Farnham Geological Society

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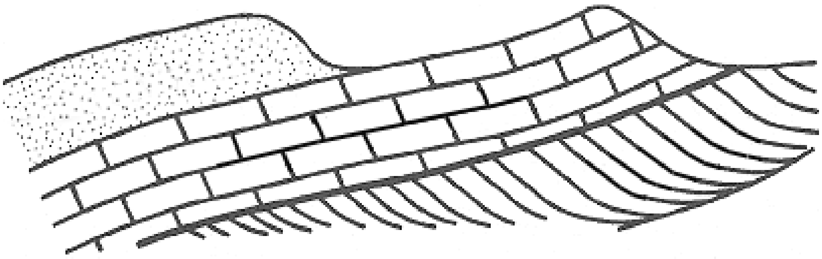

A local group within the GA

Vol. 21 No.3 **Newsletter** October 2018

Issue No: 100

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Editorial

Welcome to the 100th issue of the FGS Newsletter and, almost by way of a celebration, what a lovely summer we have enjoyed; excellent weather for geologists to go on field trips. And, this year there have been the normal rich selection of venues with local rocks and important geological sites around Godalming, Guildford and Albury, then fossil hunting in Sheppey, then the sediments and tectonics associated with the South West Peninsular and last, a trip to Sarum and Salisbury Cathedral on October 10th.

I am very grateful to those members who have supplied reports of the field trips and would encourage others to help me out; lack of new material has meant that this edition of the newsletter has had to rely on a reprint from an earlier issue to make up the 12 pages!

Liz Aston, Editor

The Society Lunch

Peter Luckham has once again succeeded in securing the lovely venue of the *Frensham Pond Hotel* for the Society's annual lunch. The invitation extends to all members, their families and friends. The details are 18th November, at 12.30 for 1.00 for an all-inclusive price of £28. We hope you will continue to support the Society but if you have any questions please contact Peter by email (p_luckham@yahoo.co.uk).

Earthquakes and active faults in Central Italy

Summary of May 2018 lecture given by Zoe Mildon, University of Plymouth

Regions in central Italy have been struck by several damaging earthquakes in the last few decades, most recently the Abruzzo, Lazio and Umbria regions were damaged during the 2016 central Italy earthquake sequence. From August to October 2016, there were three major earthquakes; the first earthquake occurred on the 24th August, ~300 people lost their lives and the town of Amatrice was badly damaged. Several other smaller villages in the surrounding region experienced near total collapse and damage of residential buildings. Subsequent earthquakes on the 26th and 30th October caused further damage to property and infrastructure, but no further fatalities.

Earthquakes are generated by slip on fault planes, and where fault planes are visible at the surface the slip can be seen as offset slopes. Over multiple earthquakes, offsets can accumulate and form fault scarps that can be several meters high. This happens where erosion rates are lower than the slip rate on the faults and where the bedrock is resistant to erosion. In central Italy, normal faults are well exposed at the surface as sloping, smooth, limestone fault scarps, which can be seen across hillsides throughout the region.

Fault scarps have formed since the end of the Last Glacial Maximum (LGM) ~15,000 years (15Ka) ago because after the end of the LGM, erosion rates reduced so that the slip rate was faster. Therefore offsets in the hillside generated by earthquakes were not eroded away and instead are preserved. Most faults are orientated perpendicular to the extension direction, which is NE-SW across the Italian peninsula.

By conducting fieldwork in central Italy and studying the fault scarps, important data can be gathered that can be used to help inform and estimate the seismic hazard. At small scales of mm or cm, striations can be measured which tell us the direction that faults move and also whether faults close together are behaving as a single fault or as multiple strands. The cumulative offset across fault scarps can be measured by making topographic profiles and interpreting the amount that the hillside is offset vertically - this is called the throw. By combining this measurement with the age of the scarps (~15,000 years), the throw rate on faults can be calculated - these values are typically on the order of 0.5–2 mm/yr. This is important because the throw rate is a proxy for the activity of the fault - a higher throw rate indicates that earthquakes are likely to occur more frequently.

Central Italy also has a long historical record of damaging earthquakes, which is made up of historical written records kept by monks. These records give an indication of dates and times that towns were damaged, as well as the amount of damage (from tiles falling off roofs to whole towns being destroyed). By using a modern-day damage scale called the Mercalli Intensity Scale, the intensity of the shaking for each town can be determined and plotted on a map. This can then be used to calculate the magnitude of the historical earthquake and identify possible faults that may have caused the earthquake, based on the distribution of towns with the highest shaking, which usually cluster around and in the hanging wall of the fault that moves. From historical records, there have been 34 earthquakes with magnitude >5.5 since 1349 A.D. in the central region of Italy. In my research, I use the record of historical earthquakes to model changes in Coulomb stress following earthquakes and use this to try and understand how this affects where future earthquakes occur.

When slip on a fault generates an earthquake, the stress in the surrounding rock volume will change – this is called Coulomb stress transfer. From investigations of earthquakes and associated aftershocks, the idea is that earthquakes are more likely to occur in areas of positive Coulomb stress transfer than negative. Coulomb stress also affects the build-up of stress on faults within elastic rebound theory, and therefore positive stress transfer can increase the stress on a fault and advance the time when the next earthquake will occur. Using this hypothesis, my research looks at the historical sequence of earthquakes in central Italy and models the Coulomb stress changes caused by each individual historical earthquake on a fault with variable geometry (as observed in the field through several weeks of detailed fieldwork). The Coulomb stress transfer from an historical earthquake is compared to the location of the next earthquake to see if the prior events influence where future earthquakes occur.

When individual earthquakes are modelled and the resultant Coulomb stress pattern compared to the locations of the next earthquake, there is not a very strong correlation. Usually the next earthquake to occur does occur on a fault where there has been positive Coulomb stress transfer from the previous earthquake, but often there are faults that have had more positive Coulomb stress transferred, but they have not ruptured. Either that or the magnitude of the stress transferred is very small (<0.01 MPa, or 0.1 bars) which is below the suggested triggering threshold. Therefore the model needs to evolve and incorporate other factors in order to explain the historical earthquake sequence in central Italy.

An additional source of transferred stress that can be considered and modelled is interseismic loading. Underneath the brittle faults in Italy, it is thought that there are ductile shear zones that slip incrementally each year at rates of 0.5–2 mm/yr (based on surface fault scarp offsets). By modelling this incremental slip, this positively stresses the brittle portions of the faults. As well as modelling the interseismic loading, the cumulative stress from multiple earthquakes over time can also be added together. When the cumulative stress is calculated for the historical earthquake sequence, it can explain the location of earthquakes better than by considering single earthquakes alone.

The presence of bends in the faults affects the cumulative Coulomb stress calculated, so the state of stress across a fault plane might be heterogeneous. One example of this is the stress on the Mt. Vettore fault, which ruptured three times on different portions of the fault during the 2016 earthquake sequence. There are two prominent bends along the fault, where the strike of the fault changes by ~20°. Associated with these two bends are regions of the fault where the cumulative Coulomb stress (from 31 earthquakes and interseismic loading since 1349 A.D.) is more negative than anywhere else on the fault plane. These negative regions coincide with the ends of the first two earthquakes that occurred in 2016 (on the 24th August and 26th October) and therefore are thought to represent stress barriers that controlled the rupture extent and therefore the size of the earthquakes.

However it is very important to note that these earthquakes could not have been predicted using this modelling approach, as many other faults in the region had higher cumulative positive stress in 2016 than the faults that ruptured, and therefore would have been identified as more likely to have an earthquake. In the future, the locations of earthquakes that will continue to occur in the region will be studied to test the hypothesis that earthquakes should occur in region of positive cumulative Coulomb stress.

Additional reading

Mildon, Z. K., G. P. Roberts, J. P. Faure Walker, and F. Iezzi (2017), Coulomb stress transfer and fault interaction over millenia on non-planar active normal faults: the Mw 6.5-5.0 seismic sequence of 2016-2017, central Italy. Geophys. J. Int.; 210 (2): 1206-1218. doi: 10.1093/gji/ggx213

Mildon, Z. K., Toda, S., Faure Walker, J. P. and Roberts, G. P. (2016a). Evaluating models of Coulomb stress transfer- is variable fault geometry important? Geophysical Research Letters, 43(24).

Livio, F., et. al, (2016). Surface faulting during the August 24, 2016, Central Italy earthquake (Mw 6.0): preliminary results. Ann. Geophysics, (11): 1–8.

Zoe Mildon

FGS field trip to Devon & Cornwall – 7th to 10th September 2018

Reported by Christine Norgate and Beryl Jarvis

The trip was described as 'the death of an ocean' – the ocean being the Rhenohercynian Ocean and its death being the result of tectonics of the Hercynian Orogeny. The trip was led by Graham Williams and the report has been written up by several of the attendees. The rocks are described under their stratigraphy and the tectonic features are included under locations.

Saturday September 8th by Christine Norgate

Saturday was a day for getting younger. First location, Codden Hill quarries, to look at its Chert Formation (Lower Carboniferous in age) which statigraphically lies above the Upper Devonian Pilton Formation and below the Crackington Formation (Middle-Upper Carboniferous age). Here is a deep, sediment-starved low energy site for deposition. The sediments are thinly bedded (cm), very fine grained, siliceous mudstone and chert with colour changes showing the bedding and many samples were enthusiastically picked up (Figure 1). Interspersed with these layers of mudstone and chert are beds of volcanic ash, bentonite, paler in colour and weathered to a softer texture.

We examined structures where less compacted material is preserved (in nodules) before subsequent compaction. At the second location a large bedding plane showed marked fracture cleavage which could be mistaken for ripple marks.

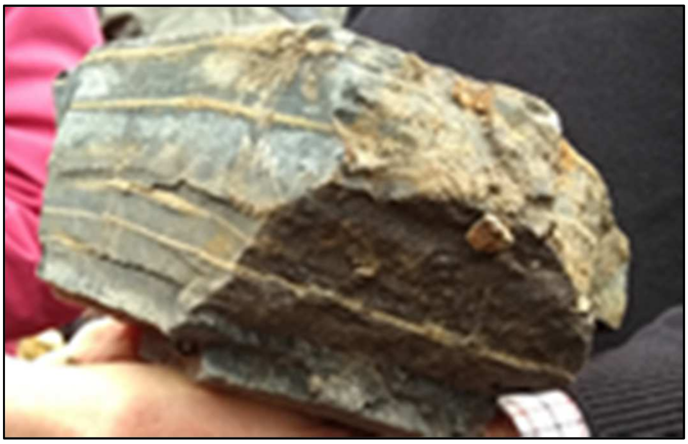


Fig. 1: Siliceous mudstone and chert with colour changes showing the bedding

Fig. 2: Bude beach platform showing thinly bedded sand and silt with some mud.

At Fremington Quay we looked at the load marks on the bases of the beds while other beds showed rippled surfaces on which the succeeding bed was laid down.

Onwards, further south to Westwood Ho, and upwards in the sequence. From the low cliffs we could see in plan view a beach platform showing thinly bedded sand and silt with some mud, Figure 2 (interpreted as delta-front turbidites). These were originally laid down in a lagoon and subjected to a later sudden turbidite event bringing in a separate sandstone layer (Figure 3). These beds have been faulted both parallel to the cliff and, post Variscan, at an angle to this.

Further along the cliff is a large cone-shaped structure of post-glacial mudstones and rounded boulders above a fossilized interglacial wave cut platform. This had been seen by some members of the party as a much larger structure years ago which suggests it will disappear soon.

Our last visit of the day was to Hartland Quay with its 'wow' factor cliff section of folded turbidite sequences. From north to south, thicker beds are folded in curves but thinner ones have the angular broken folds (Figure 4) described as 'chevron' folds by John Ramsey, father of structural geology.

Sunday Sept 9th by Beryl Jarvis

On Sunday we went to locations to see the Upper Carboniferous Bude Formation on Summerleaze Beach and Maer Cliff at Bude; then on to the slightly earlier Middle-Upper Carboniferous Crackington Formation at Crackington Haven further south along the coast.

The beds of the Bude Formation were formed in the shallow equatorial waters of a large lake (Lake Bude) on the northern margin of the Rheic Ocean; this lake represents the last vestiges of the ocean. Sediments were deposited in the river and delta systems of the Bideford Formation that received sediments from the Laurentian continent to the north: these sediments consisted of sands from the eroding continental hard rocks, and mudstones derived from the great Carboniferous forests and also from possible volcanic activity. They rested on top of the earlier Crackington Formation which had been deposited further to the south in deeper oceanic waters.

Fig. 3: A turbidite sequence of interbedded claystones (grey) and a distinct (very pale grey) layer

Fig. 4: Folding at Hartland Quay – note the thicker beds are folded in curves but thinner ones have the angular 'chevron' folding which are often broken.

The continent of Gondwana was at this time approaching from the south thus closing the Great Rheic Ocean and compressing the intervening sediments. All the compression was in a north-south direction and the folded sediments behaved according to their composition: brittle deformation for the competent sandstones and more plastic deformation for the incompetent claystones. *(NB. competent means 'able to hold themselves together'; incompetent is the opposite).*

Luckily the north Cornish coast also ran for the most part north-south so there was a wonderful cross section of folds along the length of the coast to give a real wow factor.

Our task for the day was to recognize four types of sediment association, and from these different rock types, we would be able to work out their depositional environment. The four rocks we were searching for were:

1) Dark grey/nearly black structureless mudstones;
2) Light grey mudstones with thin sandstones;
3) Sequences of amalgamated sandstone beds, forming a layer at least 1m thick; and
4) Disturbed beds.

These facies are characteristic of deep-water turbidite sandstone deposition. The textbook sequence of sediments deposited by a single turbidity or density flow event (known as a Bouma sequence) would be for the heavier (usually grey) sand grade particles to settle out first, followed by progressively finer and finer particles, then a change to lighter greys of the finer siltstone beds, then mudstones and finally the almost black deposits of the carbon-rich organic clay grade particles which are last to settle out of suspension. The association of these sediments makes up the turbidite.

Fig. 5: Amalgamated Sandstone Beds, 15x10 cm. The overlying bed has cut down into and eroded some of the top of the older, underlying bed.

Fig. 6: Flame Structures - heavier, competent, sandstone beds 'pushed down' into incompetent clay beds which squeeze up into the overlying sandstone.

At Summerleaze Beach we were immediately introduced to the energy of the sea and the wind because the flat area that we were walking over had once been sand dunes that had recently been removed by a violent storm. The rocks demonstrated that, similarly, in the past, there had been calm periods, storms, hurricanes and earthquakes with tsunamis; these different conditions had all had their effect on the amount and sequence of sediments deposited.

Studying the cliffs, we saw huge thicknesses of amalgamated sandstones (Figure 5): separate events of heavy thick layers of sandstone that gave an initial impression of solid blocks of sand; however the overlying sandstone bed(s) had eroded into the underlying, older, sandstone layer, removing any finer sediments that had formed the top of the older bed. Closer examination showed that although the top of the previous layer had been ripped away, a residual layer with traces of siltstones/mudstones remained and, in places, had been squeezed up between two beds of sand, forming for instance flame like structures (Figure 6).

Fig. 7: Load casts and groove marks on base of bed – sole structures.

Fig. 8: Carbonaceous Mudstones within Sandstone Sequences.

Where it was possible to see the underneath of a sandstone bed we could see sole marks where the sand had sunk into the softer sediments of the preceding bed (load casts) or where debris had been moved along by the current, gouging into the existing bed and leaving groove marks at the base of the upper flow; these grooves and scratch casts show the direction of movement of the sediment as it was being deposited (Figure 7).

Time scales and energy levels were important. Enormous equatorial rainstorms could bring down lots of muds through the delta/river systems. Given time and lower energy conditions, they would gradually settle out to produce thick black carbon-rich beds of mudstone that were also present at Bude (Figure 8). Over time and with compaction during burial, these had been altered to friable shales. Previously these had been collected by locals as an inferior coal, equivalent to 'nutty slack'.

Fig. 9: Sandstone–Mudstone Sequence.

Fig. 10: Disturbed layers of dark claystone within sandstone beds, interpreted to be caused by storm events.

There were many sequences of light grey mudstones with thin sandstones (Figure 9). Elsewhere we saw a single event leaving a thin sequence of sandstone, siltstone then mudstones followed by several separate sequences of just siltstone/mudstone showing that at times rainstorms had not been energetic enough to transport the heavier sand particles, but had just moved the finer clasts that had settled out before the next rainstorm. You could see finer details of deformations at the top of earlier siltstones when they were disturbed by a subsequent event. At times violent storms had produced very disturbed layers between the sediments (Figure 10).

At the Maer Cliff location, we were able to see the full impact of what compression does to rocks. All sorts of folding was present. Brittle sandstone folding was full of joints, fractures and faults, forming chevron folds, box folds and in places the folds were so tight that one limb had pushed up in relation to the other side and it was an interesting task to follow one particular bed along a sequence of folds.

The sea had slowly eroded the individual beds in the cliffs to form the current beach, which was composed of lines of sharp jagged rocks (the harder beds) running out to sea with beach sand between them in grooves of eroded softer rocks. It was noticeable that beds of the black shale had conveniently worn away and was beautifully smooth, which made walking in these places much easier. In the cliffs the black muds had produced lower angle smoother folds.

In the afternoon we went further south down the coast to Crackington Haven. Here the shales are dominant and marine in origin and said to contain goniatites (no one found any). Any bed of sandstone in this deep-water environment could only have been deposited in very energetic systems such as those produced by earthquakes and thus were interpreted as a distal turbidite sequence.

Fig. 11: Iron beds within claystone sequence

Fig. 12: Claystone/sandstone sequence in faulted subhorizontal chevron folding.

These beds have been buried deeper (beneath the Bude Formation) and there is a lot of quartz veining. There was also iron in the system. We found an interesting layer of nodules, which contained a layer of little crystals of pyrite just beneath the surface of each nodule. Iron had also migrated through the shale beds to form narrow bands (Figure 11). In places the beds had slumped and broken up, or had formed the horizontal chevron folding, sometimes associated with thrusting, as in Figure 12.

Thanks to Graham's patient and continued explanations we became more adept as the day wore on and, by the end, we were doing real detective work - determining the hows, whys, wherefores and whens of the sequences. Before we left the beach at Crackington we had independently found a sequence of rocks that we recognized as presenting an upside down attitude to the world, and what's more, we were able to work out exactly how it had got that way. (I'm sure we were right!)

Space research on the Surrey hills

Summary of June 2018 lecture given by Prof. Graziella Branduardi-Raymont, UCL, London

I would like to start by telling you a few things about the Mullard Space Science Laboratory (MSSL) and University College London (UCL). MSSL is the research base of UCL's Space and Climate Physics Department, and is located on the Surrey Hills (Figure 1), near the village of Holmbury St Mary, some 40 miles south from the main UCL London campus in Gower Street (Figure 2).

Fig. 1: MSSL from the air.

Fig. 2: UCL Quadrangle at Gower Street, London

1953 by Sir Harrie Massey (1908–1983) who used sounding rockets for upper atmosphere research. This field of study expanded so quickly that space was running out on the London campus. In 1965 the Mullard Ltd electronics company made a donation to UCL to establish MSSL. The Holmbury St Mary site was purchased, renovated and formally opened in 1967. We celebrated our 50th anniversary with an Open Day on 9 September, 2017 (Figure 3).

At MSSL we maintain a close coupling between space science and engineering disciplines, and this is facilitated by the co-location of academics and technical staff on a small and rather isolated campus, in a natural and beautiful environment!

UCL is ranked seventh among the world's top universities. It was the first university to be established in England (in 1826) after Oxford and Cambridge; first to admit students of any race, class, religion or gender. To this day it maintains a very liberal and progressive outlook.

MSSL is the largest university-based space research group in the UK, and is a unique interdisciplinary Department within UCL. For a bit of history: The 'Rocket Group' was founded in the UCL Physics Department in

MSSL academics provide teaching for the Department's Master's programmes and to some undergraduate programmes run by other UCL Departments. Through this we ensure effective knowledge transfer of the Laboratory's technology and science base to our students. Training through participation in current projects is also high on our agenda, with students getting directly involved with the state-of-the-art research carried out at MSSL.

The Laboratory has a long and distinguished record of space projects, including many collaborations with the European Space Agency (ESA), NASA, the USSR/Russia, Japan, China and India: nowadays space research is big business and the science missions we develop are not affordable by single institutes and even countries, hence we are most often involved in large international collaborations. Currently MSSL has 16 instruments operating on 15+ satellites in space, enabling research in solar physics, space plasma and planetary science and astrophysics. I say

15+ missions because we are also engaged in a programme of small satellites, and in particular the QB50 mission: this is dedicated to the study of the lower altitude layers of the Earth's atmosphere with numerous CubeSats (very small satellites, some 30x10x10cm^3 in size! Figure 4), each of them built by students and technical staff at different universities all around the world. In total, 36 CubeSats have been launched, with UCL Sat (Figure 5) being the one which MSSL was responsible to develop.

Fig.3: MSSL Common Room & visitors for 50th Anniversary.

Turning to science and to the field of astrophysics in which I work, big news recently was the discovery of electromagnetic (light) emission from the location of a source of gravitational waves (GW). This remarkable result was achieved with observations by the Swift Ultra-Violet/Optical Telescope (UVOT) that MSSL built for the Swift mission. The GW source has been interpreted as a binary neutron star merger and is named GW170817 (from the day of its discovery); it was first identified with a gamma-ray burst, and then by the Swift UVOT detection of a bright, rapidly fading UV source: this pinpointed the location and helped to identify the nature of the merger.

Fig. 4: Deployment of two of the QB50 CubeSats from the International Space Station

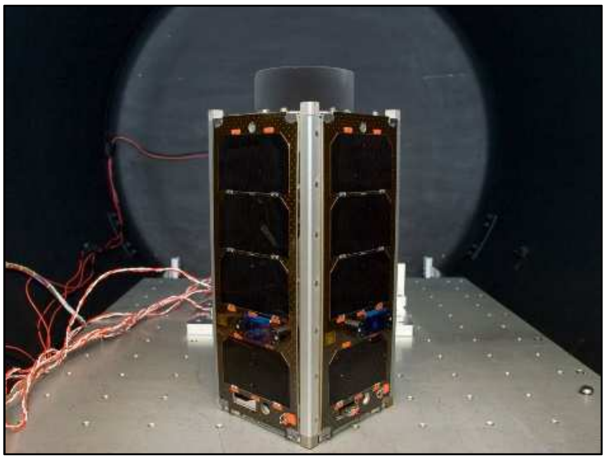


Fig. 5: UCLSat, the UCL Cubesat part of the QB50 project.

My research focuses on X-ray astronomy, on the one hand studying high resolution spectra of Active Galactic Nuclei (galaxies with supermassive black holes at their centres): data from the Reflection Grating Spectrometer (which MSSL contributed to build) on-board the XMM-Newton observatory (launched almost 19 years ago!) reveal the complex structure of absorbing and emitting clouds surrounding the nuclei (Figure 6).

On the other hand I am studying X-rays from planets, focusing on the bright X-ray aurorae (like the 'Northern Lights' we see on Earth but much more energetic) taking place on Jupiter, and also on X-rays which are produced in the vicinity of the Earth's own magnetic field. The Sun is continuously emanating charged particles embedded in magnetic fields and this 'solar wind' propagates through the solar system, also impacting the Earth and its surroundings (Figure 7), producing what we call 'space weather'. This interaction, especially at the arrival of particularly strong Coronal Mass Ejections (CMEs) from the Sun, can have serious consequences on our technological infrastructures, and on human health, in space as well as on the ground. This is why we need to find out more about solar-terrestrial relationships.

In order to improve our knowledge in this field ESA and the Chinese Academy of Sciences have joined forces to develop a mission called SMILE (Solar Wind Magnetosphere Ionosphere Link Explorer) which I am co-leading with my Chinese counterpart Prof. Chi Wang and which will be launched in the 2023 timeframe. SMILE will investigate the dynamic response of the Earth's magnetosphere to the solar wind's impact in a unique and global manner, never attempted before. SMILE will combine X-ray imaging of the dayside magnetosheath and the cusps (through the Soft X-ray Imager, or SXI; Figures 8 and 9) with simultaneous UV imaging of the N aurora and in situ monitoring of the solar wind and magnetosheath conditions, and will do all of this from a very elliptical Earth polar orbit. In this way SMILE will clarify the full chain of events that drive space weather: the injection of the solar wind in the magnetosphere, the onset and development of magnetic storms around the Earth following solar activity and the arrival of CMEs.

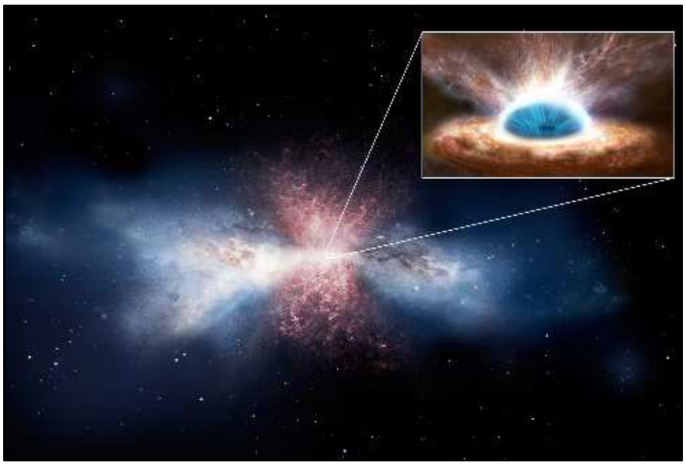


Fig. 6: Artist's impression of an active supermassive black hole at the centre of a galaxy, driving powerful outflows of gas (Credit: ESA/ATG).

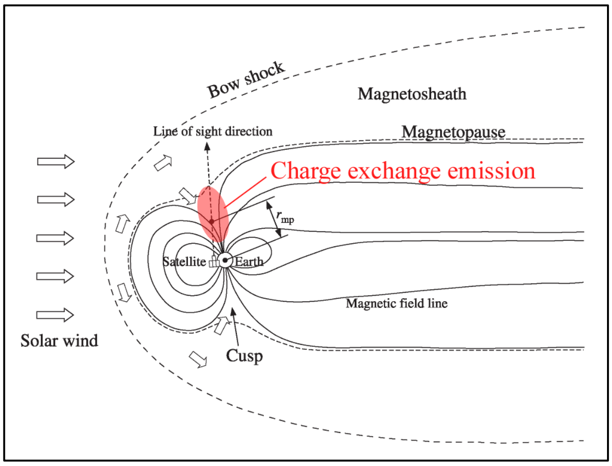


Fig. 7: Earth's magnetosphere with main plasma & magnetic field regions highlighted (from Fujimoto et al. 2007). Charge exchange process produces X-ray emission, particularly on the dayside (L in the picture) magnetosheath and in the cusps.

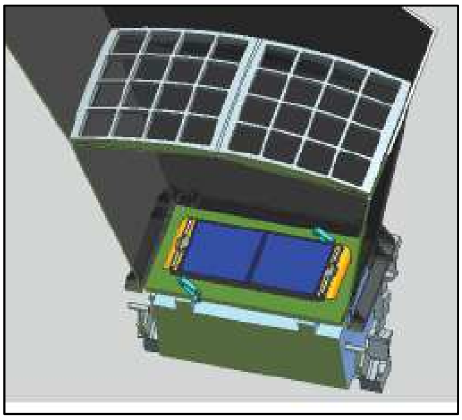


Fig. 8: Schematic representation of the SMILE SXI (from Sembay et al. 2016).

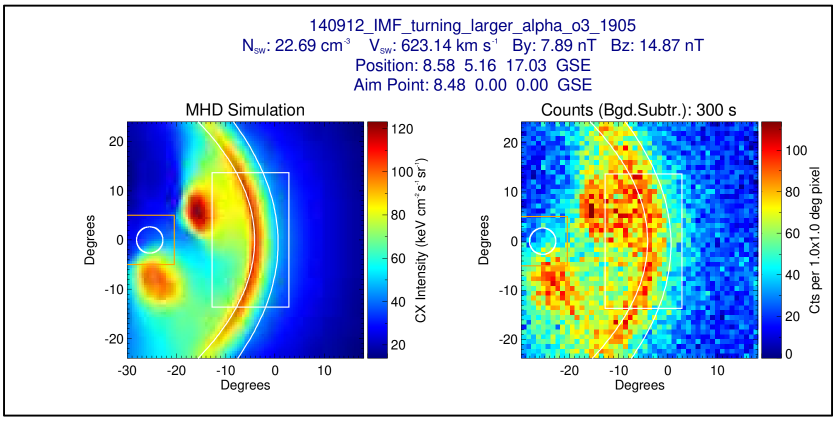


Fig. 9: Simulation of the kind of X-ray images of the magnetosheath and magnetic cusps which will be returned by SMILE SXI.

Fig. 10: SMILE in flight configuration (yellow tanks contain fuel needed to propel spacecraft into its highly elliptical Earth polar orbit).

The impact of SMILE (Figure 10) will be multifaceted: Scientifically SMILE will apply X-ray astronomical techniques to investigating the effects of the dynamic solar wind on the space around the Earth. The data that SMILE will return will lead to a better understanding of space weather and will help characterize it, with the ultimate aim being that of learning how to mitigate its implications on our technological infrastructures. Culturally and societally SMILE will strengthen and broaden our links with the Chinese, their technology base and business. SMILE is also bound to produce important contributions to outreach: the images and videos which it will return will captivate the public to science in general, and in particular to the science of the magnetic field, which has been invisible so far … with great educational potential, especially for the young.

Tiny algae may have prompted a mass extinction

Summary of article published in Nature Geoscience, and reported on the EOS website and Biogeosciences News (details at end).

Analysis of ~444Ma oceanic shales and limestone from Nevada identified compounds derived from chlorophyll with isotope ratios of nitrogen (N) matching those of modern algae. Their analysis suggested that algae must have flourished during the Late Ordovician at the expense of other phytoplankton such as cyanobacteria (which had dominated marine life for the previous billions of years).

The marine life found in Lower Palaeozoic strata, before ~445Ma ago, was rich and was dominated by trilobites, corals, and brachiopods, but it also included surface dwelling species, particularly cyanobacteria and algae. However at ~445Ma ago, most marine life died as the result of a glacial period known as the late Ordovician Glaciation.

However during the Late Ordovician the abundance of the planktonic forms was increasing worldwide; especially the algae, which soaked up atmospheric carbon (C) and stored it in their tissues. The suggestion is that when they died, they sank quickly through the water column and their remains accumulated on the ocean floor leaving the C in the deep ocean sediments. It is further suggested that such algal behaviour may have regulated the Earth's C-cycle. The removal of the C from the atmosphere worldwide would have encouraged global cooling and ultimately widespread glaciation.

These algae were flourishing and were probably larger and heavier than the cyanobacteria. If the algae were larger, they would have been heavier and would have sunk more quickly than the cyanobacteria.

If they were twice as large, then, that could have triggered rapid cooling because the C that the algae were incorporating into their bodies, was, on sinking, accumulating in the sediments. Hence the larger-bodied algae were removing the C from the atmosphere and storing it, on death, in the deep ocean sediment, and doing so a lot faster than when cyanobacteria dominated the oceans; possibly several times faster. The team cannot tell precisely how much larger the algae were vs. cyanobacteria or how much faster they sank, but such a difference would have been sufficient to have an impact.

Their model suggests that atmospheric CO_2 levels would have reduced by 50% and would have caused rapid cooling by several degrees Celsius over just a few Ma.

Their conclusions are that dead algae sinking to the floor of the ocean may have assisted in causing the Late Ordovician glaciation and the associated mass extinction (at 445Ma ago) by the removal of carbon (C) out of the atmosphere and C-cycle with long-term storage of it in the ocean sediments.

Algae may have been "*indirect killers*" and *"Seemingly benign effects, such as primary producer size and organic carbon burial, can magnify [over] geologic intervals of time"*.

Details of the Research

The research was conducted by various scientists, including, Jiaheng Shen and Ann Pearson, Harvard University, and Greg Henkes, Stony Brook University, U.S.A., Richard Pancost, Bristol University, U.K., and was published in Nature Geoscience. The publication was summarized by Katherine Kornei (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist in Kornei, K. (2018), Tiny algae may have prompted a mass extinction, EOS, 99, https://doi.org/10.1029/2018EO102539. Published on 11 July 2018. Text © 2018. The authors. CC BY-NC-ND 3.0.

Summary by Liz Aston, Editor

Interesting Articles from Various Sources *(found by John Stanley, FGS Member or Liz)*

1. An interesting video about the development of man from National Geographic Magazine Videos (NB there is a lot of advertising first) - https://video.nationalgeographic.com/video/101-videos/human-origins-101
2. Scientists are trying to determine whether Mars is tectonically active by looking for 'Marsquakes' https://eos.org/research-spotlights/searching-for-signs-of-marsquakes?utm_source=eos&utm_medium=email&utm_campaign=EosBuzz083118
3. Lovely images from space of an 8-Ma old star cluster (M21) and the younger bright Trifid Nebula (M20), just 300-Ka old. '*The Trifid Nebula is a giant star-forming cloud of gas and dust located 5,400 light-years away in the constellation Sagittarius*'.
   The second reference cited below is worth reading and describes the Trifid Nebula as *'a vibrant cloud dotted with glowing stellar "incubators." Tucked deep inside these incubators are rapidly growing embryonic stars'*. https://apod.nasa.gov/apod/ap180824.html and http://www.spitzer.caltech.edu/news/184-ssc2005-02-Spitzer-Finds-Stellar-Incubators-with-Massive-Star-Embryos
4. An article from The New Scientist, 16/09/2017, page 8 - A meteorite impact in Canada created the hottest temperature ever measured on Earth's surface – this was discovered when cubic zirconia was found at the

Mistastin crater. This temperature is inferred by the conversion of zircon $ZrSiO_4$ to cubic zirconia, ZrO_2, which has a melting point of 2370ºC.
Original source Nicholas Timms Curtain University, Perth, Australia in Earth and Planetary Science Letters, doi.org/cczc.

Zircon - $ZrSiO_4$

Zircon is an amazing mineral. It forms in silicate melts with space for a great many different elements in its atomic structure, but simplified here above, as $ZrSiO_4$ with a hardness of 7.5. It is resistant to all forms of weathering (both chemical and mechanical) and also to thermal and pressure-related metamorphism, including structural changes, furthermore it neither gains nor loses uranium (U) or lead (Pb) even at magmatic temperatures. Consequently it is an excellent mineral to use for geological dating and indeed, the dating of grains in the Jack Hills Greenstone Belt, Australia, show they have survived intact for over 4 billion years (Ga), one crystal, dated at ~4.4Ga, makes it **the** oldest bit of Earth, older than the oldest rocks which are at Porpoise Cove, NE Canada, and are ~4.3Ga[1].

The Toba caldera, N Sumatra, is a massive crater which formed ~74,000 years ago, by the Youngest Toba Tuff super-eruption (believed to be the largest volcanic eruption ever experienced by humans).In this case zircon crystals have been used to show intermittent changes in the composition of the underground magma chamber, with repeated episodes of magma recharging the magma chamber, during probably thousands of years before the super-eruption of the youngest Toba Tuff.

References:

[1] O'Neil, J., Carlson, R. W., 2017: Building Archaean Cratons from Hadean Mafic Crust, Science, Vol. 355, Issue 6330, pp. 1199-1202

[2] Reid, M. & Vazquez, J.A.; 2016: Fitful and protracted magma assembly leading to a giant eruption, Youngest Toba Tuff, Indonesia. Geochemistry, Geophysics, Geosystems, Research Article 10.1002/2016GC006641

Liz Aston, Editor

Building a granite church in The Highlands

This is a reprint of an article by the late Peter Cotton taken from FGS Newsletter - October 2009

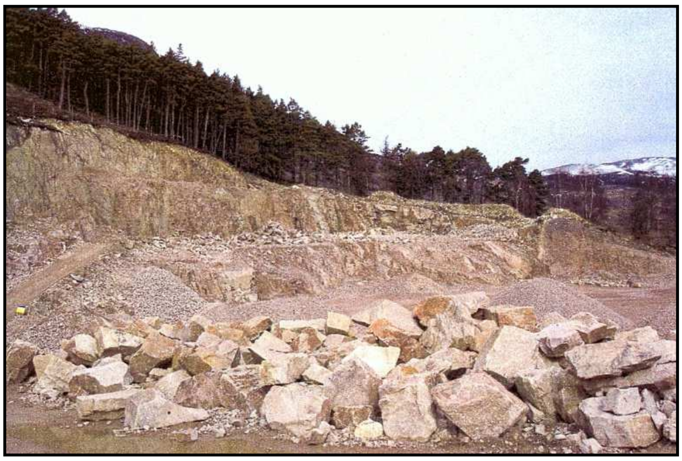
In a unique project currently being undertaken by a local architect, Robert Trembath from Churt, a church is being built on a private estate in the Scottish Grampians on the shores of Loch Ericht. It is called the Chapel of Ben Alder, overlooked by the mountain of that name (3,766 feet).

Ben Alder Lodge with mountains behind

From a geological viewpoint the fascination of this project is the sourcing of the granite blocks being used in the construction. Historic buildings in the Grampian region were largely built in local granite obtained from nine large quarries in the area. However, the Scottish granite industry no longer produces stone for building in any significant quantity; but there is a quarry at Alvie which has been able to cut large stones of a warm pink colour for carved features and ornaments.

Against this background of shortage of suitable granite blocks, it was fortunate that Robert heard about an old quarry near Aberdeen that had been used as a dump some years ago for granite stones taken from old historic buildings in Aberdeen.

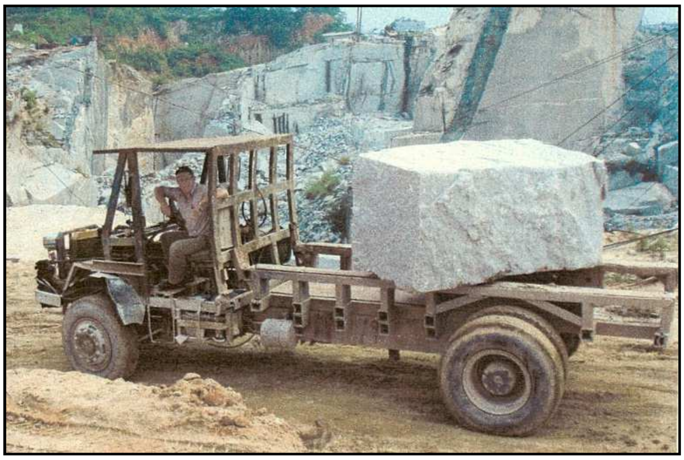
Permission was obtained from the owners, Aberdeen City Council, to remove this stone for use in the building of Ben Alder Chapel. The significant point about the use of this discarded stone was that it comprised a whole variety of colours since, when originally quarried centuries earlier, several quarries would have been needed to provide the volume of stone required, each having its distinctive colours.



The quarry at Alvie

Granite at the quarry in Aberdeen

The stone from the quarry dump has been used for the main walls of the chapel but good quality granite blocks were needed for the key features such as windows and arches. Although Alvie quarry, already referred to, was able to supply some of this better quality stone, an extensive search was mounted to find granite closely matching the colour and texture of the stone local to Ben Alder. The successful supplier was found in a small town in the Fujian province of South East China. The quarry there is 200 metres deep and a quarter of a mile across and most people of the town work with the granite and have achieved a high level of expertise.



Massive granite block weighing ~15 tonnes

The work shops

Carved granite packed in special crates prior to shipping

Sculptor at work

The final photograph shows a sculptor at work in the chapel – the craftsmen have been recruited from all over Britain – which is due to be completed this year.

Peter Cotton