Farnham Geological Society

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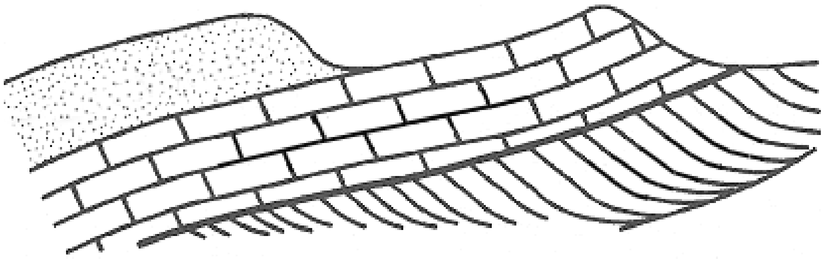

A local group within the GA

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Editorial

Apologies that this newsletter has fewer articles than usual but, together with reports from our talks, it has a long report of the summer field trip to Northumberland which has been avidly put together by various attendees who ‘volunteered’ to give their contributions. So a big thank to them for their efforts.

Also a reminder that the Annual FGS Luncheon will be held at the Frensham Pond Hotel on Sunday 28th October – names of any last minute attendees to either Mike Weaver or Peter Luckham immediately please.

Finally, please note that our AGM will be held on 11th January 2013

Liz Aston

An introduction to Ecclesiastical geology
Summary of May 2012 lecture given by Prof. John F. Potter, University of Reading

Some church historians might argue that as churches have been studied for nearly 200 years there is little more we can learn about church building structures and their age. The methods for distinguishing the age of different churches are well-established. They are:-

a. The use of architectural evidence; and most of us are familiar with the Norman arch, the Perpendicular window, etc.
b. Archaeological evidence; site excavation and the search for dateable objects such as coins or bones that can be dated by radioactive studies.
c. Documentary historical evidence; the examination of early records and writings; documents such as the Domesday Book and the writings of Bede being simple examples.

Finally, used over perhaps the last 60 years,

d. The use of cross-cutting (what geologists might call stratigraphical) relationships in the church fabric. This is where different wall fabrics can be seen to cut or abut each other in varying forms of complexity, with a simple example illustrated in Fig. 1.

This talk examined a further new and important technique, one often providing much more detailed evidence – The use of the building fabric itself, that is, the use of geology.

John Potter illustrated and described how he came to be involved with church studies. How in 1976, he was requested to view Ripley Church (Fig. 2), then on the A3. It proved to be partially built of a hard, ferruginously-cemented gravel. He realised that the gravel represented dried and hardened iron pan from the local terrace gravels: but his interest was aroused when he discovered a fragmentary ammonite within the gravels of the church. To attain its ecclesiastical position, that Oxford Clay ammonite had travelled from an area of uplifted and eroded Oxford Clay, firstly to the then deltaic Godalming area to become incorporated in the Lower Greensand Bargate Beds. This in turn became eroded by torrential post Ice Age melt waters to be carried by an 'early River Wey' and deposited in what are today recognised as terrace gravels. As an iron-pan horizon in the Taplow Gravels, it was finally, quarried (or dug-up), dried and used as a building stone by an Anglo-Saxon about 1300 years ago.

Fig. 1: Shereford Church, Norfolk. How many abrupt or cross-cutting changes can you see?

Fig. 2: Blocks of ferruginously-cemented gravel in the chancel of Ripley Church, Surrey.

In his own words, 'I was hooked'. He next viewed, Wisley, then Pyrford, Church; both contained the gravel … next the churches of the London Basin and ultimately all recognised old churches in England. In a 'voyage of discovery' these studies have now included Scotland and its islands, the Isle of Man, Ireland and recently Wales – resulting in numerous publications.

In the London Basin, he explained, the region was essentially one of clay, sand and gravel, quality building stone was absent. Resourceful early church builders, unable to carry stone from outside the region used whatever they could find – ferruginous gravel, flints, and in Essex, septarian nodules near to the London Clay beaches, and glacially derived Bunter cobbles.

One of the first principles to be established in ecclesiastical geology was the understanding that with improving means of transport over time; by hand, by cart, by river or stream, by canal, by train, etc; the rocks used could be brought from further afield. The churches in the London Basin using local materials were old. It was clear that those same churches in the London Basin were also those that displayed architecturally recognised Anglo-Saxon features. The correct geological identification of the rocks used in church walls was, therefore, important.

Stones placed in long and short style in wall corners (quoins) provided one long-recognised Anglo-Saxon structure that enabled identification. Geological inspection of these stones revealed a startling fact that the 'long' stones were placed with their bedding planes vertical (Fig. 3). As further churches were scrutinised, it became evident that whatever the shape of the stone, this unusual orientation was present in the quoin stones of nearly all Anglo-Saxon buildings long recognised by their architecture! It was not apparent in rare quoins constructed with cobbles such as flint (for it was impossible as they possessed no bedding). It was, however, occasionally evident even in ferruginous gravel as could be determined from the orientation of the included pebbles. But the Anglo-Saxons were clearly experienced stone workers and over the south of England two rock types in particular were used to make structural features such as quoins and arch jambs – the Jurassic, Barnack Stone from the Northampton area, and, in the south, the Upper Eocene, Quarr Stone from the Isle of Wight. Both were rocks which, from their unusual structure, remained strong and resistant to weathering in a vertically-bedded attitude. As this knowledge was extended further afield it became clear that the Anglo-Saxon masons worked to specified and geologically recognisable patterns of ornamentation in their church building. John found it necessary to establish a simple abbreviated nomenclature in order to describe these features (Fig.4) – BVFR: Bedding vertical, face right; BH: Bedding Horizontal; BVFL Bedding vertical, face left.

Fig. 3: A long and short quoin created in Barnack Stone in the mainly flint church of Strethall, Essex; note horiz & vert bedding.

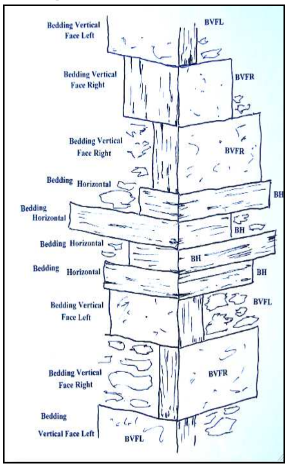


Fig. 4: A nomenclature for different stone bedding orientations detailed in this quoin.

Fig. 5: The tower of the Anglo-Saxon church at Earls Barton, Northamptonshire displays excellent pilasters.

Fig. 6: The NE chancel quoin, Wittering Church (Peterborough) has quoins cut back so all stones look of equal width.

Anglo-Saxon features such as pilasters displayed similar ornamentation (Fig.5). Across England, over time new features of Anglo-Saxon stonework were discovered; these included the existence of chiselled cut backs in stonework to make stones appear of the same width (Fig.6) and horizontal banding (Fig.7).

Fig. 7: Hadstock Church in Essex possesses double-splayed windows & remnants of horiz. colour banding in brown Bunter cobbles.

With no fixed boundary between 'Scotland' and 'England' in the past, many Anglo-Saxon churches identified in Northumberland, and Scottish church historians stating no stone churches of this period were present in Scotland, John was offered a challenge. Would a geological examination of the stonework in the churches find similar patterns? The result was positive, as subsequently was the case for Ireland and Wales. But Anglo-Saxons were not the inhabitants of these countries; the style of stonework was clearly a fashion – to this fashion John has given the name Patterned.

With no easily worked, suitably strong and weather resistant stone such as Barnack present in the countries outside England it was understandable that structures like pilasters could not be created. Intractable rocks such as volcanic lavas, greywackes and typically massive Carboniferous limestone proved impossible to work to create cut backs or pilasters with just hammer and chisel. Various well-bedded coarse sandstones, as found in the Carboniferous, became the norm for structural purposes in quoins and jambs and these, when placed with vertical bedding provide the major form of evidence for the Patterned style. These valued sandstones used in quoins and church dressings had often been carried to the churches over relatively long distances along rivers and streams. However, the early character of a church tends to be first indicated by the wall fabric. When this was built of very local rocks, and particularly boulders which could be used with little or no modification, the wall would be early in construction.

John explained that it was impossible in one lecture to give more than a limited introduction to Ecclesiastical Geology. There was plenty of evidence to show that different fashions in stonework occurred in the past and the Patterned style was one of a number. The subject was particularly suitable for study by those who knew their local rocks for they could more readily identify the stonework in the churches. Stones imported from a distance into a church could on occasions provide something of the past social status of a church. And finally, rocks found in the walls of churches could enable a geologist to use the church for the purposes of geological mapping, this he had demonstrated in showing the extent of the Anglian ice sheet in the London Basin.

For those who wished to learn more, John reminded members that he conducted a church related Geology trip each year for the Geologists' Association – the next, to Middlesex churches on the 22nd September.

John F. Potter

The Oldest Galaxy

Scientist Garth Illingworth, professor of astronomy and astrophysics, at the University of California, analyzing the Hubble telescope's images, has recently discovered what he believes to be a small galaxy of blue stars, and which he believes to be the oldest object in the universe discovered to date - a galaxy dating back to 13.2Ga, some 500Ma after the Big Bang. This ancient galaxy shows as an extremely faint, blue object with numerous stars being formed within it and is interpreted as a compact galaxy of blue stars, an object significantly smaller than the Milky Way.

He has also found some 50 galaxies which date back to 13.05Ga; this increase in the number of galaxies represents a ten-fold increase in the rate of star birth during that 150Ma period, a short period in cosmic terms, and suggests that the birth of stars would continue to increase with increasing time after the Big Bang.

The Big Bang theory suggests that the universe was 'born' 13.7Ga as a single violent event and that all galaxies have formed, from gaseous clouds, since then, the galaxies getting younger as the universe has expanded, presumably in all directions. Our galaxy, the Milky Way is just one of the many galaxies and dates back to xxx.

It is thought that astronomers will discover more ancient galaxies of approximately 13Ga or older when the next generation of telescopes are developed and working.

Details were published in the January issue of Nature.

Weblinks supplied by various members:

- Milky Way and Night Sky video - http://www.stumbleupon.com/to/s/90xufP
- Giant Pterosaur - http://www.msnbc.msn.com/id/44906871/ns/technology_and_science-science/#.Tp1KfL_LLFl
- Fossil footprints, Boulder museum, Colorado - http://www.examiner.com/science-news-in-boulder/world-class-fossil-footprint-museum-to-move-to-cu-boulder
- Giant mountain range, Vesta Asteroid - http://www.nasa.gov/mission_pages/dawn/news/dawn20111010.html
- Large landslide, Vesta Asteroid - http://blogs.agu.org/landslideblog/2011/10/14/a-very-large-landslide-on-the-vesta-asteroid-and-a-challenge-for-you/?
- Maps of the ocean crust etc. - http://www.ngdc.noaa.gov/mgg/image/crustalimages.html
- Turkish earthquakes' poster - http://earthquake.usgs.gov/earthquakes/eqarchives/poster/2011/20111023.php
- Supervolcanoes - http://oregonstate.edu/ua/ncs/archives/2011/oct/scientists-find-possible-trigger-volcanic-super-eruptions
- Saturn pictures - http://www.jpl.nasa.gov/news/news.cfm?release=2011-359&cid=release_2011-359#4
- Earth from International Space Station (ISS) - http://www.lovethesepics.com/2011/10/iss-envy-breathtaking-views-of-earth/

A website which provides daily updates on news and information about geology from across the world, across the disciplines and across the academic, media and other sources is http://geology.com/. The website is American and has a lot of geological news although it is frequently biased by American news and information.

Liz Aston

FGS field trip to Northumberland & Borders, 10 – 16 June 2012

The Field Trip to Northumberland and the Borders was organised by Graham Williams and led by Lesley Dunlop who had given us an interesting talk on the Geology of Northumberland, on the Friday before the field meeting. The trip provided members with excellent examples of various structural features including Hutton's famous unconformity at Siccar Point and at Jedburgh; Carboniferous sedimentation in the Northumbrian Basin and igneous rocks of various ages and types, including Whin Sill, Cheviot Granite and Devonian volcanics. The following report has been written up by three teams of volunteers.

Hutton and his famous Unconformity

James Hutton (1726-97) is known as the founder of modern geology. He was a local gentleman farmer when he discovered the unconformity at Siccar Point and a qualified physician, agriculturalist and manufacturer of chemicals. He was active in what is known as the Scottish Enlightenment and was a founder member of the Royal Society of Edinburgh (RSE), associating with the likes of John Playfair, Adam Smith and David Hume. Hutton distrusted Archbishop Ussher's evaluation of the age of the earth as dating from 4,004 BC, arrived at by Ussher from close literal reading of the Bible: Hutton believed the earth to be aeons old.

Hutton discovered a number of unconformities, the first being near Newton Point, on Arran. Others followed, the most well-known being here at Siccar Point, on the coast about 15 miles north of Berwick-upon-Tweed. It is justly famous not only for its importance in the development of Hutton's thinking but also for its spectacular setting, the different rock colours, and because, being washed by the sea, it remains clear of vegetation that obscures some other sites. It presents an ideal exposure for study provided the tide is out, and its historical significance makes it a place of pilgrimage for all geologists.

Hutton found the unconformity (Fig. 1) when on a boat trip from Dunglass with his friends Playfair and Sir James Hall, the latter being a landowner and also a geologist. In his paper read to the RSE in 1775 Hutton explained his understanding of the slowness of geological processes, concluding, 'We see no vestige of a beginning – no prospect of an end'. In 1805 Playfair wrote 'On landing at Siccar Point we found that we actually trod on the primeval rock.....', and 'The mind seemed to grow giddy looking down into the abyss of time'. Science had released Ussher.

Fig. 1: Hutton's Unconformity, Siccar Point

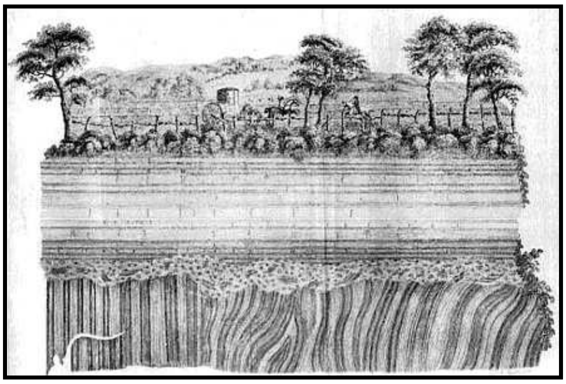


Fig. 2: Sketch of Hutton's unconformity at Jedburgh

An unconformity can be defined as 'a surface between two successive strata, which represents a missing interval in the geological record and is produced by an interruption in deposition'. Where the beds above an unconformity are not parallel with those beneath, as here, it is termed an angular unconformity.

In the case of Hutton's unconformity, the missing interval of time between the deposition of the sediments below and above the unconformity surface was long enough to allow significant earth movements and subsequent erosion of the underlying beds.

Burnmouth and Eyemouth - Silurian and Devonian Deposits

The Lower Silurian greywackes, which form the beds underlying the unconformity were laid down in a deep sea environment as slurries under turbulent conditions, as indicated by their structure and lithology. These turbidite deposits formed about 450Ma and were subsequently compressed and folded almost vertically, then eroded prior to deposition of the overlying Early Devonian volcanic rocks.

Fig. 3: Burnmouth: Silurian greywackes, base of a vertically dipping turbidite with distinct sole structures caused by the turbid flow.

Fig. 4: Eyemouth: Vent agglomerate of Early Devonian age

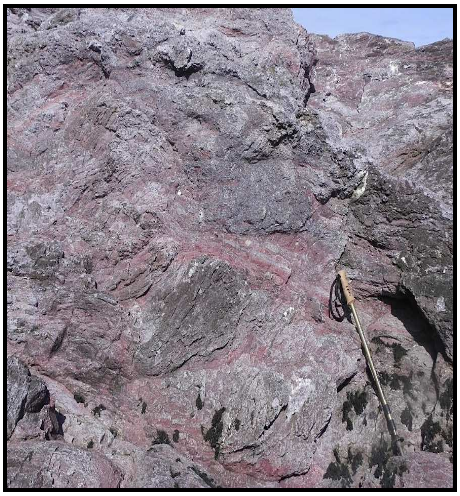


Fig. 5: Devonian agglomerate showing evidence of flow

The Devonian sequence (Figs 4 & 5) comprises a mixture of andesitic lavas and agglomerates and a classic suite of red coloured Old Red Sandstone sediments - sandstones and conglomerates, deposited on a broad coastal plain. The Devonian sequence is about 345 Ma old and the unconformity therefore represents a gap of at least 55 Ma, during which time other sediments may have been deposited over the Silurian greywackes but subsequently lost through erosion. From Siccar point we travelled to a road cutting in the cliff north of Burnmouth overlooking the harbour and beach; where near vertical Lower Carboniferous beds of the Cementstone Group and Fell Sandstone Group, downfaulted against Silurian rocks, are exposed on the foreshore. In the cliffs above, the Old Red Sandstone has been faulted against Silurian greywackes.

Fig. 6 (R): Faulting at Burnmouth

Fig. 7: Andesitic dyke at Burnmouth

The coastal section between Eyemouth and Burnmouth provided many examples of faulting and folding associated with deformation during late Llandovery to Wenlock time. A roadside outcrop revealed highly folded Silurian greywackes. They consist of a series of competent and incompetent beds showing a variation from sandy mudstones/shales to fine grained sandstones. The rocks had undergone compression into tight folds (beds dipping at angles of 50°-60°) some of which have been faulted out along the fold axes and strong cleavage is visible in the less competent beds. Earth movements have been further evidenced by minor faulting particularly of competent beds (Fig. 6) and mineralisation (calcite) along fractures and in the noses of folds. The way up of the beds is shown by the spectacular sole marks (Fig. 3).

The deposits were later intruded by a dyke about 4m wide, probably along pre-existing zones of weakness (Fig. 7). The dyke comprises a pink andesite with chilled margins and phenocrysts of feldspar in the centre.

Palaeogeographically, by the end of the Silurian the Iapetus Ocean had considerably narrowed and turbulent flows of poorly sorted material allowed the deposition of the thick sequences of greywackes. By the late Silurian/Early Devonian plate movement resulting in continental collision generated magma at depth, which gave rise to the intrusions and volcanic activity of the area. Compressional events produced intense folds in the Silurian and Early Devonian rocks.

At the far end of Eyemouth beach, exposures of Devonian agglomerate occur on the foreshore. These rocks, pyroxene andesites, consist of igneous clasts in an igneous matrix and display a texture suggesting they are autobrecciated lavas (Fig. 4). Fragments vary in size and shape and the pyroxenes and feldspars often form phenocrysts. The colour of the rock varies from pink to grey with green areas of reduction spots. Some outcrops show flow banding (Fig. 5).

Back towards the car park, a channel in the cliff agglomerate has been infilled with dark red unconsolidated material derived from the Silurian and Old Red Sandstone deposits. The flow structures (imbrication) within provide evidence for a pre-Devensian stream flowing towards the sea (Fig. 8).

Fig. 8: Eyemouth: Pleistocene (Devensian) channel in Devonian agglomerate, infilled with derived ORS.

Fig. 9: Group Photo on Holy Island - the end of lovely sunny days down by the sea!

Carboniferous Sedimentation in the Northumbrian Basin

Fault blocks resulting from Tectonic extension during the Carboniferous formed a 'Block and Basin' topography. The Northumberland trough was bounded to the north by the Cheviot Block, and to the south by the Alston Block. This block and basin topography controlled sedimentation; shallow marine and terrestrial deposits (including deltaic sediments) over the 'Block' regions pass laterally into deeper marine sediments (including turbidites) in the 'Basin' regions.

We saw various examples of the early Carboniferous sediments deposited over the Cheviot Block, including:

- braided river sandstones of the Fell Sandstone Formation at Bowden Doors;
- deltaic mudstone/sandstone sequences (including cementstones) adjacent to Berwick Golf Course and at Willy's Hole on the Whiteadder Water.
- marine limestones at Harkness Point (Bamburgh), St Cuthbert's Beach (Holy Island) and Berwick lighthouse;

The Fell Sandstone Formation outcrops as a series of impressive NW-SE crags. At Bowden Doors, the Formation dips at 5-10° SSE and is mainly a gritty, coarse-grained sandstone locally grading to fine-grained sandstone (Fig. 10). Very well developed cross-bedding indicates a current from the NW, which together with the presence of steep sided channels, ripple marks and a lack of fossils, are typical of a braided river system. The lithologies are immature, containing clasts of silica, iron, mica and feldspars suggesting a nearby derivation from the Cheviot volcano and pluton to the west. The maximum thickness of the Formation is 350m around Rothbury. The rock varies greatly in colour due to the variable oxidization of the iron.

Corby Crags provide a spectacular view to the south, with Edlingham Castle (13thC) and Church (10thC) in the foreground built of Fell Sandstone (Fig. 11). This Sandstone was also taken to Lindisfarne to construct the priory, church and castle. Bamburgh Castle, built on the Whin Sill, is underlain by highly oxidized mica/quartz sandstone, with dramatic cross-bedding seen at the war memorial.

At Harkness Point, a 50cm sequence of deltaic mudstones and sandstones lay atop a thick limestone, and had been baked by an overlying dolerite sill. In the cliffs below Berwick Golf Course, a thick classic deltaic sequence of Carboniferous age, namely, an interbedded mudstone-sandstone sequence with thin coal beds. This sequence overlay a steeply dipping limestone sequence. On the north river bank at Willy's Hole, there were near horizontal beds of fine-grained sandstone, siltstone and mudstone with abundant plant material (Fig. 12). Some beds are cemented with calcite, and are called cementstones. A distant view of Barrow Scar in the Upper Coquet Valley showed a considerable thickness of these early Carboniferous sediments.

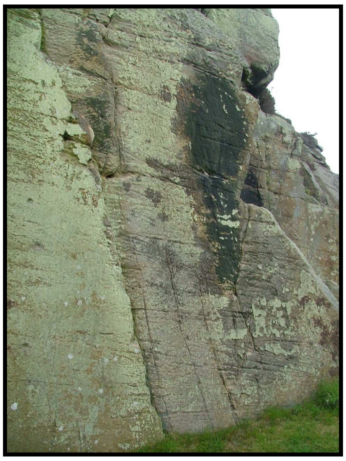


Fig. 10: Fell Sandstone at Bowden Doors

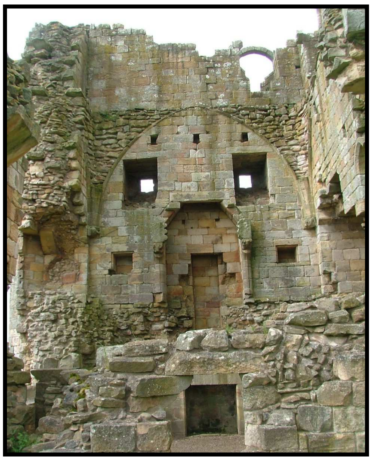


Fig. 11: Fell Sandstone in Edlingham Castle

Fig. 12: Willy's Hole - Cementstone on cross-bedded sandstone overlying a mudstone sequence

At Harkness Point, there were thick beds, dipping 15°N, of very fossiliferous marine limestone containing corals, bryozoans, gastropods and bivalves. The beds were cut by a dolerite intrusion. At St Cuthbert's Beach, similar limestone has been baked and metamorphosed by a large E-W dolerite dyke. The limestone beds had been gently folded and exhibited en echelon tension gashes on the anticline crests (Fig. 13). Similarly, the spectacular 80cm cubed blocks of crinoidal limestone below Berwick Lighthouse displayed even more precise tension gashes (Fig. 14); go to http://mountainbeltway.wordpress.com/2010/08/24/tipping-your-tension-gash/ for a very good demonstration of tension gashes and how they form.

Fig. 13: Folded limestone at St Cuthbert's Beach

Fig. 14: Steeply dipping sequence of Carboniferous Limestone, Berwick golf course

Igneous Rocks

During this field trip we were able to visit the two major igneous features of the area – the Cheviot Igneous Complex and the Great Whin Sill.

Cheviot Igneous Complex

The Cheviot Igneous Complex was formed in the Early Devonian around 400Ma at the time of the closing of the Iapetus suture and the Caledonide Orogeny. Activity began with an explosive phase, followed by an outpouring of andesitic lavas and ended with the emplacement of the Cheviot granite batholith. We were able to see all three phases. We saw evidence of the first explosive phase in the beach at Eyemouth with boulders and exposures of volcanic agglomerate and also of auto-brecciated rhyolitic lava, which indicated pulsing of the igneous activity – time to solidify followed by later pressure. Clasts were up to 20cm in diameter and contained phenocrysts of feldspar and pyroxene. In the lavas there was clear evidence of flow-banding.

After the explosive phase came an effusive phase where mostly andesitic lavas built a very large volcano. The area of exposure today is well over 30km across. The main source of the lavas is unknown, but we saw one of the feeder dykes cutting through Silurian greywackes on a steep path up from Burnmouth bay. This dyke is about 4m wide and porphyritic in texture with a fine grained chilled margin. We were able to see the lavas at a number of localities including in the Harthope Burn valley, not far SW of Wooler. The Harthope Burn flows off the eastern and south-eastern side of The Cheviot (815m). At Earle Bridge Quarry we got our first proper look at the dark andesitic lava with its phenocrysts of pink and white feldspar and biotite and we saw evidence of flow-banding. The intermediate composition indicated that the igneous material had risen through continental crust on its way to the surface.

A couple of miles upstream is a north-bank tributary of the Harthope Burn, the Carey Burn. Here we walked up past three beautifully defined alluvial terraces cut into moraine to view more exposures of porphyritic andesite. Some of the feldspars and pyroxenes here showed signs of alteration to yellow epidote and to dark green chlorite as we neared the contact with the Cheviot granite. On another day we penetrated into the remote recesses of Upper Coquetdale not far from Chew Green Roman Fort. Here at Blindburn, Buckham's Bridge and up to Fulhope farm, we visited another series of exposures of andesitic lava with phenocrysts of feldspar and pyroxene. Some of the feldspars had been hydrothermally altered to greenish sericite mica. There was evidence of multiple lava flows with layers of vesicles in the tops of individual flows.

We saw our best exposure of the final phase of the Cheviot Igneous Complex, the intrusion the granite batholith, which took place about 380Ma, back in the Harthope Burn area. Two miles above Carey Burn where we had seen andesitic lavas, another north-bank tributary, the Hawsen Burn, ran right along the contact between the lavas and the granite.

The Cheviots area is not one where exposures abound. The rounded green boggy slopes cut into by deep valleys with steep convex slopes mean that exposures can be hard to find. However, our intrepid leader, Lesley, climbed down to the stream to retrieve specimens of the granite for us to examine. Here the granite is a very fine-grained pinkish microgranite, probably indicating rapid cooling near the roof of the intrusion. The less adventurous members of the party were still able to see from the path winding high above the stream that we were on the edge of the granite's metamorphic aureole. Close to the granite, the earlier lavas had been baked to hornfels. And there was also evidence of hydrothermal alteration with striking black blobs and stringers of the boron-rich mineral tourmaline, plus epidote.

Great Whin Sill Complex

The second great igneous feature of the area is the Great Whin Sill. Although the Whin Sill's most well known exposure is capped by Hadrian's Wall, other notable land features are Bamburgh Castle, Lindisfarne Castle on Holy Island and the Farne Islands. We did not visit the impressive Hadrian's Wall but saw the Complex at Bamburgh Castle (with festivities on the castle green awaiting the arrival of the Olympic Torch) and Lindisfarne Castle on Holy Island.

'Sill' is a North of England quarryman's term for any more or less horizontal or flat-lying body of rock and it is the Whin Sill that has given the name sill to geological science.

The Great Whin Sill as a whole underlies a considerable area of North East England and can be up to 70m thick. The Sill swarm greatly influences both the geography and geology of this region of the UK. While much of the outcrop is a single layer it splits into at least five layers in places with an associated feeder dyke swarm with three or more dykes visible on Holy Island, which have the same composition as the sill.

The Whin Sill swarm lies in a roughly arcuate outcrop that extends from the Farne Islands in the north to Lundale, in the Pennies, to the south. It was intruded, into Carboniferous Limestone, at 295Ma at the same time as the Variscan / Armorican / Hercynian Orogeny in latest Carboniferous or earliest Permian times. It came from a magma source or sources that remain to be indentified but are associated with the Variscan Orogeny. The crust under what is now Northern England was under excessive stress and ruptured, leading to the outpouring of several hundreds of cubic kilometres of magma at up to 1100C. The adjacent rocks were much modified by the intrusion of vast volumes of molten magma.

We were not able to see the exposure on the seaward side of Bamburgh Castle where the sill transgresses across red Carboniferous sandstone. It is overgrown, but approximately 1km north of the Castle lie Harkness Rocks where the sill is exposed in the beach.

Although variously estimated to be up to 70m thick, top and bottom features of the intrusion are visible on the beach tens of metres apart across a fault zone near Stag Rock. The exposed top surface shows a distinct chilled margin where the black basalt magma cooled against the Carboniferous Limestone country rock. Gas bubbles (now amygdales, some containing quartz and calcite crystals) occur near the top of the body (Fig. 15). They are elongated, indicating an NE-SW direction of the lava flow. Slightly further in from the margin there are ropy flow structures where the lava cooled less quickly and flowed for longer. The basalt is very fine grained at the margin but coarser away from the edge. A short distance north of this the sill had been up-faulted at a small fault scarp and beyond that was revealed to have transgressed into mudstones of the Yoredale Group.

Fig. 15: Elongated gas bubbles indicate proximity to the top of the sill and also show direction of flow.

Fig. 16: Flow texture within amygdales along the same axis as the gas bubbles.

Figure 16 shows lava flow texture in an amygdale, which occurs along the same axis as the elongated gas bubbles (NE-SW). The bottom of the sill is intruded into horizontally bedded cementstone, sitting on a Carboniferous Limestone platform (Figure 17). Figure 18 records a coral fossil in the exposed surface of the limestone.

On Holy Island the Whin Sill Complex is represented by the Holy Island Dyke and a large portion of the bedrock was seen to be entrained along the edge of a dyke (Fig. 19). The dyke runs along the southern edge of the island and is split into en echelon stretches by N-S faults. The tiny St Cuthbert's Isle is one such segment. We visited the stretch to the east beneath the low mound of Heugh Hill. Here the cliff line in part runs exactly along the vertical margin of the dyke. We could see the fine-grained, shiny edge of the dark dolerite and behind that the coarser grained and fractured interior of the dyke. Plastered onto the dyke/cliff edge were thin slivers and blobs of country rock, metamorphosed limestone (real marble), some of it with a sugary texture. Here the country rock is the Acre Limestone, part of the Carboniferous Limestone.

Scarcely 1km to the east lay the iconic Lindisfarne Castle upstanding on its separate en echelon stretch of dyke. We could appreciate the en echelon nature of the stretches of dyke from a metre or so up on top of the lowly Heugh Hill and also get some idea of the thickness of the dyke, 10–30m width.

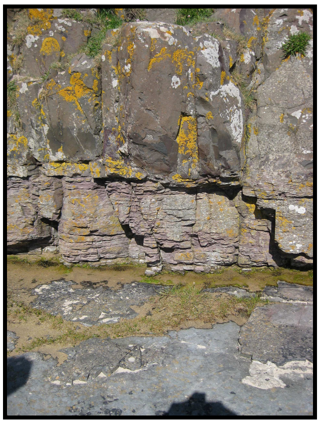


Fig. 17 (L): The base of the sill cross cuts the bedding of the Carb. Lst.

Fig. 18 (above): A fossil coral is exposed on the limestone surface

Fig. 19: Bedrock caught up and entrained into the edge of an associated dyke on Holy Island

This locality made a fitting end to a wonderful field trip.

Various Society Members who went on the field trip

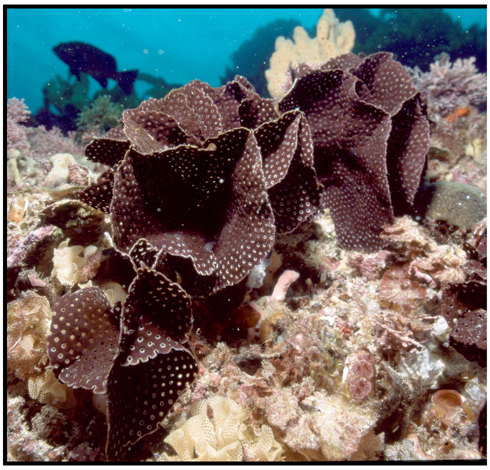
The natural history of fossil and living bryozoans
Summary of September 2012 lecture given by Dr. Paul Taylor, Natural History Museum, London

Despite numbering more than 6000 living species, and having a rich fossil record, bryozoans are one of the least known of all animal phyla. Beachcombers in Britain finding bryozoans frequently mistake them for seaweeds: a very common item among the flotsam and jetsam cast ashore during storms is Flustra foliacea, a slightly crinkly, pale brown bryozoan with the popular name ‘horn wrack’, wrack being a name usually reserved for true seaweeds. Lace-like encrustations covering the surfaces of true seaweeds represent other types of bryozoans, usually either the ‘common sea-mat’ Membranipora membranacea, or the ‘hairy sea-mat Electra pilosa. In deeper waters of the continental shelf, a far greater diversity of bryozoans may be found growing on shells and rock. Some of these species resemble miniature trees, while others have flattened fronds forming box-like structures. On the quaysides of fishing ports it is often possible to observe crab or lobster pots that became densely covered in bryozoans during periods of temporary loss on the seabed. In fact, bryozoans are regarded as major fouling organisms in the sea - at the time of wooden sailing vessels the growth of bryozoans on ships’ hulls was a major nuisance. Ironically, one of the most prominent fouling species – Bugula neritina – was found in the 1970s to be the unique host of a species of symbiotic bacteria that produces a complex organic compound called bryostatin capable of arresting the growth of human cancer cells. This previously troublesome bryozoan is now of value to the pharmaceutical industry. It is worth remarking that whereas most bryozoans live in the sea, there are some species that inhabit freshwater lakes and rivers, although these are of no geological importance as they lack fossilizable skeletons.

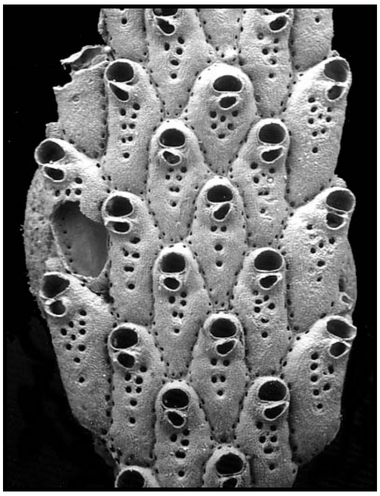
All bryozoans share one attribute – they construct colonies consisting of numerous individuals that are genetically identical clones. In fact bryozoans are the only animal phylum in which every species is colonial. The individuals in the bryozoan colony are known as zooids and, primitively, all have exactly the same appearance and are able to perform all necessary life functions, including feeding and reproduction. However, one of the fascinating features of bryozoans is polymorphism whereby different zooids are adapted for particular functions.

As bryozoan zooids are seldom more than one millimetre in size, in order to obtain a good appreciation of their morphology, and how this varies between species, we need to use a microscope, preferably a scanning electron microscope capable of producing crisp images at magnifications of several hundred times. Zoologists studying modern bryozoans routinely bleach them to remove all traces of the soft parts, rendering the specimens into the condition of well-preserved fossils. This procedure reflects the fact that most of the features used in bryozoan identification occur in the skeleton, which places the taxonomy of fossil bryozoans on the same footing as that of recent bryozoans.

The millimetric scale of bryozoan zooids normally allows them to be distinguished from colonial corals in which the individuals are more often a centimetre or so in diameter. Corals also possess radiating septa, absent in bryozoans. However, the shapes of bryozoan and coral colonies can be confusingly similar and establishing their true identity may require microscopic study. Despite their resemblance to corals, bryozoans are, in fact, more closely related to brachiopods and molluscs.



Adeona - a living bryozoan from Western Australia.



An SEM image of Adeonellopsis, an Eocene London Clay bryozoan.

Meandropora tubipora from the Pliocene Coralline Crag of Suffolk

The great majority of bryozoans have resistant skeletons of calcite that are readily fossilized. Fossil bryozoans can be found in sedimentary rocks ranging from Ordovician to Recent, sometimes in sufficient abundance to form bryozoan limestones, such as the Pliocene Coralline Crag of Suffolk. Colonies that grew as erect bushes or fronds are commonly broken up into small stick-like or platy fragments, whereas encrusting colonies may be preserved intact on the surfaces of brachiopod shells or other hard substrates. For instance, Echinocorys tests from the Cretaceous Chalk are invariably encrusted by one or more bryozoan colonies that colonized these echinoids after they had died. Because so few fossil collectors place much value on bryozoans, once you know what to look for, they are more easily collected than most other fossils. A study of a newly opened road-cutting near Cincinnati, Ohio, exposing fossiliferous Ordovician rocks, showed how the proportion of bryozoans on the outcrop increased through a period of ten years as collectors preferentially removed the corals, brachiopods, trilobites and crinoids while leaving behind the bryozoans.

To understand the natural history of living and fossil bryozoans it is useful to consider the challenges faced by these animals in order to survive on the sea-bed: specifically, how do bryozoans feed, avoid being the food of others, defend themselves against competitors, and reproduce?

Like many animals living on the sea-bed, bryozoans are immobile suspension feeders. They capture and ingest tiny planktonic plants suspended in the water column. Each feeding zooid has a crown of tentacles shaped like an inverted cone, with the mouth at the centre where the bases of the tentacles converge. Minute cilia aligned along the sides of the tentacles beat in coordination to create a current of water that propels food particles towards the mouth. During the last few decades it has become apparent that the feeding currents established by individual zooids may interact to produce a colonial current system allowing more effective feeding. Features preserved in the skeletons of fossil bryozoans allow us to reconstruct these colonial current systems. Dimples called monticules often cover the surfaces of bushy fossil bryozoans. Observations of living bryozoans having the same feature has shown how each monticule corresponds with a site where water, filtered of plankton, is expelled from the colony surface.

Other fossil bryozoan colonies have a net-like appearance comprising branches with zooids opening only on one side enclosing holes (fenestrules). In this case, filtered water is expelled through the holes. Compared with bryozoans employing the monticule-based current system, the fenestrule-based system is more efficient and, as might be predicted by Natural Selection, colonies with fenestrules became more numerous through geological time. To be more accurate, fenestrule-bearing colonies increased in abundance through the Palaeozoic - witness the prolific fenestellid bryozoans found in Late Palaeozoic strata - before the catastrophic end-Permian mass extinction wiped the slate clean. The same trend was then repeated by different taxonomic groups of bryozoans during the Mesozoic and Cenozoic.

Human beings do not eat bryozoans but they do feature in the diets of many marine predators, including some sea-slugs (nudibranchs), sea-spiders (pycnogonids), sea-urchins (echinoids) and fishes. The methods employed by bryozoans to defend themselves against these predators vary according to the predator. All bryozoans have retractable tentacle crowns that can be withdrawn rapidly into the comparative safety of the tubular or box-shaped skeleton of the zooid when danger threatens. Indeed, the existence of a nervous system linking one zooid to the next means that if a potential predator touches the tentacle crown of one zooid, those of the neighbouring zooids over a given area of the colony will retract too. Primitive species of cheilostome bryozoans, the dominant group in modern seas, have the frontal surface of the zooid covered by a soft membrane, making them vulnerable to some kinds of predators. In more advanced species, however, this membrane is overgrown by a calcareous wall, providing a degree of protection. But this strategy is useless against large predators (e.g. grazing echinoids) capable of rupturing the calcification. Poisons provide an alternative means of defence that is effective against predators of all sizes. For example, the horn-wrack Flustra foliacea is highly toxic to fish.

However, the most interesting type of defence available to bryozoans is seen in the avicularia of cheilostomes. Named for their resemblance with a bird's head, these polymorphic zooids have a jaw-like mandible that can be clamped shut over the body of potential predators such as worms or sea-spider legs. Despite their minute size, avicularia are extremely strong and are capable of holding onto the would-be predator until it dies. It is worth remarking that, whereas a successful act of predation on a unitary animal by definition causes its death, in the case of bryozoans (and other colonial animals) predation can result in the death of one or a few zooids but not the entire colony, a phenomenon called partial mortality. The predator in these cases has a parasite-like relationship with its prey.

Generally speaking, planktonic food is so abundant in the oceans that bryozoans do not compete for this resource. In contrast, living space is frequently a limited resource that is actively competed for. The result of such spatial competition is the overgrowth of one colony by another, readily seen in sheet-like colonies attached to the surfaces of shells and rocks. There are many ways in which bryozoans can increase their chances of winning living space. These include growing quickly, being of large size, and producing long spines at the edge of the colony, like a Macedonian phalanx, making it difficult for competitors to progress forward. As competition for living space is typically frozen during fossilization, it is possible to infer which bryozoan species were the dominant competitors and which were subordinate in fossil communities containing encrusting bryozoans. The fossil record furnishes few, if any, other instances where competition between ancient animals can be so clearly observed.

Bryozoans have two main parts to their life cycles. One is the growth of colonies by the asexual budding of new zooids. The other is sexual reproduction, which results in the production of larvae that swim away from the parent colony and settle elsewhere, usually within a few hours or days, to form a new colony. In most bryozoan species the embryos that develop into larvae are brooded for a period before being released into the sea. Brooding in cheilostome bryozoans normally takes place in hood-like structures called ovicells. Because ovicells are skeletal structures, bryozoan pregnancies are readily observable in fossils as far back as the Albian stage of the Cretaceous when this type of brooding first evolved in cheilostomes. One of the most surprising aspects is that ovicells are constructed not by the zooid that produced the embryo but by the next zooid in series. Some of the oldest ovicells found in fossil cheilostomes were cage-like structures built by spines that had an original role in defending the surface of this succeeding zooid. Like the nutritional support provided to the defensive, non-feeding avicularia by the feeding zooids in a bryozoan colony, this is another example of cooperation between the zooids for the good of the colony as a whole.

Finally, where can fossil bryozoans be found in England? The Coralline Crag Formation of Suffolk has been mentioned already. More than 100 species of bryozoans have been recorded from this Pliocene deposit, some of which are described and illustrated on the following website: http://neogenebryozoans.myspecies.info/

Bryozoans occur more sparingly in the Eocene London Clay but are locally common in the Upper Cretaceous Chalk and in limestones of Middle Jurassic age. As noted above, tests of the common Chalk echinoid Echinocorys provided prime substrates for encrusting bryozoans, and fragments of delicate erect bryozoan colonies are also locally numerous in the Chalk. Bryozoans are abundant in the Lower Cretaceous (Aptian) Lower Greensand, especially the Faringdon Sponge Gravel of Oxfordshire. The Polyzoa Bed in the Lower Inferior Oolite of Cleeve Hill, Gloucestershire, is a good place to collect Middle Jurassic bryozoans (Polyzoa is an old name for Bryozoa). Another Middle Jurassic deposit misnamed on account of its abundant bryozoans is the Millepore Bed of North Yorkshire, containing the bryozoan Millepora straminea (now Collapora straminea). The Permian Magnesian Limestone of County Durham, and Lower Carboniferous limestones throughout the British Isles are good sources of Late Palaeozoic bryozoans, especially net-like fenestellids. The best Silurian bryozoans are to be found in the Wenlock Limestone, both in the type area of Shropshire and also at the famous Wrens Nest site in Dudley. Ordovician bryozoans are less common in Britain and are often preserved as moulds.

Much remains to be learned about bryozoans, both living and fossil. There are countless species awaiting formal description, and many question marks remain over even the most basic aspects of their biology. As immobile colonial animals, bryozoans have lifestyles utterly different from those of the mobile unitary animals most familiar to humans, stretching our concept of what it is to be an animal.

Paul Taylor