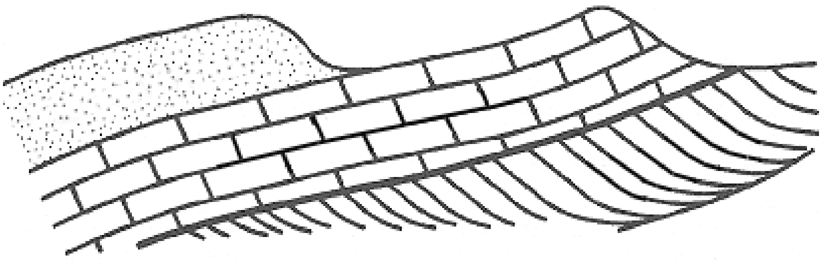
Farnham Geological Society

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

Farnhamia farnhamensis



A local group within the GA

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Newsletter

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Editorial

2017 was another busy year for the Society and the three Newsletters have managed to reflect much of those activities – both from talks and field trips. You will see from the lists of field trips and talks below, that 2018 looks to be just as active and hopefully we will see many of you at the talks and/or on the field trips.

Erratum

I apologise for the error in the 'Building Stones of Farnham' article in the last newsletter where I recorded that Sally Pritchard had written the report. Dr Diana Smith led the trip round Farnham and the report was written by Rosemary Cozens; Sally merely forwarded the report to me, which is where the confusion entered. Sincere apologies.

Obituaries

It is my sad job at this time of year to reflect on those people who have been attached to the Society and who have passed away in the last year. Dorothy Whitehead died in the Spring following a brave battle against illness, leaving Alan, an active member of the FGS; John Wilson also died last year, John was an expert on Corals at the Institute of Oceanography and gave several lectures to the Society, often at short notice, and became an Honorary Member; and last but by no means least Alan Bromley, his main loves were two-fold: granite and how to find and mine its minerals, and concrete for which he was a recognized expert witness in court cases. His wife, Lesley, always accompanied him, taking videos for FGS despite the weather and other conditions. They will all be sadly missed and we send our sincerest condolences to their loved ones.

Thank You

The Committee want to thank Christine, daughter of Tony Brown who kindly donated £25 to the Society when she sold her father, Tony's, rock grinder/cutting machine. He had been an active member and committee member of the Society for many years.

FGS Lunch

This was well attended again this year. Peter and Mike successfully negotiated a good deal for Members in the lovely surroundings of Frensham Ponds Hotel. The 2018 Lunch will be held on 18th November 2018 – so you have no reason now to miss it. It has always been very popular with good food, pleasant wine and good company of course. Mike and/or Peter will be happy to give you any extra information that you might need or like.

Silver Members …

Not a reflection on hair colour, rather a way of recognizing 25-years of membership to Farnham Geological Society. And the culprits are: Margaret Bourgoing, Colin Brash, Janet Catchpole, Barry Eade, Edward (Ted) Finch, Ian Hacker, Kate Jemmett, Lyn Linse, Peter Luckham, Pam Minett, Paul Olver, Joan Prosser, Mike Weaver, John Williams. **Well done to all of you**!

… And to Others On Field Trips (See Photos Below)

How FGS members get to grips with geology on our field trips. I came across these photographs by chance – they were taken at Ploumanach, Brittany, where there was a good example of volcanic rocks from mixed basic and acidic magmas. I thought they gave a good representation of Graham Williams's many field trips over the years.

Liz Aston

FGS Stand At The GA Festival Of Geology - 2017

Compiled by Sally Pritchard and Janet Catchpole

This year, Graham and Susan Williams passed the task of preparing the Society's display at the GA Festival of Geology, held on 5th November to Sally Pritchard, our Membership Secretary. Together with Janet Catchpole and Judith Wilson, they produced a wonderful display of images, rocks and a summary of our field trip to Mull and its wonderful Tertiary volcanic rock suite. The stand was well attended and visited by many interested parties, including many FGS members, from memory they included Janet Phillips (who provided the photographic record for us) and those who looked after the stand whilst Sally and Janet attended lectures etc., e.g. John Williams, Paul Gossage, the Norgates, Jean and Jonathan to name but a few (apologies to anyone who has not been mentioned).

Above: Sally Pritchard manning the FGS Stand, at the GA Festival of Geology, University College London.
Right: Janet Catchpole beside the full display.

The Farnham Quaternary River Terraces and Their Importance Within the Thames Palaeolithic Record

Summary of April 2017 lecture given by Dr. David Bridgland, Durham University

Modern understanding of the complex climatic record from the latter half of the Quaternary has allowed a meaningful pattern to be recognized within the archive of stone-tool types collected from river terrace deposits in the Thames system. That system benefits from a richness of fossils (especially mammalian and molluscan) within its Pleistocene sediments and the abundance of flint from the Chalk as a high-quality raw material for tool making during the Palaeolithic. Thus the record from the Thames, and especially from its lowermost reach east of London, is second to none in terms of representation of Quaternary palaeo-climate and evidence for early human activity (Figure 1).

The archaeology can be summarized under three broad groups, which correspond with Modes 1, 2 and 3 as defined by the archaeologist Grahame Clark (World Prehistory, 1969): Mode 1 = the Clactonian industry, comprising cores and flakes, with no core preparation and no formal tools, Mode 2 = hand axes (= Acheulian) and Mode 3 = Levallois technology, with core preparation. It is the hand axes of Mode 2 that were preferentially amassed during the years of extraction of gravel by hand, providing huge collections of such material in museums all over Britain and western Europe. There is considerable variety of hand axe forms, with different classification schemes developed during many years of research, notable amongst which was the definition of six hand axe groups by the Oxford archaeologist Derek Roe, established in the 1960s from exhaustive studies of the museum collections. Roe's groups are summarized in Table 1, which also shows the age to which each group would now be assigned (an interpretation impossible at the time of Roe's research, when the complexity of Quaternary climatic fluctuation was not fully understood).

The Thames sequence, as illustrated in Figure 1, has been important in establishing both the record of Quaternary palaeo-climate and the episodes to which the hand axe groups belong. The groups can thus be plotted onto the terrace sequences in different parts of the Thames valley (see Figures 1 and 2).

River terraces near Farnham were also rich sources of Palaeolithic material in the early 20th Century, summarized by Henry Bury and Kenneth Oakley. Derek Roe recognized an assemblage attributable to his Group V (see Table 1) in the highest of the Farnham terraces, designated 'A' (Figure 3).

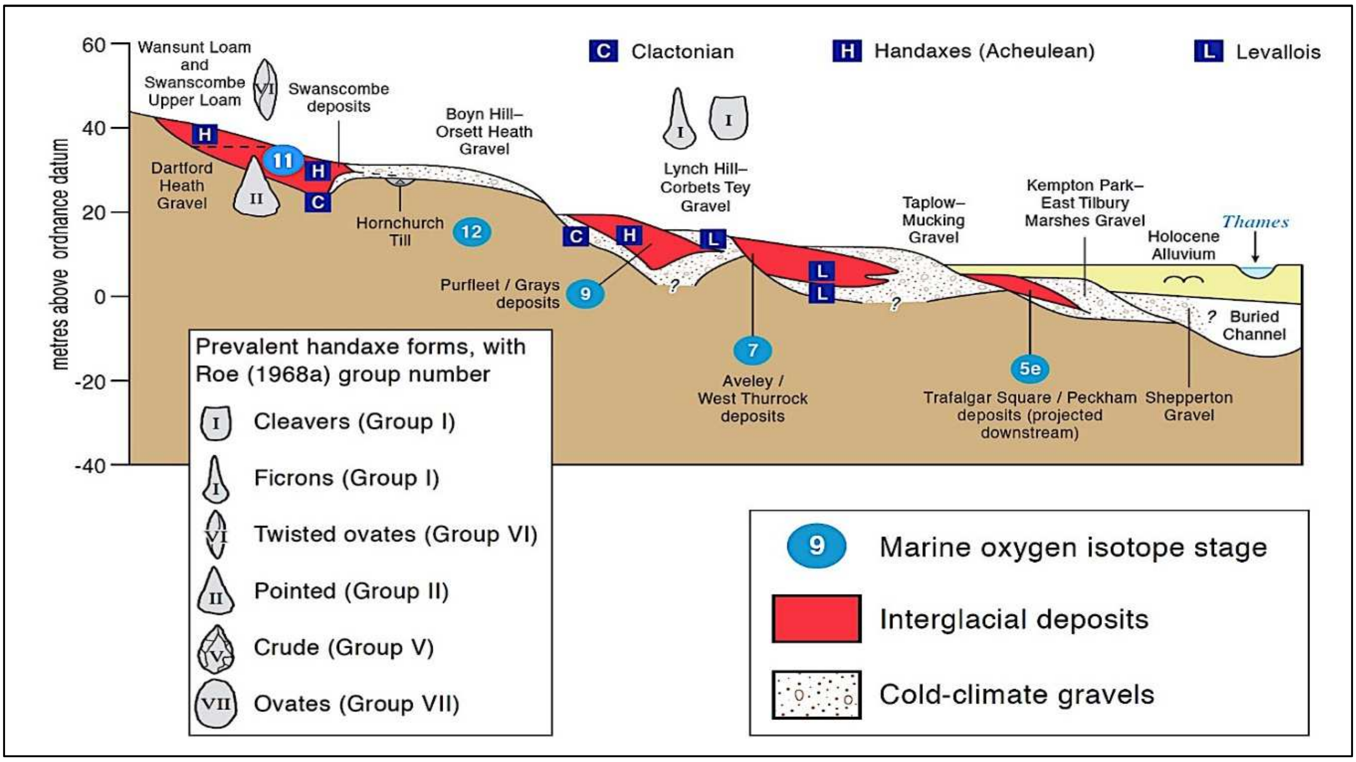


Fig. 1: Idealized cross section through Pleistocene terraces in Lo. Thames, E of London, showing cold-climate gravels & interglacial sediments, formed by fluctuations between glacial & interglacial climate in the Quaternary. Marine oxygen isotope stages (MIS) for different sediment parcels are shown, from MIS 12, the greatest British glaciation (~450Ka ago) to MIS 5e, the early part of stage 5, the youngest of 4 interglacials represented here (warm periods have odd numbers, the Holocene is MIS 1). Also shown are different archaeology types, note Derek Roe hand axe groups.

Although no other material from Farnham was considered to represent a high-integrity assemblage, it is apparent that hand axes from the next oldest terrace ('B') resemble those from the Boyn Hill Terrace of the Thames, e.g. at Swanscombe and those from Terrace 'C' resemble those from the Lynch Hill Terrace of the Thames. Furthermore, Levallois technology appears in the next terrace ('C') and is well developed in the next ('D'), inviting comparison with the Lynch Hill and the Taplow of the Tames, respectively (compare with Figure 1). Thus there is a valuable Palaeolithic record from the Farnham terraces, one that is potential value as a means of correlation with the main River Thames (only attempted previously by projection of terrace remnants along longitudinal profiles of the river system).

Fig. 2: Similar diagram to Figure 1, but showing the sequence W of London, where older terraces are preserved. For further explanation, see full description in text of Figure 1.

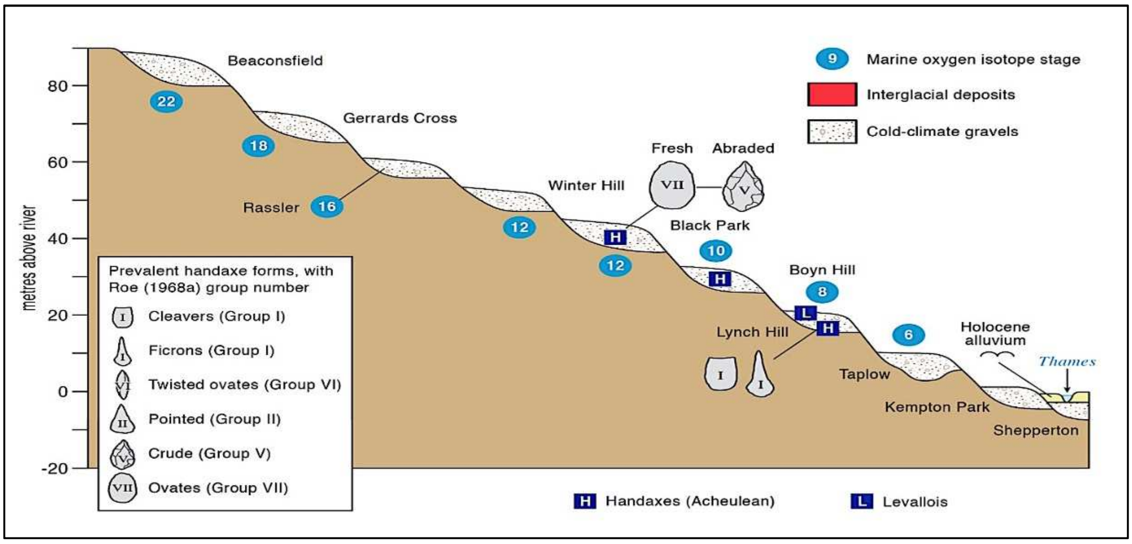
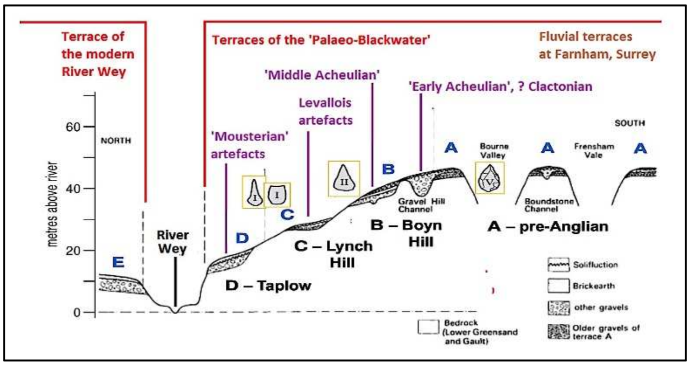


Fig. 3: Cross section through the Blackwater / Wey terraces at Farnham, showing Palaeolithic material that characterizes certain levels (see caption to Figure 1). Updated from John Wymer's 'The lower Palaeolithic Occupation of Britain' (1999).



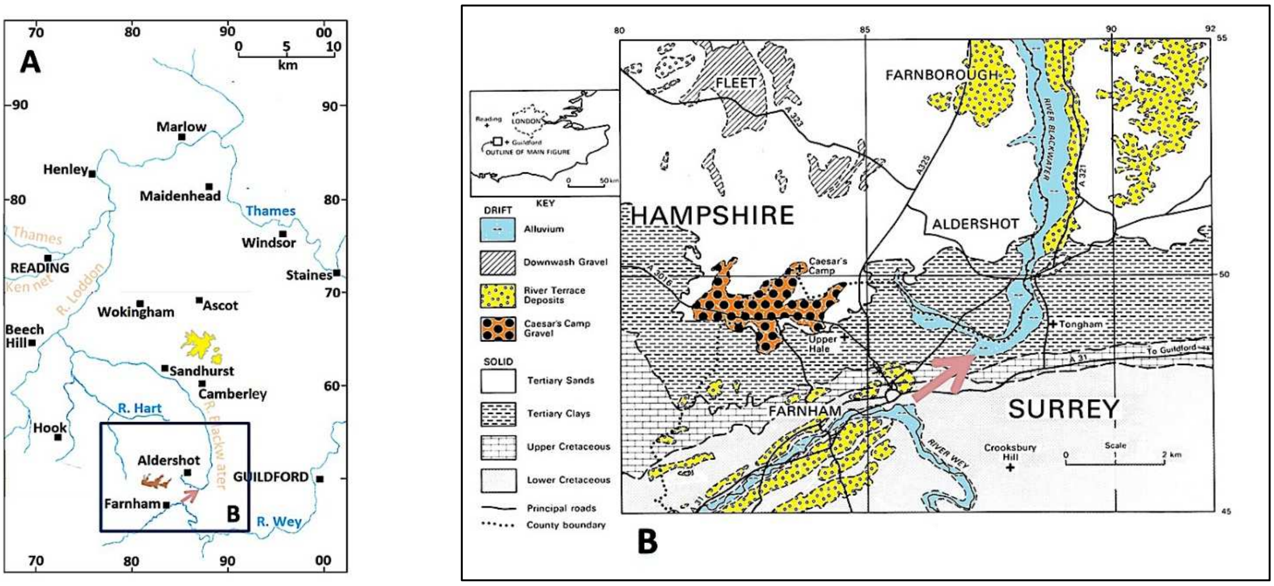


Fig. 4: The Farnham terraces in relation to the Thames drainage system SW of London. The former drainage route of the Farnham Wey into the Blackwater is arrowed. A – drainage in the wider region; B – geology of the Farnham–Aldershot area.

A complication in Figure 4, is that when these terraces were formed on the floodplain of the river system at Farnham when this was the headwater stream of the River Blackwater, which is now confined to the area to the north of the Chalk outcrop. It was recognized by Bury (amongst others) that the Farnham stream was 'captured' from the Blackwater by the River Wey (Figure 4), between the formation of Terraces D and E, an interpretation supported by the copious amounts of Lower Greensand clasts within the older terrace deposits of the Blackwater system, clearly derived from the Lower Cretaceous strata of the Farnham area.

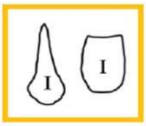
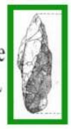
←	Pointed tradition	→	←	Ovate tradition	→
Group I (with cleavers)	Group II (with ovates)	Group III (plano-convex)	Group V (crude, narrow)	Group VI (more pointed)	Group VII (less pointed)
MIS 9–8 Furze Platt Bakers Farm Cuxton Stoke Newington 	MIS 11 Swanscombe MG Chadwell St Mary (Hoxne UI) Dovercourt Hitchin (Foxhall Road Red Gravel) 	MIS 9 Wolvercote 	MIS 15–13 Fordwich Farnham terrace A Warren Hill worn (Kents Cavern Breccia) 	MIS 11 Elveden Bowman's Lodge Swanscombe UL (Wansunt) (Foxhall Road Grey Clays) (Hoxne LI) MIS 13–12 Caversham Middle Palaeolithic Shide, Pan Farm Oldbury 	MIS 13 High Lodge Warren Hill fresh Highlands Farm Corfe Mullen (Boxgrove) 

Table 1: Derek Roe's hand axe groups, showing updates based on the work of Mark White (Durham Archaeology).

The Biggest Volcano on Earth

Summary of talk given by Dr. Julie Prytulak, Senior Lecturer, Imperial College London

This lecture focused on large igneous provinces (LIPs) and explored why they do not necessarily conform to conventional locations of magma genesis based on plate tectonics. The lecture introduced the International Ocean Discovery Program and Expedition 324 to the Shatsky Rise LIP as one of the most effective ways of sampling the rocks hidden beneath the ocean floor. One of the most publicized results of Expedition 324 was the discovery of arguably the largest single volcanic edifice on Earth.

LIPs are defined having magmatic volumes of over 100,000 km^3, emplaced during a relatively short time (i.e. a few Ma). Some more famous examples include the Parana-Etendeka Province, which was instrumental in linking the South American and African continents, the Deccan flood basalts in India and the Siberian Traps in Russia. On land, LIPs often have distinct jointed columnar basalts (Figure 1).

The existence of LIPs without a clear link to a plate boundary like mid-ocean ridge basalts, 'hotspot' ocean island basalts, or subduction-related arc basalts, makes them problematic to explain with conventional plate tectonics. One of the more popular theories is that they represent the first impingement of a deep thermal mantle plume on the overriding plate. An entire cottage industry has sprung up which tries to link LIPs with a trail of subsequent hotspot-related ocean islands (Figure 2).

However, there are those that doubt the very existence of mantle plumes (see www.mantleplumes.org/ for some intriguing debates) and instead propose that the outpouring of LIPs may be related to shallow, compositionally driven, mantle melting. Thus resolving the origin of LIPs has profound implications for our understanding of how the Earth works.

All of the more recognizable examples of LIPs given above are on land. However, the ocean floor also boasts a wide array of LIPs and is comparatively unexplored. One of the few ways in which high fidelity sampling of the ocean floor is achieved is through scientific ocean drilling.

The first organized international effort to drill the ocean floor was Project MoHole from 1958 to 1966 - before the acceptance of plate tectonics. This endeavour aimed to drill through the mohorovicic (Moho) discontinuity – the boundary between crust and mantle defined by geophysical information. Sadly, this goal was not realized, however, the work spawned the Deep Sea Drilling Project (DSDP; 1966 to 1985). It also should be noted that there are currently continued efforts to penetrate and recover samples from this key boundary in the interior of the Earth (see Witze, 2015).

DSDP was followed by the Ocean Drilling Project (ODP: 1985 to 2004), the Integrated Ocean Drilling Project (IODP: 2004 to 2010) and the current iteration of the International Ocean Discovery Program (IODP: 2010 to present day), see Figure 3. The spirit of international, multi-disciplinary research that permeates these expeditions is without doubt some of the best practice that science has to offer. The results of these expeditions have lead to transformative understanding of how the Earth works, including 'ground-truthing' mid-ocean ridge spreading and thus confirming one of the corner stones of plate tectonics. The IODP has an incredibly useful number of resources available at its website (www.iodp.org), which includes free access to all initial scientific reports from the history of the program. One can clearly spend days perusing the wealth of information the IODP has to offer.

Fig. 1: Example of Columnar Basalts on the Isle of Staffa, Scotland. (Photo: J. Prytulak, 2017).

Fig. 3: (opposite) Current Infrastructure of IODP.

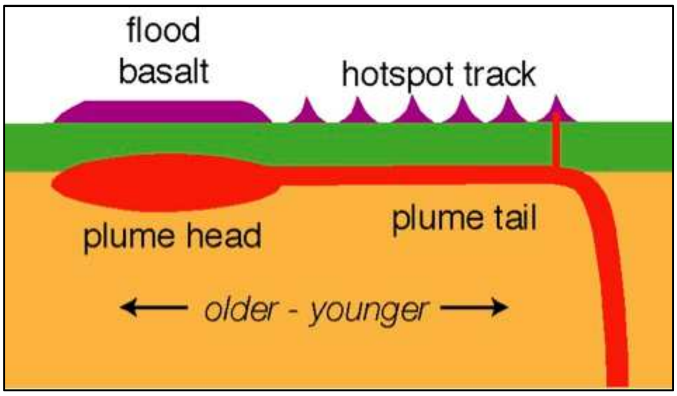
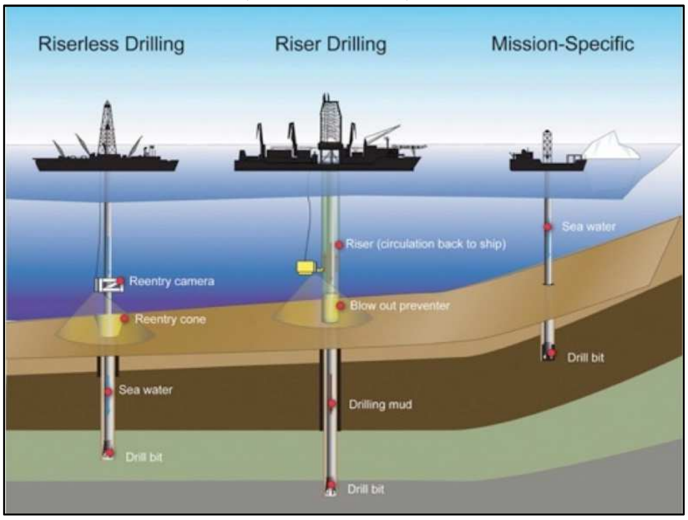


Fig. 2: Schematic of Flood Basalts in a LIP, Resulting from the Arrival of the Plume Head, Followed by a Trail of Hotspot Basalts from the Tail of the Plume.



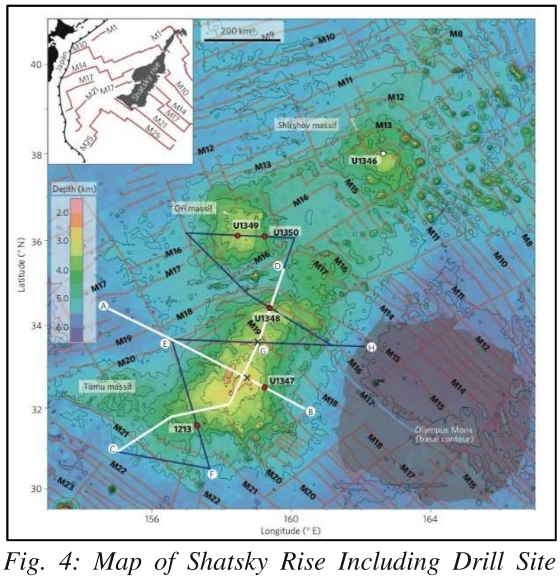


Fig. 4: Map of Shatsky Rise Including Drill Site Locations and Magnetic Lineations (from Sager et al. 2013).

Fig. 5: 'Before and After' photo of Styrofoam Cups that were lowered to >3 km water depth at Shatsky – they shrank, and were then returned to the surface (Photo Credit: J. Prytulak)

This lecture also gave some insight into what it is like to participate as a scientist on an IODP cruise in terms of the day-to-day, 12-hour shifts, for 8 weeks, with no breaks. An intensive environment to be sure, but also an extremely scientifically rewarding experience. The lecture brought together the challenges we have in understanding the origin of LIPs with the technical abilities of the IODP by discussing Expedition 324 to the Shatsky Rise, a LIP in the Northwest Pacific ocean. Shatsky consists of >2.5 million km^3 of lava and covers an area larger than the British Isles (Figure 4). Its highest point is currently >2km below the surface of the ocean.

Shatsky is ideally suited to testing whether it originated from shallow mantle processes, thus arguing for compositionally driven melting, or if there is chemical evidence for the involvement of a deep thermal mantle plume to initiate mantle melting. Specifically, we sought to play a matching game where we can measure the isotope composition of the lavas and see if they look like mid-ocean ridge basalts, arguing for a shallow origin, or if they look more like ocean island basalts, arguing for the involvement of a mantle plume. One of the most unique features of the Shatsky Rise it that it lies at a fossil triple junction, the timing of magmatic activity can be precisely reconstructed via magnetic lineations of the three plates. This is not possible in other oceanic LIPs like Kerguelen, which erupted during the Cretaceous Quiet Period, a time when reversals of the Earth's magnetic field were infrequent.

Drilling the Shatsky Rise was no small task, as it is one of the most isolated areas on the planet, lying approximately equidistant from Japan and Hawaii. Sailing during the typhoon season also introduced some hazardous aspects to the expedition. Once situated above the Shatsky Rise, Expedition 324 then had to drop a drill pipe through >3 km of water to reach the ocean floor (see Figure 5), core the lavas, and return those precious samples to the surface.

Expedition 324 recovered over 580m of lava from Shatsky and their samples are the focus of ongoing research. Intriguingly, the isotope composition measured on the lavas is most similar to mid-ocean ridge basalts (See Heydolph et. al. 2014). Combined with geochemical data, is the fact that the Shatsky Rise lies at a fossil triple junction. The odds of a mantle plume arriving by chance at such a triple junction seem unlikely, with a probability of 0.4%. On the whole, most of the evidence at Shatsky points to a shallow mantle origin. That is not, however, to say that mantle plumes do not exist. The evidence for an active plume under Hawaii, for example, is overwhelming.

Finally, as is often the case, the most publicity received from this cruise was from an unexpected result. LIPs on land are usually characterized by linear fissure eruptions over a wide area. On Shatsky, detailed seismic reflection work by co-chief Will Sager reconstructed one of the massive parts of Shatsky – the TAMU massive - and argues that it is a single volcanic edifice (Sager et al., 2013). If true, this makes the TAMU massif of the Shatsky Rise the largest volcano on Earth!

For more information on IODP and the UK's involvement, please visit: https://www.bgs.ac.uk/iodp/home.html & https://www.iodp.org and Results from Expedition 324: http://publications.iodp.org/proceedings/324/324title.htm

References

Heydolph, K., Murphy, D.T., Geldmacher, J., Romanove, I.V., Greene, A., Hoernle, K., Weis, D., Mahoney, J. 2014. Plume versus plate origin for the Shatsky Rise oceanic plateau (NW Pacific): insights from Nd, Pb and Hf isotopes. Lithos, 200-201, 49-63.

Sager, W.W., Zhang, J., Korenaga, J., Sano, T., Koppers, A.A.P., Widdowson, M., Mahoney, J.J. 2013. An immense shield volcano within the Shatsky Rise oceanic plateau, northwest Pacific Ocean. Nature Geoscience, 6, 976-981.

Witze, A. 2015. Drill ship targets Earth's mantle. Nature, 528, 15-17.

Ardalanish Bay, Mull

Reported By Sally Pritchard, FGS Member – FGS Field trip May 2017

Ardalanish Bay is a site of Special Scientific Interest and lies in South West Mull, south of Bunesson and a short walk from our excellent hotel. The wide beach hosts a variety of rock types and walking eastward from the central access path we first encountered interbedded metasediments of clay based pelites some of which are garnetiferous, banded with psammites glistening with muscovite mica. These belong to the Ardalanish Striped and Banded Formation and represent low grade metamorphism of a sedimentary sequence of clays with sandstones, probably deposited 1000 – 870 Ma ago. In places these rocks, part of the Assapol Group of the Moine Supergroup (Neoproterozoic) adjoin masses of darker garnet rich amphibolites, the porphyroblasts of garnet ranging up to 4mm in size (see Figure 1).

Within some outcrops there are small-scale features of intense folding. The presence of the amphibolites is interpreted as being the metamorphosed equivalents of sheets of basic igneous material, probably dolerite that have intruded the sequence.

Further E along the beach, outcrops reveal remarkable evidence of folding producing 45° to near vertical beds. Within these structures, secondary folds occur. The more competent, coarser psammitic metasediments show more open folds of low amplitude and the less competent, pelitic ones, tight almost isoclinal folds with smaller, minor folds on their limbs (Figure 2). Whilst boudinage features in some vertical beds, where tension gashes have developed, give a 'nipped in waist' structure (Figure 3).

Fig. 1: Striped and banded formation.

Fig. 2: Minor folds on limb of larger fold.

Fig. 3: Boudinage structure as bed extends along fold limb.

Fig. 4a: Synform.

Fig. 4b: Ptygmatic folds on limb of synform in Fig. 4a.

Fig. 5: Crush zone on N side of gulley obliterates one limb of fold.

In places, prominent axial planar cleavage can be seen in the more pelitic units especially in the hinge zones of folds. Still further eastward, in a gully, is a synform which has ptygmatic folds on its E limb (Figures 4a and 4b). 0n the W limb, graded beds act as a way up indicator proving the fold is the right way up. On the S side of the gully a crush zone showed faulting out of the fold limb adjacent to the synform which has been completely obliterated on the N side of the gully (Figure 5). Psammitic beds nearby, exhibit parallel tension gashes at right angles to the bedding planes and are partially infilled with quartz (Figures 6a and b).

Towards the back of the beach, on our return to our hotel, a meticulous search was made of a large outcrop for the new minerals produced by high grade regional metamorphism (blue kyanite crystals, which form at very high pressures during regional metamorphism). We were rewarded with sightings of possibly pink andalusite (Figure 7), replacing the kyanite, as a result of the thermal metamorphism effects caused by the emplacement of the nearby Ross of Mull Granite in the Devonian during the Caledonian Orogeny (andalusite forms in a low pressure environment with moderate temperatures during thermal metamorphism). They are both forms of the alumino silicate, Al_2SiO_5.

Fig. 6a: Quartz tension gashes reflect local extension on limb of fold.

Fig. 6b: Close up of quartz tension gash

Fig. 7: Close up of blue kyanite,; elsewhere it is replaced by andalusite from thermal metamorphism.

Meteorites, Craters And Astroblemes
Researched and Summarized by Liz Aston

As huge meteors or comets have been identified and blamed for at least one mass extinction (the K-Pg boundary mass extinction and the end of the dinosaurs etc.) I thought it worth looking into just how many examples there are in the literature. But first I will give a clarification of frequent terms, using Wikipedia descriptions*:*
"A ***meteoroid****: a small rocky or metallic body in outer space. Meteoroids are significantly smaller than asteroids, and range in size from small grains to 1m wide objects. Objects smaller than this are classified as* ***micrometeoroids*** *or space dust. Most are fragments from comets or asteroids, whereas others are collision impact debris ejected from bodies such as Moon or Mars".*

When a meteoroid, comet, or asteroid enters Earth's atmosphere at a speed typically >20 km/s, aerodynamic heating of that object produces a streak of light … called a ***meteor*** *or 'shooting star'. A series of many meteors appearing seconds or minutes apart … is called a meteor shower. If that object withstands ablation from its passage through the atmosphere as a meteor and impacts with the ground, it is then called a* ***meteorite****.*

An estimated 15,000 tonnes of … different forms of space dust enter Earth's atmosphere each year."

Other terms are*:* ***Bolide****: a large (usually >10km diameter), brilliant meteor, especially one that explodes; or fireball* and ***astrobleme*** (*'star wound'*) or ***impact crater:*** the name for the scar on the Earth's surface left by the impact of a major meteor or comet - an eroded remnant of a huge crater. Most old impact craters on Earth are eroded or buried and masked, unlike the pristine craters of the Moon and other terrestrial planets. However, they may still be recognizable by their geological character and confirmed by associated shocked quartz, shatter cones, extra-terrestrial material, subsurface mapping or geophysics.

Impact craters are now accepted geological features within the Solar System the impact event at the K-Pg boundary and the collision of Shoemaker-Levy 9 comet with Jupiter have proved such collisions are a significant process. This process differs from other geological processes (e.g. volcanism) by the extreme speeds, pressures, temperatures and high strain rates involved, and by the almost instantaneous nature of the impact. Just 186 definite impact structures are recognized on Earth (Figure 1). Other 'circular' structures are deemed to be of uncertain origin as there is no evidence of shock deformation or traces of extra-terrestrial matter.

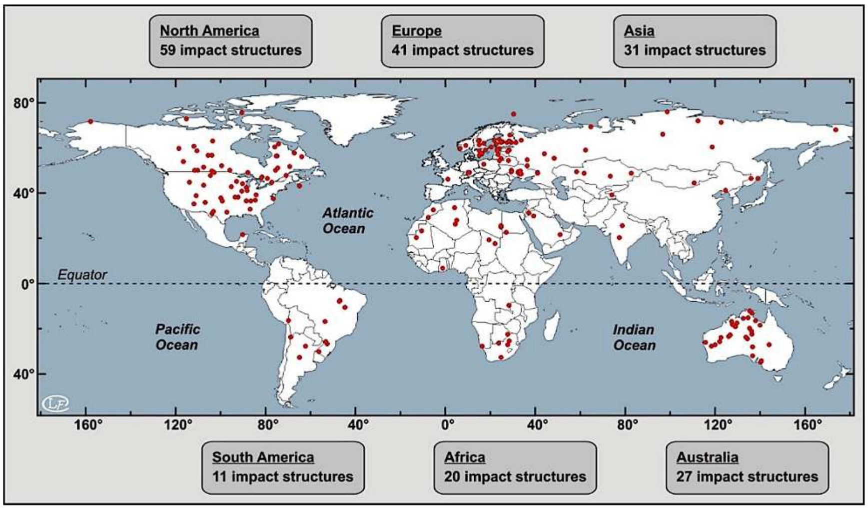


Fig. 1: The Distribution Of Known Astroblemes Across The Globe.

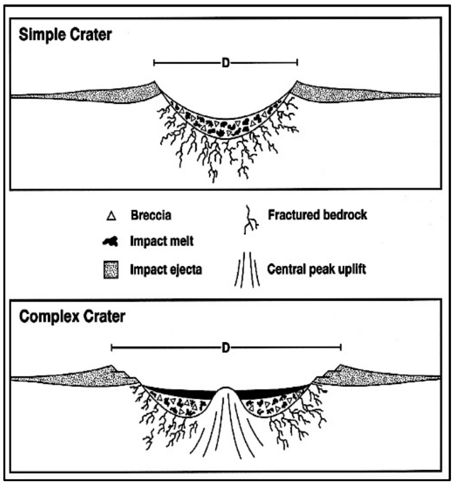


Fig. 2: Simple & Complex Craters

The oldest craters are the Dhala crater (1.6-2.5 Ga), the Suavjärvi crater ~2.4 Ga and the Vredefort Dome 2.02 Ga. The youngest known craters are Sikhote Alin (1947) 27 m in diameter and Wabar (~1725) ~116 m in diameter. No large impact crater (i.e. >100 km diameter) has formed within the last 1,000 yrs.

The craters on the Moon and terrestrial planets, Mars, Venus, and Mercury have provided morphological details of the different types of craters – and these are discussed first.

Lunar Crater Morphology From: Lunar and Planetary Institute, Centre for Lunar Science and Exploration http://www.lpi.usra.edu/exploration/training/illustrations/craterMorphology/

Simple Craters: If the crater is <20 km, the crater is a simple bowl-shaped and lowest on the structure scale. The bowl walls succumb to gravity leaving a partially filled floor with rim debris and melt rock. This is the most common crater in the 10-20 km range. A good example is 15km Hortensius, between Kepler and Reinhold.

Complex craters exhibit structures such as central peaks, inner terraced rim walls and outer concentric faulted zones. These craters are thought to be from the collapse of a simple, bowl-shaped ‘transient crater’, which forms immediately after impact; but the extreme impact energy compresses and melts the underlying surface causing it to rebound into a central peak system. The crater wall takes on a terraced structure breached by vents as radial facture zones or concentric faults. Central peaks occur in craters >15 km, but may disappear if >200km diameter when inner mountain rings occur. Examples are Triesnecker and Tycho.

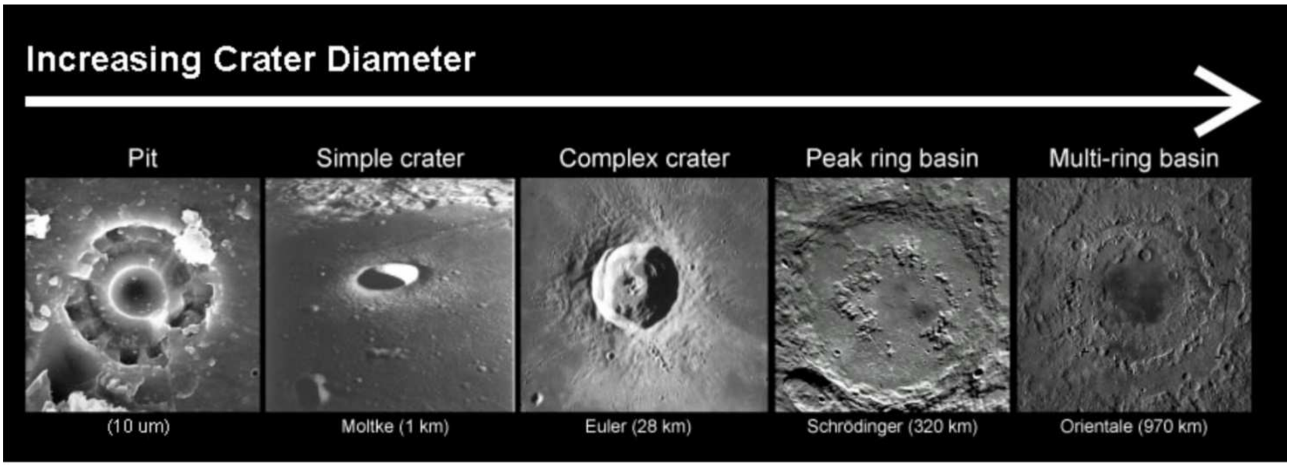


Fig. 3: Crater diameter sizes: (a) 10μm pit on ~465μm-diam’ spherule, Luna 16 landing site; (b) Simple: 1km crater called Moltke; (c) Complex: 28km crater called Euler; (d); 320km Peak ring impact basin called Schrödinger; and (e) 970km Multi-ring impact basin called Orientale. (Hartung, Hörz, McKay, and Baiamonte, 1972) Image Credit: LPI (Priyanka Sharma)

Craters on Earth: On Earth just simple (bowl-shaped) craters and complex impact craters (a central uplift, a flat floor, and inward collapse around the rim) occur as shown in Figure 2. The larger craters are often filled by impact breccias. On the other planets, much larger structures, x00–x000 km and multi-ring basins occur. Astroblemes are not related to the small impacts but to the major craters and structures associated with massive meteors (bolides) – several km in diameter. Two impact craters from Canada and one from S Africa are discussed below.

Fig. 4: Pingualuit crater, Nunavik, N Quebec, Canada. It contains a lake named Lake Pingualuk.

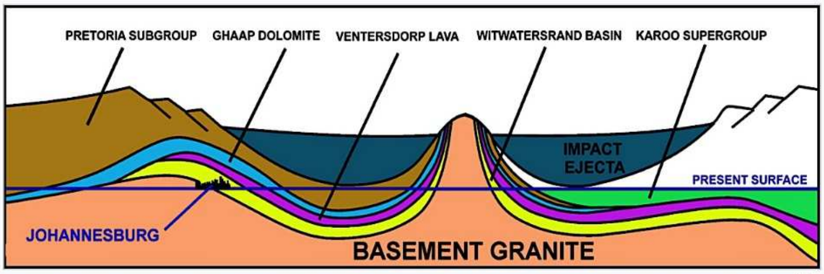
A Simple Bowl-shaped Crater: The Pingualuit Crater, Quebec

The Pingualuit crater was formed by a meteor impact 1.4Ma ago, the melt rocks showed planar deformation features. The Ir, Ni, Co and Cr enrichments found in impact melt samples suggest that the meteorite was chondritic in nature. The crater is 3.44 km in diameter, rising 160 m around the rim above the surrounding tundra and is 400 m deep. The lake fills the hollow, and is one of the deepest lakes in North America.

The lake has no inlets or apparent outlets, so water accumulates from rain and snow and is only lost through evaporation.

An Astrobleme: The Vredefort crater in South Africa is the largest verified impact crater on Earth (Figures 5, 6). The crater is estimated to be ~2 Ga old and lies on the ~3.9Ga Kaapvaal craton. It is one of the few multiple-ringed impact craters on Earth, larger than the Sudbury Basin (250km) or Chicxulub Crater Mexico, (180km).

The original crater had a diameter of ~300 km (now eroded away) with a partial ring of hills 70 km in diameter - the remains of a dome created by the rebound of rock below the impact site. The 40 km diameter centre of the Vredefort crater consists of a granite dome, where the liquefied rocks splashed up in the wake of the meteor as it penetrated the surface. The asteroid that hit Vredefort is estimated to have been one of the largest ever to strike Earth (ca. 10–15 km in diameter). The bolide that created the Sudbury Basin could have been even larger.



A schematic diagram of a NE (left) to SW (right) cross-section through the 2020 million year old Vredefort impact crater and how it distorted the contemporary geological structures. The present erosion level is shown. Johannesburg is located where the Witwatersrand Basin (the yellow layer) is exposed at the "present surface" line, just inside the crater rim, on the left. Not to scale.

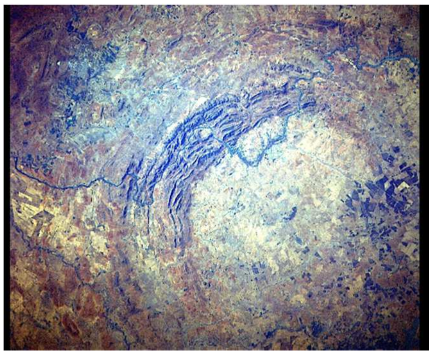


Fig. 5 (Left)
Fig. 6: Above: The Vredefort Crater from Google Earth

The impact distorted the Witwatersrand Basin quartzites and ironstones (~3 Ga), the Ventersdorp lavas and the younger Transvaal Supergroup (2.65-2.05 Ga) which include the Ghaap Dolomite. These rocks form partial concentric rings round the crater at distances from ~35 km from the centre.

From about halfway through the central area, the order of the rocks is reversed. Moving outwards towards where the crater rim used to be, the Ghaap Dolomite group resurfaces at 60 km from the centre, followed by an arc of Ventersdorp lavas, beyond which, at between 80 and 120 km from the centre, the Witwatersrand rocks re-emerge to form an interrupted arc (see the cross section diagram above).

An astrobleme: The Archaean Sudbury Igneous Complex, ~1.85 Ga, is an impact melt sheet in Canada (Figure 7). It is part of the Sudbury Basin impact structure, and is usually classified as a lopolith, an intrusive igneous body however it is a melt sheet which formed as the result of a bolide impact, not a magmatic intrusion.

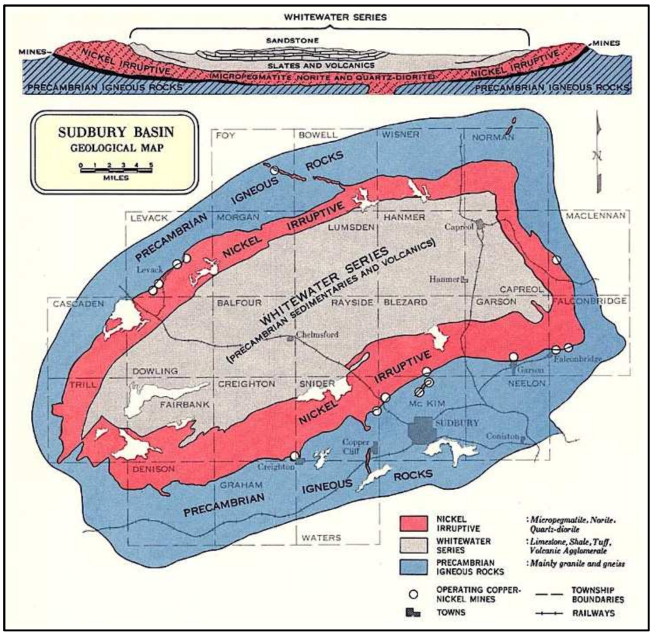


Fig. 7: Left: Geological map of Sudbury Basin

The Sudbury Structure is located on the Canadian Shield in the city of Greater Sudbury, N Ontario. It is dated at 1.85 Ga in the Paleoproterozoic Era. The full extent is 62 km long, 30 km wide and 15 km deep, although the modern ground surface is much shallower.

The basin formed as a result of an impact into the Nuna supercontinent from a bolide ~10–15 km in diameter. Debris from the impact was scattered over an area of 1,600,000 km^2, thrown >800 km (rock fragments ejected by the impact have been found as far as Minnesota).

Models suggest that for such a large impact, debris was most likely scattered globally. Its present size is believed to be a smaller portion of the 250 km round crater that the bolide originally created. Subsequent geological processes have deformed the crater into the current smaller oval shape.

Sudbury Basin is the second-largest impact crater on Earth, after the 300 km Vredefort crater. It has several main units which are:

- the Sudbury Igneous Complex (SIC), the Whitewater Group, and footwall brecciated country rocks that include offset dykes and the Sub layer.
- The SIC is a stratified impact melt sheet composed of a sub layer norite, mafic norite, felsic norite, quartz gabbro, and granophyre.
- The Whitewater Group - a suevite *(a breccia of glass, crystal or lithic fragments & partly melted material, formed during the impact event)* and sedimentary packages - fallback breccias and carbonaceous sediments of meteorite origin.

- Footwall rocks, associated with the impact event, consist of Sudbury Breccia (pseudo-tachylite), footwall breccia, radial and concentric quartz dioritic breccia dykes (polymict impact melt breccias), and the discontinuous sub-layer.

The Sudbury structure has been deformed by 5 main orogenic events between 1.89 Ga and 1.0 Ga and a later impact at 37 Ma. Because of these events and eons of erosion, it is difficult to constrain the actual size of the Sudbury crater, neither the diameter of the original transient crater, nor the final rim diameter.

The meteor impact features include shatter cones, shock-deformed quartz crystals in the underlying rock. Analysis of the concentration and distribution of siderophile elements as well as the size of the area where the impact melted the rock indicated that a comet rather than an asteroid most likely caused the crater.

The crater filled with magma containing Ni, Cu, Pt, Pd, Au and other metals and Sudbury is one of the world's largest suppliers of Ni and Cu ores. Most of these mineral deposits are found on the outer rim of the basin.

FGS Monthly lectures 2018

12th January	John Williams FGS Member Graham Williams FGS Chairman	Quarrying The magnetism of Geology
9th February	Dr Chiara Petrone Natural History Museum	Danger and Beauty of Explosive Volcanoes
16th March **3rd Friday**	Dr Paul Taylor Natural History Museum	The Beringer Fossil Fraud
20th April **3rd Friday**	Dr Paul Kenrick Natural History Museum	The Evolution of Land Plants
18th May **3rd Friday**	Dr Zoe Mildon Plymouth University	Earthquakes and Active Faults in Central Italy
8th June	Dr Graziella Branduardi-Raymond University College, London	Space research on Surrey Hills
13th July	John Lonergan Consultant	Influence of Geology on Transport Routes around Farnham
August	No Meeting	
21st September **3rd Friday**	Dr Ian Williamson Consultant	Life & Landscape during the Formation of the Palaeocene Lava Fields of the Hebridean Igneous Province.
12th October	Dr Susannah Maidment University of Brighton	How To Weigh A Dinosaur
9th November	Emeritus Professor Andy Gale Portsmouth University	The Cretaceous World – Living in a Greenhouse
14th December	Professor Chris Jackson Imperial College, London	Jungle Volcano in the Congo

FGS Field Trips 2018

Thursday - Sunday April 26-29th	Geology of the Glamorgan Coast	An Exploration Led by Dr Graham Williams
Sunday – Thursday May 13-17th	The Roots of the Hercynian Mountains	Metamorphosed Devonian Marine Sediments Led by Mark Eller
Sunday June 10th	Regionally Important Geological Sites (RIGS) Around Godalming	A Beginner's Guide to the Local Rocks Led by Dr Graham Williams
Sunday July 15th	RIGS Around Guildford and Albury	More Local Rocks Joint Meeting with Reading Geological Society
Sunday August 12th	Fossil Hunting in Sheppey	55Ma Old Tropical Plants and Animals Led by Fred Clouter
Friday to Sunday September 7-10th	Death of an Ocean	Deposits & Tectonics of a Dying Ocean in Devon & Cornwall Led by Dr Graham Williams
Wednesday October 10th	Old Sarum and Salisbury Cathedral	Building Stones Studies Led by FGS Member John Williams