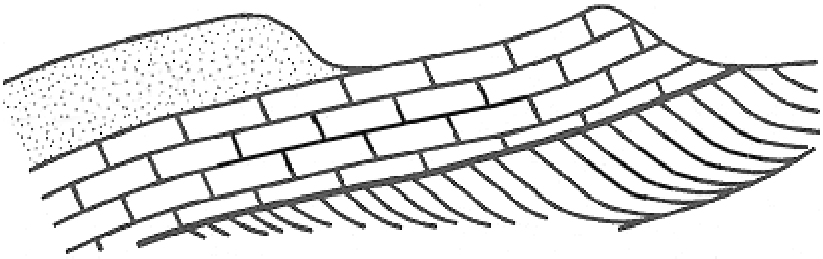
Farnham Geological Society

[**www.farnhamgeosoc.org.uk**]

Farnhamia farnhamensis



A local group within the GA

Vol. 20 No.1

Newsletter

Issue No: 95

February 2017

List of contents

Editorial

I hope you enjoy this edition of FGS Newsletter – another very varied bunch of topics – thanks to Janet Catchpole's sourcing of speakers. If you are passionate about one particular geological item, then feel free to send it to me, I may not be able to include it immediately if there is pressure on space but I will do my best. Mike Rubra is passionate about history and our (often very long distant) ancestors and their activities so he has provided me with a discussion on Box Hill and the industrial past of the Weald. Interestingly, when we built our house in 1987, we bought our bricks from the brick makers situated in the quarry, and using Upper Greensand, near Farnham Sands, and giving the bricks a delightful gentle pinkish hue. Sadly they have now had to close.

Obituaries

It is always my sad duty to record the deaths of our members; this year there are three – Jim Phillips, the husband of Janet who has been a stalwart on the committee for many years; Peter, husband of Pam who was another long-standing member and last Harry, my husband. Our condolences go out to their families and we will miss them all, patiently tagging along with their wives on field trips - cycling miles over the moors in Jim's case and (physically) holding me up in Harry's case.

Geology course details:

I will be re-starting/continuing the geology course in March 2017 at Hawley Hill, Blackwater (2nd Tuesdays in the month) and Farley Hill, Reading (3rd Tuesdays in the month). The course is technical but relaxed. Both venues have easy, safe, off-road parking. If you are interested but not yet enrolled, please contact me at newsletters.fgs@gmail.com.

Box Hill: a different look at the hill

Mike Rubra, Member of Farnham Geological Society

After an interesting morning looking for fossils at the famous Smokejacks brick pit in September last year, we went to Box Hill, where, by the memorial to Sir Leopold Salomons commemorating the gift of Box Hill to the nation in 1914, Jean Davies described the sequence of the geology we could see in front of us to the Chalk hills of the South Downs 26 miles away, our geological twin.

However the wonderful rural view seen today is unusual and perhaps misleading. Hardly any industries, except farming, can be seen today. But from prehistoric times up to the mid 1900s, along the North Downs from

Oxted to Farnham, there were numerous and frequent pits and quarries of all sizes and ages from which mineral resources were extracted and processed.

There were Tertiary and Quaternary sands and gravels on the hilltops that were used for buildings, roads and tracks; plentiful flints from the Chalk, dug out or waste from lime burning, used for building; White Chalk for agriculture, fillers and purifying town gas and Grey Chalk for lime and for hydraulic cement, and, to add to clay for brick making. Upper Greensand stone was quarried for building, as a refractory and to whiten stonework; Gault Clay and brickearth were there for bricks and tiles. In the Lower Greensand, Folkestone sandstones were dug for building and in some pits for glass and iron foundry work; building stone was quarried from the Hythe and Bargate Beds and abundant Weald Clay and London Clay pits were dug for bricks and tiles.

Further south Horsham slabs and Paludina Limestone could be found. Once used by the Romans, in the 1840's, Fullers' Earth was dug commercially at Nutfield from the Sandgate Beds for use as an adsorptive in the chemical, wool and textile industries (and in pet care), and, as a synthetic bentonite, in tunnelling and drilling. The most recent industry is oil taken from an almost invisible site in Brockham.

Many of these industries have a long history in the Mole Valley District. Iron Age builders quarried stone for the ramparts of their forts on the Greensand escarpment; we have excavated two Roman tile kilns, one on London Clay the other on Gault Clay; we know that local Roman builders and farmers used Chalk and that their farms and villas were of Chalk and Greensand and mortar was used. We have found a kiln used in the construction of one villa, but their pits are now hidden by later workings; a medieval Chalk pit in Westhumble was dug to extract Chalk rock.

Mole Valley is not large, about 100 sq. miles. A colleague, Peter Tarplee, in his 1995 S.I.H.G guide, ‘The Industrial History of Mole Valley’ describes the local industries. The numbers of those with geological relevance are summarised here: Brick and tile making: 15; Commercial Chalk pits: 6; Limekilns and pits: 13; Sand and gravel pits: 26; Stone quarries: 8; Iron workings: 3. These are the main industries that still exist or for which records are available. I have added other pits identifiable locally, but excluded the small, undateable, agricultural Chalk pits that feature on the Downs.

These industries were not only in the countryside but also within the local towns. There were four Folkestone sand pits close to the centre of Dorking and at least ten more were dug beneath townhouses. There was also a large lime works on the edge of town. Leatherhead had a large lime works near its centre and a brickworks on the nearby London Clay. There were quarries at Reigate in the Greensand, the ‘Reigate Stone’ still to be seen in local buildings and walls, often badly weathered (this stone was also used in the Reigate Roman kiln). A Folkestone sand pit and a Gault Clay pit were nearby. This town too has numerous sandpits beneath its houses and from the ‘Road Tunnel’. Ashtead had three brickworks in London Clay and a Roman tile kiln in the Forest.

There are a few Mole Valley brickworks and sandpits still producing but many redundant workings have been reused as car parks, building sites, industrial estates, nature reserves and for landfill and are much less obvious in the landscape. Indeed some old clay pits are now water features.

In the 1750s, Mole Valley roads were improved and turnpikes built. In 1849 the Reading to Redhill railway opened, followed in 1867 by the connection of Horsham to London. Coal replaced wood and charcoal, furnaces and kilns were improved, became continuously operated so productivity rose, and products could then be delivered easily and cheaply. The population grew, houses were needed, houses required land.

But not one of these industries was on Box Hill despite its identical geology and no traces of earlier occupation were identified in a recent landscape survey. The only buildings now, are an 1890s ‘fort’, a 19th Centruy lodge and a keeper's house; the lodge is where John Logie Baird tested his early television in 1929-1932. There is a very clear division between Box Hill and industries.

Box Hill has been visited for many years, at least back to the Bronze Age, ca. 2,500BC, as shown by two burial mounds near the ‘viewpoint’. One of the earliest known visitors was the Elizabethan writer William Camden who mentioned both the Hill and the Mole (1586). John Evelyn (1656) admired its trees. Celia Fiennes (1662-1741) and Daniel Defoe (1724-6) both described the Hill as a ‘playground for the gentry of Epsom’, after their day at the races.

Jane Austen in ‘Emma’ (1818) writes of an ‘unsatisfactory picnic’ on the Hill. Both 19th Century John Keats and George Meredith, who lived there, knew the Hill well. But not one of these writers mentions any of the industries that were all around, even if not actually on the Hill. Were they accepted as a normal part of the landscape like a smithy or mill? Or was it just that there were none on the Hill itself because it was part of a private estate?

Then how were all these visitors able to visit this place, walk on it, use it as a ‘playground’? There were large estates all around the Hill, Norbury Park, Deepdene, Denbies, Bury Hill and Betchworth Castle. For these estates to function, they had to accept that public roads and tracks needed to cross their lands to get to local towns, villages and markets, although some owners applied tolls. The roads and tracks across Box Hill could be used by anyone.

There was a manor at Betchworth at Domesday, held for the King. It was divided into three, Brockham, and, East and W Betchworth. W Betchworth probably had an earthwork castle and a deer park and included all of Box

Hill. The castle was built of stone in 1379 and was rebuilt as a fortified Manor House in 1449. Part of this house was pulled down in 1691.

Henry Thomas Hope of Deepdene Estate bought Betchworth Estate, with Box Hill, in 1834 and turned the old house into a ‘romantic ruin’. With further additions, by 1838 Deepdene Estate extended from Blackbrook in the S, N to the Box Hill Zig Zag road (the Parish Road), took in much of Dorking town, and went to the east as far as Brockham, a huge area.

In 1909 the Chancellor of the Exchequer, David Lloyd George in his ‘Peoples' Budget’ proposed a Land Value Tax on undeveloped land and a Capital Gains Tax on profits from sales of land, as well as general Income Tax rises. These were to finance his proposed social welfare programme that included state pensions, school meals, Labour Exchanges and free medical treatment for wage earners. Controversially it was defeated by the Conservatives in ‘The Lords’, resulting in a General Election, again won by the Liberals and the Budget was approved in 1910.

In 1909, aware of the Budget proposals, the trustees of Deepdene Estate put 230 acres of the undeveloped land of Box Hill for sale on the open market, but this would have deprived the ordinary people, who had enjoyed the Hill for centuries, of their place of recreation, their ‘playground’. Not at all what the Chancellor had intended!

As a result of negotiations by Sir Robert Hunter, a co-founder of the National Trust, in 1912 Sir Leopold Salomons of Norbury Estate bought Box Hill for £16,000 to ‘protect it from development’, giving it to the Nation in 1914. The Hill was saved for the people by the new National Trust Act (1906) that had been passed by the Government only a few years before. Ironically the Land Value Tax did not give the desired results and it was quietly withdrawn after the war.

So that is why the great view from Box Hill is misleading, because all around there were busy industries, but they were kept at a distance by the many previous owners of W Betchworth Estate, and they still are, but now by the Trust. One can only wonder what ‘our’ Hill might have looked like now if its two defenders had ignored the Chancellor's Welfare Budget proposals.

Mike Rubra, FGS Member

Details of FGS Monthly Meetings - 2017

Date	Speaker	Title of lecture
13th January	AGM and John Greenwood, FGS	*Geology and Tunneling*
10th February	Dr Chris Duffin, Natural History Museum	*Lapis Lazuli*
17th March	Dr David Walmsey, Consultant	*It was not my Fault*
21st April	Dr David Bridgeland, Durham University	*Evidence for Early Human Activities from Pleistocene River Terraces*
12th May	Dr Richard Ghail, Imperial College	*Venus Geology*
9th June	Dr Hayden Bailey, Consultant	*Provenance – the search for a source*
14th July	Dr Diana Smith, Open University	*Building Stones of Farnham Walk*
August	No meeting	
8th September	Dr David Gill, Wandle Trust	*Geological Evolution of the Wandle from Source to Mouth*
13th October	Dr Adrian Rundle, Natural History Museum	*Introduction to microfossils*
10th November	Dr Julie Prytulak, Imperial College	*The biggest volcano in the World*
8th December	Humphrey Knight, CRU International	*Antimony: Critical metal mineral deposits in South West England*
12th January 2018	Annual General Meeting	

Resolving the early record of animal evolution from Ediacaran biota

Summary of November 2016 lecture given by Dr Alex Liu, University of Cambridge

It was a long time since I thought about any fossils, let alone the start of animal life in the Precambrian. Things have certainly moved on since then and the current knowledge and thoughts drawn together in this lecture were quite an eye opener, if I ever get close to any Precambrian rocks a close up inspection will be done.

The lecture started with a picture of a dinosaur, how much we know about some extinct organisms, before moving on to the topic of the evening's lecture on Ediacaran Biota, about which scientists knew very little until recently. The Ediacaran period is at the very end of the Proterozoic (Neoproterozoic) and butts against the Cambrian with its extensive list of fossils (Figure 1). Until the 1950's it was thought that there was no animal life prior to the Cambrian.

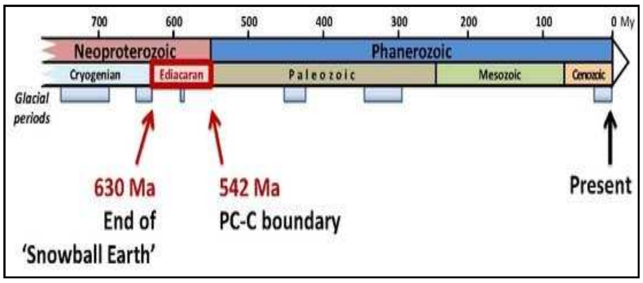


Fig. 1: Ediacaran Period – the youngest of the Precambrian intervals.

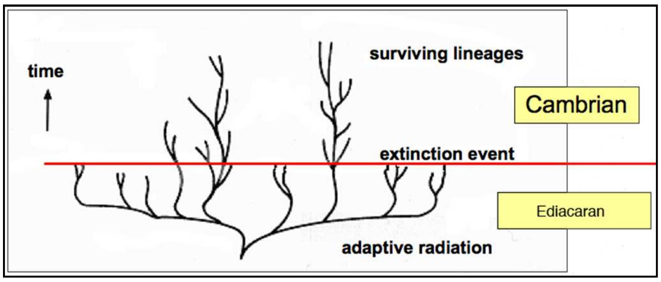


Fig. 2: Dramatic changes at the end of the Precambrian.

The first Ediacaran fossil, Charnia, was found in Leicestershire's Charnwood Forest; since then, with diligent searching, numerous fossiliferous sites have been found globally. The microbial world has existed since about 3.8Ga and continues to the present. The change from single cells to large Proterozoic eukaryotes may have occurred at 1.56Ga in China but were definitely present in China at 635Ma.

Well-formed, recognisable animal fossils were present in the Cambrian from about 530Ma and this explosion started at 541Ma. What life transcends the Precambrian Cambrian junction? (Figure 2). What was going on globally in the late Proterozoic to bring on these momentous biological changes in the 400Ma prior to the Cambrian? The known major Neoproterozoic global events that occurred were global glaciations, a rise in atmospheric oxygen levels, and tectonic upheaval resulting in the breakup of the supercontinent Rodinia.

The numerous fossiliferous Ediacaran localities are distributed unevenly across the Globe. To date the oldest confirmed large and complex Ediacaran fossils that have been described and dated are at:

- The Lantian Biota in China of about 600Ma;
- Ediacara fossils from South Australia;
- White Sea, Russia, at 555Ma;
- Australia and China, algal forms at 551Ma;
- Namibian forms which have been correlated to an area in the USA at 545Ma;
- South America, South Africa and China have tubular and mineralised fossils at 545Ma.

It has been difficult to say whether the fossils are animals, algae, fungi, or entirely extinct groups of organisms, so grouping them into specific families is only slowly being resolved (Figures 3 and 4).

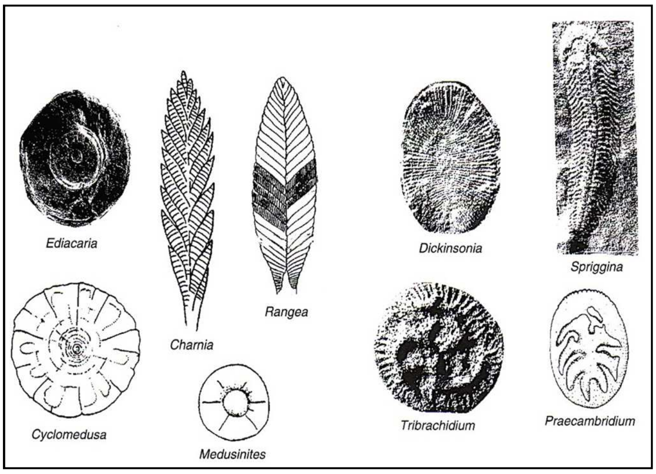


Fig. 3: Examples of the varied Ediacaran Biota.

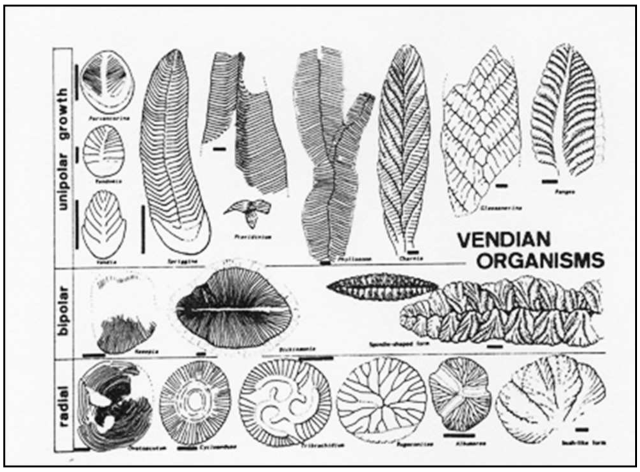


Fig. 4: Evolution of the Ediacaran Biota.

The past confusion amongst scientists has led to the perception that the Ediacaran biota organisms are enigmatic, weird and problematic. However, newer finds are very slowly defining their lineage and improving correlation of global sites, allowing researchers the opportunity to identify the causes and consequences of early animal evolution.

One of the author's favoured sites is in Newfoundland, at a place called Mistaken Point, which is now a UNESCO World Heritage site and protected. Fossils here are ca. 575Ma old and their soft tissues are preserved due to sudden catastrophic burial of the benthic community by volcanic ash, turbidites or storm events. Once the organisms were killed, decomposition occurred and their outer surfaces were mineralized. Newfoundland has thousands of Ediacaran fossils, but many of them have been difficult to identify as animals or anything else. Studies into their growth, reproductive strategies, and ecological interactions are beginning to reveal findings that will enable scientists to determine what these creatures were.

Although palaeontologists are struggling to identify many of the actual Ediacaran fossil taxa, definite evidence of animal life is found in trace fossils such as burrows and linear surface impressions from that interval, but the animals that created these marks have yet to be identified. A comparison was shown; e.g. modern snail traces have been compared with helminthoidichnites trace fossils from the Ediacaran. The Ediacaran trace fossils fit into a gradual progression in the evolution of traces and behaviour through the Ediacaran into the Cambrian (Figure 5).

One of the questions being asked is 'are the palaeontologists looking in the right place and at the right scale for animal traces?'. Meiofaunal traces (Micro fauna) are being found in the Guaicurus Formation of Brazil, dated at about 543Ma.

CT scanning is now enabling 3D reconstruction and confirming, through trace fossils, that there were early animals, but much more work is required to tie one type of trace fossils to a specific animal. The current main sites under investigation are:

- Corumba Group, Brazil
- Nama Group, Namibia;
- White Sea NW Russia;
- South China Platform;
- Avalon; Newfoundland & England.

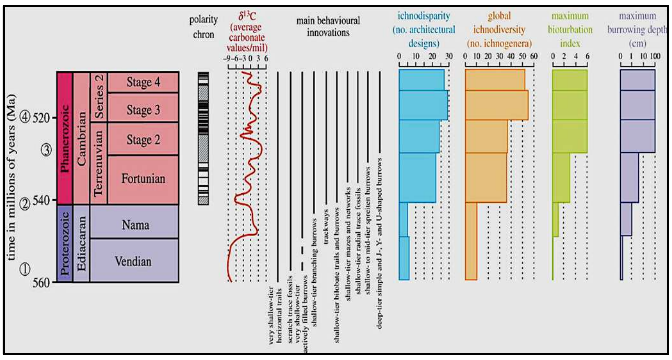


Fig. 5: Evolution of the Ediacaran Biota: *http://rspb.royalsocietypublishing.org/content/281/1780/20140038.*

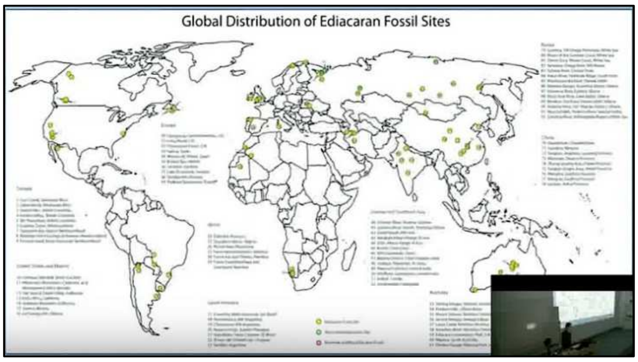


Fig. 6: Distribution of Ediacaran Fossil Sites, taken from the lecture by Alex at*:* *https://www.youtube.com/watch?v=hh0OKAuphyM*

Ga – Billion years (10^9) Ma – Million years (10^6)

Dr Alex Liu is a palaeontologist who studies fossils of the Ediacaran Period. He completed both his undergraduate degree in Earth Sciences, and his doctorate, at the University of Oxford. He then took up Research Fellowships at the Universities of Cambridge and Bristol, and is now Lecturer in Palaeobiology at the University of Cambridge.

Additional comments by John Stanley, Member FGS

Acritarchs - in general, any small, non-acid soluble (i.e. non-carbonate, non-siliceous) organic structure that cannot otherwise be accounted for is classified as an acritarch. They include the remains of a wide range of quite different kinds of organisms - ranging from the egg cases of small metazoans to resting cysts of many different kinds of chlorophyta (green algae). It is likely that some acritarch species represent the resting stages (cysts) of algae that were ancestral to the dinoflagellates. The nature of the organisms associated with older acritarchs is generally not well understood, though many are probably related to unicellular marine algae. In theory, when the biological source (taxon) of an acritarch does become known, that particular microfossil is removed from the acritarchs and classified with its proper group.

While the classification of acritarchs into form genera is entirely artificial, it is not without merit, as the form taxa show traits similar to those of genuine taxa - for example an 'explosion' in the Cambrian and a mass extinction at the end of the Permian.

Protist - Protists are the members of an informal grouping of diverse eukaryotic organisms that are not animals, plants or fungi. They do not form a natural group, or class, but are often grouped together for convenience, like algae or invertebrates. Besides their relatively simple levels of organization, protists do not necessarily have much in common. When used, the term ‘protists’ is now considered to mean similar-appearing but diverse phyla that are not related through an exclusive common ancestor, and that have different life cycles, trophic levels, modes of locomotion, and cellular structures. In the classification system of Lynn Margulis, the term protist is reserved for microscopic organisms, while the more inclusive term Protoctista is applied to a biological kingdom which includes certain large multicellular eukaryotes, such as kelp, red algae and slime moulds. Other workers use the term protist more broadly, to encompass both microbial eukaryotes and macroscopic organisms that do not fit into the other traditional kingdoms.

Reference: Lynn Margulis (http://evolution.berkeley.edu/evolibrary/article/history_24),

What meteorites tell us about asteroids

Summary of October 2016 lecture given by Dr Hilary Downes, University College, London

Why should we study (or pay for scientists to study) meteorites? Several reasons come to mind: first, they are left-over material from the beginning of the Solar System, so they can tell us about how the Solar System formed, including how small planetary bodies such as asteroids were formed. From this, we may learn more about how larger planets such as the Earth evolved. Another reason is that there are several hundred ‘Earth-crossing’ asteroids, of which one may impact onto the Earth in a manner not dissimilar from the event at the Cretaceous-Tertiary boundary. So it is important that we understand what they are made of and how they behave.

How can we obtain pieces of an asteroid? The expensive way is to send a space probe to the surface of a nearby asteroid and bring a piece back. The Japanese Space Agency JAXA have already done this with their aptly-named ‘Hayabusa’ (meaning ‘hawk’) probe which touched down on the surface of a small asteroid called 25143 Itokawa and returned a few tiny fragments to Earth. The mission was only partially successful but from the crumbs which were collected we can easily recognise that Itokawa is an asteroid identical in mineralogy and compositions to a variety of meteorites called LL chondrites. (*For more details about this mission go to http://www.psrd.hawaii.edu/Aug11/Itokawaparticles.html)*. Further missions are planned by JAXA (Hayabusa 2) and NASA (OSIRIS-REx) which hope to return samples from a variety of different asteroid types.

However, a much cheaper option is to collect asteroids that have come to Earth! An excellent example is given by asteroid 2008TC3 that was discovered on October 6th 2008 by the Catalina Sky Survey whose job it is to search the skies for dangerous asteroids. A day later it entered the Earth’s atmosphere and broke up in a spectacular fireball over northern Sudan. Approximately 600 meteorites were collected from the Sudanese desert in the months which followed by teams of US and Sudanese scientists (and numerous student volunteers). These meteorites were named (in time-honoured tradition) after the nearest geographical point of interest, in this case a railway station, so becoming known as Almahata Sitta (‘Railway Station 6’). Despite the costs of hiring buses and feeding volunteers, this mission was a lot cheaper and (in terms of amount of freshly recovered asteroid material) more successful than any sample return space mission will be for many years to come! See NASA’s Near-Earth Object program website for further details of the tracking and entry of 2008TC3 *(http://neo.jpl.nasa.gov/news/2008tc3.html).*

Three different types of meteorites are commonly described in textbooks: stony meteorites, iron meteorites and stony-irons. However this is not a particularly useful classification, and nowadays we divide them into two main groups depending on their history: undifferentiated (stony meteorites that show no sign of having melted or differentiated inside an asteroid) and differentiated ones (which include the irons, stony irons, meteorites from Mars, the Moon and asteroid 4Vesta, together with ones made of basalt or peridotite for which a parent asteroid has not yet been identified).

One particular type of differentiated meteorite has caught my attention. They are ureilites, which are similar in many ways to the mantle xenoliths which you can pick up on Earth particularly in places like Lanzarote in the Canary Islands. Ureilites are coarse-grained rocks composed largely of olivine and pyroxene, with some minor carbon phases (graphite and diamond) and some metal and sulphide phases. Unlike mantle xenoliths, their minerals show evidence of having experienced shock and reduction. These meteorites are old (4563Ma, or 4.563Ga) so they give us an idea of what went on in the early years of the Solar System (which is thought to be 4567Ma, or 4.563Ga old).

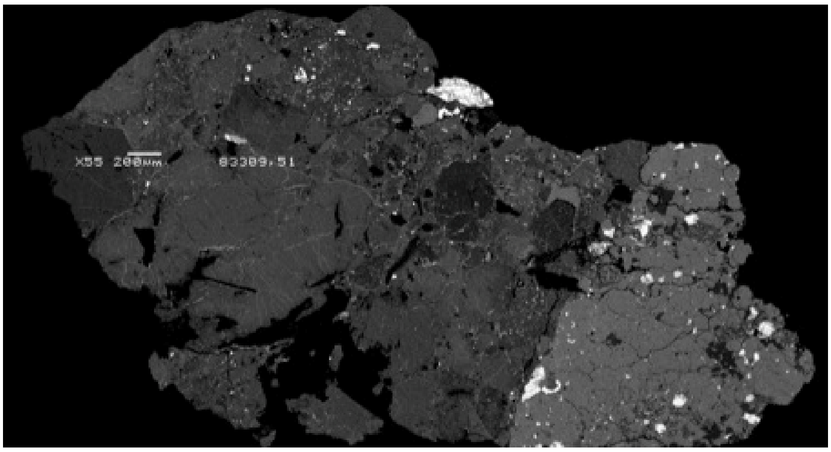


Fig. 1a: Back-Scattered Electron Image of Whole Fragment from Sample eet83309,51.

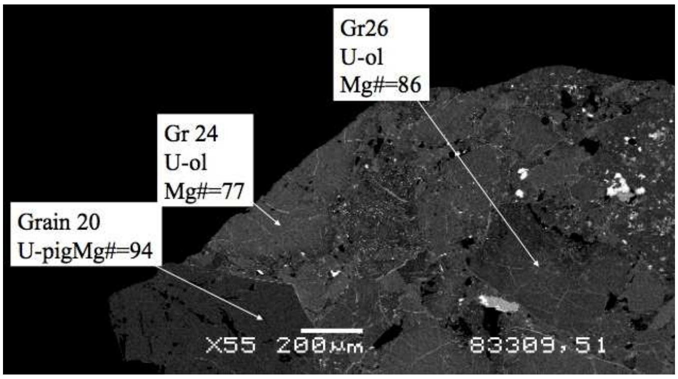


Fig. 1b (L) Clasts along top LHS of Fig. 1a.

.

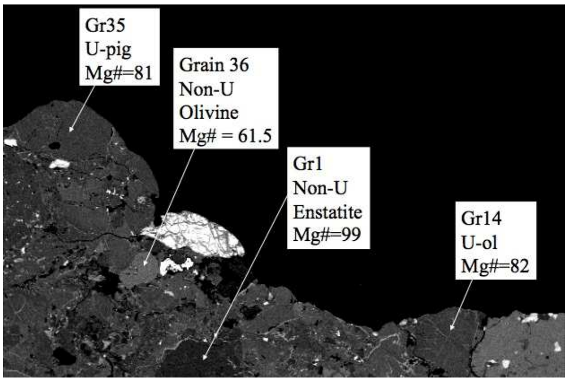


Fig. 1c (R): Clasts along top RHS of Fig. 1a

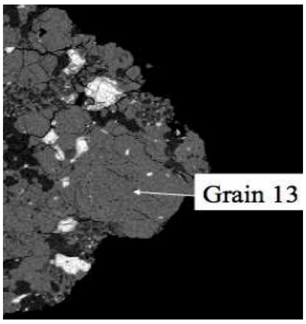


Fig. 1d: Olivine in R-Chondrite Clast

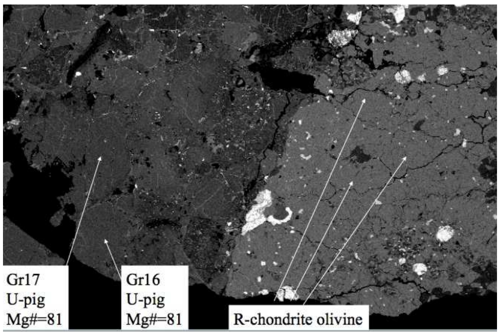


Fig. 1e: Clasts along bottom of Fig. 1a.

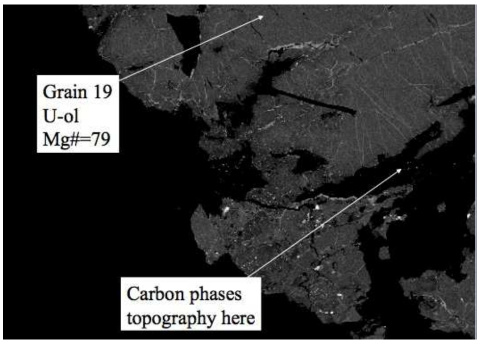


Fig. 1f: Clasts along bottom LHS of Fig. 1a above.

Fig. 1, views a-f: Back-Scattered Electron Images of a Typical Brecciated Ureilite Meteorite from Antarctica - Sample eet83309,51.

Several of the ureilites are breccias and probably are derived from the surface regolith of the parent asteroid (Figure 1). They contain material which has been reworked from the entire asteroid, like a terrestrial sandstone might contain material from an entire sedimentary basin. They also contain foreign fragments which are not ureilitic in composition or mineralogy, implying that meteorites from elsewhere in the Solar System have landed on the surface of the parent asteroid of ureilites over geological time. The Almahata Sitta meteorite turned out to be composed of similar ureilite clasts, together with a large number of foreign fragments.

Using an electron microprobe, I have investigated clasts within several ureilite regolith breccia meteorites found in Antarctica and Australia. I have shown that the clasts show an identical compositional distribution to that found in all known ureilite meteorites, so that we have samples from the whole parent body. I also discovered exotic fragments of other known meteorite types, including the rare R-chondrites and E-chondrites *(author's note: R-chondrites or rumurutiites are highly oxidised meteorites and contain Fe-rich olivine and fewer chondrules than normal chondrite; E-chondrites are enstatite-chondrites, enstatite is an orthorhombic pyroxene mineral ($MgSiO_3$)).*

I then used a more advanced piece of equipment called a Secondary Ion Mass Spectrometer, which can analyse all three isotopes of oxygen in a polished mineral, so that I could determine the fingerprint of oxygen isotopes in each fragment, to confirm my earlier findings. From this, it is clear that the asteroidal mantle represented by the ureilite parent asteroid is very different from that of the Earth, in terms of having a wide range of mineral compositions and oxygen isotope ratios (whereas Earth's mantle is very homogeneous in these characteristics). From this I have deduced that the ureilite parent asteroid never experienced a 'magma ocean' stage in its development. Other planets and asteroids which have much more homogeneous compositions probably became so hot sometime in their history that their entire mantle was molten and able to mix effectively.

Finally, among the unusual clasts I have found in ureilites, a piece of granite which has a composition unlike that of any Earth granite has been found. We don't know where it has come from, but perhaps it is a tiny fragment of a lost planet similar to Mars. We have also discovered opal, a hydrated silicate mineral which may be telling us something about the movement of water around the early solar system. As usual, research leaves us with more questions than answers!

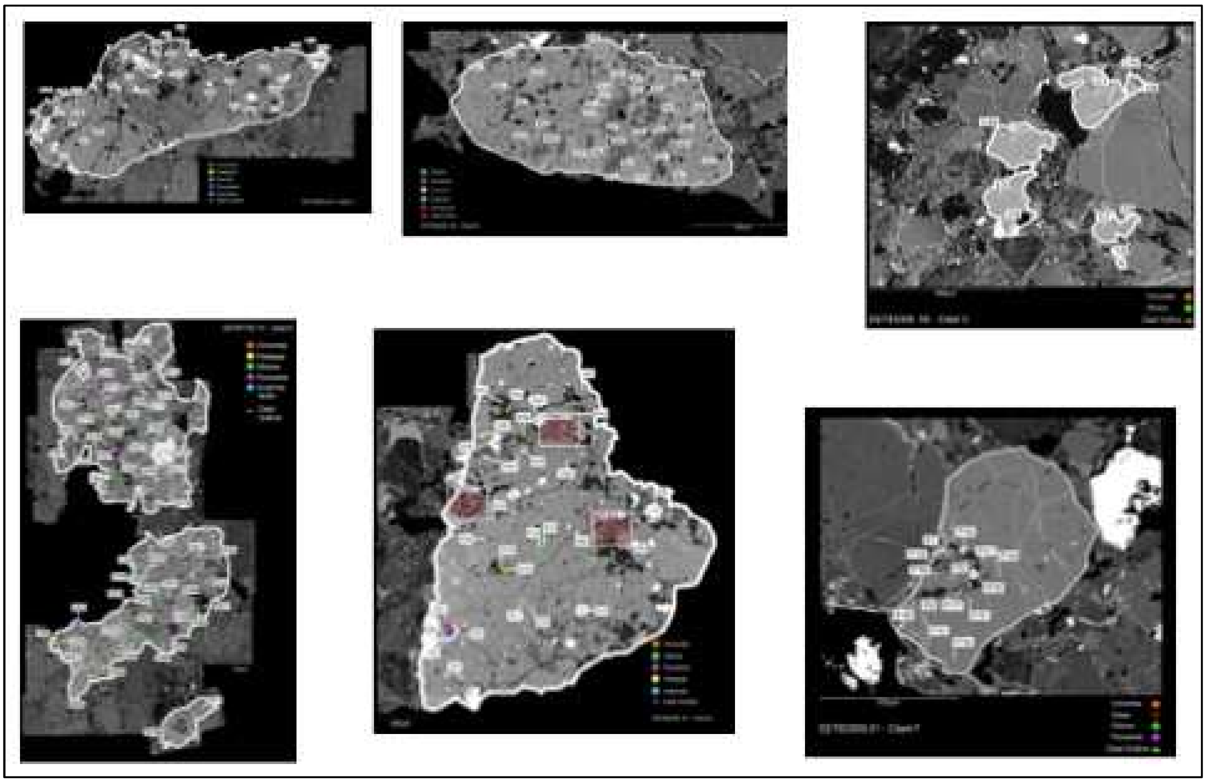


Fig. 2: Back-Scattered Electron Image of Foreign Fragments in Ureilite Breccias, Some of Which Represent Samples that are Unknown in our Meteorite Collections.

Tunnelling & geology – Thames tideway tunnels and London's sewer system

Summary of January 2017 lecture given by John Greenwood, Member of Farnham Geological Society

The Thames Tideway Tunnels project was the culmination of my career as a Civil Engineer. Leaving Imperial College, I joined Thames Water and worked on reservoirs, treatment works, pumping stations, pipelines and tunnels for potable water and sewers. I started the early work to resolve the problem of the overflow discharges into the Tidal Thames, which resulted in the Thames Tideway Tunnels project. The Geology of the London Basin was fundamental in the development of the concept design and implementation of the project.

There are 57 Combined Sewer Overflows (CSOs) discharging around 39Mm^3 of sewage on an average year into the Tidal Thames. These discharges occur virtually every time it rains and are often fatal to aquatic life and potentially dangerous for river users. It is environmental pollution on a large scale. In the early 1800s, surface water drained to the then tributaries of the Thames, which were open, tidal rivers and creeks - the Westbourne, Tybourne, Kings Scholars Pond, Hole Bourne and Fleet (N of the river) and Effra and Earl (to S). To create more building land they were diverted into brick culverts and backfilled, becoming the 'Lost Rivers of London' and by default the initial main sewers for London.

With continued development, more surface water drainage connected to the lost rivers. Foul sewage was dealt with by cess pits but with densely packed buildings, increasing population and improved water supply, the volume of foul sewage increased and overwhelmed the 250,000 cess pits. Contamination of the water supplies was inevitable as were the outbreaks of cholera and other water borne diseases.

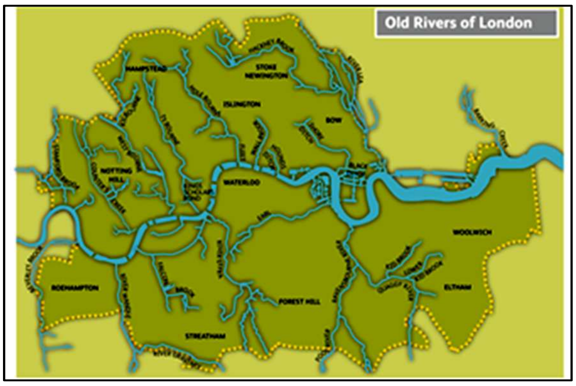


Fig. 1: Old Rivers of London.

Fig. 2: Main sewers in 1856.

An expedient, though short-sighted, measure of blocking up the cess pits and connecting foul drainage to the existing surface water drainage system was implemented during the 1840s. London's sewers became a fully combined sewer system discharging foul sewage direct to the Thames via the main sewers (Lost Rivers) and pollution drifted back and forth with the tide (both domestic and industrial waste: slaughter houses, tanneries); pollution worsened culminating in the Great Stink of 1858. Cholera was thought to be air born, spread by the stink or Miasma, so Parliament, in fear of their lives, promptly passed the Bill giving authority to Bazalgette's interceptor sewer system, which had been delayed for several years by five Royal Commissions.

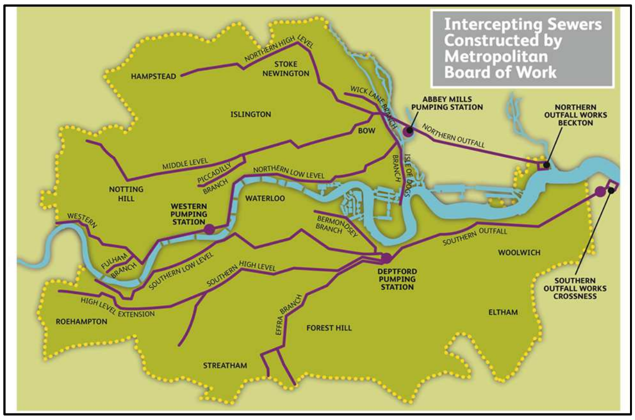


Fig. 3: Intercepting Sewers – Metropolitan Area

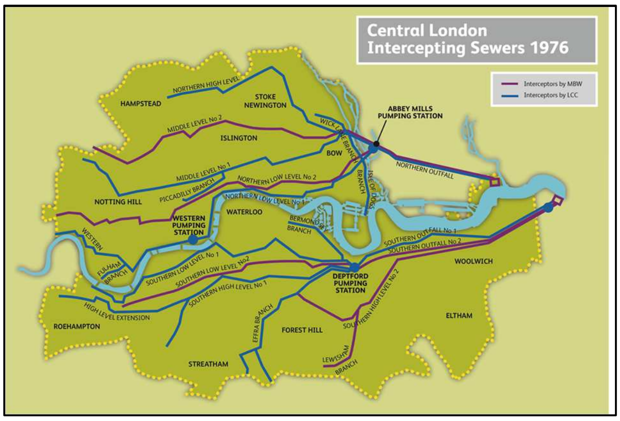


Fig. 4: Intercepting Sewers - Central London

Bazalgette's system intercepted the daily foul flow from the surface water drainage system and the main sewers and routed the flow to Beckton, N of the river, and to Crossness, S of the river. There the flow was held in huge reservoirs and released twice daily on the outgoing tide. As London expanded, duplicate interceptor sewers were constructed, treatment works were implemented at Beckton and Crossness and storm relief sewers and pumping stations were constructed to relieve flooding during heavy rainfall. Today London's sewer system comprises three layers: the main sewers overlaying the interceptor sewers with the storm relief sewers at the lowest level. However when it rains the system still relies on discharging untreated sewage into the tidal Thames via the overflows, main sewers and storm relief sewers.

When complete the Thames Tideway Tunnels will intercept, attenuate and transfer flow to Beckton Sewage Treatment Works (STW) where it will be pumped and controlled to treatment. There are two parts:

1. The Lee Tunnel, already constructed and commissioned, is 6.9km long, 7.2m diameter and runs between Abbey Mills Pumping Station (near Stratford in East London) and Beckton STW. It intercepts Abbey Mills CSO, the single largest CSO. At Beckton it culminates in the pumping station which transfers the intercepted flows to the works.
2. The Thames Tunnel - 25km long, 7.2m diameter, up to 70m deep - running from Acton in the W, following the River Thames eastwards before it connects to the Lee Tunnel at Abbey Mills. Along the way it will intercept the remaining CSOs.

Modern soft ground Tunnel Boring Machines (TBM)

The art and science of tunnelling has advanced considerably in recent decades. Modern machines are a far cry from the early 'heroic' days of a pick, shovel and manpower. They meet modern health and safety standards, have greater certainty of success with tighter economics, tackling more difficult ground conditions. This requires more detailed knowledge and understanding of the anticipated ground conditions, i.e. the geology.

There are two main types of soft ground TBMs that are appropriate for the geology in the Thames Basin: 1) Earth Pressure Balance Machine (EPBM) and 2) Mixed Shield (or Slurry) Machine (MSM). Each machine consists of a cutting head at the front of the shield, a steel cylinder that holds the cut ground in place until the lining is constructed behind. The cutting head and shield is pushed forward by powerful hydraulic rams. The head incorporates cutting disks and sharp picks made from hardened steel; it is mounted on a large bearing and is rotated by a powerful motor to effect excavation of the ground. When the cutting head has advanced enough for another ring of concrete segments, it is stopped and the rams retracted to allow the individual segments to be lifted into place with a hydraulic arm. The ring is completed with a keystone and then the cycle begins again. The main difference between the two types of machine is the principle of how stability at the excavated face is maintained. The EPBM uses a bentonite slurry, injected at the face to lubricate and condition the excavated material, which is 'churned' into a thick toothpaste-like consistency and removed at a controlled rate by a screw conveyor and transferred to a train which takes the material out of the tunnel.

For the MSM larger quantities of Bentonite slurry are pumped into the excavation chamber via a feed pipe. The excavated material is mixed into the slurry and the slurry is removed via the return pipe and transferred to the slurry separation plant located at the surface. The excavated material is settled out and the slurry decanted off for re-use.

EPBMs are particularly efficient in relatively consistent geological strata (clays and sands). However, variations in ground conditions and water pressures make it difficult to maintain the pressure balance at the face. When variable conditions are anticipated (e.g. Lambeth Group or Chalk with flints), then a MSM is more effective. The face pressure can be maintained or varied in a more flexible manner using the slurry feed and return. For an even more rapid response some machines incorporate a compressed air feed. When excavating in Chalk MSMs incorporate a flint crusher in the slurry return. Here a large eccentrically rotating cone causes the flint nodules to grind and knock against each other thus breaking them down.

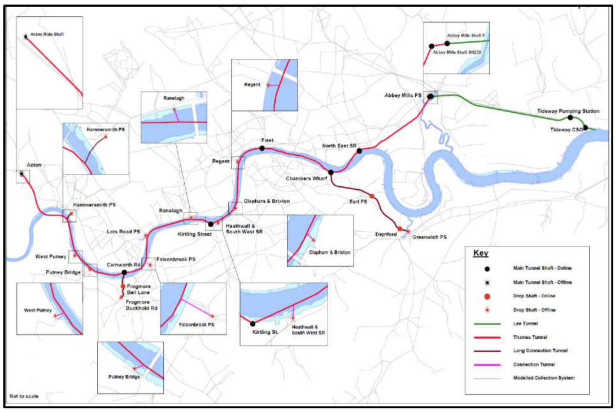


Fig. 5: New intercepts planned

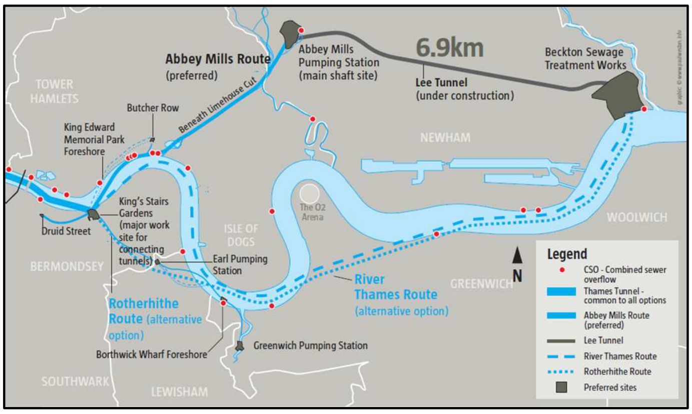


Fig. 6: Overall route for tideway tunnel

Geology and its influence on the design and implementation of the Thames Tideway Tunnels

The importance of the geological site investigation to determine the strata and soil parameters together with the interpretation by geological experts cannot be overstated. Hundreds of boreholes were excavated, many within the river, some in excess of 100m deep. All were logged and a significant proportion retained as reference samples. Groundwater horizons were identified and many boreholes retained as monitoring stations. A wide range of tests and inspections were carried out to establish the physical, structural and chemical characteristics of the rock types.

Some of the main factors that influenced the design of the Thames Tideway Tunnels project were overall route and layout, sectioning of the works and selection of TBMs and Shaft construction.

Overall route and layout: In the initial route the Thames and Lee Tunnels joined at Beckton adjacent to the proposed pumping station. The extent and influence of the Greenwich Fault zone at the W end of the Lee Tunnel was an area of obvious concern; and during the geological investigation an extensive graben feature was also discovered near the E end at Plaistow which would mean a tunnel face of half Thanet Sand and half Chalk over ca. 1.5km. It would have proved a challenge to keep the TBM level in such conditions. Further investigation revealed a deeper but shorter section of the graben over a distance of about 400m, so the Lee Tunnel was lowered at Abbey Mills and given a shallower gradient as it passed through this deeper section of the graben avoiding the remainder. This approach minimised the tunnelling risk and made the pumping station and overflow shafts at Beckton shallower, so the Thames Tunnel could physically join the Lee Tunnel at Abbey Mills saving ca, 7km of main tunnel. A smaller diameter link tunnel to the Greenwich Pumping Station CSO was required together with significant reworking of the tunnel operation to avoid having to intercept a ‘lone’ CSO at Charlton.

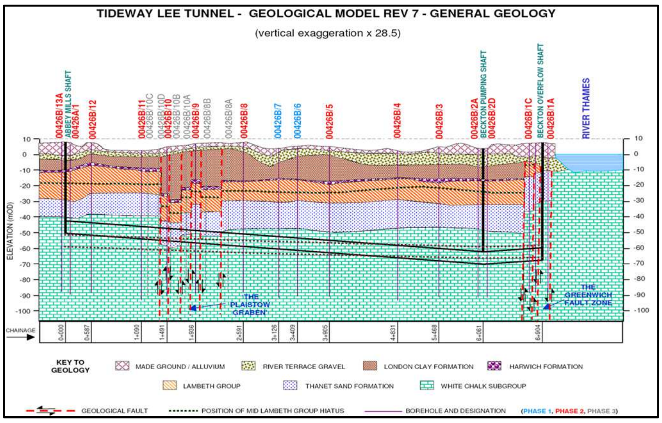


Fig. 7: Tideway Lee Tunnel – General Geology

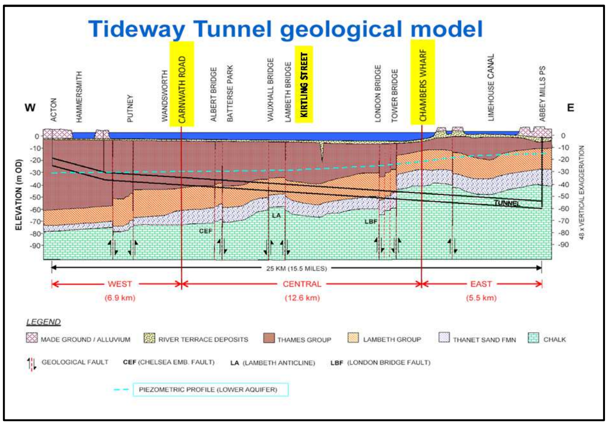


Fig. 8: Tideway Tunnel Geological Model

Geological Sections and shaft construction

The geological section through the proposed elevation of the Thames Tunnel (Figures 7 and 8) shows clearly that many different strata are encountered along its length. The tunnel is constructed with TBMs launched from large main shafts and collected at reception shafts at the other end. These construction shafts are used to divert intercepted flow from the CSO into the tunnel or to facilitate connection of the smaller link tunnels. It is impossible to swap between TBMs whilst tunnelling, so the tunnel needs to be sectioned for appropriate TBMs.

Three main sections were developed: 1) in W: Carnworth Rd to Acton (mainly London Clay so EPBM); 2) in E: Chambers Wharf to Abbey Mills (all Chalk so MSM); 3) Central Section of two tunnels: Kirtling St in E (Lambeth Group, Thanet Sands and Chalk, so MSM) and W drive (Lambeth Group (ideally MSM) then London Clay (ideally EPBM). What will the contractor finally decided.

The proximity of the Lee Tunnel to the Greenwich fault system requires shaft construction to be robust and exclude groundwater ingress. There is direct hydraulic connectivity with the Thames (and North Sea) afforded by the faults in the Chalk. The Diaphragm Wall technique has been used to construct shafts at Beckton and Abbey Mills where variable strata and water pressures occur and will most likely to be used for most shafts. Only the W shafts, through London Clay only, are likely to be constructed in the traditional ‘excavate and underpin’ method.

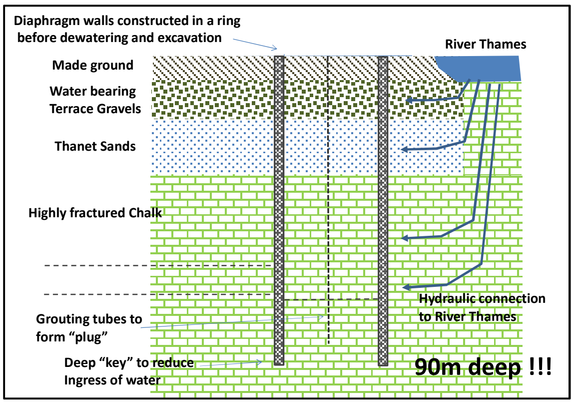


Fig. 9: Ring of walls constructed before dewatering & excavation

Deep slots are excavated with a ‘Hydrofraise’ machine using bentonite slurry to support the ground and to remove the excavated material. When three adjacent slots have been excavated, steel reinforcement cages are lowered and concrete pumped in from the base, displacing the slurry and forming an in situ reinforced concrete panel, the panels are constructed from the surface in a circle forming a cylinder. Tubes are drilled to inject cement grout to seal fractures and prevent water ingress. The diaphragm walls extend several meters below the base to form a cut off curtain and prevent water ingress and groundwater flow during excavation. It is virtually impossible to stop groundwater flow if it becomes significant. Pumping at ever increasing rates is often the only solution but runs the risk of ground erosion or even catastrophic collapse.

Conclusion

It is clear that the geology of the London Basin had a significant influence on the design and construction of the Thames Tideway Tunnels. But it also impacted on other aspects of the tunnelling:

- the surface/sub-surface deposits of clay and saturated river gravels meant that alternative methods of surface water control (to reduce flows in the sewers and thus the overflows) using separation and infiltration would not have been effective;

- because of the general hydrogeology of the London Basin and its importance as a water source, secondary lining of tunnels and shafts is an important feature to reduce pollution risk from the deep sewer system;
- as groundwater levels in the London Basin continue to recover, air that had been drawn into the ground is now being displaced and is sometimes trapped under impervious domed strata. These trapped, pressurised ‘balloons’ of gas are anoxic, the O_2 having been used up by oxidation processes. Once the impervious strata are punctured, explosive anoxic gas is released.

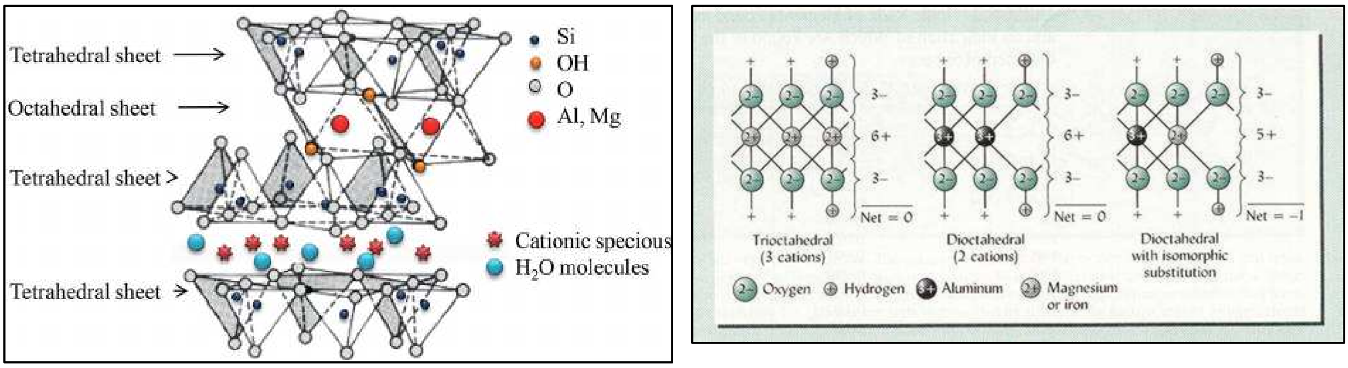
The Importance of geological site investigations cannot be understated. Not only should this cover the ‘standard’ requirements of identifying the strata (what’s there and what’s in it?) and the soil parameters (physical, structural and chemical) but critically the interpretation between the boreholes so that the full spectrum of potential risks can be assessed and appropriate contingency plans developed. The mantra of ‘no surprises’ and always have a plan B (and plan C) applies.

However in all this heady mix of wonderful geology, engineering and hydraulics together with sewer modelling, environmental assessment, archaeological study, conservation, planning, consultation, statutory and political measures, one must not forget the purpose of the project - to prevent the discharge of sewage into the Thames.

Additional Comments by John Stanley, FGS Member

Bentonite is an industrial name of mined clays and also ones that are refined; two main classes of bentonite exist: Na bentonites and Ca bentonite. Mined bentonites contain mainly montmorillonite, one of the smectite clays, and a wide range of other minerals including quartz, feldspars, zeolites and carbonates. By refining, the level of montmorillonite can be raised from ~ 40% to >80%. Montmorillonite is formed by the devitrification and accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash.

When refined bentonite is dispersed in water, highly stable colloidal suspensions are formed with high viscosity and thixotropy. At high enough concentrations, these suspensions begin to take on the characteristics of a gel. Suspensions form when water molecules penetrate platelets and H bridge bonds form. The platelets become isolated from each other, while bonded through interposition water. When still, a mesh forms, incorporating water, and it jellifies. Conversely, under mechanical stress, the bonds partially break and the platelets can move more freely and viscosity is lower than whilst at rest. This reversible sol-gel-sol process is known as thixotropy and these properties, shown by bentonite aqueous suspensions, are exploited in drilling slurries. Montmorillonite is industrially a very important clay mineral as it has a cation exchange capacity.



Diagrams showing the sheet structure of the clay mineral smectite, montmorillonite. Image from:
https://www.bodenkunde-projekte.hu-berlin.de/tropics/pcboku10.agrar.hu-berlin.de/cocoon/tropen/isomorph.jpg

The individual crystals of montmorillonite clay are not tightly bound hence water can intervene, causing the clay to swell. The water content of montmorillonite is variable and increases in volume when it absorbs water.

Chemically, it is hydrated Na, Ca, Al, Mg, silicate hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2\cdot nH_2O$;
K, Fe, and other cations are common substitutes, and the exact ratio of cations varies with source.

The different types of bentonite are each named after their respective dominant element.

NB: Abbreviations above are hydrogen (H), potassium (K), sodium (Na), calcium (Ca), iron (Fe), magnesium (Mg), silica (Si), oxygen (O) and aluminium (Al).

Field Trips 2017

Mar 26:	*Albury*	**Apl 30**:	*Nymans Garden*
May 21-28:	*Mull & Iona*	**July 2:**	*Kímmeridge’s new museum*
Aug 11-13:	*Suffolk crags*	**Sept 17**:	*Hengistbury & Hordle*

Sep 30 – Oct 3: *Isle of Wight*