form a central hollow, later filled with more minerals. Adjacent wedge-shaped segments of the cracked, expanding spherule move outwards and away from each other, helping form the typical star-shaped interior. Silica and clays filling the cavity can later dry out, shrink and crack, producing more internal structures such as interesting patterns of mineral-filled cracks. Later, silica-rich solutions may enter the cavity and fill it with banded agate, chalcedony, clear quartz crystals or amethyst. Solutions of different composition seep in at various times, leaving behind several layers of different minerals." ***Source: The Australian Museum.***

Janey Haselden

Interesting geology on the coast of Shetland

The coast of Shetland is unusual because the islands are surrounded by deep water, i.e. there is no shelf surrounding the islands. This means that the waves pound the cliffs with much greater force than in most parts of the UK. One result is the common occurrence of deep inlets from the coast, locally known as 'Geos', which result from the waves exploiting points of weakness in the cliff face.

Fig. 1

Fig. 2

These geos have formed in different rock types around the islands. **Fig. 1** shows a typical example of a geo. The pile of large rocks at the blind end of the geo is the typical appearance with large rocks being deposited following heavy seas.

One result of geos forming is that an observer gets a very good view of the rocks just from walking around the top of the geo – often a much better view than you would be able to get from an inaccessible cliff. **Fig. 2** shows alternating solid layers and volcanic ash in the side of a geo. **Fig. 3** shows another geo formed within sandstone. This is a very good example of large-scale aeolian (wind-blown) cross-bedding within sand dunes prior to lithification (**Fig. 4**).

Fig. 3

Fig. 4

Fig. 5

In south-west Shetland there is a geomorphological feature of national importance. This is the St Ninian's tombolo, the largest geomorphologically active sand tombolo in Britain. St Ninian's Isle is a small island off the west coast of the southernmost part of mainland Shetland – see map **Fig. 5**. It is joined to the mainland by a strip of sand shown in **Fig. 6**. This strip of sand is the tombolo.

Fig. 5

A tombolo forms when there is exact symmetry so that the waves going round the south of the Isle are equivalent in force to the waves going round the north of the Isle. When the waves from north and south meet round the leeside of the Isle they cancel each other out and deposit any sand they had been carrying. If you look at the map again, you can see that the West coast of the mainland runs almost exactly north-south, which is perpendicular to the prevailing wind from the west.

Information from

'St Ninian's Tombolo' by J. D Hansom.

http://jncc.defra.gov.uk/pdf/gcrdb/GCRsiteaccount1930.pdf

The tombolo most likely formed during a period of rising relative sea level. The relative sea level history of Shetland is one of progressive submergence since the decay of the late Devensian ice-sheet. Dating of submerged peats in many of the sheltered voes and sounds indicate that c. 5500 years BP relative sea level stood around 9 m lower than at present. Depositional features such as tombolos, spits and bars are relatively common along recently submerged coasts, although in the Northern Isles tombolos are typically formed of shingle. The extensive sand tombolo of St Ninian's Isle, which is linked to the contemporary nearshore sediment circulation system, is distinctive in terms of its scale, composition and dynamism.

*The tombolo is composed almost entirely of medium-grained sand (D_{50} = 0.24 mm) with a carbonate content of around 50%. However, there is evidence that the beach sand overlies a gravel base. Flinn **(1974)** identified 'a rock base presumably of pebbles' at a depth of c. 2 m in two distinct locations using a probe and in several areas of the beach a scattering of flat pebbles lie on the surface.*

It experiences changes in intertidal width and profile characteristics as a result of tidal and weather events. During low spring tides the tombolo is 60–70 m wide, while during the highest spring tides the central part may be completely covered in water. Typically the central part of the tombolo is 20–30 m wide at high tide.

Flinn, D. (1974) *The coastline in Shetland. In The Natural Environment of Shetland: Proceedings of the Nature Conservancy Council Symposium held in Edinburgh, 29–30 January, 1974* (ed. R. Goodier), Nature Conservancy Council, Edinburgh, pp. 13–25.

Chris Simpson

A visit to the Isle of Arran and Hutton's Unconformity

I have been to the Isle of Arran in the Clyde estuary twice. First as a student in 1954 and then in 2017 with Joe Botting's palaeontological group. I remember precious little of the first trip, apart from the ferry, which made an impression and, once on the island, sheltering from a blizzard somewhere up Goatfell.

That was before the days of "Ro-Ro". In '54 a more modest ferry went from Fairlie to Brodick and comprised a small steamer which sported a polished brass plate stating that she served as HMS Goatfell (**Fig. 1)** during the war, firstly as a minesweeper and then, with guns bolted to the deck, as an ack-ack vessel. One could get close and personal to the rather beautiful triple expansion steam engine too. It is a shame that such a vessel met an ignominious end. Sold to Bass-Charrington, she served as a floating pub tied up to the Victoria Embankment until she caught fire in 1980 and was finally scrapped. Her engines were rescued and are at a museum near Liphook, but not on display.

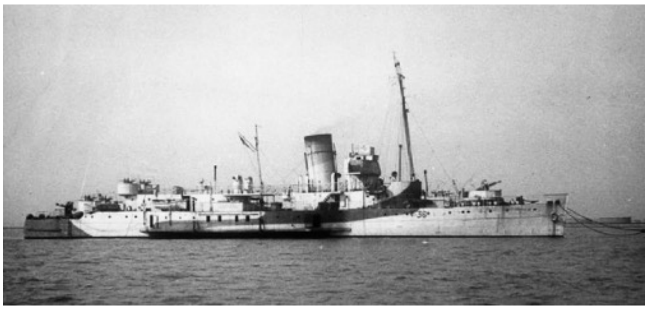


Fig. 1 *Ferry Caledonia as HMS Goatfell*

Arran exemplifies Scottish geology in miniature, igneous, metamorphic, sedimentary and both "Highland" and "Midland Valley" types.

James Hutton, the "Father of Modern Geology", and his Unconformity

Walking round the north east coast, at the most northerly point of the island, you will encounter "Hutton's Unconformity". There are a number of "Hutton's Unconformities", but this was the first one he found. A better known one is at Siccar Point, Berwickshire (**Fig. 2**), and another famous one is near Jedburgh (**Fig. 3**). They are mentioned in the first chapter of every geology text book and represent a key moment in our understanding of the world we live in, when the literal biblical model of how our planet got to be how it is, was shown to be untenable. Hutton realised that an angular unconformity, where bedded sedimentary rocks, all presumably laid down horizontally, overlaid beds at a different angle, must represent a very long time interval during which normal processes of erosion, deposition and vertical movement occurred. He founded the "uniformitarian" movement.

Fig. 2 *Unconformity at Siccar Point. © Dave Souza/Wikimedia Commons*

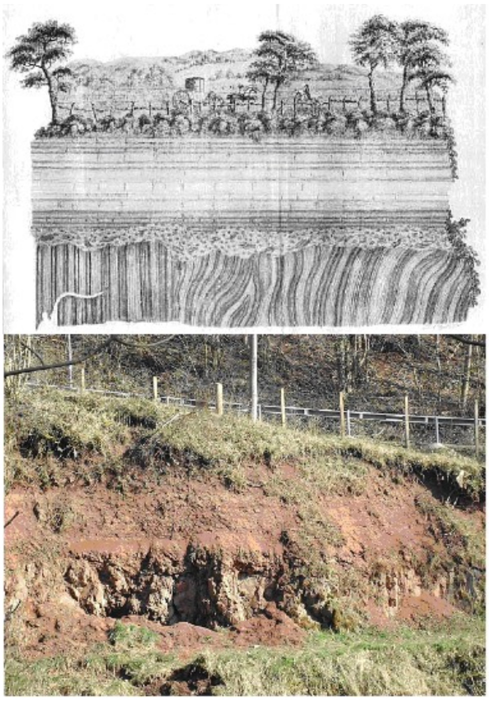


Fig. 3 *Unconformity near Jedburgh with John Clerk's sketch above, lost until the 1960s! © Dave Souza/Wikimedia Commons*

It is quite astonishing that, at this very significant location, there is nothing to indicate how special it is, no sign, no information board, no monument! Even passing locals were unaware of the location and indeed, it took a while to locate it precisely (**Figs. 4 & 5**).

Fig. 4 *'Is this it?' Hutton's Unconformity on Arran.*

Fig. 5 *Hutton's Unconformity on Arran.*

But, what of Hutton himself, and how is it that, outside of a specialised discipline, he is so unrecognised?

He was born in Edinburgh, the son of a merchant who died when he was 3 years old. At High School he excelled at maths and chemistry but on leaving, he was apprenticed to a lawyer. He preferred chemistry and unsurprisingly, was sacked at the age of 18. He then became a physician's assistant, attended lectures at the University and, further studying, went on to Paris before graduating MD from Leiden.

Returning to Edinburgh in 1750, he teamed up with schoolfriend James Davy to start a successful factory making sal ammoniac from soot.

He took seriously the management of a family farm in Berwickshire, going to Norfolk and Holland to study best methods. He was not averse to getting mud on his boots and could not resist sticking his nose into every ditch and quarry. Presumably this paid off as he was eventually able to afford a manager.

It was the time of The Enlightenment, when Edinburgh was at its zenith and he was rubbing shoulders with John Playfair, the mathematician, Joseph Black, the chemist and Adam Smith, the economist. In 1783 he read a paper to the Royal Society of Edinburgh on his *"Theory of Earth"* in which, contra to biblical teaching, he proposed that:

1. *Land was not original, but composed of products of earlier lands (Like found on the shoreline).*

2. *Before the present there had been earlier lands with tides and currents like at present.*

3. *The sea had been inhabited by animals as at present.*

So the land had been produced by processes which operated as at present.

For this to occur, two things were required:

1. Means for sediment to consolidate into rock.

2. Means of altering elevation

Later he went on a tour with John Clerk to confirm his theory, visiting Glen Tilt, where he noted granite penetrated the "schistus" and cooked the contact showing that it cooled from molten and was not precipitated from water as Werner's Neptunian/catastrophic theory postulated. Similar effects were noted at "Hutton's Section" in Edinburgh. That and his various unconformities all confirmed his theories. His *"Theory of the Earth, with Proofs and Illustrations"* was published in 1795.

This made little impact, possibly because his language was somewhat tedious and convoluted; however his friend, John Playfair later wrote *"Illustrations of the Huttonian theory of the Earth"* (1802) which proved popular and was taken up by Charles Lyell in his *"Principles of Geology"*.

Hutton and Darwin

As such, Hutton significantly influenced Darwin and it is worth noting that Darwin took both these books on board the Beagle.

Hutton also advocated uniformitarianism for living creatures – evolution, in a sense – and even suggested natural selection as a possible mechanism affecting them. Quoting directly from *"Investigation of the Principles of Knowledge, volume 2."*

"...if an organised body is not in the situation and circumstances best adapted to its sustenance and propagation, then, in conceiving an indefinite variety among the individuals of that species, we must be assured, that, on the one hand, those which depart most from the best adapted constitution, will be the most liable to perish, while, on the other hand, those organised bodies, which most approach to the best constitution for the present circumstances, will be best adapted to continue, in preserving themselves and multiplying the individuals of their race."

Hutton gave the example that where dogs survived through "swiftness of foot and quickness of sight... the most defective in respect of those necessary qualities, would be the most subject to perish, and that those who employed them in greatest perfection... would be those who would remain, to preserve themselves, and to continue the races"

Bearing in mind that was published in 1794 and the *"Origin of Species"* in 1859 how is it that, outside his subject, his unconformities and his 'section', Hutton is memorialised by one garden, one Institute (since 2011) and one road (James Hutton Road since 2016); whereas Darwin has innumerable roads, colleges, universities, towns and even a city to his name!

It may be because Hutton was neither an aristocrat nor an academic. We only have one indifferent portrait of him (**Fig. 6**) in which he appears rather po-faced, not the man with mud on his boots with his nose in a ditch! Not being an academic, he was casual about his publications, he actually lost 70 illustrations for his final masterpiece which only turned up in the 1960s! (One such is the sketch in **Fig. 3**)

Fig. 6 *James Hutton By Henry Raeburn*

The Corriegills Pitchstone

I have been intrigued by pitchstones for some time because they are very rare, but several varieties occur among the dykes and sills in the British Tertiary Volcanic Province. In thin section, they are quite unlike any other rock; so I stayed on an extra day to visit the Corriegills location on the coast a few miles south of Brodick.

Fig. 7 *Pitchstone exposure*

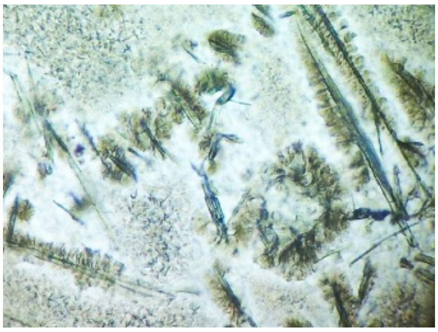


Fig. 8 *Pitchstone thin section ("Fir trees" are ~100 micron).*

The exposure did not disappoint, it is in the cliff, above high water mark and looks like black marble (**Fig. 7**). Similar to obsidian, pitchstone is less glassy, has a hackly fracture and contains more water. It has a granitic chemical composition and in thin section (**Fig. 8**) is glassy with masses of feathery growths resembling little fir trees of the order 100 micron long. There are also clouds of very small crystallites showing some flow structure which are depleted near the growths. The suggestion is that the larger growths are hornblende but the crystallites are indeterminate. Pitchstones contain 5 to 10% water, far more than obsidian and this has profound effects. Water has the ability to break the polymer chain in silicates and reduce viscosity. It is thought pitchstones could originate by contamination of basaltic magmas with hydrous crustal material thus producing a low viscosity high silica melt which solidifies to a glass if cooled quickly as a dyke or sill..

Pitchstone is a rock the structure and derivation of which are still in debate.

Tony Thorp

Members Photographs

Some examples of plant fossils from Paul Lane's collection from the coal measures of South Wales.

Alethopteris frond *An example of a seed fern.*

Alethopteris pinnae

Lepidostrobus *Seed cone of a Lepidodendron species.*

Calamites *stem*