KNOWLE QUARRY, SHROPSHIRE: EARTH SCIENCE BRIEFING FOR THE SITE

NOTE: There is an animated sequence, with narration suitable for use with pupils, to illustrate many of the points made here. See the final file in the **KNO1 Index**, called "**wenlock08**" in order to download it. This animated sequence file [**wenlock08.exe**] should be viewed prior to the visit.

A. Introduction
At any one site it is helpful to think of interpreting the evidence preserved in the rocks as a recurring pattern of events, often referred to as the rock cycle: These events are:

a) **Transport and deposition** of fragments, forming sedimentary rocks, thereby laying down the evidence for a new rock cycle;
b) **Deformation** (including folding, faulting, intrusion by igneous rocks or metamorphism); and
c) **Uplift, weathering and erosion**, leading to deposition of sedimentary rocks at the beginning of the next cycle.

The energy driving the first and last parts of this cycle is derived from sunlight which powers the weather, the rains, rivers and wave action. The second part of the cycle, however, is driven by energy from inside the Earth where the internal heat energy is translated into lateral and vertical movements of the crust as explained by Plate Tectonic Theory. The results include folding, faulting, metamorphism, igneous activity and the creation and destruction of ocean crust and the formation of fold mountains. The rocks along Wenlock Edge are important in that they are part of a remarkable story of crustal evolution which brought together northern parts of the British Isles with the southern parts, about 430 million years ago.

The evidence for the events in The Rock Cycle can be "read" from the rocks in any exposure. However, some parts of the story are always missing, because geological evidence has many "gaps" in it caused by a combination of sediments never having been deposited and preserved in the first place, loss by erosion, and the fact that much is still buried and unknown. This means it is important to remember that the "story" at any one site is but fragments of a single Earth Science story that has an "invisible "prologue" and "epilogue" each millions of years long, but for which we cannot see the evidence at any one site, because it is not available to us.

B. The Plate Tectonic Summary.
This story requires that we bring together evidence from many parts of the British Isles and covering almost 130 million years of geological time. In detail the story is complex, but this briefing concentrates on the broad picture outlining how the evidence allows us to reconstruct the Plate Tectonic movements of the pieces of crust we now call the British Isles.

Since Plate Tectonics Theory suggests that pieces of continental crust have moved and collided to form new combinations, and that earlier oceans have disappeared from between them, some unfamiliar names are required to describe these earlier "oceans" and "continents. See **Figure 1.**

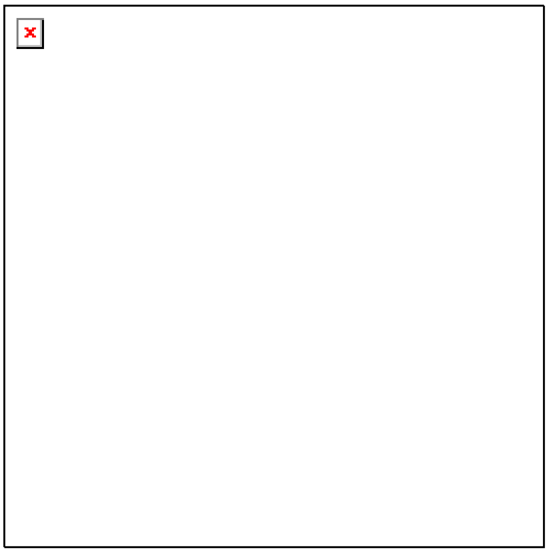


Figure 1. Distribution of Northern Continents about 430 Million Years ago.

In simplified terms, the northern and southern "halves" of the British Isles were once separated by a large marine area called the Iapetus Ocean, which was slowly being closed by Plate Tectonic forces. The shelf seas on both the north west (Scotland) and south-eastern edges of this ocean were sites where beds of limestone and sandstone with bottom living animals now present as fossils, were deposited. Between the land and the true ocean crust were deeper marine basins where muds (now slates) were deposited along with planktonic graptolites. (See **Figure 2**).

By 390 million years ago the Iapetus Ocean was completely closed, and the intervening sediments were squeezed up into a fold mountain range the equivalent of the Himalayas today. This mountain range "welded" together two parts of an enormous continent which was astride the equator and allowed red desert sediments to accumulate on its surface. (See **Figure 1**). These pieces of continent remained "welded" together into one large super-continent, until about 150 million years ago when rifting split the western "USA" apart from the eastern, "British Isles" part, and a spreading ridge opened up a new ocean, now called the Atlantic.

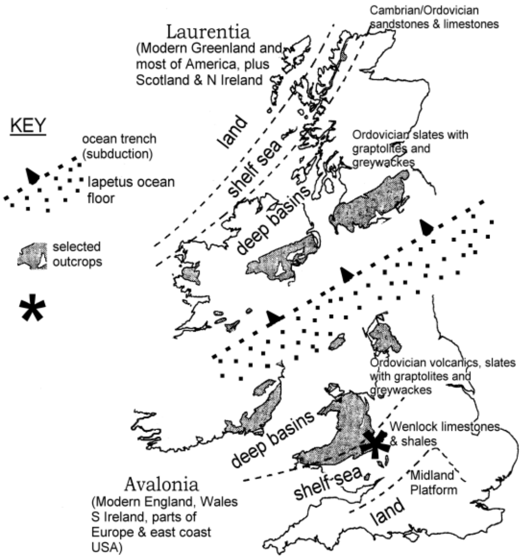


Figure 2. The British Isles (500 to 420 Million Years Ago.)

Figure 2 illustrates many of the relationships, but should be treated with caution as it includes selected information over more than 130 million years to illustrate the story. It does not represent the situation at any one point in time. Here the focus is on the south eastern area around Wenlock Edge.

C. The Lower Palaeozoic "Rock Cycle".
Here this (very simplified) piece of earth history is regarded as the story of a single rock cycle taking place on the south east side of the Iapetus Ocean. Events on the northern edge of the Iapetus Ocean were broadly similar.

i) Transport and Deposition.
In what is now **England** the land area of the **Midland Platform** is only known from boreholes, but represents the terrestrial continental crust on the south east side of the Iapetus ocean. Although we have no details, this land area was undergoing physical and chemical weathering and erosion, with the sand, mud and dissolved salts being transported to the ocean. In the area we now call **Shropshire** the sea flooded over the land area in the Cambrian and Ordovician periods, around 500 million years ago, creating an area of shelf sea deposits. These are sandstones, muds (now shales) and limestones containing many bottom-living marine fossils, including trilobites, corals and brachiopods, as well as planktonic graptolites. This pattern of deposition continued till 420 million years ago, with reef knolls developing on the edge of the shallow water seas during the Silurian period.

At the same time, slightly further to the north-west the conditions, and the deposits are very different. At **Long Mountain**, just 30 kilometres away from where the Wenlock Limestones were being deposited at Knowle Quarry, black graptolitic shales were being deposited in a deep marine basin, indicating a rapid transition from shelf sea to very deep water.

In **Wales** and the **Lake District** muddy sandstones, called greywackes, and muds (now metamorphosed to slates) with planktonic life forms called graptolites were deposited in a series of deeper basins, separated by submerged "rises". Volcanic activity, often with explosive acidic lavas and tuffs was also common during the Ordovician, but faded away during the Silurian period. (See **Figure 2**).

ii) Deformation. Uplift and Erosion.

Around 410 million years ago, profound changes were occurring as Plate Tectonic forces caused the two pieces of continent to collide as the Iapetus Ocean closed uniting "Scotland" with "England" as part of one "super-continent" (See **Figure 1**). The beds in Shropshire became tilted to 10 degrees to the south east and were faulted by brittle fractures. Uplift of the area led to a land area being formed across the equator. This led to terrestrial freshwater deposits, followed by red Devonian desert muds and sands being deposited over the area, marking the beginning of the next rock cycle. To the north, and in Scotland, the effects of fold mountain building were much more severe and included regional metamorphism, turning muds into slates, and volcanicity.

Today the dipping beds of Wenlock Edge have been excavated by weathering and erosion from below their later covering of rocks and are again being eroded away. The different resistance to weathering has led to the characteristic landscape of limestone dip and scarp slopes for which the area has become noted, with the softer clays being eroded into vales.

D. The Evidence For Plate Tectonics.

The evidence for Plate Tectonics Theory comes from a variety of sources, each of which gives a coherent story of crustal evolution and movement, which is supported by evidence from the other sources.

i. **Continental "fit":** the interlocking shapes of adjacent continental shapes have long drawn comment. The complimentary South American and African coastlines, being just one of many examples. This idea is reinforced by the realisation that some larger continents are made up of several smaller pieces of continent "welded" together by the metamorphic rocks formed in the roots of ancient fold mountain belts. Rather like India can now be seen as part of Asia, welded on by the Himalayan Mountains.

ii. **Zonal coherence**: When previously joined continents are reunited, it isn't just the shape that "fits". Fossil provinces and climatic zones, as well as geological structures can all be traced across the "joins" in sensible patterns: glacial deposits are re-located close to the poles, whilst coal deposits are found to have formed near the equator, for example.

iii. **Ocean Floor magnetic anomalies**: The magnetic "stripes" on the ocean floor can be "removed" one by one (by computer) to recreate in reverse the details of the spreading that separated continents. Unfortunately all the ocean floor older than about 200 million years has been destroyed by subduction at ocean trenches, so for continents rifted apart before this we have to rely on combinations of the other pieces of evidence.

iv. "**Polar Wandering Curves**": This is an old and misleading name. The position of the north pole does "wobble" a bit, but it doesn't move around. However, the continents do. Studies of the magnetic fields "frozen" into rocks, such as lavas, when they cooled below their Curie Point, allow us to pinpoint the "fossilised" position of the north magnetic pole at the time of formation. When later rocks, form on top of a moving continent, then measurements from rocks of known, but different ages will produce a series of different plots for the north pole – joined by a line called a "polar wandering curve". By sliding the "fossil" north pole back to its correct (modern) position we discover by what direction and amount to slide the continent to get its position at that particular time.

v. **"No overlap":** At any one time, of course, the position of continents cannot overlap, unless they are parts that have formed after rifting, like delta areas such as the Mississippi.

vi. **Detailed field work**: Over the last 40 years detailed work on many of the separated continents have provided dates and supporting evidence for the broader picture. Most geologists accept that the general timing and development of the continental crust is now known.

NOTE: to see an animation of crustal movement from 750 million years ago to the present day see the website at http://www.ucmp.berkeley.edu/geology/tecall1_4.avi or the one with this material called **Wenlock 08** (See **KNO1 Index**).

E. Reconstructed Plate Movements For The Lower Palaeozoic.

More than a century ago, by using the **Principles of Uniformitarianism and Superposition** geologists were able to work out the environments of deposition of these beds, and the sequence in which they changed over time. However, there remained some difficulties with the resulting interpretations.

The bottom-living trilobite species in Scotland were very similar to those of eastern USA (3000 km away) but very different from those in Wales (less than 1000 km away). In addition, the supposed large continental area supplying sediment to the north west of Scotland is now quite clearly not there. Over the last forty years the detailed work on Plate Tectonic Theory has enabled a coherent explanation to be constructed for the large sideways movements of continental pieces. See **Figures 3, 4 & 5**.

Around 570 million years ago all of the continents were in very different positions to the ones they occupy today. A large piece of continental crust (called Laurasia, and now forming Greenland & North America) was slowly moving northwards, from near the south polar circle towards the equator. Over the next 150 million years the large landmass over the south pole was to be rifted apart to produce two more slabs of continental crust (labelled A and B in **Figure 4**). Each of these would drift northwards eventually to form parts of England and Europe.

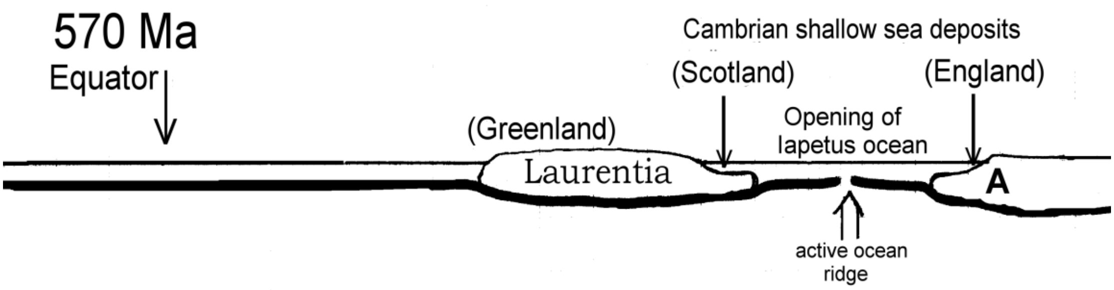


Figure 3. The position of continents in the Cambrian.

About 480 million years ago, close to the south pole, a sliver of continental crust (given the name Avalonia) was rifted away from a larger land mass by a spreading ridge. The rifting process thinned the crust and allowed the continental edges on both side of the rift to sag, and become flooded by the sea, resulting in marine deposition in what is now part of Scotland and England.

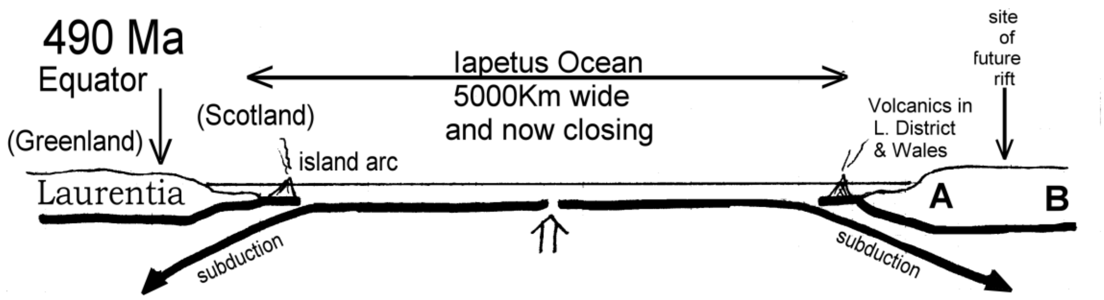


Figure 4. The position of continents in the Silurian.

As Avalonia converged on Laurasia the intervening ocean, called Iapetus, began to close, and eventually disappeared. This implies at least one, destructive margin, or ocean trench, between the two continents, but other evidence suggests there were at times two. (See **Figure 4**). The flooding of the continental edges in the Cambrian, the differences between Scottish trilobites species and those of Wales (but not American ones) and the disappearing ocean crust now have an explanation: they were separated by a large, and uncross-able Iapetus Ocean floor which has now been subducted into the mantle.

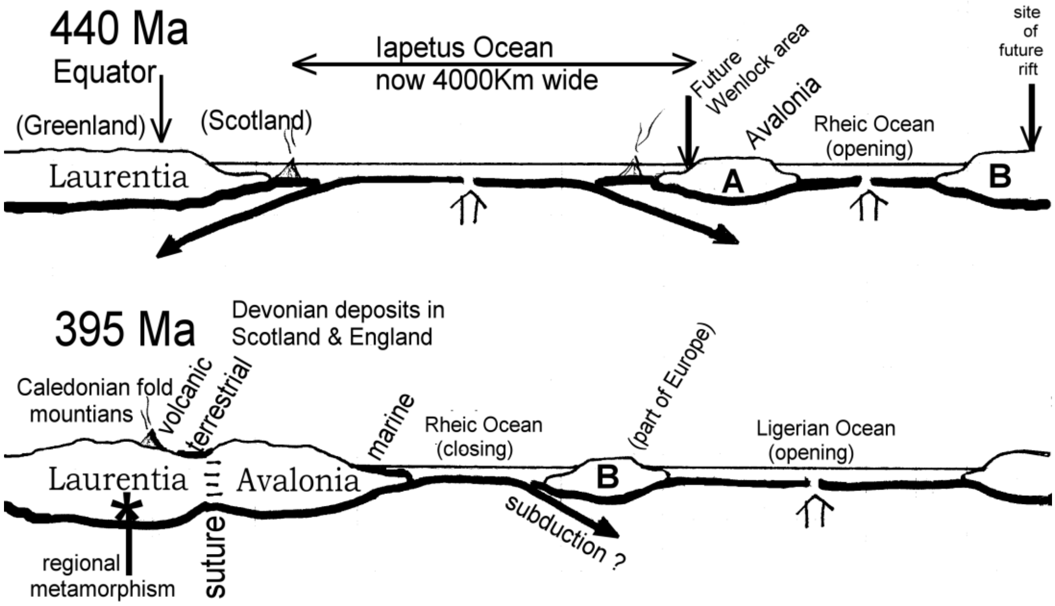


Figure 5. The position of continents in the Silurian & Devonian.

By late Silurian times (about 410 million years ago) the collision was more or less complete. The fold mountains and the resulting deformation (including metamorphism of the rocks in Scotland) thickened the crust and caused uplift, resulting in the terrestrial deposits of the Devonian period across Scotland and large parts of England. In the Wenlock area tilting and faulting occurred. Avalonia had now become "welded" onto Laurentia.

By late Silurian time the southern edge of Avalonia (now Cornwall) was on the edge of a huge continent. Here deeper water marine deposits were being formed, later to be welded onto part of Europe as the Rheic Ocean closed, leading to the Variscan fold mountain belt across Europe, and the emplacement of the Cornish granites about 290 million years ago.

The geology of Knowle Quarry represents only a tiny part of this larger story. It is the deposition of Silurian shelf sea muds and limestones, with reefs, followed by uplift, tilting and faulting.

F. Mass extinction.
There are five recognised mass extinctions in the fossil record since the beginning of the Palaeozoic. This does not include the sixth mass extinction that some scientists think is currently being caused by human activity, and which could prompt useful discussion with groups. (See **Figure 6.**).

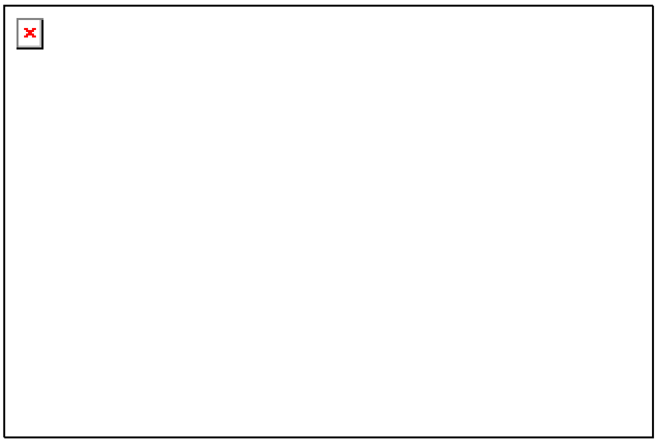
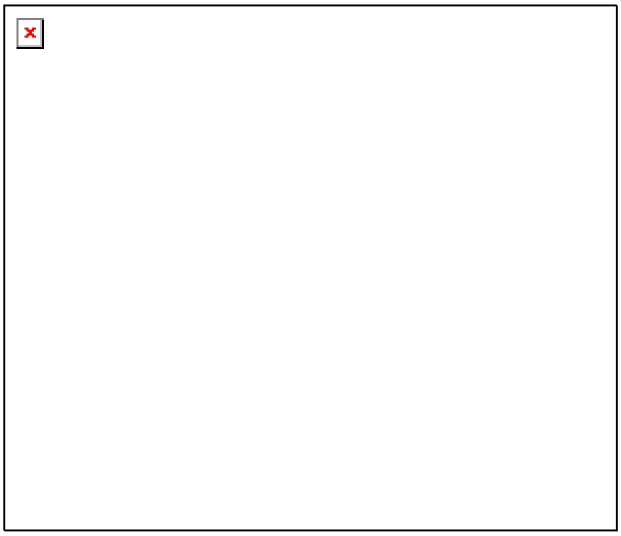


Figure 6. The occurrence of mass extinctions during the last 500 million years.



By the Carboniferous some Lower Palaeozoic genera and groups are already extinct and gone forever, and new ones are present. For example: planktonic graptolites, common in the early Palaeozoic (old life), are gone; corals become common and brachiopods remain abundant, although there are many new species. “Ammonites” including straight forms as well as the more common coiled ones, become common. At this time land living vertebrates appear in the fossil record as amphibians.

Figure 7. Examples of changes in fossil genera over the last 500 Ma.

Mass extinction 5 is the one popularised as ending the reign of the dinosaurs at the end of the Cretaceous and may have been the result of a bolide (asteroid) collision at Chicxulub at Yucatan, South America. The following evolution of new species resulted in a further change in life on Earth to the animals we know today, including Homo sapiens. This is called the Cenozoic (seen life) and these changes in fossilised life allow us to identify the relative age of the rocks by the fossils they contain (**Principle of Rocks Identified by their Contained Fossils)**.

Interestingly the numbers of foraminifera, which are marine planktonic (floating) organisms with a mode of life similar to graptolites, continue their steady increase of numbers through all five periods of mass extinctions that have been recognised in the fossil record of the last 500 million years. Many of the plant species from the Carboniferous are also extinct, although a close relative of one group *Equesites* (horsetails) is still extant.

An important feature of this evidence is that species with very similar habitats show very different responses during these periods of mass extinction. Theories about the possible explanations for mass extinctions has included: planetary collision with an asteroid; reduction of marine shallow water habitats due to continental collision; sudden increases in volcanic activity changing the opacity of the atmosphere and reducing sunlight (and photosynthesis.); increased predation, or competition from other newly evolved species.

Time of Mass Extinction (approx)	% Loss Of Species	Suggestions on Possible / Likely Cause
440 million years ago	-50%	May be linked to changes due to glacial conditions in the southern hemisphere, for which there is good evidence.
380 million years ago	-50%	The decline spreads over a large period and may be linked to drop in sea level reducing circulation and oxygen content.
260 million years ago	-80% to -90%	This huge loss of life, linked in time to massive volcanic eruptions in what is now India which may have blocked out sunlight.
200 million years ago	-50%	Impact by asteroid has been suggested, but the evidence for changes in sea level reducing circulation and oxygen content is perhaps more convincing.
65 million years ago	-50%	Very strong evidence for an impact crater at Chicxulub, Yucatan and related rock deposits around the Caribbean. There were also volcanic eruptions at this time

Table 1. Summary of mass extinctions.

G. Geological Time.
It is only possible to get an **absolute age** in millions of years, for a geological event if it is possible to use radiometric dating techniques. The most usual form of dating for geological events is to establish a **relative age**: i.e. which order the events in a sequence occurred. Thus geologists use two concepts of time, an **absolute time scale**, and a **relative time scale**. Research is constantly attempting to improve accuracy of the absolute timescale, and the match between the two.

The fundamental geological principle is **The Principle of Uniformitarianism:** which states that the biological, physical and chemical processes we see today, operated in much the same way in the past, i.e. “The present is the key to the past”. In establishing the **relative time scale** the following six laws and principles are used:

1. **Law of Original Horizontality:** All sedimentary rocks were originally laid down in a more or less horizontal attitude.
2. **Principle of Lateral Continuity**: In principle, a sedimentary rock is laid down in a layer (or bed) that extends sideways (originally horizontally) and a bed may therefore be found in other places.
3. **Principle of Superposition**: In any sequence of strata that has not been overturned the topmost layer is always the youngest and the lowermost layer the oldest.
4. **Principle of Faunal and Floral Succession**: Fossil organisms have succeeded one another in a definite recognisable order over geological time. It follows that the same combinations of fossils in rocks have a similar (relative, not absolute) age, as do the rocks that contain them. This means that the relative age of sedimentary rocks may be identified by the fossils they contain.
5. **Principle of Cross-Cutting Relationships:** Any structure (fold, fault, weathering surface, igneous rock intrusion, etc.) which cuts across or otherwise deforms strata must be younger than the rocks and structures it cuts across or deforms.
6. **Principle of Included Fragments:** Particles are older than rock masses in which they are included. So the pebbles in a conglomerate are from rocks older than the conglomerate itself.

REFERENCES:
Toghill P (1990) **Geology In Shropshire**, published by Swan Hill Press.

Williams Glyn (1997) **The Wenlock Limestone Industry, an historical note**, available from the author through Much Wenlock Museum.

WEBSITES: http://www.ucmp.berkeley.edu/geology/tecall1_4.avi

www.shropshirerocks.org