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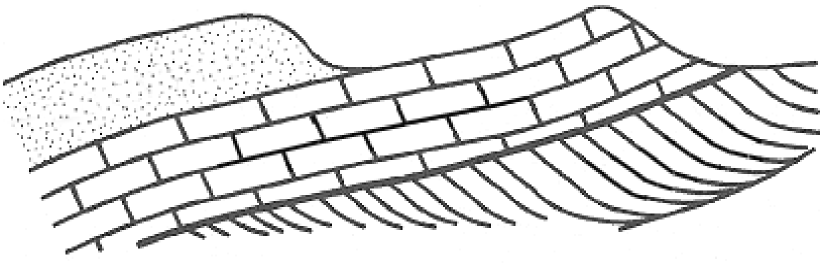

A local group within the GA

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Editorial

Obituaries: It is with great sadness that I have to report the sudden death of David Stephens in November and of Geoffrey Fogwill and Audrey Price in December. All supported the Society for many years and had been regular attendees at both the meetings and field trips.

Honours: On a happier note, I am delighted to report that twelve of our present members have supported the Society for 25 years or more. Their support and hard work has done much to create a successful and widely respected FGS. Many of these members have worked on the committee, particularly in the early days, often in the active roles of Chairman, Secretary or Treasurer: Margaret Bourgoing, Jill & Colin Brash, Janet Catchpole, Marybeth Hovenden, Kate Jemmett, Lyn Linse, Peter Luckham, Joan Prosser, Shirley Stephens, Mike Weaver and John Williams. Some are still committee members - true dedication. There are also three Honorary Members of FGS who made major contributions in the early days of the Society: Ted Finch, Paul Olver and John Wilson.

We warmly thank all of these members for their unstinting efforts on our behalf.

Liz Aston, Editor

The meaning of meteorites

Summary of September 2014 lecture given by Ted Nield, Geological Society, London

Are meteorites always bad news? *Not so!* Every day we scan our newspapers not only for news of events but to get some handle on what they can possibly mean. But instinctively, we understand that, in human and political affairs, cause and effect are hard to pin down. History is not physics.

Writing this article in the centenary year of World War One, it occurs to me that when Gavrilo Princip squeezed the trigger on 28 June 1914 and killed an Archduke in Sarajevo, the bullets emerged from the muzzle of his gun with a degree of certainty not dissimilar to that with which, given enough information, astronomers can predict when an asteroid, observed sufficiently in advance, will fall from its orbit and where it will land. So much is physics.

The impact of those bullets on the bodies of Franz Ferdinand and his wife Sophie that summer day was likely, but not certain, to cause their deaths (people often survive gunshot wounds). But that those deaths would drag the world into the Great War, and bring extinction to the old European order, was even more unpredictable, because the consequence relies as much (if not more) upon the context of the event as the event itself.

Geologists, writing the history of the Earth, are familiar with the importance of context. Their science remains history – a tale of how a complex system unfolded through time, steered by chance events that were not inevitable. That those turning points were significant does not mean they or their effects were inevitable. Run the tape again, and you might not get the same result.

This makes interpreting the old news gleaned from the geological past difficult, and fascinating. The further back we go, the less comparable the modern Earth becomes. Life today is not as it was 50 MA, let alone 300, 400 or 500 million. A meteorite impact today, even though it be identical to one long ago, need not therefore produce the same effect on our, changed biosphere.

Life on Earth has suffered five mass extinctions, each leaving an indelible mark, since the emergence of complex life just over half a billion years ago. They were all “sudden”. Something must have caused them all - but what? Did each have a single cause? Did they have different causes? Did each have many causes? Could any one factor ever be enough to extinguish 90% of all living things? These questions are important, because asking the wrong question – or failing to examine one’s implicit preconceptions – is a frequent trap for the unwary scientist, especially when that scientist is operating outside his or her original discipline.

In its quest to understand the Earth, geology draws in experts from many disciplines. Classically trained geologists and palaeontologists understand their subject’s historical nature; and like all historians they tend to mistrust pat explanations. Scientists from non-historical disciplines, physics in particular, have different criteria for judging whether a story sounds more or less likely to be true. In physics, the principle of Occam’s Razor packs a hefty punch. The simplest, most parsimonious explanation is always best. But not in history. History is messy and complex.

When meteorites fall from the sky, witnesses are drawn, like readers scanning today’s news, to search for meaning. What does this event mean – for me? The answer depends, for the most part, upon context – life-experiences, intellectual baggage, expectations. Peasants saw disaster. Kings saw victory. And academics – well, they didn’t believe it. Until the last decades of the 18th Century, learned men deferred to Aristotle and Newton – neither of whom allowed any grit into the celestial clockwork. This was an easy line to hold, because until 1794 (when a meteorite finally exploded in full view of Siena’s professors and educated Grand Tourists) the only witnesses had been peasants.

For example, in 1768, a meteorite shower not far from Le Mans, France, was investigated by a group of aristocratic savants (including Antoine Lavoisier, father of modern chemistry). They dismissed eyewitness accounts and ascribed the fallen stones to lightning. Thirty five years later, in 1803, a similar fall only 100km away, in a radically changed political context, had a very different outcome. Post-revolutionary France had formed an Institut National out of its royal predecessor, and sent in one Jean-Baptiste Biot (of ‘biotite’ fame). Paysans were now citoyens, and their observations were treated with respect - enabling Biot finally to break free of centuries of prejudice and bring the idea of “stones from the sky” closer to the scientific mainstream. Same event, different context, different outcome. The effect of meteorite strikes upon life on Earth is, similarly, likely to depend heavily upon circumstances.

It took a long time for geologists to embrace meteorite strikes. In the mid 1970s their subject was obsessed by the plate-tectonic revolution, but was otherwise still in thrall to a Victorian assumption that nothing “sudden” could possibly achieve anything lasting in Earth history. Mass extinctions therefore were - a little embarrassing, and tended to be rationalised away. I was lucky enough to study with the leading British opponent of such “gradualism” – Professor Derek Victor Ager (1926-95). Derek realised that a 24-hour hurricane could leave more trace of itself in sediments than intervening ages without name. The rock record was, he held, a scandal-sheet, recording the Earth’s rare, exciting moments, and largely ignoring its more frequent longueurs. This was the “neocatastrophist” revolution.

By the time the seventies were out, suddenness was rehabilitated - with a vengeance. While looking for something else entirely, geologist Walter Alvarez, his Nobel-prizewinning physicist father Luis Alvarez, discovered (and in 1980, with Frank Asaro and Helen Michel, published) a paper about a thin, iridium-rich layer separating the Cretaceous and Tertiary periods; a horizon marked by one of the big five mass extinctions, when dinosaurs and much else of the Mesozoic world order vanished. Because the iridium could only have come from space (Earth’s crust being heavily depleted in it), there must have been a massive impact. The mass extinction, it seemed, had not been merely “geologically” sudden (a million years or so). It had happened in a day – a day that led to our world, with us in it, just as surely as Princip’s bullets had created post-war Europe.

Those brought up to think like physicists (as most impact scientists are) found it easy to accept this impact as the extinction’s sole cause; but geologists were, and remain, wary. Physicists like it, because it is simple and parsimonious. Geologists mistrust it for the same reason. As historians, they feel it in their bones that there is no imperative that the simplest explanation also be rightest.

Only one of the many huge craters that pepper the Earth has ever been linked to a mass extinction event – and that is Chicxulub Crater, offshore Mexico. Even this, according to some, is 300,000 years too old to record the dino-killer impact. Also, one of the other “big five” extinctions coincides with an impact - including the biggest of all, the end-Permian extinction 250Ma. The end-Cretaceous Earth was also already dying, from the effects of unimaginably intense volcanic eruptions India – effusions orders of magnitude bigger than anything humanity has experienced (or will ever experience, if it's lucky). Unlike impacts, every mass extinction can be correlated with one of these. Could it be, then, that the K-T meteorite only had the effect it did because, like Princip's bullet, it arrived at the right time, as old order was already tottering?

New discoveries have even linked meteorites to one of life's greatest ever diversifications. Back in the Middle Ordovician (470 MA), the world was sparsely populated by simple marine organisms, Earth was bombarded by countless meteorites over a period perhaps exceeding a million years following a collision in the Asteroid Belt. Falls became so common that geologists are finding fossil meteorite material in sediments of this age all over the world. Most intriguingly, these amazing discoveries (first in Sweden, now being extrapolated worldwide by Prof. Birger Schmitz of Lund University) may help explain a baffling burst of evolutionary diversification – the biggest after the so-called "Cambrian explosion" when complex animals first appeared. This is known as the "Great Ordovician Biodiversity Event (GOBE), which has puzzled palaeontologists since it was uncovered by computer analysis of species data in the early 1980s.

The theory goes that bombardments sterilized large areas and so broke the stranglehold of endemic species, allowing new opportunist species to invade and thus increase biodiversity - an ecological phenomenon known as the Intermediate Disturbance Effect. Such biodiversity increases would feed through, in time, to faster evolutionary diversification.

So when we read of a meteorite fall today, we should perhaps reflect that what may have been bad for T. rex 65Ma was, in the end, good for birds and aardvarks and us; and that had it not been for a collision between asteroids that showered the mid-Ordovician Earth, T. rex himself might never have had his big chance. Indeed, as with all incoming news, the meaning you derive rather depends on where you stand.

Ted Nield: Incoming! - or, why we should stop worrying and learn to love the meteorite, published, Granta, 2011.

Field trip to North Yorkshire – June 2014 - Flamborough Head

Flamborough Head protrudes 6km into the North Sea due to the relatively hard nature of the Chalk Group rocks. Yorkshire Chalk differs greatly from its southern softer and more porous counterpart. It is so hard that in the past it was used as a local building stone, e.g. the old lighthouse at Flamborough Head, and forms large boulders amongst the chalk and flint cobbles and pebbles of the bays we visited. The hardness could possibly be a result of thermal activity from deep-seated magma associated with the increase in volcanic activity and sea floor spreading during the opening of the Atlantic in the Cretaceous. The bands of marl could have formed from volcanic ash produced at this time. Yorkshire flints are grey and more brittle than their black southern equivalent and doubtless would not have made suitable tools for ancient Man.

Marine conditions prevailed throughout the Cretaceous in Yorkshire, the Chalk was the last sediment to be deposited. In the Late Cretaceous and the Tertiary, as the Tethys Ocean closed, the area was subjected to deformation and erosion in which time much of the Yorkshire Chalk could have disappeared.

The cliffs of the Flamborough area expose a continuous Chalk succession from the base of the Upper Cretaceous Series (Hunstanton Red Chalk Formation, Speeton Cliff) to the lower part of the Lower Campanian succession (top of the preserved Flamborough Chalk Formation, Sewerby Steps). The succession is comparable with that of the Chalk Group, North Sea Basin, and dates from 100-70Ma. Fossils are scarce and include brachiopods, bivalves, sea urchins and sponges.

The regional dip in Yorkshire is about 10°S and three localities were visited in order to see the following lithological units in the Chalk succession.

Flamborough Chalk Formation	No flint	Santonian to early Campanian
Burnham Chalk Formation	Grey tabular flint	Late Turonian to early Santonian
Welton Chalk Formation	Grey flint nodules	Turonian

At Thornwick Bay, at the base of the cliff, lies the Welton Chalk Formation, overlain by the Burnham Chalk Formation, which has a basal, rubbly, nodular sponge bed with the prominent Ravendale Flint above. Higher up the sequence are the Triple Tabular Flints (see Figure 1 - the top of the umbrella conveniently marks the junction between the Welton and Burnham Formations). The flint and marl bands within the Chalk serve as marker beds for correlation. The marls are thought to be expressions of volcanic activity at this time. They have a prominent effect on the landscape, flints forming the scarps of the Yorkshire Wolds and the erosion of marls leading to the subsequent formation of caves and stacks common along this stretch of Yorkshire coast.

Further along the coast, at North Landing, the Welton/Burnham Formation boundary lies near the bottom of the cliffs at the cave floors. An exceptional feature here is the large paramoudra flint, almost 1m in width, which is a flint replaced burrow where excessive flint production at margins has taken place (Figure 2). Fossils are scarce here as at the previous location.


Fig. 1: Umbrella top at Welton / Burnham Chalk boundary, above are Ravendale & Triple Flint Bands


Fig. 2: Large paramoudra


Fig. 3: Stylolites in chalk caused by pressure-dissolution of chalks and accumulation of insoluble material

Visiting our third location at Selwick Bay by Flamborough Head proved to be a highly thought provoking experience owing to the complex nature of the geology. The northernmost part of the bay is almost all Flamborough Chalk Formation and is devoid of flints and the southerly part is mostly Burnham Chalk Formation deposited 85 - 80 Ma.

When facing the steps at the back of the beach the complicated nature of the geology is evidenced by the variety of structures and textures present. Chalk here has suffered complex tectonic stresses resulting in different intensities of folding and faulting. Folds vary from relatively large/open to small/tight, visible in the vertical cliffs and on the horizontal wave cut beach (Figures 4-6). Faults vary from thrust to normal faults (Figure 7).

Stylolites have developed, found at all three locations (refer back to Figure 3), both horizontal and vertical at this site, caused by dissolution of chalk due to pressure perpendicular to the plane of the stylolite. Flint bands are common and Figure 9 shows the continuous, and Figure 10, the nodular, flint bands from Thornwick.


Fig. 4: Tight folds in Chalk at Flamborough Head, displayed on beach wavecut platform.


Fig. 5: Close up of fold limb in Fig. 6 below, note horizontal fault running through centre of exposure


Fig. 6: Faulted fold in cliffs, see close up of northern limb above.


Fig. 7: Flamborough Head Chalk shows thrust faults


Fig. 8: Fault breccia

Figs. 9, 10: Flint bands in chalk beds (Thornwick): continuous (Fig. 9, left), and nodular (Fig.10, right), note edges of nodules appear to coincide with fractures.

Fig. 11: Conjugate fault zone

To the right of the new steps is a section of cliff where the beds are highly contorted and older beds have been thrust over younger. Part of this forms a promontory as a mass of crushed almost horizontally lying material with imbricate faults. This is part of the Flamborough Fault Zone, which trends in an E-W direction. Breccia-infilled fractures are seen on the foreshore (Figure 8). To the N occurs a near-horizontal fault (Figure 6) and a number of smaller ones. Other faults seen include a normal fault indicating extension and pressure release and also a pair of what resemble conjugate faults (Figure 11). Other minor structural features included extension cracks filled with calcite mostly observed in boulders on the beach. In the northern cliff face we looked for both horizontal and vertical stylolites. There were numerous conjugate faults with areas of erosion at their intersections with marl seams. Several modern caves have developed along fault planes.

As usual Graham's magic weather wand worked wonders - the weather at Flamborough Head was surprisingly kind, the rest of the country suffering a variation between thick low cloud, or continual very heavy to torrential rain.

Sally Pritchard

Field trip to Pett Level & Fairlight Cove - 19 October 2014

We met at the Smuggler Inn, Pett village and set off towards Cliff End along a pebbly, sandy beach bordered by cliffs (Figure 1) with a falling tide. To quote Graham's excellent introduction. We were to explore:
"...early Cretaceous (Berriasian to Valanginian age) river and lake sediments which have provided some of the finest plant and land animal fossils of this age, in the world. The sediments show "text book" examples of sediment structures characteristic of a fluvial braid plain depositional environment.....Pett Level and Fairlight Cove probably experienced a Mediterranean Climate with hot dry summers and warm wet winters."

Here the coastline is eroding so rapidly that interesting exposures are frequent events. Our route was littered with fine examples of death assemblage moulds of the small bivalve mollusc *Neomiodon* from the Wadhurst Clay. These came from many rock falls at the base of the cliffs, and indicated increasingly drying conditions. Also present were carbonized wood remains, possible *Cyclad* remains, siderite nodules, *quillwort* stems/roots, tiny fish and bone parts and vertical horsetail *Equisitites* roots in situ. Many examples of apparent "burrows" along the bedding planes were in fact narrow water channels trending in one direction. We saw more evidence of river systems in the cliff sediments.

The Cliff End Sandstone (ca. 10m thick) was deposited within the Wadhurst Clay Formation. It consists of sand and silt bands. The upper part consists of massive ca. 1-2m thick beds, below which lie thinner rhythmically deposited beds of organic sandstone, some containing charcoal (suggesting periodic forest fires). The Wadhurst Clay Formation consists largely of clay/silt layers. Here the Wealden sandstone cliffs reach their easternmost point.

There was both an extensional (normal) fault, and a large compressional (reverse) fault, where the Ashdown Formation on the left had been pushed up so high that the sediments across the fault could not be matched in the adjacent Cliff End Sandstone (Figure 2).


Fig. 1: The Lo. Cretaceous sediments (Ashdown Sst, Cliff End Sst, Wadhurst Fm) in the cliffs at Fairlight.


Fig. 2: Cliff End Fault – compressional tectonics, part of the Alpine Tertiary movements, which created the Wealden anticline.

As the tide receded we came upon a well defined dinosaur footprint; possibly this came from the Upper Ashdown Formation. It was an upside-down impression, so obviously not in situ! (Figure 3).

Starved ripple features in the sediments (Figure 4) are an indication of limited amounts of sand being available for deposition. They have a barchan-like shape. The thin dark band centre, also Figure 4, shows where iron has filtered down to the top of a lower, more impervious bed. Water escape features associated with collapse of sediments were also identified (Figure 5).

On our return to Pett Level the tide was low enough for us to see the remains of ancient rooted trees rising above the sand. Work has recently been started by archaeologists to determine the age and variety of trees in this forest, which is thought to have been extensive. Preserved hazelnuts have been carbon dated to 5,200 BC, and oak, birch and hazel remains have been identified. Mesolithic flint tools have also been found in a cave here. Sea levels could have been about 30m lower than today, and the area would have provided good hunting grounds for people.


Fig. 3: Cast of dinosaur footprint (viewed from below)


Fig. 4: Starved ripples


Fig. 5: Water escape structures – water escapes upwards and the sediment slumps down.

The species of trees and the presence of peat here are similar to those found at Bouldnor on the coast of the Isle of Wight (about 135km away as the crow flies) where sub-aqua investigations by archaeologists at the University of Southampton are being carried out. A collection of Mesolithic tranchet axes and picks have been found on a peaty land surface that was flooded when the sea rose quite quickly nearly 8,000 years ago. Apparently a friendly lobster unearthed one or two artefacts!

The day ended in the Smuggler Inn, with tea and apple cake. A great day out was had by all, and grateful thanks go to Graham for doing all his hard work, including an excellent handout.

Joan Prosser

Field trip to the Durham Coast – June 2014 – Chaotic magnesium limestones

In the summer of 2014, FGS members visited the Durham coast to study Upper Permian Magnesian Limestone. The Jurassic sections visited on the same trip have been reported in the October 2014 newsletter. The Creaceous sequence at Flamborough Head is also reported here.

England was at ca.10-15°N during the Permian (250-290Ma), in the middle of the Pangaea super-continent - a very hot, dry desert. Prolonged erosion during early and middle Permian times formed a low relief landscape with large inland drainage basins that lay below sea level. During the late Permian, a link formed to the open ocean to the N, and these basins were catastrophically flooded to form the Zechstein Sea; flooding may have taken as little as six years. The Zechstein Sea extended from NE England across N. Europe beyond Poland, and lasted about 5Ma before global eustatic sea level fall returned the area to desert conditions.

The Zechstein Sea flooded a number of times; however, the extremely hot climate resulted in rapid evaporation and precipitation/deposition of classic evaporite sequences - limestone, succeeded by gypsum then salt. In the basin centre (beneath the North Sea) there are thick layers of salt; at the basin margin in Durham, the sequence is dominated by (magnesian) limestone, with limited deposition of gypsum. The first three cycles of the succession can be seen along the Durham coast; from the bottom upwards, these are referred to as Z1 (i.e. Zechstein 1), Z2 and Z3. Gypsum ($CaSO_4.2(H_2O)$) loses water during burial diagenesis to form anhydrite ($CaSO_4$).

We visited Trow Point, Marsden Bay, Roker, and Seaham, and I was amazed at the frequency of chaotic, brecciated limestones we saw. How did they form? Interpretation suggests several different methods, as below.

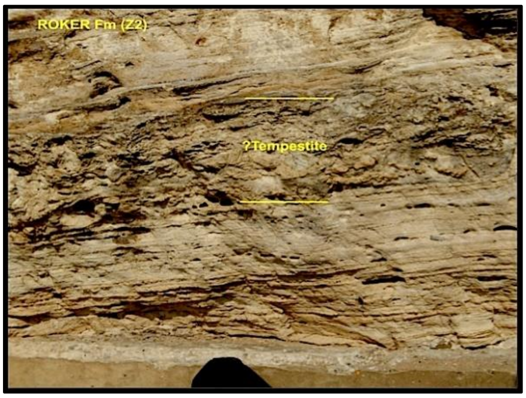

Fig. 1: Hendon Parade; a chaotic limestone bed within otherwise undisturbed Roker Fm (Z2), perhaps the result of a severe storm (tempestite).

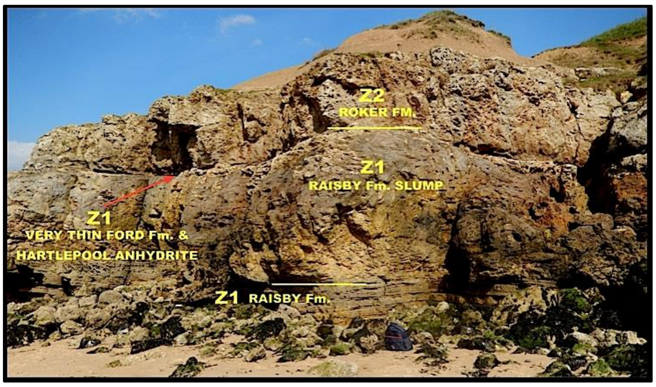

Fig. 2: Raisby Fm. (Z1) submarine slide: lower part is undisturbed; the chaotic limest. of upper part shows a contemporaneous submarine slide. Foundered Roker Fm. (Z2): limest. beds (lo. Z2) foundered when underlying Hartlepool Anhydrite Fm. (up. Z1) dissolved away.

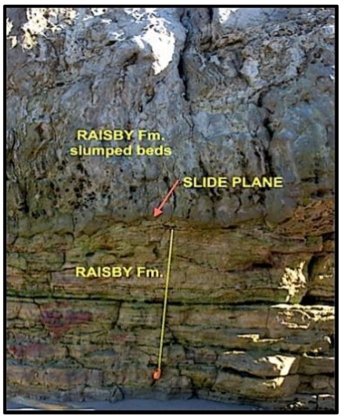

Fig. 3: Trow Point: The lower part of the Raisby Fm. (Z1) is undisturbed. The slide plane is an irregular, eroded surface upon which the slumped sequence rests.

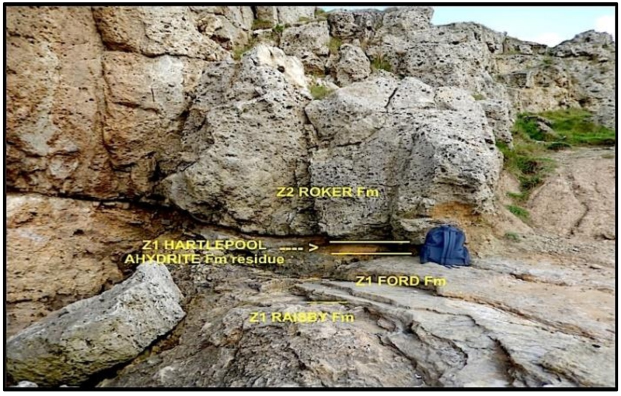

Fig. 4: Trow Point: Brecciated Roker Fm. (Z2). Only a very thin residue remains of the Hartlepool Anhydrite Fm. (Z1); its dissolution led to the foundering of overlying Roker Fm. (Z2).

Tempestites: At Hendon Promenade (Figure 1), a well-bedded Roker Fm. (Z2) limestone sequence was interrupted by a number of beds, about 10-15cm thick, of brecciated, rolled limestone fragments perhaps the consequence of massive storms ripping up and re-depositing the seabed.

Slump (Figures 2 and 3): At Trow Point, the Raisby Fm. (Z1) limestone exhibits two distinct lithologies. The lower part is an orderly well-bedded limestone sequence (Figure 3); the upper part (still Raisby Fm.) is composed of the same material but is severely disturbed and brecciated (Figures 2, 3). There is an irregular erosion surface between the two lithologies (Figure 3). The beds are clearly slumped, and the British Geological Survey (BGS) has mapped out a very large area of this slumped material that suggests lateral transport of up to 11km down a low angle submarine slope - a spectacular contemporaneous slope failure.

Foundered breccias (Figures 2 and 4): The thick Z1, Z2, Z3 limestone/gypsum/salt evaporite sequences, characteristic of the basin centre (under the N Sea and Germany), thin towards the Durham coast (evidenced from oil company seismic data). However, along the Durham coast, little remains of the gypsum/salt beds. They have been dissolved away, presumably by near surface connate fresh water. As a consequence, overlying limestone beds (not easily dissolved) collapsed to form chaotic, brecciated units with little remaining of the original bedding.

At Trow Point (Figure 2), the Roker Fm. (Z2) provides a classic example. The Hartlepool Anhydrite Fm. (Z1) was dissolved to leave only a few cm residue (Figure 4) leading to collapse of the overlying Roker Fm. (Z2).

Postscript: Note, there are, of course, other ways in which to form brecciated limestone, particularly where rocks are faulted, but relatively speaking, these are boring bulk standard phenomena!!

Graham M Williams

FGS field trip to Somerset – 5 to 7 October 2014

Day 1 – Portishead: We parked on the sea front in good weather and walked SW along the coast in the direction of Kilkenny Bay then returned and walked NE to Woodhill Bay after lunch. The succession is made of E-dipping Devonian ORS about 350Ma, succeeded unconformably by continental Triassic sediments. The maroon red colour (I am told) of much of the sequence, backed up by the character of the sediments and sedimentary structures indicates a continental fluvial environment. Both lower and upper ORS are exposed with an unconformity between them due to a period of uplift and erosion prior to later deposition, Figure 1.

At the end of Carboniferous times, the Hercynian or Variscan orogeny folded and uplifted the rocks. Erosion occurred prior to deposition of late Triassic sediments. The whole of the Carboniferous, Permian and much of Triassic succession is missing (a gap of ca. 80Ma), Figure 2.

The Triassic sediments are coarse breccias, formed as flash floods, and alluvial fan sediments, deposited under arid conditions when the UK was at a similar latitude to the present day Sahara desert. They were deposited unconformably as an irregular cover on folded and eroded Devonian rocks, Figure 3. So there are unconformities between Triassic breccias and Upper Devonian fluvial sediments and between Upper ORS (Portishead beds) and Lower ORS (Black Nore Sandstone).

The Woodhill Bay Triassic continental sediments contain reworked Lower Carboniferous crinoids, very confusing! The fold structures are of small amplitude, but a small number of anticlinal and synclinal folds were seen on the beach. Dog tooth spar crystals of calcite were seen in the cliff.

During the sojourn to the SW, Graham located a large block of sandstone on the beach which had fine beds at the base but the top surface was irregular, Figure 4. He said on a previous trip the leader had described this as a fossil soil surface but he was of the opinion that it was a calcrete, formed near the (Devonian?) water table.

A good beginning to another excellent field trip!

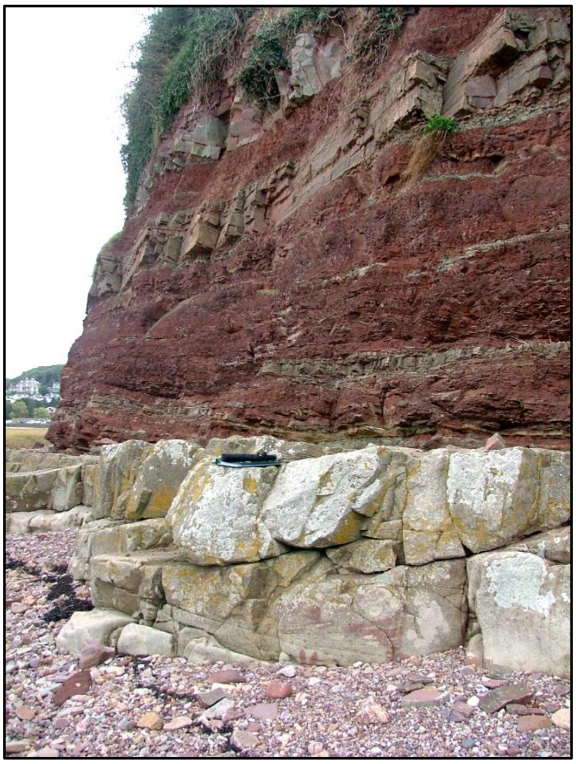

Fig.1: Upper ORS rests unconformably on eroded surface of Lower ORS.

Figs. 2 (above) & 3 (below): Unconformity between Triassic wadi deposits over ORS (Black Nore Sst Fm).

Fig. 4: Calcrete (white carbonate) in ORS sediments.

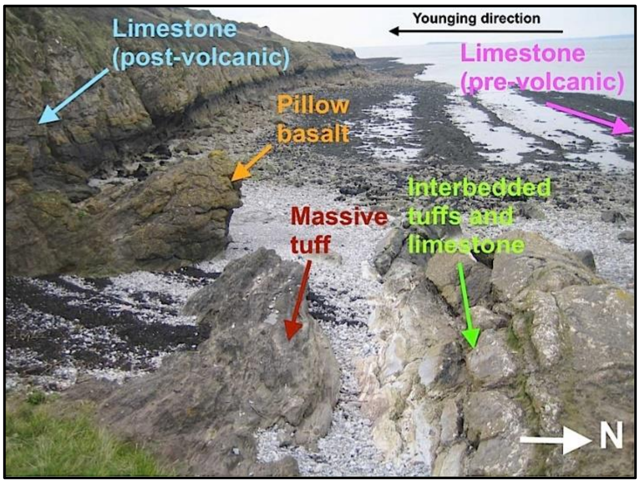

Fig. 5: Lower Carboniferous sequence, Middle Hope

Day 2 – Sand Bay - Middle Hope Volcanics

Having climbed the steps to the top of the Swallow Cliff headland, north of Weston-super-Mare, we descended to a pebbled beach where the rocks record a fiery episode that took place around 350Ma.

Such is the importance of Middle Hope in the geological story that it is officially designated as an SSSI (Site of Special Scientific Interest) as well as being a RIGS (Regionally Important Geological Site).

Fig. 6: Interbedded limests and tuffs of the Middle Hope Volc. Mbr.

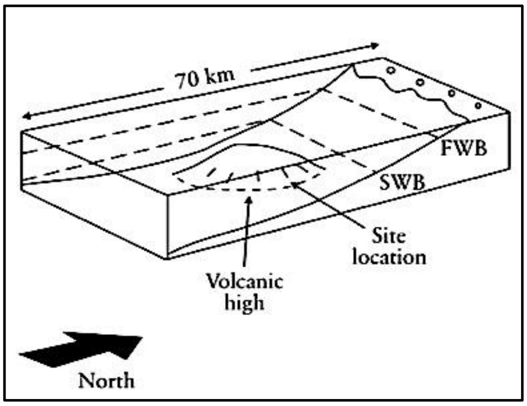

Fig. 7: Block diagram outlining suggested depositional environment of Middle Hope interbedded volcanic sequence.

Fig. 8: Graham beside basalt pillow lava of Middle Hope Volc. Mbr.

S-dipping beds of the Black Rock Limestone sub-group of the Lower Carboniferous period protrude from the shingle, as a series of low ridges, younging in a N to S direction (see Figure 5). These are highly fossiliferous, with crinoid, brachiopod, coral fragments, and traces of burrowing organisms, indicative of a calm submarine environment. Beginning with the oldest rocks, these show no sign of vulcanism but conditions in the area were to change dramatically.

The next ridge of tilted rocks comprises interbedded limestones and tuffs (Figure 6), indicating sporadic volcanic outbursts of increasing intensity. Some conglomeritic deposits seen here are thought to have formed from pyroclastic debris, flowing down a carbonate ramp (see Figure 7).

But then, the nearby vulcanism overwhelms the area, spewing out great quantities of volcanic ash to form the massive tuff of the Middle Hope Volcanic Member. The rock is green-black in colour and 5-10m thick, with lapilli-rich zones. The prominent calcite veining is associated with later tectonic events.

Finally, on top of the tuff, a layer of basalt pillow lava 4.5m thick (Figure 8) shows classic pillow shapes. At this stage, an extrusive flow of lava cooled below sea level and created the pillows. The upper surface of the basalt shows amygdales (voids formed in the molten lava by bubbles of gas) later filled with calcite.

Last, the vulcanism ceased and calcareous sediment deposition resumed, leaving the igneous material sandwiched between Black Rock Limestone beds. The entire succession was subsequently tilted during the Variscan Orogeny at the end of the Carboniferous period.

Day 3 - The Rhaetian, the final stage of the Triassic.

At Blue Anchor Bay, high cliffs of the Branscombe Mudstone Formation are stained red from ferric iron. Associated green marls (ferrous iron) showed traces of roots, thin sandstones and squashed rip up deposits were seen. These features are all indicative of deposition in a desert environment with ephemeral player lakes. Faults with minimal displacement were also present.

Then, dramatically, a high, pale-banded cliff appears. This is the Blue Anchor Formation, overlain by the Westbury and then the Lilstock Formations. A normal fault, downfall to E, separates the cliffs and can be traced running through the wave cut platform and towards the line of the bay. Below the Blue Anchor cliffs, the limestone rocks yielded interesting examples of 'beef' (veins of fibrous calcite, usually parallel to bedding), 'sun stones' (septarian nodules), fossils (especially ammonites), ripples marks and pebbles with sponge like surfaces but a solid limestone interior. All this indicates a dramatic change from desert conditions to a shallow marine environment.

The Atlantic was about to open and associated tensile stress caused rifting and basin subsidence. Most eye-catching of all were alabaster (gypsum) deposits, some stained red by ferric iron.

We were reminded of the evaporation cycle within restricted marine basins: calcite carbonates precipitate from sea water first, then gypsum and lastly, evaporites (particularly salt) from the remaining hypersaline waters. With burial, the gypsum dehydrates to anyhydrite, but then commonly rehydrates, near the surface, to gypsum.

We walked W along the beach to identify the Triassic/Jurassic boundary, defined by the absence of many ammonites. Despite the fame of this, the most destructive of all mass extinctions, no change in lithology could be seen. The extinction occurred at ca. '*201Ma, in as short a period as 10,000 years. Some 22% of all marine families, 53% of all genera, an estimated 76-84% of all species disappeared. In the sea, the largest entire group to die out was the strange eel-like conodonts. Reef ecosystems were decimated. Ammonites, brachiopods and bivalves were also badly affected, with the latter losing over 90% of its species'. (National History Museum)*

From the cliff top at Kilve, we looked down on a complex wave cut platform. The confusing patterns of swirls and lines could best be explained by post depositional faulting. At Lilstock, our final site for the day, we looked at the Penarth Group and thus filled the gap between the Blue Anchor and the Blue Lias beds we had seen at Blue Anchor Bay.

Ian Hacker, Mary Clarke and Janet Philips

Earth's climate evolution – A voyage of discovery

Summary of October 2014 lecture given by Dr. Colin Summerhayes, Scott Polar Institute, Cambridge

The general public is confused about climate change, not least because it gets conflicting messages. One of those comes from within the geological community. It is the mindless mantra 'the climate is always changing'. Well, of course it is, but the real question is - how is it changing, and why, and at what rates? If we know the answers to those questions we can understand much better what the climate is doing now, and what it might be expected to do in the future. The answers lie buried in the world of palaeoclimatology, a topic not all that well known even to geologists, especially if they earn their living by practicing some other aspect of geology.

The savants of the late 18th century, like Lamarck and Cuvier, knew that the world was cooling. Lyell absorbed their knowledge in deriving his "Principles of Geology", in 1830. His own and other studies of fossil molluscs confirmed that Europe had cooled since the Eocene. Being familiar with Humboldt's isothermal lines that divided the world into climate zones, Lyell reasoned that if those zones had remained constant through time, he could explain climate change by having the continents migrate across them. Thinking about the erratic blocks and boulder clay of the recent past, and not knowing anything about the great ice sheets of Greenland or Antarctica, he deduced that Europe had moved into iceberg-strewn polar seas. His contemporary Agassiz thought differently. Erratic blocks and boulder clay were the relics of a great ice sheet: God's Great Plough. Agassiz was right. But so was Lyell, in the sense that we now know the floor of the deep North Atlantic is strewn with debris from iceberg armadas. They did not, however, cross Britain.

Wegener put the meat on the bones of Lyell's moving continents, with his concept of continental drift. He was attacking the entrenched position of Eduard Suess from Vienna, and Suess's followers in America, and was ridiculed for his lack of a mechanism for drift, and for being a meteorologist. Wegener worked closely with eminent climatologist Wladimir Köppen to superimpose climate data on his reconstruction maps. They attracted some believers, but Wegener was not vindicated until plate tectonics came along in the 1960s, enabling people like Edward Bullard and Alan Smith at Cambridge to start making quite accurate palaeoreconstruction maps. By the late 1970s a group led by Fred Ziegler, at Chicago, had begun rewriting Wegener and Köppen by plotting palaeoclimate data on reconstruction maps made by Chris Scotese. Oil companies paid for the work, being keen to see the results.

Aside from palaeogeographic mapping as an aid to understanding past climate change, it was realised that celestial mechanics played a role.

1. The Earth's orbit changes from almost circular to elliptical, with the Sun off centre, in cycles 100,000 and 400,000 years long. A circular orbit means a warmer Earth.
2. The tilt of the Earth's axis changes from 24° to 21° and back over 41,000 years.
3. And, the position of the Earth in winter migrates around the Earth's orbit in a precession cycle 21,000 years long.

In the 1860s, James Croll used astronomical data to calculate the history of Earth's insolation (energy received from the sun) due to the eccentricity cycle, over the past 3Ma years, and 1Ma into the future - the first climate prediction. His work was refined in the early 19th century by Milutin Milankovitch, who showed that northern hemisphere glaciations were driven by the amount of summer insolation at 65°N. In the late 1970s, André Berger refined those calculations yet further. And Nick Shackleton, along with Jim Hays and John Imbrie, showed that variations in insolation at 65°N over the past 1Ma correlated tightly with indications of cooling and warming seen in oxygen isotopes from foraminifera in undisturbed deep sea cores. This was a breakthrough almost as great as plate tectonics.

Insolation declined at 65°N during the Holocene, taking Earth into a neoglacial period over the past 4,000 years that culminated in Europe's Little Ice Age (LIA). Insolation is still low and will remain so for a few thousand years. We should still be in the neoglacial LIA. Why are we not? The answer is CO_2. In 1859 John Tyndall published the results of experiments demonstrating that H_2O-vapour, CO_2, N_2O and O_3 absorbed and re-emitted infrared radiation. He deduced that variations in these gases in the atmosphere could explain variations in past climate. Swedish geologist Arvid Högbom thought that variations in CO_2 could explain the fluctuations of the Ice Age, and asked his chemist colleague Svante Arrhenius to see if that were possible. Arrhenius calculated that a fall by 0.6 x modern CO_2 would cause a drop of 5°C, enabling a glaciation to occur. American geologist T.C. Chamberlin used those findings in 1899 to support a theory of climate change reliant upon changes in atmospheric CO_2. He was the first to suggest that the deposition of masses of coal in the Carboniferous would have stripped CO_2 from the atmosphere, causing a glaciation.

However, we still lacked detailed information about the spectrum of CO_2 in the atmosphere. It was finally developed in the early 1950s with funds from the US military, which wanted to be able to detect the heat from the engines of enemy jet aircraft. Gilbert Plass used the new data to upgrade Arrhenius's findings, reporting in 1956 how fluctuations in CO_2 could help to explain glacial-interglacial change, and warning of the dangers to our climate if emissions of CO_2 increased exponentially. It took a while for geologists to wake up. But by 1983 Bob Berner was making geochemical models demonstrating how the supply of CO_2 from volcanoes was balanced by the take up of CO_2 by chemical weathering. The two were not always in equilibrium. Fluctuations in CO_2 over the past 500Ma caused changes in climate. To test his ideas it was necessary to find proxies for CO_2. Most promising of these were the size and density of stomata on leaves. Leaf data plus multiple other sources of proxy data, showed that CO_2 rose at the end of the Cretaceous to a peak in the mid Eocene, then fell to the present.

Was that pattern matched by temperature? In the 1950s, Harold Urey showed that the oxygen isotopic composition of seawater varied with temperature. Hence the isotopic composition of organisms growing in seawater would reflect the temperature of the water they grew in. Cesare Emiliani showed that the isotopic composition of deep-sea foraminifera varied through time, seeing that as an indicator of glacial-interglacial change. Nick Shackleton agreed. The latest oxygen isotope profiles from deep ocean drill cores, produced by Jim Zachos, show the detail of climate change through time over the past 70Ma in great detail. The pattern parallels that of CO_2, making if highly likely that Berner was right. Fluctuations in CO_2 through time control planetary temperatures on the coarse scale. A good example comes from the Palaeocene-Eocene boundary, where Zachos found carbon isotopic evidence for the expulsion of 1000+ gigatonnes of carbon into the atmosphere, which forced a rise in temperature of 5-6°C, a rise in sea level of about 15m, and a rise in the carbonate compensation depth that caused deep ocean carbonate sediments to dissolve (i.e. deep ocean waters became more acid). Warming in the mid-Pliocene was similarly associated with a rise in sea level – this time of up to 20m.

Within the Ice Age, the orbital fluctuations in insolation drove changes from glacial to interglacial. But they were not enough to account for all of the temperature rise and fall. Evidently, as the ocean warmed it released CO_2, which contributed to the warming through positive feedback. It accounted for 30-50% of each major temperature rise. Recent work by Frederic Parrenin showed in 2013 that CO^2 and temperature in Antarctic ice rose synchronously at the end of the last glaciation. There was no lag between them. The last four big interglacials were all warmer than today's interglacial (the Holocene) by 2-3°C. For that reason, sea level was higher then by between 4 and 9m.

The message from geology is clear. Raise CO_2 and temperature goes up, the ocean expands, ice melts, and sea level rises. This is exactly what you would expect from basic physics.

That brings us to the effect of direct fluctuations in solar energy - the 11-year sunspot cycle and its bundling into the 208-year long Suess or DeVries Cycle. When solar output is high, cosmic rays are deflected. When solar output is weak, cosmic rays form ^{14}C and ^{10}Be radionuclides in Earth's outer atmosphere. Measuring these nuclides in ice cores and tree rings shows how the Sun's energy has varied with time over the past 1000 years. It was high in the Medieval Warm Period (MWP) and until recently appeared to be just as high around 1960 (though recent data from Clette et al (2014) suggest that the so-called modern solar maximum between 1950 and 1990 was not as high as had previously been thought). Solar output was much lower at times during the Little Ice Age (LIA), though some periods of the LIA were as warm as the MWP. Palaeoclimate data show that the temperatures of the past 1000 years fluctuated within a natural envelope. Its mean was driven by the neoglacial orbital insolation, and its extremes by variations in solar output.

The rise in CO_2 since the start of the Industrial Revolution took our temperatures way above that natural envelope. CO_2 from bubbles of fossil air in ice cores averages about 280ppm for most of the past 1000 years until 1769, when James Watt patented his steam engine. After that they rise exponentially until they map on to measurements of CO_2 in background air from South Pole and other remote places. In contrast with the rise in CO_2, which has shot up dramatically since 1950, solar energy remained more or less constant between 1960 and 1990 before beginning to decline. Earth's temperature in that period has followed CO_2, not solar energy.

To conclude, I am reminded of the closing lines of the Geological Society of London's Statement on Climate Change: *"In the light of the evidence presented here it is reasonable to conclude that emitting further large amounts of CO_2 into the atmosphere over time is likely to be unwise, uncomfortable though that fact may be"* (http://www.geolsoc.org.uk/climaterecord). Hutton was right - provided that the appropriate conditions are repeated, a study of past and present conditions is a good guide to what may happen hereafter. Geologists can make predictions (in the oil business they do it every time they drill a hole).

Reference: Clette, F., Svalgaard, L., Vaquero, J.M., and Cliver, E.W., 2014, Revisiting the sunspot number. Solar and Stellar Astrophysics (in press).

Farnham Geological Society Programme for 2015

Date	Speaker	Subject
9 January	Dr John Williams, FGS	Geology from a Train Seat
11 February	Dr Zoe Barnett, Royal Holloway College	Sills and Shallow Magma Chambers
20 March **3rd Friday**	Dr Philippa Mason, Imperial College London	tba
10 April	Dr Richard Wall, University College London	tba
8 May	Dr David Bone?	tba
12 June	Dr Hilary Downes	Asteroids
10 July	Members Evening	tba
11 September	Dr Mike Streule, Imperial College London	History of Tectonics in the Alps
9 October	Dr Paul Taylor, Natural History Museum	A Brief History of Time in 10 Fossils
6 November **1st Friday**	Dr Matthew Pope University College London	English Channel Neanderthals
11 December	Dr Gina Barnes, SOAS, London	Jade: its Tectonic Formation, Geochemistry and Archaeology in East Asia
2016 – Jan 8	AGM	tba