GEOSCIENTIST

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The Fellowship Magazine of the Geological Society of London

@geoscientistmag

[A PEAK AT PLANETARY DEFENCE]

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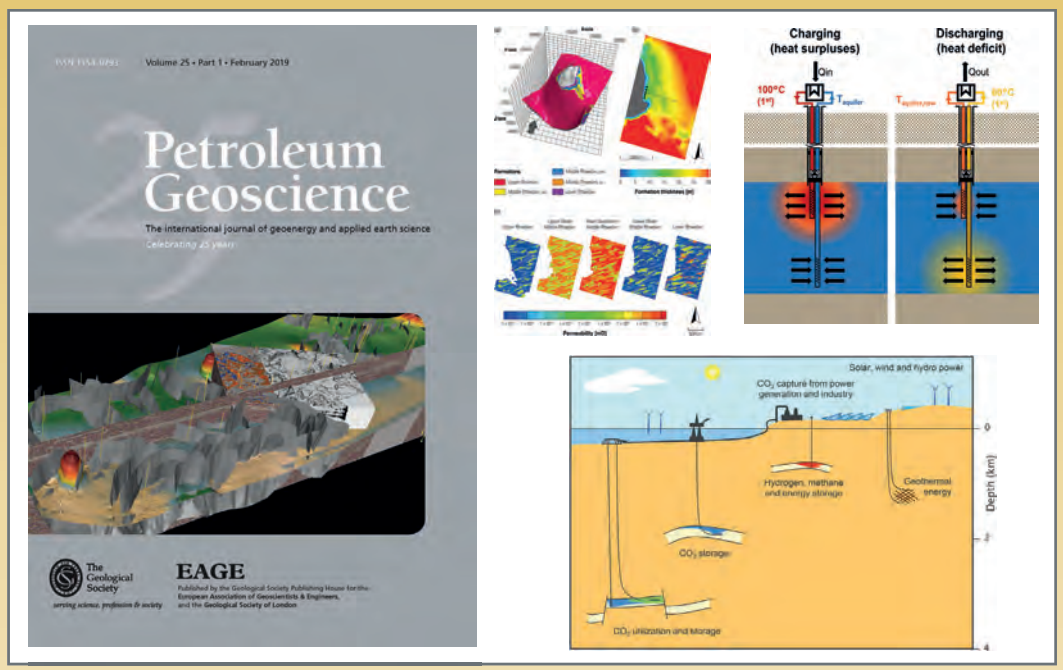
The Geological Society
serving science, profession & society

Lyell Collection
Geological Society publications online

Petroleum Geoscience

The international journal of geoenergy and applied earth science

Looking to the future



We are pleased to announce that, during its 25th anniversary year, *Petroleum Geoscience* has decided to introduce a new series of papers on the theme of Energy Geoscience.

Petroleum Geoscience already publishes papers on geoscience aspects of energy storage, CO_2 storage and geothermal energy, although our current content is mainly research related to hydrocarbon exploration and production. Research focused on new and emerging topics, such as cyclic storage of gas or geothermal energy, will represent an increasing fraction of the Journal's coverage and deserve a more specific home. By introducing the Energy Geoscience Series, we hope to create a channel for the anticipated growth in non-petroleum related aspects of geoenergy and applied earth science.

We continue to invite papers on any aspect of geoenergy and applied earth science, but now authors are able to choose between submission under Energy Geoscience alongside the traditional categories under Petroleum Geoscience or one of the more specific Thematic Set topics we choose to run from time to time.

Despite this important and stimulating interest in new forms of energy, the use of hydrocarbons remains essential to human society, and novel and innovative papers on the geoscience of petroleum will continue to be a vital part of our geoscience portfolio. We look forward to receiving a continuing stream of high-quality research papers across all aspects of applied geoscience.

Explore *Petroleum Geoscience* content in the Lyell Collection
https://pg.lyellcollection.org

More information on *Petroleum Geoscience* and how to submit a paper
www.geolsoc.org.uk/Publications/Journals/Petroleum-Geoscience

Geoscientist is the Fellowship magazine of the Geological Society of London

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Cover image: A natural trench in the reef underwater, Pacific ocean © Shutterstock

ON THE COVER:

FEATURES

REGULARS

ONLINE SPECIAL

GREAT GLOBAL GEOTOURISM SITES

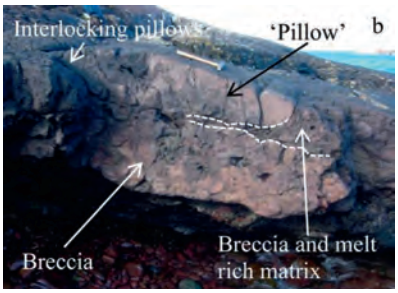
TO HELP RAISE THE GLOBAL PROFILE OF GEOLOGY, MURRAY GRAY PROPOSES LAUNCHING AN INTERNATIONAL PROJECT ON GEOTOURISM.

Latest news from the **Publishing House**

The Mesoproterozoic Stac Fada proximal ejecta blanket, NW Scotland: constraints on crater location from field observations, anisotropy of magnetic susceptibility, petrography and geochemistry

By Kenneth Amor, Stephen P. Hesselbo, Don Porcelli, Adam Price, Naomi Saunders, Martin Sykes, Jennifer Stevanović and Conal MacNiocaill

The Stac Fada Member of the Mesoproterozoic Stoer Group (Torridon Supergroup) in NW Scotland is a proximal ejecta blanket surrounding an unidentified asteroid impact crater. A combination of field observations of the ejecta deposit and underlying strata, the geographical distribution of terrane-identified basement clasts found embedded in the impactite, and anisotropy of magnetic susceptibility of the impact melt rocks at different locations can constrain the crater location to be about 15–20 km WNW



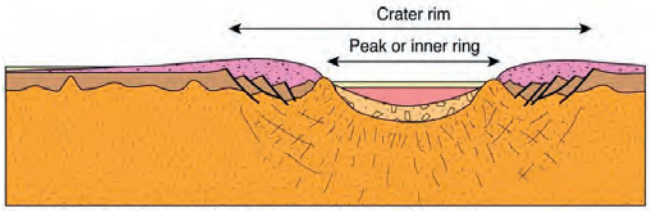
➤ Read the full abstract and paper in the Lyell Collection https://jgs.lyellcollection.org/content/early/2019/06/04/jgs2018-093

A reassessment of the proposed 'Lairg Impact Structure' and its potential implications for the deep structure of northern Scotland

By Michael J. Simms and Kord Ernstson

The Lairg Gravity Low may represent a buried impact crater c. 40 km across that was the source of the 1.2 Ga Stac Fada Member ejecta deposit but the gravity anomaly is too large to represent a simple crater and there is no evidence of a central peak. Reanalysis of the point Bouguer gravity data reveals a ring of positive anomalies around the central low, suggesting that it might represent the eroded central part of a larger complex crater. The inner or peak rings of complex craters show a broadly consistent 2:1 relationship between ring diameter and total crater diameter...

➤ Read more here https://jgs.lyellcollection.org/content/early/2019/04/30/jgs2017-161



End of Poll a' Mhuilt Member deposition. ~1170 Ma

> ASTEROID MONITORING AND IMPACT MITIGATION IS SWIFTLY MOVING FROM THE REALMS OF SCIENCE FICTION TO REALITY

FROM THE EDITOR'S DESK:

Planetary defence

Early morning on June 30th 1908, a column of blue light glowed in the sky above the remote Tunguska region of Siberia. Minutes later, a huge explosion and shock wave flattened over 2,000 square kilometres of forest, knocked people from their feet and shattered windows in villages tens of kilometres away. Although no impact crater has ever been found, the mysterious event is attributed to the mid-air explosion of a meteor, potentially 40-190 metres across, making Tunguska the largest cosmic impact event ever witnessed by humans.

Thousands of meteors intersect our planet's orbital path every year. Most burn up in the atmosphere before reaching Earth's surface. Rarely, such as during the Great Meteor Procession of 1860 (see page 18), meteors merely graze the Earth, passing straight through the atmosphere to re-enter space. Others, like Tunguska, are more damaging—whether they reach the ground or not. In February 2013, a 20-metre-wide meteor tore apart in the skies above Chelyabinsk, Russia. The shock wave smashed windows and damaged over 7,000 buildings, injuring around 1,500 people.

Earth's surface is littered with the scars of many damaging asteroid impacts. The most famous, the Chicxulub Crater buried beneath the Yucatan Peninsula, Mexico, is thought to have been created by an asteroid impact ~66 million years ago that drove the extinction of the dinosaurs. The best preserved is the Barringer or Meteor Crater in Arizona, created just 50,000 years ago. And one recently discovered is a 1.2-billion-year old impact crater in northwest Scotland—though its precise location is debated (Amor *et al. J.GSL* 2019; Simms & Ernstson, *J.GSL* 2019).

Given our vulnerability, space agencies across the globe are monitoring our skies—with increasing success. In the early hours of June 22, telescopes at the University of Hawaii detected a small asteroid before it entered Earth's atmosphere. About 12 hours later, a meteor (subsequently determined to be the same object) burned up in the sky above the Caribbean Sea. The event is significant because it marks the first time that astronomers have tracked an asteroid with sufficient lead-in time to issue a warning.

Of course, simply tracking near-Earth objects with the aim of evacuating potential impact sites is insufficient—we must actively mitigate those impacts that are likely to be devastating. To this end, numerous techniques have been proposed, with most aiming to alter the trajectory of an asteroid that is on a collision course with Earth.

One of the more mature proposals is the joint NASA and ESA Asteroid Impact and Deflection Assessment (AIDA) mission. The mission's target is the binary system Didymos, composed of the asteroid Didymead and its satellite, Didymoon, which will pass close to Earth in 2022. During the approach, NASA aims to crash a spacecraft, the Double Asteroid Redirection Test (DART), into Didymoon to alter its trajectory. Three years later, ESA will send a follow-up craft, Hera, to carry out a post-mortem examination.

This may sound like something from a Hollywood movie, but, if successful, this ambitious mission will demonstrate the viability of asteroid deflection as a planetary defence technique, should we ever need to safeguard our world. Science fiction, it seems, is rapidly becoming science fact.

Meteor crater, Arizona

DR AMY WHITCHURCH, EDITOR - amy.whitchurch@geolsoc.org.uk @geoscientistmag

SOCIETY *NEWS*

SOCIETY'S AWARDS 2020 – MAKE YOUR NOMINATIONS

Fellows of the Society are encouraged to submit nominations for the Society's Awards for 2020, writes George Jameson.

With the aim of broadening the demographics of those nominations put forward, this year we set ourselves a goal to revamp the awards process. Undertaking a holistic review of the procedures, focusing on the nominations, application, submission, judging and assessment processes and criteria.

Our guidance documents have been revamped and help in explaining how to go about nominating a person you feel is deserving of a Society Award.

Check out our new Awards booklet, which shows all of the changes made and how easy the whole process is, by visiting: **https://www.geolsoc.org.uk/About/Awards-Grants-and-Bursaries/Society-Awards**

Full details of how to make nominations can also be found there.

Remember nominations must be received at the Society **no later than 27 September 2019.**

LYELL'S NOTEBOOKS

Charles Lyell's notebooks, currently in private hands, are due to be sold abroad. Government has imposed a temporary export ban to enable fundraising to purchase them and to make them publicly available online. If successful, the new home of the Lyell notebooks will be the University of Edinburgh Library, already home to the largest collection of Lyell material. The University of Edinburgh is leading the fund-raising and has launched a dedicated website: https://www.ed.ac.uk/giving/save-lyell-notebooks.

The Geological Society is supporting efforts through a letter from the President, which is now published on the above website, and by making available for use an image of the Lyell portrait that hangs in the Lyell Room at Burlington House. The temporary export ban had an initial deadline of 15 July, but the fundraising has made significant progress, so the deadline has been extended until **15 October 2019**. For more information about the notebooks, the appeal, and to pledge a donation, please visit the website.

Portrait of Sir Charles Lyell (1797-1875) © Geological Society of London.

HONORARY FELLOWSHIP

Following a proposal from the External Relations Committee, Council recommends the following candidate for election to Honorary Fellowship at a future Ordinary General Meeting.

Professor Khin Zaw

Khin Zaw is Professor of Economic Geology at the Centre for Ore Deposits and Earth Sciences (CODES), in the School of Natural Sciences, University of Tasmania. He is the pre-eminent mineral deposits geologist in South East Asia, has supervised numerous MSc and PhD dissertations on economic and other Earth science topics, and has participated in and organised sessions in numerous conferences in South East Asia.

To further the study of the geosciences in Myanmar, and to provide a forum and support for Myanmar geoscientists, Prof Khin Zaw, together with Dr Yin Yin New, founded the Myanmar Applied Earth Sciences Association (MAESA) in 2016. MAESA arranges conferences and workshops with the aim of promoting the geosciences and mineral resources of Myanmar, and collaboration with foreign geoscientists, mineral companies and geoscience organisations, such as this Society.

Prof Khin Zaw studied Geology at the University of Rangoon, graduating in 1968. After obtaining an MSc in 1969 from Queen's University in Canada, he was appointed to a lectureship in the University of Yangon, Myanmar. However, he incurred the displeasure of the Military Government and was dismissed from his post. Eventually, Khin Zaw was allowed to leave Myanmar with his family to study for a PhD at the University of Tasmania in Hobart, Australia.

After obtaining his PhD, Khin Zaw joined the CODES ARC (Centre of Excellence in Ore Deposits) group at the University of Tasmania, specialising in the economic geology of South East Asia.

What your society is doing
at home and abroad

SOCIETY DISCUSSION GROUP 2019 – ALL WELCOME!

The Geological Society Discussion Group exists to promote discussion in a social setting on a variety of geoscience topics. Our meetings take place in the evening, at a range of different venues in London, when a topical subject is raised by an invited speaker and debated over dinner.

Come and broaden you mind and your network! The meetings are open to all—Fellows, their guests and non-Fellows.

- 'Critically stressed Earth', Jonathan Turner (Director, Radioactive Waste Management) - 18 September, Kings Head, Mayfair.
- 'UK Onshore earthquakes—natural or anthropogenic?', Stephen Hicks (Imperial College) - 23 October, Bumpkins, South Kensington.
- Members' geological object 'show and tell' evening - 4 December, Athenaeum, Pall Mall.

For more information, please go to: **www.geolsoc.org.uk/Groups-and-Networks/Specialist-Groups/Geological-Society-Discussion-Group.** To make a reservation, please contact: **conference@geolsoc.org.uk**

EARTH SCIENCE WEEK 2019

Earth Science Week 2019 takes place on 12-20 October, with a theme of 'Geoscience is for everyone'.

If you're thinking of running an event this year, you can apply for up to £150 to help! Visit **www.geolsoc.org.uk/earthscienceweek** where you can register your event and submit a grant application. The deadline to apply for grants is Monday 19 August, although you can continue to register your event without applying for a grant until Friday 4 October.

Earth Science Week is an annual celebration of the geology all around us. Taking place in an increasing number of countries around the world, the week aims to raise awareness of the geosciences through public events like geowalks, talks, open days and hands-on activities.

Anyone can participate by either running or attending an event. Contact **outreach@geolsoc.org.uk** if you'd like more information on how to get involved!

12-20 October 2019
'Geoscience is for everyone'
Earth Science Week

ESW PHOTOGRAPHY COMPETITION

The Earth Science Week photography competition is back! This year, for the first time, we're inviting entries featuring geology from all over the world. Entry is free to all, and there's no limit on how many images you can enter. As always, 12 winners will be displayed at Burlington House during Earth Science Week and feature in our 2020 calendar. The top three images will also win cash prizes.

You can email your entries to **outreach@geolsoc.org.uk**. The deadline to enter is 9am on Monday 23 September. Full details can be found at **www.geolsoc.org.uk/photocompetition**.

Last year's winning image, 'Bow Fiddle Rock' by Andy Leonard

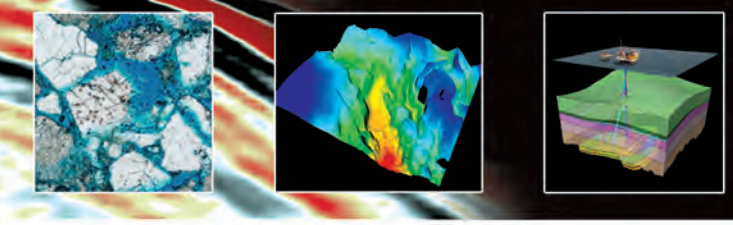
PUBLIC LECTURE SERIES

Diamond windows into the deep Earth

Speaker: Kate Kiseeva, University College Cork, Ireland; University of Oxford, UK
Location: North East Futures UTC, Newcastle upon Tyne
Date: 14 August
Time: 18.00 Tea & Coffee; 18.30 Lecture begins

Further Information
Please visit **www.geolsoc.org.uk/GSL-Regional-Lecture-Aug**. Tickets are now available on Eventbrite.co.uk and will work on a first come first serve basis.

Contact: The Geological Society, Burlington House, Piccadilly, London W1J 0BG T: **+44 (0) 20 7434 9944** E: **conference@geolsoc.org.uk**



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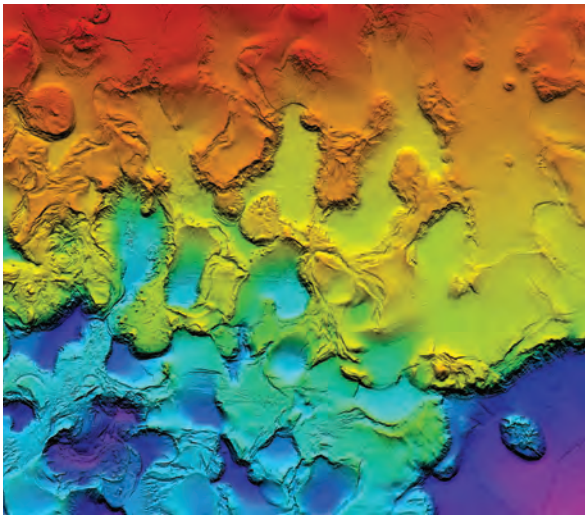
Salt Tectonics:

Understanding Rocks that Flow

29-31 October 2019

The Geological Society, Burlington House, Piccadilly, London



The complex behavioural and rheological characteristics of salt can strongly influence the structural and stratigraphic evolution of a basin. With many of the largest hydrocarbon provinces existing within salt-related basins understanding of the processes involved in salt tectonics has important scientific and economic implications for geological research and hydrocarbon exploration.

Modern high-resolution 3D seismic data with improved imaging of salt structures in combination with more advanced physical and numerical modelling techniques revolutionises the way we see salt tectonics and the role of salt structures.

This three-day international conference aims to bring together leading academic and industry geoscientists to discuss new techniques and case studies, and to capture an up to date assessment of our understanding of salt tectonic processes including:

- Geographical case studies; e.g. North Sea, Gulf of Mexico, Persian Gulf, Campos Basin
- Salt tectonics in extensional and contractional settings
- Halokinetic sequence stratigraphy
- Analytical methods of interpreting salt in seismic data
- Physical and numerical modelling of salt tectonics
- Implications of salt tectonics for hydrocarbon exploration.

Convenors:

James Hammerstein
Royal Holloway University of London

Jürgen Adam
Royal Holloway University of London

Clare Bond
University of Aberdeen and Tectonic Studies Group

Christina Von Nicolai
BP

For further information please contact:

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Great global geotourism sites

To raise geology's global profile, **Murray Gray** presses the Society to support an international project on geotourism

In 2014, the Geological Society of London, together with partner organizations, ran a "100 Great Geosites" project in the UK and Ireland (**https://www.geolsoc.org.uk/100geosites**). Over 400 sites were nominated and the public were invited to vote for their favourites. 1,500 votes were received, with the 100 most popular being placed into 10 groups.

According to Professor Rob Butler, Chairman of the Geoconservation Committee, the project generated a "pretty major media storm" amounting to some of the largest ever media interest in a Geological Society topic. Given the low profile of geology, geoheritage and geoconservation in many countries, I believe there is a case for repeating the Great Geosites project at a global scale?

Selection

We would need to determine how many sites and what criteria to use in our selection. Certainly, the public must be able to easily and safely visit the locations, and we must consider visual impact, site quality, educational potential and the availability of sufficient tourist facilities. The sites should be globally distributed, rather than focussed on a single continent, and should reflect the geodiversity of the planet.

With these strictures in mind, I propose a number of sites for potential inclusion. For example, the Iguaçu Falls represent the world's most complex waterfall system, with 275 individual falls tumbling over two main horizontal lava flows. Most geosites are static, but this highly dynamic site has good tourist facilities, including trails over the water, helicopter and boat trips, visitor centres and restaurants.

The Great Barrier Reef may seem a surprising site to champion, given that most visitors are interested in the reef ecology rather than its geology. However, it is believed that the reef started to grow 20,000 years ago, when world sea-level was 120 m lower. As sea-levels rose, coral growth kept pace, creating the massive structure we see today.

There ought to be a karst site on the list, and South China Karst and Ha Long Bay together contain world-class examples of tower and cone karst, as well as giant dolines, river gorges, cave systems and the stone forest of Shilin.

The World's most impressive *in situ* dinosaur site must be the dinosaur footprint site at Parque Cretácico, Cal Orcko, near Surce, southern Bolivia. Here, over 5,000 footprints from 15 dinosaur species are preserved.

The Golden Circle tourist route in south-west Iceland includes Thingvellir, where the North American and European plates are moving apart at about 3 cm per year, resulting in open fissures, some of which have walking or canoe trails through them.

Finally, Cape Town and Rio de Janeiro both reflect the important and close association between human settlements and their physical settings.

Debate

These sites are not intended as a definitive list. Rather, I hope they will trigger discussion and start a process that may lead to a list of top geotourism sites endorsed by the geological community, which can then be promoted to the public through the media. Endorsement should come through national and international organisations such as the Geological Society of London, as well as the IUGS's *International Commission on Geoheritage* and the IUCN's *Geoheritage Specialist Group*.

Murray Gray (FGS) is Honorary Professor in the School of Geography at Queen Mary University of London; e-mail: j.m.gray@qmul.ac.uk. The full article, including more detailed justification for each proposed site, is available online

SOAPBOX CALLING!

Soapbox is open to contributions from all Fellows. You can always write a letter to the Editor, of course, but perhaps you feel you need more space?

If you can write it entertainingly in **500 words**, the Editor would like to hear from you. Email your piece, and a self-portrait, to **amy.whitchurch@geolsoc.org.uk.** Copy can only be accepted electronically. No diagrams, tables or other illustrations please.

Pictures should be of print quality – please take photographs on the largest setting on your camera, with a plain background.

Precedence will always be given to more topical contributions. Any one contributor may not appear more often than once per volume (once every 12 months).

> GIVEN THE LOW PROFILE OF GEOLOGY, GEOHERITAGE AND GEOCONSERVATION IN MANY COUNTRIES, PERHAPS THERE IS A CASE FOR REPEATING THE GREAT GEOSITES PROJECT AT A GLOBAL SCALE?

SCIENCE, SEAMOUNTS AND SOCIETY

In reviewing the distribution and formation of seamounts, **Tony Watts** highlights the societal implications of these abundant oceanic features and the urgent need for more seafloor mapping

It has been more than one hundred years since the publication of Sir John Murray's 'bathymetrical chart' of the world's ocean basins. Compiled from lead-line surveys during expeditions such as *Challenger* and *Michael Sars*, the coloured contour map revealed for the first time the nature of Earth's surface beneath the oceans and the outline of the continental margins, the Mid-Atlantic Ridge and the intervening abyssal plains (Fig. 1). Profiles showed, however, that apart from the prominence of a few widely scattered islands such as the Azores, the seafloor of the oceans was smooth and featureless—a view that persisted for about the next four decades.

The development of new technologies during World War II dramatically altered this view. Arguably the most important was the Precision Depth Recorder (PDR), which used a hull-mounted acoustic transducer/receiver to continuously measure two-way reflection time and hence depth. The Princeton academic, Harry Hess, who had been given command of the troop-carrying ship USS *Cape Johnston*, for example, used a PDR to chart 160 flat-topped bathymetric features in the Pacific Ocean, rising up to 4.5 km above the seafloor. He named them guyots, in honour of the Swiss born geographer and Princeton Professor, Arnold H. Guyot. Hess (*Amer. J. Science* 1946), and considered them as volcanic oceanic islands that had been wave trimmed prior to subsidence below sea level.

After more than three centuries of discovery on sailing ships, we know there are 1,770 ocean islands (all but one was

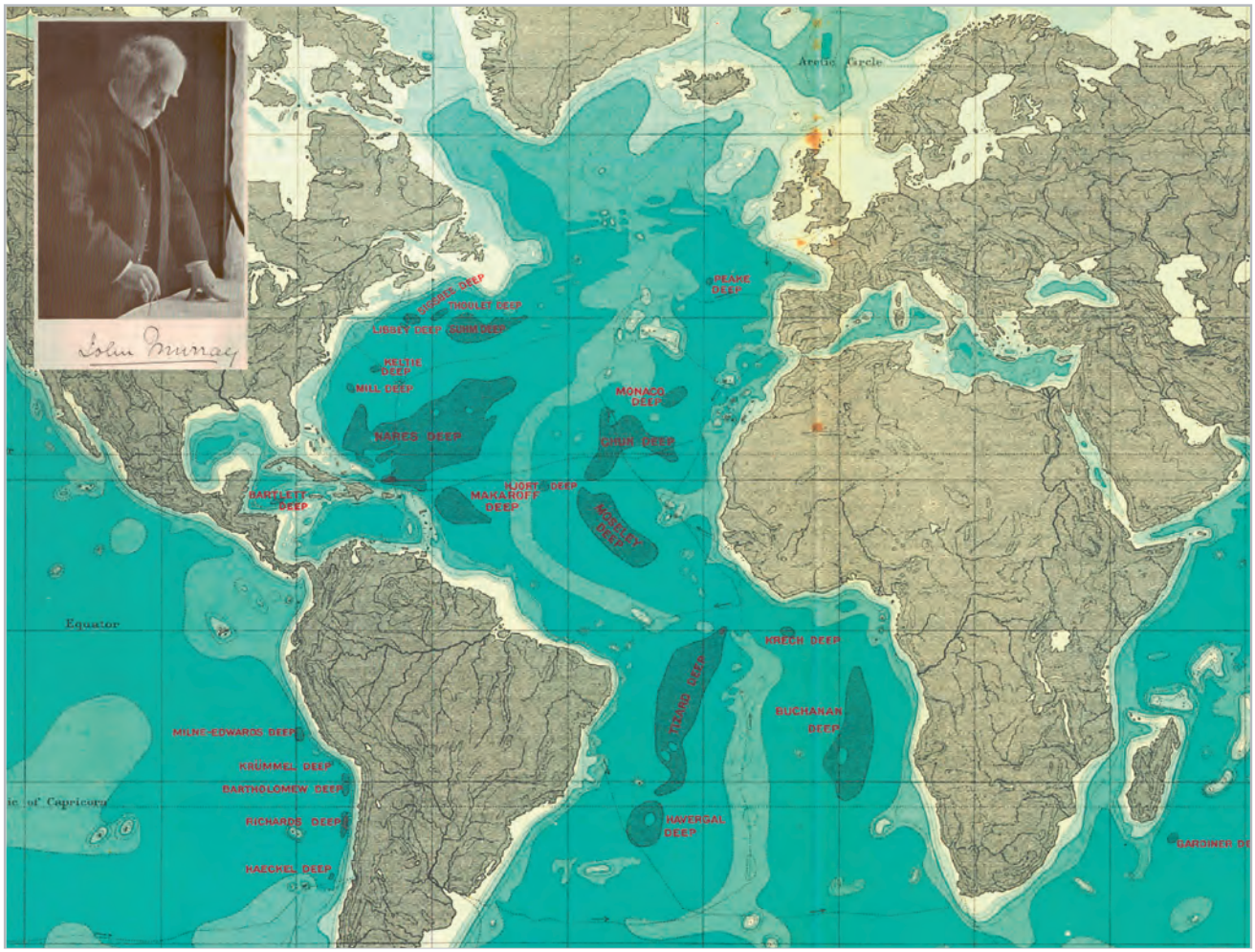

Fig 1: Sir John Murray and his 'bathymetrical chart' of the Atlantic, western Indian and eastern Pacific oceans published in 1912. Constructed from ~3,200 soundings made with pre-stressed hemp rope and lead weights on British and other survey ships. Abyssal plains ('deeps') correspond to depths >3,000 fathoms (5,486 m). Chart produced by John G. Bartholomew, cartographer to the King

discovered by 1840). 47 are active volcanoes. Approximately 439 are atolls (Goldberg, *Atoll Research Bulletin* 2016), which Charles Darwin hypothesized in 1842 comprise coral reefs that had grown upwards on the summit of volcanoes as they subsided below sea level.

While we now attribute the subsidence of guyots and atolls to sinking of the oceanic plate as it ages and cools, their spatial distribution raises questions about the origin of volcanic activity on Earth. The Smithsonian Global Volcano Program (SGVP), for example, lists 1,535 volcanoes that have been active since the Holocene, the large majority of which are associated with compressional plate boundaries, where one plate is underthrust by another (e.g. the circum-Pacific) and extensional plate boundaries, where the plates are moving apart (e.g. East Africa). Yet, the large majority of guyots and atolls are located in the interior of plates, far from plate boundaries (Fig. 2b).

Here I show that when 'seamounts' are added into the mix, most of which are also volcanic in origin (Fig. 3), the spatial extent of magmatic activity on Earth changes even more dramatically. Indeed, the distribution raises important scientific questions about Earth's 'magmatic pulse' and the origin of intra-plate volcanism, as well as societal questions about the role that seafloor volcanoes play in navigation, fisheries and geohazards.

What is a seamount?

In his 1964 book, *Marine Geology of the Pacific*, Bill Menard defined a seamount as:

"a more or less isolated elevation of the sea floor with a circular or elliptical plan, at least 1 km of relief, comparatively steep slopes and relatively small summit area"

Menard estimated there were about 2,000 seamounts greater than 1 km high in the ocean basins. Satellite-derived gravity and ship PDR data, however, show there are >14,500 seamounts higher than 1 km. A large concentration is found in the western Pacific Ocean (Figs 2, 4). Some of these seamounts are growing up on the seafloor and may become islands, while others were once islands that are now sinking.

An important technological development in the late 1980s was the introduction of multibeam swath bathymetry systems. These had an advantage over PDRs in that rather than determining water depth immediately beneath a ship's hull, they insonified a broad swath of the seafloor, up to 2.5 times the water depth. Such systems ▶

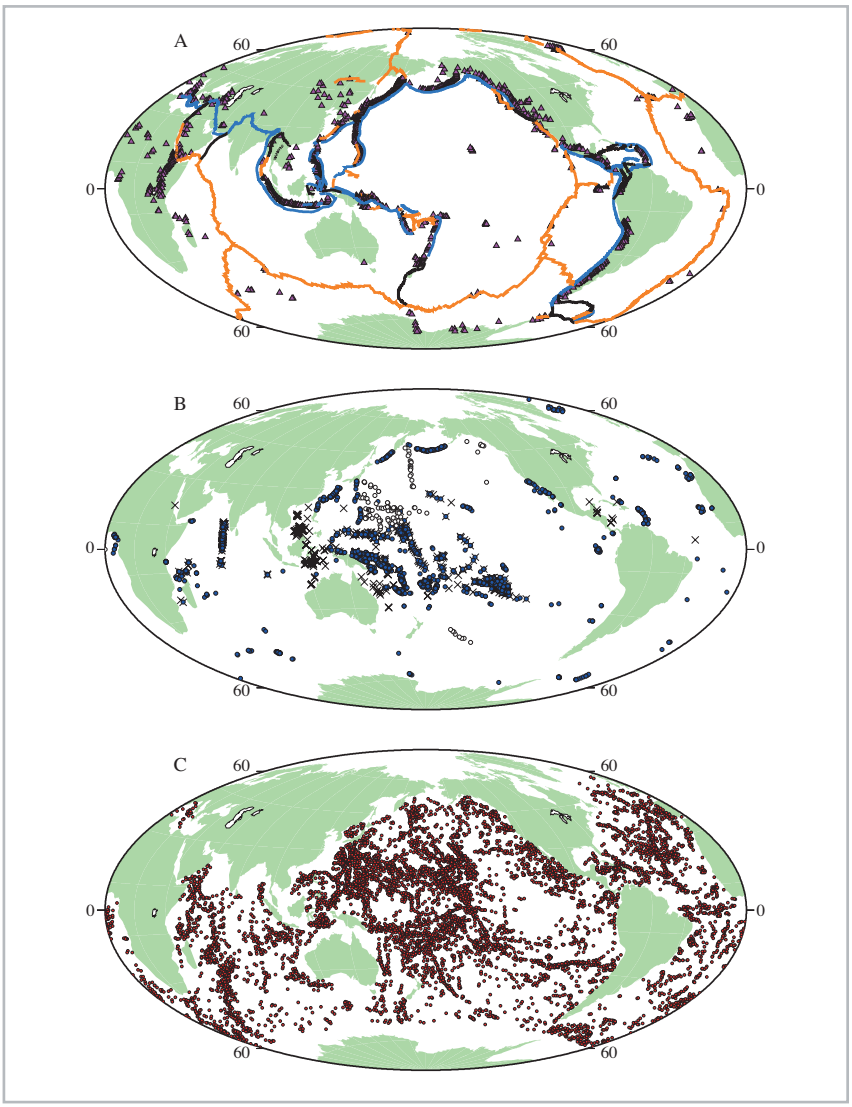

Fig 2: a) Holocene-Recent volcanoes (filled purple triangles, from https://volcano.si.edu/), compared to boundaries of major plates (blue, subduction zones; orange, mid-ocean ridges; black, transform/strike-slip faults). b) Ocean islands (filled blue circles), atolls (×). Guyots (unfilled circles, distribution incomplete) were once islands. c) Seamounts (filled red circles) with height above seafloor > 1,344 m, the height of Ben Nevis, the UK's highest mountain. (Data sources: Nunn, 1994; Goldberg, 2016; Smoot & King, 1997; Caplan-Auerback et al., 2000; Hillier & Watts, 2007)

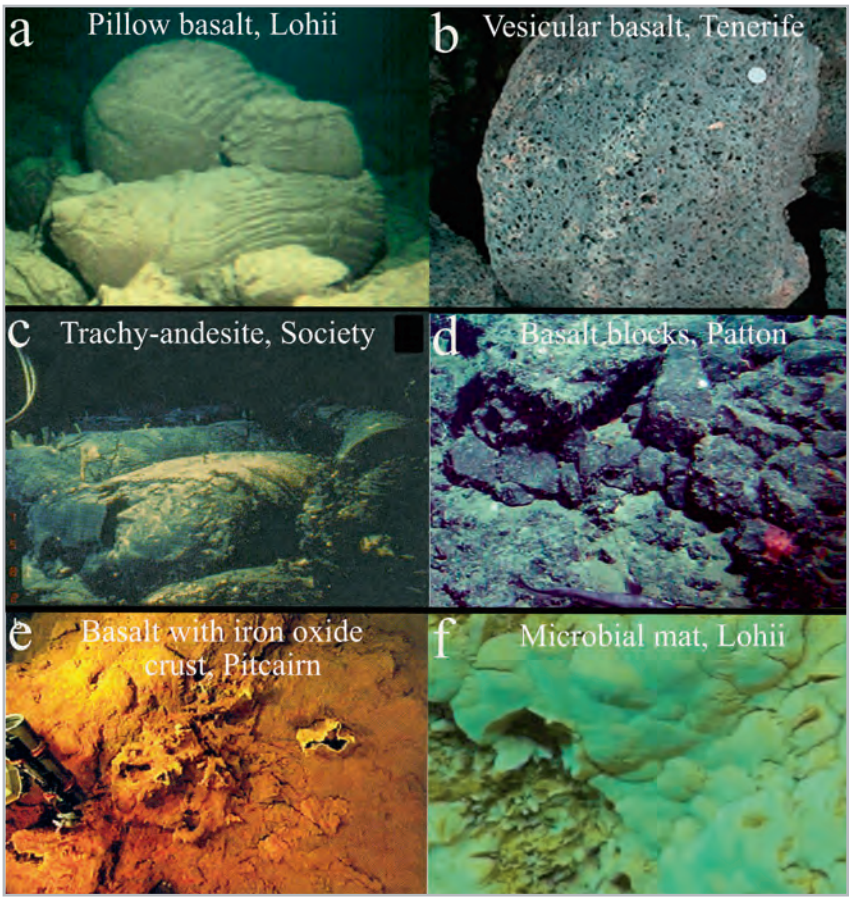

Fig. 3: The flanks of intra-plate oceanic islands and seamounts comprise mainly basaltic rocks that are geochemically distinct from basalts sampled at mid-ocean ridges and islands arcs. Products of seawater-Fe-Mg reactions (e,f) are an important source of microbial life. (a, A. Malahoff, U.Hawaii, 1980; c, Binard et al. & e, Scholten et al., both in: Ocean Hotspots. Hekinian et al. (eds) 2004 ©Springer; d, Public domain; f, Chan et al., 2016 CC-BY 4.0. c,e are exempt from CC licence, reprinted by permission from SpringerNature SNCSC).

revealed the morphology of seamounts, guyots, atolls and ocean islands in unprecedented detail, for example those along the Hawaiian-Emperor seamount chain in the central Pacific Ocean (Fig. 5). Other islands to have had their submarine slopes swath mapped include the Canary and Cape Verde in the Atlantic Ocean, and La Reunion and Kerguelen in the Indian Ocean. However, the number of swath surveys carried out to date is limited and only about 10-12% of the seafloor has been insonified.

Seamount dynamics

While we still do not know how many seamounts are growing and sinking, field observations suggest they are important to fully understanding Earth history and environmental change. Field sample and scientific drill data suggest that there have been bursts of volcanism in the oceans, for example the 90 to 100 -million-year 'event' that created many of the seamounts and oceanic plateaus in the central Pacific Ocean (e.g. Shatsky Rise, Hess Rise, Mid-Pacific Mountains). There may have been other such volcanic events in the Pacific Ocean, peaking in the Eocene and Late Jurassic. Once formed seamounts are susceptible to modification by large-scale sector collapse, as manifest by scalloped coastlines, submarine debris flows and the emplacement of large blocks on the seafloor. Such processes operate on time scales on the order of hundreds of thousands of years as seen, for example, in the Icod and La Orotava landslides on the north flank of Tenerife in the Canary Islands.

In historical times, seamounts show surprising variability on scales that greatly exceed their terrestrial counterparts. The number of historically active volcanoes in the SGVP data set is 538, about 35% of the total number of volcanoes younger than Holocene. If a similar percentage of seamounts higher than 1 km are active, then we might expect upwards of about 5,000 historically active volcanoes on the ocean floor. We know, however, only a few (~12) from floating pumice and discoloured water, Remotely Operated Vehicle (ROV) observations, and repeat swath bathymetry surveys.

One of the best-surveyed active

submarine volcanoes is Monowai in the Tonga-Kermadec arc, southwest Pacific Ocean. The volcano (Fig. 6) was swath surveyed in 1998, 2004, 2007, 2011 and 2013. Large differences, up to several tens of metres, were measured between the surveys. During the 32-day-long cruise of M/V *SONNE* in 2011, the volcano was surveyed twice. Seismic data recorded on Rarotonga (Cook Islands) revealed that the volcano erupted during May 17-22, 2011 and surveys with swath bathymetry before and after the eruption showed dramatic differences: the seafloor depth on the cone summit shallowed by up to 70 m and deepened by up to 18 m.

The seismic events recorded on Rarotonga were generated by the rapid emplacement of volcanic rock onto the seafloor. They originated as hydroacoustic waves that had become trapped in the SOund Fixing And Ranging (SOFAR) channel, the low velocity sound layer in the ocean that transmits whale calls. When these waves, known as *T*-waves, impact an ocean island they convert to body waves and, depending on noise levels, may be recorded on a seismic station on an ocean island.

Another recorder of *T*-waves are the hydrophone stations maintained by the Consortium for Test-Ban Treaty Organization (CTBTO). Three hydrophones are deployed on tethers in the SOFAR channel so a *T*-wave generated by an active submarine volcano will, if it is not obstructed, have a unique back azimuth when it arrives at a station. Explosive activity at Monowai, for example, has a back azimuth of 243.8° at a station located south of Juan Fernandez Island in the eastern Pacific Ocean (Fig. 7) and provide a means to continually monitor the submarine volcanic centre. Remarkably, the T-waves are able to transmit across the south Pacific Ocean despite possible bathymetric obstructions on the Louisville Ridge, East Pacific Rise and Chile Ridge. A recent study of these data by Dirk Metz (Oxford University) reveals that Monowai has erupted some 82 times over a 3.5-year period, making it arguably the most active volcano on Earth.

Origin of seamounts

Away from island arcs, many seamounts form distinct lines that progressively increase in age away from an active volcano and can be explained by absolute motion of a tectonic plate over a fixed mantle hotspot. The 7,000-km-long Hawaiian-Emperor seamount chain in the central Pacific Ocean is arguably the best-known example of ▶

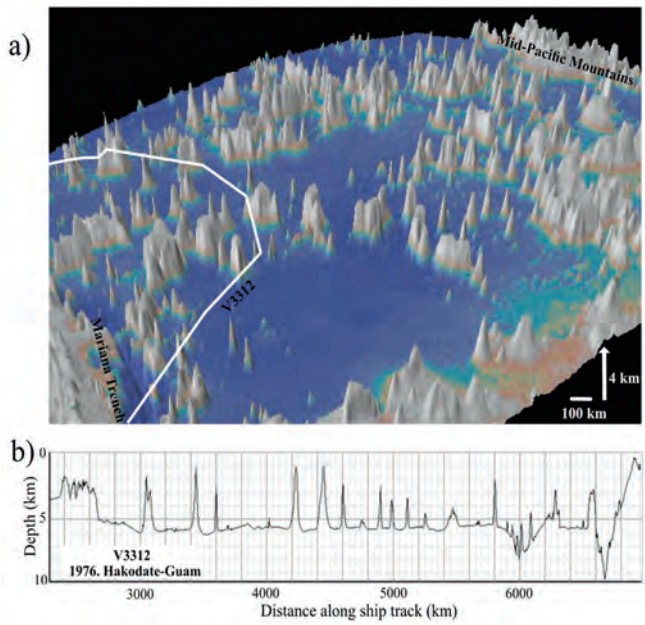

Fig 4: Western Pacific Ocean seafloor bathymetry, between the Mariana Trench and the Mid-Pacific Mountains. a) Perspective view to NE (gridded data set from Ryan et al., G3 2009; GeoMapApp, http://www.geomapapp.org/; Marine Geoscience Data System, www.marine-geo.org). Vertical exaggeration ×25. Scale approximate. White line illustrates the ship track of R/V Vema cruise V3312. b) PDR bathymetry profile along the Vema ship track.

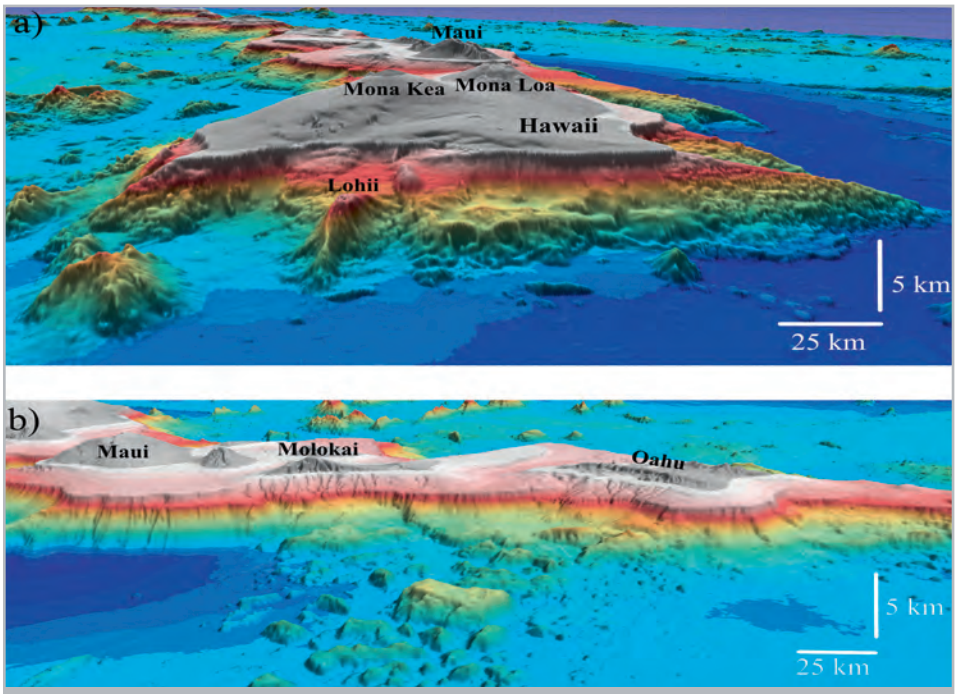

Fig 5: Submarine flanks of the Hawaiian Islands (perspective views). a) SE flank of Hawaii. b) N flank of Maui, Molokai and Oahu. 4x Vert. exagg. (Data: Ryan et al., 2009; http://www.geomapapp.org/; www.marine-geo.org)

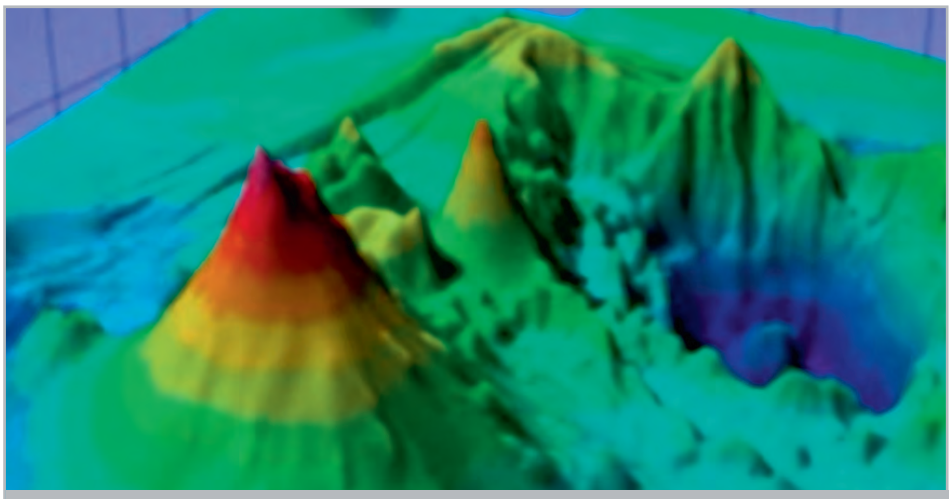

Fig. 6: Monowai in the Tonga-Kermadec island arc (perspective view, towards NW), SW Pacific Ocean. A ~1,000-m-high, 10-12-km-wide stratovolcanic cone with parasitic cones and a flanking ~500-m-deep, 7-10-km-wide caldera with ring faults and a central mound. (Data: SONNE Cruise 215; https://www.bodc.ac.uk/.)

▶ such a hotspot track. Seamounts increase in age from ~20 ka at the young end of the chain, through ~50 Ma at the Hawaiian-Emperor 'bend', to ~80 Ma at the old end of the chain. The young end comprises ocean islands that are superimposed on a broad topographic swell ~1.5 km in height, which gravity and seismic data suggest is supported by a deep mantle plume, while the old end is characterized by guyots and an absence of a swell.

A fixed hotspot origin for the seamount chain is supported by palaeomagnetic data that show the Hawaiian ridge, up to the 'bend', formed at or near the present-day latitude of the Hawaiian hotspot. But, palaeomagnetic data show that the Emperor Seamounts, beyond the 'bend', formed at a latitude up to 15° north of the current location of the hotspot. John Tarduno (University of Rochester) and colleagues have interpreted this as evidence that during 50 to 80 Ma, the Hawaiian hotspot was not fixed with respect to the deep mantle and had migrated south while the plate moved north.

While palaeomagnetic data suggest the Louisville Ridge, a seamount chain with a ~50 Ma 'bend' in the southwest Pacific Ocean, may also have formed at a fixed mantle hotspot, other volcanic lines are more difficult to explain. Some show an age progression, yet form close to a mid-ocean ridge (e.g. the Lamont Seamounts close to the East Pacific Rise) and have been attributed to a 'mini hotspot' at the ridge. Others (e.g. the Puka Puka Seamounts, south-central Pacific) show no evidence of an age progression and have been attributed to magmatically filled tension cracks generated by stresses set up in the Pacific Plate by processes such as a slab pull, convective instabilities and mantle dynamics.

Most difficult to explain are the numerous isolated seamounts that litter the seafloor (Fig. 2c). Some occur in regions of plate flexure at trench-outer rises (e.g. the 'petit spot' volcanoes in

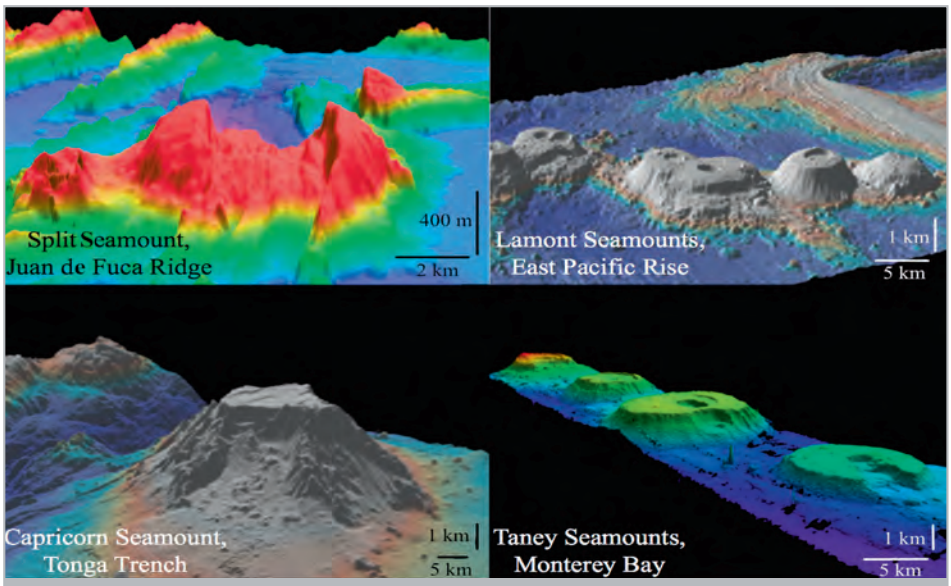

Fig. 8: Isolated seamounts and short seamount chains (Pacific Ocean, perspective views). Data: Carbotte et al., 2006; Coumans et al., 2015; Ryan et al., 2009; http://www.geomapapp.org/; www.marine-geo.org; Split image courtesy of Bill Ryan). Vert. exagg. from ×2 (Taney) to ×5 (Split). Scales approx. Capricorn's flat top tilts toward Tonga Trench. Sector collapses on Capricorn, Taney and Lamont seamounts. Summit craters on Lamont and Taney seamounts.

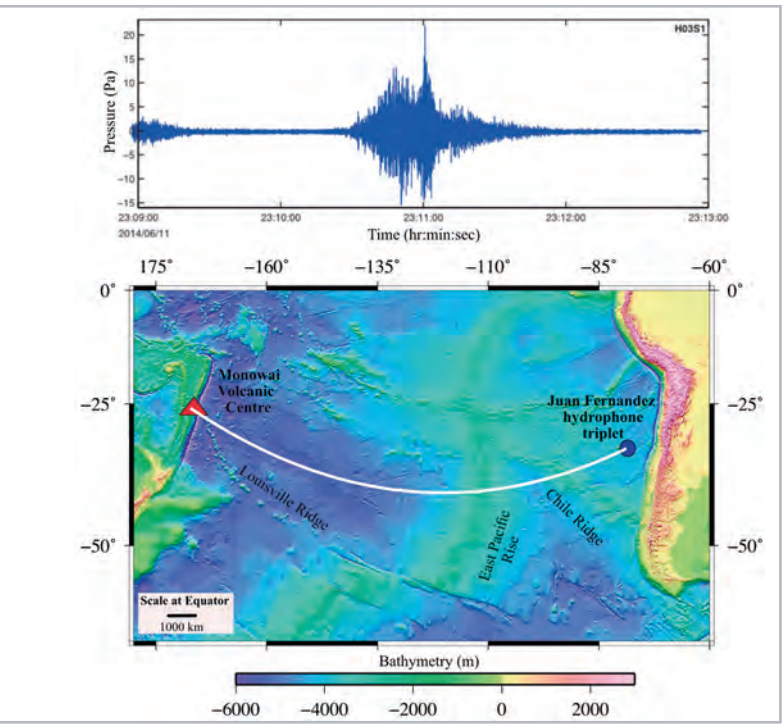

Fig. 7: Typical T-wave generated by volcanic activity at Monowai in the Tonga-Kermadec arc and recorded at hydrophone stations south of Juan Fernandez Island, eastern Pacific Ocean. (data replotted from Metz et al., 2018).

Fig. 9: USS San Francisco in Guam (Jan 2005). The submarine collided with an uncharted seamount while travelling at 33 knots between Guam and Brisbane. One sailor was killed, 115 were injured. (Credit: US Navy photo by Photographer 039, Mate 2nd Class Mark Allen Leonesio [Public domain])

the western Pacific), submarine volcanic loads (e.g. the 'North and South Arch' volcanics of the Hawaiian Islands) and along transform faults and 'leaky' fracture zones, where plate-bending stresses may be high enough to cause faulting. Others are too widely scattered and show no obvious link to regions of loading and flexure. The occurrence of so many scattered seamounts implies an extensive melt source in or below the oceanic crust and lithosphere. The observation by Nicholas Schmerr (NASA Goddard) and colleagues of seismic precursors to underside reflections from the crust between an earthquake and a receiver that suggest an age-independent discontinuity (the Gutenberg discontinuity) at about 65±10 km depth is therefore an exciting development, especially as it might reflect an ocean-wide, thin zone of partial melt.

Seamounts and society

While the origin of seamounts, especially the isolated ones, remains a scientific enigma, they are significant in a number of ways that impact society. Seamounts have steep slopes (up to ~25°) and rise abruptly above the regional seafloor depth, so are potential hazards for navigation. This was illustrated in a tragic accident in 2005. The USS *San Francisco*, a nuclear attack submarine, collided with an uncharted seamount at 160 m depth, between Pikelot and Lamotrek atolls in the western Pacific Ocean (Fig. 9). Four minutes prior to the collision, the seafloor depth was measured at 2,000 m.

Seamounts also act as seismicity moderators, tsunami wave scatterers, oceanographic "dip sticks" and biodiversity "hotspots". Seamounts carried by plate motions towards a trench, for example, are potential asperities on a subduction zone megathrust and may either inhibit or promote seismic activity. Furthermore, if intact when subducted into a trench, seamounts may disrupt the forearc (the region between the trench and arc) and cause submarine landslides. And seamounts may diffract earthquake-generated tsunami waves, which may, in turn, focus the waves more along one segment of coastline than another. Finally, seamounts may be sites of a tidal-induced ocean turbulence, which aids in bringing nutrients from the flank of a seamount to its summit. Indeed, some of our favourite fish and their predators are found on the summits of seamounts and seamounts have been targeted by the fishing industry, although not always with a positive outcome for their coral habitats, as for example in the Graveyard Seamounts, east of New Zealand (Fig. 10).

Limits of exploration

The lack of field data limits our exploration of seamounts. The number of scientific research cruises with PDRs onboard increased rapidly following World War II, but has been in a steady decline since the early 1970s. Single-beam bathymetry ship-track coverage is therefore limited, especially in the south Pacific Ocean, south of latitude 26° S (Fig. 11, Despite their large surface area, seafloor the size of the UK, Germany and France has been sampled by the equivalent of just 8, 8 and 5 ship tracks, respectively. Seafloor equivalent to entire countries (e.g. Greece, Bulgaria and Poland) has barely been sampled at all). Multibeam swath bathymetry coverage is even sparser. Imagine the difficulty in determining the geology of a country the size of France from just a few transects of geophysical data!

The challenge becomes even clearer when we consider the number of seamounts that might exist in the ▶

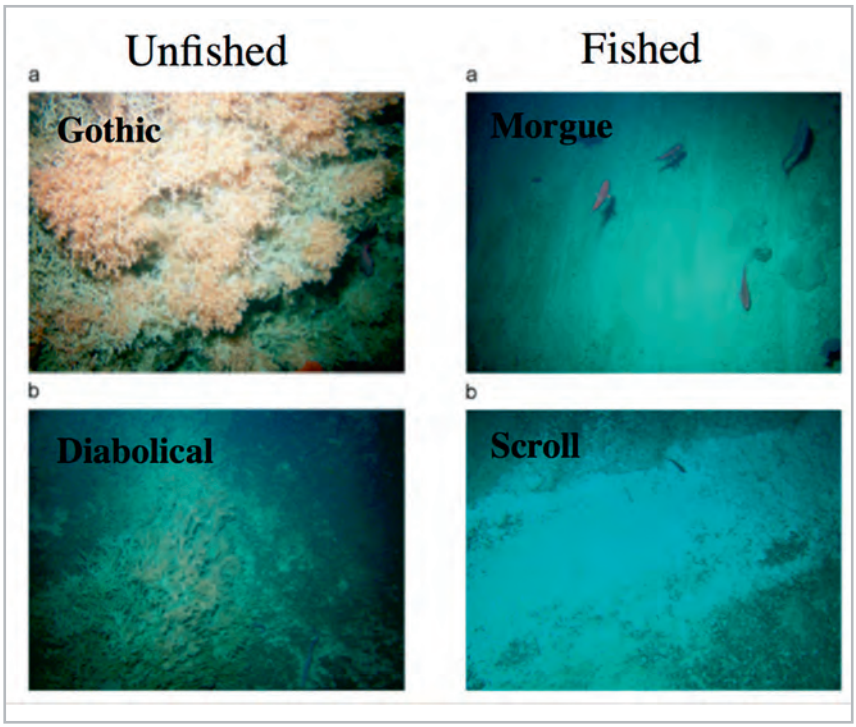

Fig. 10: Unfished and fished seamounts in the Graveyard Seamounts, east of New Zealand. Unfished seamounts have extensive cold-water corals that support a diverse array of invertebrates. Corals are removed from fished seamounts by bottom trawlers that leave their marks in the pelagic drape. (Images reproduced from Clark & Rowden, Deep-Sea Res.2009 © Elsevier)

world's oceans. Satellite-derived gravity data have found most, if not all large seamounts, but few of the small ones, while ship PDRs have found some large seamounts (ships tend to avoid the largest seamounts!) and many of the small ones (Fig. 12). If we assume that satellites have found *all* the seamounts with heights between say 2 and 9 km, then the relationship between the number and height of seamounts in this height range can be extrapolated into the domain of the smaller, yet still significant seamounts, taking into account the relationship found in the ship data. When we do this, we find that there may be upwards of ~30,000 seamounts in the height range of 1 to 2 km that still remain to be discovered!

So, what might Sir John Murray and the other great bathymetric chart makers of the last century, such as Heezen and Tharp, Uchipi and Emery, and Fisher and Mammerickx, have made of this challenge? Surely, they would have wanted the ocean floor to be mapped in its entirety? Walter Smith and Karen Marks (Laboratory for Satellite Altimetry, National Oceanic and Atmospheric Administration; NOAA) estimate that it will take about 200 ship years (e.g. 20 ships for 10 years) to completely swath map the world's ocean basins and their margins. Incidents such as the loss of flight MH370 and the 2004 and 2005 Java-Sumatra megathrust earthquakes suggest that we should start soon in order to build a global database that can be used as a reference to compare with new data, so enabling changes in seafloor depth to be detected. The challenge will require international collaboration and will take time and cost money (Mayer *et al. Geosciences* 2018).

> WHAT MIGHT SIR JOHN MURRAY AND THE OTHER GREAT BATHYMETRIC CHART MAKERS OF THE LAST CENTURY, SUCH AS HEEZEN AND THARP, UCHIPI AND EMERY, AND FISHER AND MAMMERICKX, HAVE MADE OF THIS CHALLENGE? SURELY, THEY WOULD HAVE WANTED THE OCEAN FLOOR TO BE MAPPED IN ITS ENTIRETY?

We could begin now, however, by encouraging academic research ships with onboard swath systems to record data not only in their survey regions, but during transits to and from a focus site. Such efforts could be enhanced by public engagement using 'ships of opportunity', for example cruise ships, Navy vessels and 'megayachts'. Only then might we be able to put to rest the well-known cliché that we know the surfaces of the Moon, Mars and Venus better than we know the surface of our own planet.

—Full figure captions are available online

Tony Watts is a Professor of Marine Geology and Geophysics at Oxford University; e-mail: tony.watts@earth.ox.ac.uk

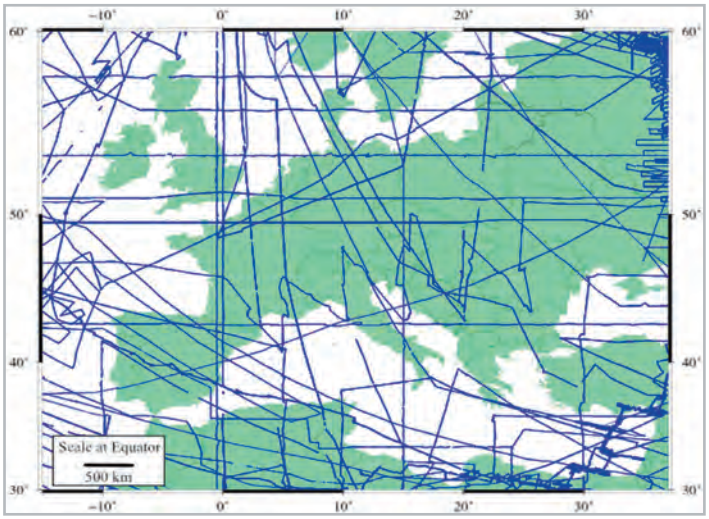

Fig. 11: All available single-beam bathymetry, gravity and magnetic ship-track data in part of the central Pacific Ocean (-165° to -113° longitude and -56° to -26° latitude) superimposed at the same scale on a map of Europe (blue lines, ship tracks; grey lines, national boundaries). (Data from http://www.geomapapp.org/)

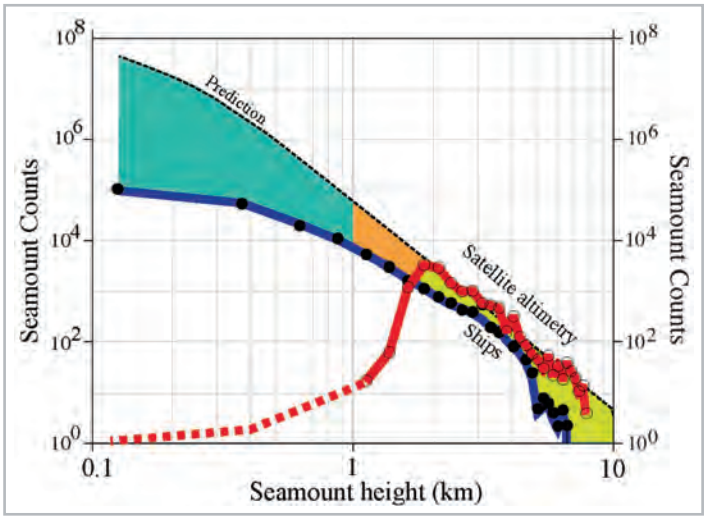

Fig. 12: No. of seamounts vs. seamount height above regional seafloor depth. Satellite data (red line) reveal nearly all the large seamounts, while surface ship data (blue line) reveal most small seamounts. Orange/green shaded region suggests many seamounts are undiscovered, tens of thousands of which may have heights up to 1-2 km. (Data replotted from Hillier & Watts, 2007)

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—The full reference list is available with the online version of the article

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WHEN STARS FELL TO EARTH

Meteor shower

Himalayan and US meteor showers during 1860 are documented in poetry, art and astronomical accounts. **Douglas Palmer** ponders potential connections

One hundred and 59 years ago, on July 14th 1860, the people of the remote Himalayan hill station of Dharmsala in Himalchal Pradesh, north-western India were treated to the awesome sight of 'shooting stars' burning up as they plunged through the atmosphere into the surrounding landscape. The locals reported seeing 'flames of fire, nine feet in length and clouds of dust as the incandescent fragments landed' (Sedgwick Museum archives). Awed they may have been, but not too frightened to try to retrieve some of the heavenly bodies. On doing so, the locals were in for a surprise—though not in the way you might expect.

Empire's reach

1860 was just three years after the Indian Rebellion, the uprising against the British East India Company and the British Crown, and Earl Canning was still the British Governor General. The local population of Dharmsala had increased in number, with the newly garrisoned Gurkha Light Infantry along with the seasonal influx of colonial administrators and their families escaping the heat of Delhi. The British presence and their observation of the celestial drama drew the phenomenon to the attention of the Geological Survey of India, which was then directed by an Irish geologist, Thomas Oldham. An investigation was ordered.

Hot news!

The investigating officer reported that eye-witnesses 'ran to the spot to pick up the pieces. Before they had held them in their hands half a minute they had to drop them…' (Sedgwick Museum archives). However, the reason was not what was expected. The report continued by saying it was '…owing to the intensity of the cold which quite benumbed their fingers…'. As surprised and puzzled as the locals, the officer continued '…considering the fact that they were apparently but a moment before in a state of ignition, is very remarkable, each stone that fell bore unmistakable marks of partial fusion' (Sedgwick Museum archives).

What the people of Dharmsala had in fact experienced was the intense coldness of deep space from where the meteorites originated. Despite their surface fusion, the low thermal conductivity and size of each rocky meteorite before they fragmented preserved their low temperature.

Poet, prince and president

That might have been the end of the story, but for an unlikely combination of events in New York State. A few days after the Dharmsala meteorite, in New York on the night of July 20, 1860 the great American poet Walt Whitman [1819-1892] saw a 'strange huge meteor procession, dazzling and clear, shooting over our heads' and wrote of it in his poem *Year of the Meteors*. The brief description was tantalising, for what kind of meteorite event had he actually seen?

The full stanza of Whitman's poem conflates the appearance of the meteors with three other major American events of 1860. There was the June arrival in New York of Brunel's leviathan, the *Great Eastern* on her maiden voyage, the October state visit of the 18-year-old Prince of Wales and the November election of Abraham Lincoln to the presidency. For Whitman and many others, such an astronomical event was '*Year of meteors! Brooding year!*' and filled with foreboding—which the subsequent outbreak of the American Civil War seemed to confirm.

And a painter

Whitman was not the only observant artist on the night of July 20th. One of America's most famous landscape painters, Frederick Church [1826-1900] was equally impressed by the same event. Influenced by Humboldt's vision of the interconnectedness of nature and Ruskin's emphasis on close observation, Church was greatly interested in the scientific portrayal of nature. By 1860, he was the most ▶

famous and successful American painter and could afford to buy a farm in Hudson, New York. And, he was there on his honeymoon on the night of July 20th at 9.49 pm when the meteoritic fireballs passed horizontally overhead. They took some 30 seconds to cross the night sky, from the Great Lakes towards New York State and out over the Atlantic.

Church saw enough of the unexpected and dramatic succession of bright fireballs to paint 'The Meteor of 1860'. In this painting, Church clearly shows a train of fireballs following the same trajectory across the night sky with such brightness that their incandescence is reflected in the lake waters below. But despite his fame, Church's painting did not become widely known because he kept it in his farmhouse bedroom for many years. The painting was not connected with Whitman's poem for another 150 years. Whitman scholars had been puzzling over what had prompted his poem until 2010, when rediscovery of the Church painting allowed the connection to be made (*Olson et al., Sky & Telescope Magazine* 2010).

Great Meteor Procession

The rare and remarkable astronomical event observed in the USA is now recognised as 'The Great Meteor Procession of 1860'. It was the result of a meteor breaking up as it entered the atmosphere and forming a train of fireballs all following similar paths. In this event, the meteor is thought to have entered the atmosphere at such a low angle that it became what is known as an 'Earth-grazing' meteor. It glanced through the upper atmosphere and returned to space.

The extraordinary sightings in Dharmsala and New York took place less than a week apart. This intriguing coincidence does not appear to have been previously commented upon, but prompts the question of whether the events were in anyway related. Fragments of the Dharmsala meteorites are preserved in the University of Cambridge's Sedgwick Museum, and appear to be the only tangible evidence of the incident. But, given the New York meteors merely passed through our atmosphere, is unlikely we'll ever know whether these falling stars were sourced from similar parts of our Solar System.

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The Dharmsala stony meteorite was recovered in July 1860 and sent to the 'Museum of Geology' (now the Sedgwick Museum), University of Cambridge by the Indian Geological Survey (image Sedgwick Museum archives)

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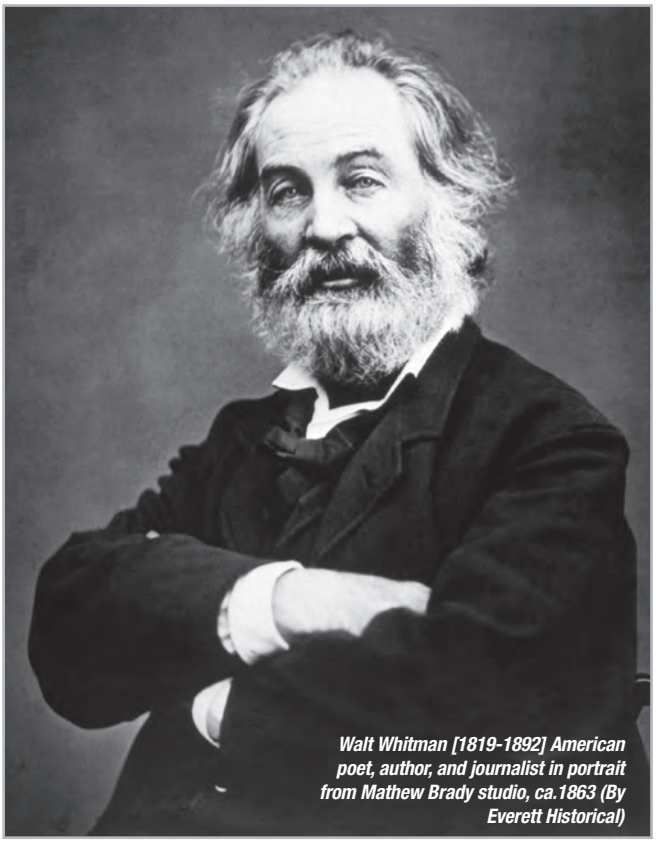
The Meteor of 1860 by Frederic Edwin Church [1826-1900] (Courtesy of Judith Filenbaum Hernstadt. Public Domain)



Walt Whitman [1819-1892] American poet, author, and journalist in portrait from Mathew Brady studio, ca.1863 (By Everett Historical)

Frederic Edwin Church [1826-1900] (Mathew Brady, Public Domain)

Beyond Extinction: The Eternal Ocean. Climate change & the continuity of life

This visually stunning book is summarised superbly by the author: "This book is nothing more than an unbridled celebration of life, over time, in that eternal ocean". The work explores, as discovered through the personal journey of the author, the history and evolution of life, its role in the Earth system and how we fit into it. The book successfully breaks down complex issues including the evolution of life and deep time into understandable bits.

We begin at Earth's creation during the Hadean which, after a million-year downpour, resulted in a vast ocean filled with anaerobic marine life. Slowly but surely that life, fighting the rusting of Earth's crust, altered the composition of the atmosphere to one rich in oxygen, leading to the dominance of aerobic life and ultimately us, Homo Sapiens.

The book continues with a chronology that tracks the evolution of life and Earth up to and including the brief evolution and history of Homo Sapiens, into the Enlightenment of the 18th Century. This section focusses on geology and fossils and how their discovery has ultimately led to enlightened rationalism and understanding of geologic time.

With this understanding of ancient life and the concept of deep time, it is possible for us to understand how the world was not all that different "back then" and in fact life's story is more about continuity than extinction. The text investigates mass-extinction events and, with a focus on animals, uses examples, charts and beautiful images. A traffic light system of species extinction, biological/evolutionary innovation and species continuations are presented. These sections explore evolutionary innovations, including skeletons, eyes, the egg and the migration of animals from the oceans to land, as well as departures from the fossils record, like the Trilobites, Belemnites, Ammonites and "Sea Dragons", amongst others.

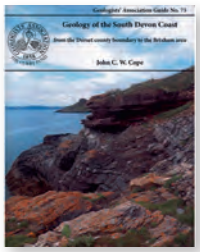
However, the primary message of this book can be found in the chapter on Continuities, which, through a multitude of phyla (including Cnidaria, Mollusca, Echinodermata etc.), explores the idea that life tends towards continuity and not change. This message of continuity is described very well. When asked "How do you survive a catastrophe?" Just ask any Nautilus as they thrived for 500 million years, living through five mass-extinctions! The final chapter discusses our place in this world, considering what we have learnt about deep time and the continuity of life.

I really enjoyed reading this book. It is a strong story about where our species fits on Earth.

Reviewed by: ***Simon Kettle***

BEYOND EXTINCTION: THE ETERNAL OCEAN. CLIMATE CHANGE & THE CONTINUITY OF LIFE
by Wolfgang Grulke, 2019. Published by: At One Communications, 224 pp. ISBN: 9781916039407 (hbk.) (Available from June 2019).
List Price: £38.00 W: https://www.geolsoc.org.uk/MPBEXmitchell/978-0-12-803382-1

Geology of the South Devon Coast: From the Dorset County Boundary to the Brixham Area



This field guide to the South Devon coast carries a sub-title because there is a constant debate, even in Devon, over what constitutes South Devon or South-East Devon. In essence, it continues the story of the Dorset Coast westwards within the districts of East Devon, Teignbridge and Torbay.

Like all Geologists' Association Field Guides of modern times, this guide is both colourful and informative, with a wealth of small maps and photographs coupled with access and parking information. The East Devon part of the guide clearly includes the UNESCO Dorset and East Devon World Heritage Site (the 'Jurassic Coast') and while this is a mouthful, abbreviating it to Heritage Coast can be confusing. Equally, the English Riviera UNESCO Global Geopark, is another mouthful, although it is scarcely mentioned.

The introductory pages include a digest of all the terminology connected to the stratigraphy and for some this can appear to be a daunting read. The importance of Devon in the establishment of the Devonian System is mentioned, though the early work on the counties of South-West England by Sir Henry De La Beche (1839) is not mentioned. The early work on the Torbay area (and elsewhere in South-West England) by William Pengelly and other founder members of the Devonshire Association is deserving of greater mention because they tackled such issues as cave exploration, the formation of the Dartmoor Granite, sea-level changes (including raised beaches, submerged forests, etc.) and the origin of the 'Red Beds' in the Torbay area.

The guide is genuinely comprehensive in coverage and one must avoid the temptation to pick on what is missing rather than what is covered. That said, there are three areas that could have been used more fully in explaining the geology of the area covered by the guide. The first of these is Ladram Bay where there is a description of the succession and the presence of rhizoconcretions (calcareous concretions developed around plant roots). There is, however, no mention of the famous occurrence of rhynchosaurs in these strata, especially around Ladram Bay. Clearly not every visitor will find bones of these vertebrates, but being aware that they can be present might mean that they are spotted by those looking at these river channel sandstones. There are very good 'dioramas' available that could have been used (with suitable permissions) to illustrate the palaeoecology of the succession.

The other also concerns the 'Red Beds' along by the railway line between Dawlish Station and Langstone Rock. While the channels filled with breccias are mentioned, one can obtain really good images of floods of coarse sediment apparently stopping in mid-flow, presumably having run out of energy within the dune sands or perhaps even water.

In many parts of the succession there has been microfossil and palynological research that has contributed to our understanding of the stratigraphy or the palaeoenvironments. Very little of this is mentioned and while it is fully appreciated that such fossils are not seen in the field, the interpretations are still important in the overall understanding of the area covered by the guide.

In summary, this is another valuable

contribution to the Geologists' Association range of field guides and I am sure that it will become popular amongst visitors to the area, many of whom come as part of organized groups.

Reviewed by: ***Malcolm B. Hart***

GEOLOGY OF THE SOUTH DEVON COAST: FROM THE DORSET COUNTY BOUNDARY TO THE BRIXHAM AREA
by Cope, J.C.W., 2017. Geologists' Association Guide No. 73, 122pp. (pbk.) **List price: £ 12.00 Fellow's price: £ 9.00 W: https://www.geolsoc.org.uk/GA073**

Great Geologists

I wish I had had this book, the first of its kind, as an undergraduate. Back then, a seasoned, wise researcher informed me that, Kuhnian scientific revolutions and paradigm shifts notwithstanding, there is no such thing as a theory neutral observation. In other words, when we write of something new to us, we interpret it using our existing theoretical knowledge. If we don't, we write science fiction. In presenting 35 great geologists' summarized biographies in chronological order (I cannot discuss them all, so my apologies to James Hutton), Simmons has produced a very readable book showing how the work of successive geoscientists built, and still builds, on their predecessors'. We learn that some of our present geological theories and methods have very deep roots.

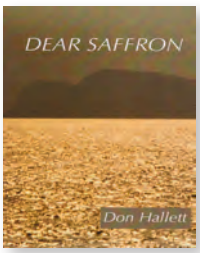
The histories commence with Nicolas Steno and end with Maureen Raymo (and include, of course, the Geological Society's Janet Watson). Biostratigraphy is shown to range back to William Smith. Sedgewick's and Murchison's contributions to the classification of the stratigraphic record into distinct time periods are covered, as is their great falling out over the Cambrian-Silurian issue. Lapworth is lauded for his solution to this—the erection of the Ordovician Period. Alcide d'Orbigny, despite his palaeontological work, is described as being "the architect of the cornerstone of chronostratigaphy". His view of successive unconformity-bounded marine transgressions is regarded as being the first step on the road to sequence stratigraphy. That road we follow through Grabau's expression of Palaeozoic transgressions and regressions, via Milankovich, to Vail's sea-slug model of sedimentation and eustacy curve. Wegener's model of continental drift is shown to have been inspired not only by looking at an atlas, but also by a comment by Krenkel regarding the geological similarities between Brazil and west Africa, and by Keilhack's work on the distribution of Carboniferous glacial drift across the southern continents. We follow this to plate tectonics, though Arthur Holmes, Marie Tharp's maps, Harry Hess and Fred Vine to John Tuzo Wilson. That geological research is a continuous, developmental process is made clear.

Simmons asks, have we have reached 'Peak Geoscience'? Have we discovered the main paradigms, being left with only small projects that fill gaps in our knowledge? This he doubts. Technological advances and data science will tease out patterns in geological data beyond the capacity for easy recognition by humans. What an exciting prospect! I recommend Simmons' book to higher undergraduates, graduates and aging geologists alike, it being a source of awe and inspiration.

Reviewed by: ***Brent Wilson***

GREAT GEOLOGISTS
by M.D. Simmons (2018). Published by Halliburton, Abingdon, UK. 141 p. ISBN 978-1-9160054-1-9 (print), 978-1-9160054-0-2 (ebook).
List Price: Free (Available as a free gift to the geoscience community from Mike and his employers, Halliburton) W: https://view.joomag.com/exploration-insights-great-geos-ebook/0172709001539012700?short

Dear Saffron



We are all told sometime 'You ought to write a book about your life and times'. *Dear Saffron* is that book for Don Hallett, but written in an innovative approach in the form of 73 letters (chapters) to be read by his granddaughter, Saffron. The scene is 'One day, while rummaging through the attic, you come across a trunk which belonged to your grandfather. You open it and find amongst other items a bundle of letters, addressed to '*Dear Saffron*'. Intrigued, you begin to read.'

Dear Saffron progresses chronologically from letter 1, with family history of grandparents, parents and their route to Halifax, Yorkshire, where Don was born in 1939, via his schooling, university (Durham) and doctorate (University College London), up to letter 73, 2016 when the book was written.

The letters cover the various jobs Don had as he progressed in upstream petroleum exploration geology. These included Esso Exploration in Senegal, Sonatrach in Algeria, BNOC on North Sea exploration and Chief Geologist of its privatised successor Britoil, then Sirte Oil Company, Libya, 1987-1997 and finally as a Consultant Petroleum Geologist, specialising on Libya.

It is an absorbing personal story including friends, family, marriages, births, deaths, tours, holidays and more, by an author who has the ability to paint an image in a sentence or two. His style is to start at one point then move to other points, but the whole letter fits together. We learn of the reasons for the author's career moves, including the ramifications of the break-up of Britoil by Margaret Thatcher, and the personalities of some of the bosses.

There are many fascinating observations of what caught the author's eye, covering history, geography, places, travel and people such as Gaddafi. A search on Wikipedia could flesh-out many of the points. However, Don states (p399) 'most of my letters have been about places and events but very little about my interests and beliefs'. I agree: the early letters gave good pictures of Algeria and Libya, but I would have liked to have seen the reasons for the later trips, maps of the places and geography, more on the petroleum geology, Don's professional views on what he actually did and what gave him reward. But ultimately, *Dear Saffron* is the autobiography of Don Hallett.

Did I enjoy the book? Yes. I was left feeling that I would have liked my grandfather to leave me such a treasure trunk. I found it a gentle read suitable for bedtime, a long journey or airport wait.

Reviewed by: ***Richard Dawe***

DEAR SAFFRON
by Don Hallett, 2018. Published by: Little Henry Publishing, 13 York House, Courtlands, Sheen Road, Richmond TW10 5BD, UK 407pp. (pbk.) ISBN: 978-1-5272-2273-1
List price: £18.00 W: www.waterstones.com

Characterization of Ore Forming Systems from Geological Geochemical and Geophysical Studies

The discovery of economically viable mineral resources is increasingly rare, despite the increased expenditure associated with this activity due to exhaustion of easier-to-locate resources. Most ore deposits mined in the past or currently being extracted are at or near Earth's surface, and were often discovered serendipitously. However, to meet future demand for mineral resources, exploration success will require a more rigorous approach. Exploration will need to be more accurate, based on informed models of Earth's crust that utilize all available geological, geochemical and geophysical information, and paired with an understanding of how ore-forming systems relate to Earth's evolving structure. Advances in the detection and interpretation techniques for geophysical and geochemical data will greatly help with the location of such deposits. However, the basis for successful exploration of mineral deposits will require a more fundamental understanding of the processes that form economic mineral deposits and the identification of where such processes could occur. As exploration moves into more remote, complex or deeper geological terrain such skills will become increasingly more important.

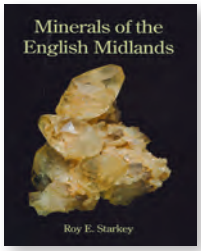
This volume, therefore, is timely and provides just such information. It brings together a series of papers with a very broad range of interests connected to the study of mineral deposits in Earth's crust to develop a better understanding of the formation and location of such deposits, to aid ore-genesis studies and mineral exploration. The papers are broadly split into five sections: (i) applying advanced microscale geochemical detection and characterization methods; (ii) introducing more rigorous 3D Earth models; (iii) exploring critical behaviour and coupled processes; (iv) evaluating the role of geodynamic and tectonic setting; and (v) applying 3D structural models to characterize specific ore-forming systems.

The papers are well written, provoking and informative. The volume, as expected from this well-established series, is extremely well edited and put together and, despite the number of papers and authors, is largely free of errors or typographic mistakes. The introduction to the book is available as an open access paper and is worth reading as a standalone article or summary of the volume. My only small dissatisfaction with the volume is the lack of examples illustrating where the ideas put forward in the volume have been applied. Hopefully the editors will correct this minor shortcoming with a follow up volume documenting real-world exploration studies. It is possible that those reading the volume will be able to contribute.

Reviewed by: ***Robert Bowell***

CHARACTERIZATION OF ORE FORMING SYSTEMS FROM GEOLOGICAL GEOCHEMICAL AND GEOPHYSICAL STUDIES
by K. Gessner, T.G. Blenkinsop & P. Sorjonen-Ward (eds), 2018. Geological Society of London SP 453, 416 pp. ISBN: 9781786203137 (hbk.)
List Price: £120.00 Fellow's price: £ 60.00 W: https://www.geolsoc.org.uk/SP453

Minerals of the English Midlands



This is an amazing book and a credit to the author. It has been a pleasure to review such an erudite and lavishly illustrated volume.

The book documents the rich mineralogical heritage of the Midland Counties of Cheshire, Derbyshire, Gloucestershire, Herefordshire, Leicestershire and Rutland, Northamptonshire, Nottinghamshire, Oxfordshire, Shropshire, Staffordshire, Warwickshire, West Midlands and Worcestershire.

It begins with an overview of the history and geography of the area, which defines the character of the thirteen counties, followed by a lavishly illustrated chapter on geology and then a description of the mineral deposits.

Each of the counties mineral wealth is explored in the next thirteen chapters, all beautifully illustrated with colour photographs of mineral specimens and topographic features, with almost every image taken by the author who is a very competent photographer. There are also maps, diagrams and historical photographs that enhance the well-written and informative text.

The first county chapter is Cheshire, my home county, and was a delight to read. There is an excellent review of the salt industry, covering both mined salt and brine extraction (with many historic photographs of both), the subsequent subsidence caused by the industry, and the modern technology used in salt and brine extraction. Then follows a detailed account of the Alderley Edge copper mineralization, accompanied by the author's delightful mineral photographs.

As I read this chapter, I found myself constantly looking up the references in the text. The reference section is an extremely useful feature of this book, running to 16 pages and making this volume the obvious starting place for any future researcher.

This thorough research is concluded by three very significant chapters on 'Collectors and Collecting', 'Mineral Dealers' and 'Decorative Stones'. The first of these, as the author states, is not all-inclusive, but does give a historical overview and includes modern collectors. Then follows an overview of museum collections relating to these counties. The chapter on mineral dealers follows a similar format, starting with historical dealers and including some still active today. I was pleased to see listed and illustrated the premises of Gregory and Bottley—an establishment I frequented in the 1960s. The final chapter on decorative stones has some excellent photographs of Derbyshire's unique 'Blue John'.

This work has all the attractiveness of a quality coffee table book, but it is much more than that; it is a monograph it its own right and the result of meticulous research over many years. This book holds its head high as a genuine scientific work. I highly recommend it. All that is needed now is for someone to produce books of similar quality for Northern England, and Devon and Cornwall and our cup will certainly runneth over.

Reviewed by: ***Richard Porter***

MINERALS OF THE ENGLISH MIDLANDS
by Roy E. Starkey, 2018. Published by British Mineralogy Publications, Bromsgrove Worcestershire, UK. 426 pp. ISBN: 978-0-9930182-3-7 (pbk.)
List Price: £35.00 ISBN: 978-0-9930182-2-0 (hbk.) List Price: £50.00 W: https://britishmineralogy.com/

DISTANT THUNDER

Credit where credit is due

Geologist and science writer Nina Morgan applauds a remarkably frank revelation

No doubt many of the early geologists received essential encouragement, inspiration and practical assistance from their wives, sisters and daughters. But generally they did not publicly acknowledge the help they received. However, one who did was the geologist John Phillips [1800-1874], the orphaned nephew of William Smith [1769-1839]. Smith paid for John's schooling and introduced him to the science of geology. In 1829, John, then working as the keeper of the Yorkshire Philosophical Society Museum, invited his sister Anne to join him in York. Neither married and the two lived together and supported each other emotionally, practically and intellectually for the next 33 years, until her death in 1862.

Geological companion

Almost from the moment they were reunited, Anne became involved in John's geological work, and letters to her from both John and William Smith suggest that she was very well educated, and very knowledgeable about geology. But the 'public debut' of her geological prowess came in 1842 when she discovered a vital piece of evidence about the origin of the Malverns.

In general terms, the Malvern Hills consist of a central Precambrian core of igneous intrusives bounded by a north-south trending fault, surrounded by Triassic sediments and marls on the east, and on the west by Cambrian and Silurian sediments, which lap unconformably onto the intrusives. In the 19th century the origin of the Malvern Hills was a hot—and very controversial—topic. On one side was Sir Roderick Murchison [1792-1871], who believed that the Malvern Ridge was intruded as a hot body after the Silurian sediments were laid down. On the other was Phillips, then working for the Geological Survey, who thought that the ridge was already elevated and cooled before the Silurian rocks were laid down. Phillips based his case on the fact that where the Silurian sediments are found in contact with the volcanics, they are not affected by metamorphism. He reasoned that as the Silurian seas lapped up against the ridge, fragments of the volcanics could have been eroded off and incorporated to form a conglomerate at the base of the Silurian. To clinch his argument, he needed to find the conglomerate.

Miss Phillips's conglomerate

On 1 August 1842, while Phillips was busy showing Murchison and other geologists around to explain his theories, Anne, who was staying with her brother in Malvern, went out in the field and found broken blocks of the conglomerate. Within a week she and John, accompanied by John's boss, Sir Henry De la Beche [1796-1855], managed to locate a place where the conglomerate was in contact with the intrusive.

Phillips quickly went into print with a report of the find in the October 1842 issue of the *London, Edinburgh and Dublin Philosophical Magazine and Journal of Science*. He described how, while he was in the field discussing the origin of the Malverns with other geologists:

"... My Sister, knowing the interest I felt in tracing out the history of the stratification visible in these trap [volcanic] hills, sought diligently for organic remains in the midst of and on the western flanks of the sienitic [syenitic] masses of the North hill and Sugar-loaf hill. In this most unpromising search she was entirely successful, and collected from the midst of heaps of fallen stones, which seemed to be all trap, several masses richly charged with organic remains, and full of feldspar, quartz, and hornblende, in grains and large lumps ...It was, in fact, certainly and evidently a conglomerate full of Silurian shells, and pebbles and fragments of the sienitic, felspatho- quartzose and other rock-masses of the Malvern hills." The rock became known as Miss Phillips's conglomerate—and samples of it soon became highly collectable items on geology field trips.

Phillips repeated this account, slightly abbreviated, in his 1848 Geological Survey Memoir. Considering that from its origin in 1835, the Geological Survey remained an all-male preserve until the early 20th century, that must have taken some doing!

End notes: References include: Morgan, N., Anne Phillips and the Mystery of the Malverns, *Geoscientist*, **16/7** 2006; Morgan, N, 2007, Anne Phillips: John Phillips's Geological Companion, *Geol. Soc. Spec. Pub.* **281**, pp 265 -275; Morrell, Jack, *John Phillips and the Business of Victorian Science*, ISBN 1840142391; and Phillips, J., 1848, *Geol.* Survey Memoir , **Vol 2, Part 1**, , pp. 66-67.

* **Nina Morgan** is a geologist and science writer based near Oxford. Her latest book, *The Geology of Oxford Gravestones*, is available via www.gravestonegeology.uk

Geoscientists in the news and on the move in the UK, Europe and worldwide

Hong Kong Regional Group liaison

John Talbot (Vice-President, Chartership) reports on recent meetings with the Hong Kong Regional Group

Taking advantage of my trip to Hong Kong in May, the Regional Group (HKRG) organised two events, which I was invited to lead. Trudy Kwong, the HKRG Secretary, arranged a Chartership workshop for early career geoscientists on Wednesday 22 May.

Over 40 people attended—a record turnout, indicating a real need to run similar events on a regular basis. Of those attending (see image), about a third are members of various company training schemes accredited by the Society and of which there are presently seven in the region, with two more companies in the process of application and assessment.

The following evening, Kevin Styles, the Regional Group's Chair, had organised a seminar and roundtable discussion for Sponsors and Scrutineers. About 50% of the Hong Kong Scrutineers attended – also an excellent turnout.

Both evenings commenced with short presentations, followed by an extensive discussion and a general Q&A session. Before the first evening's meeting closed and dinner was served, I was available for one-to-one dialogue with the Chartership workshop attendees.

To round off a concentrated series of liaison meetings in Hong Kong, Burlington House was pleased to reciprocate their Regional Group's warm hospitality, when Kevin Styles visited the UK and attended our Chartership and Professional Committees, as well as the next day's AGM and President's Day.

CAROUSEL

All Fellows of the Society are entitled to entries in this column. Please email amy.whitchurch@geolsoc.org.uk, quoting your Fellowship number.

◆ Melanie Leng

Professor Melanie Leng, Chief Scientist for Environmental Change Adaptation and Resilience at the British Geological Survey was awarded an MBE in the Queen's Birthday Honours list 2019.

◆ Pavlos Tyrologou

Pavlos Tyrologou, a GSL Fellow and Chartered Geologist based in Greece, was elected External Relations Officer for the European Federation of Geologists at the May council meeting in Delft, The Netherlands.

◆ Patrick De Deckker

Professor Patrick De Deckker of the Australian National University, Canberra (and Honorary Fellow of the GSL) has been awarded the Brady Medal of The Micropalaeontological Society.

◆ Wolfgang E. Schollnberger

Dr. Wolfgang E. Schollnberger, former Technology Vice President with Amoco Corp. and BP plc., was recently named an Honorary Member of the Austrian Geological Society in recognition of his merits in support of the Society and its scientific goals.

Staff Matters

Eleanor Lewis, Website Content Co-ordinator, **Patricia Petrovic**, Receptionist, **Darren Prewter**, Data Clerk, and **David Riach**, Head of Events, have left the Society. The Society wishes them all well for the future and thanks them for their valuable contribution to its work over the years.

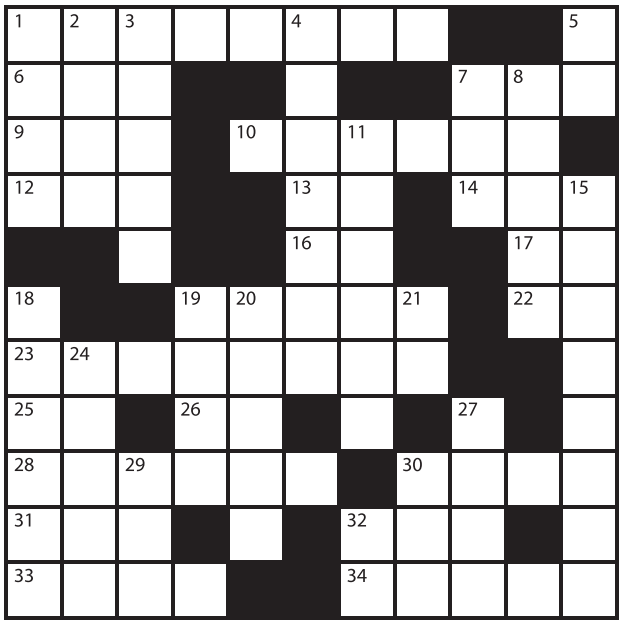
The Society notes with sadness the passing of:

Black, John H *
Bradshaw, Reginald
Broecker, Wallace *
Burke, Kevin Charles Anthony *
Butler, Raymond John Thomas *
Clayton, Keith *
Crossley Nutt, Michael John *
Herries-Davies, Gordon L *
Huckerby, John Andrew *
Jobbins, Alan *
Osmaston, Miles *
Rocha, Rogerio *
Simpson, Peter Robert *
Westhead, Robert Keith
Whitham, Andrew Gordon

In the interests of recording Fellows' work for posterity, the Society publishes obituaries online, and in *Geoscientist*. Bold, recent additions to the list; * Fellows for whom no obituarist has been commissioned; § biographical material lodged with the Society.

If you would like to contribute an obituary, please email amy.whitchurch@geolsoc.org.uk to be commissioned. You can read the guidance for authors at www.geolsoc.org.uk/obituaries. To save yourself unnecessary work, please do not write anything until you have received a commissioning letter.

Deceased Fellows for whom no obituary is forthcoming have their names and dates recorded in a Roll of Honour at www.geolsoc.org.uk/obituaries.



Crossword

Across
1 Period of the deposit used to face Norwich Cathedral, quarried at 33ac (8)
6 Native of 2d (3)
7 District and river in the Prefecture of Hyogo (3)
9 Salt commonly used in scintillation detectors (3)
10 Mixed woodland and pasture typical of 23ac (6)
12 A unit of resistance (3)
13 See 16
14/5d A tortilla chip with cheese (5)
16/13 Hydrogeologist who developed the concept of regional groundwater flow (4)
17 Principal metal in limestone (2)
19 "- of Damocles", a stalactite in Ingleborough Cave (5)
22 100 litres (2)
23 Where you will find 19 & 30ac, 1, 2 & 24d (8)
25 Mystical Asian syllable (2)
26 Sent an e-mail (2)
28 Uplifted block for example Armorican "-" (6)
30 Metal mined until recently at Salsigne (4)
31 Alternative to the RGB colour system used in satellite imagery (3)
32 "I wasn't a hero I was a little "-" in a big wheel" (Frank Mouque) (3)
33 City where William I is buried (4)
34 Aeolian silt recognized by 4d as important for the construction of airfields (5)

Down
1 Mission to study the evolution of Jupiter (4)
2 Location of Bingham Canyon copper mine (4)
3 City where champagne is matured in chalk caves (5)
4 Military geologist later head of department at Birmingham (7)
5 See 14 ac
7 Institut Géographique National (3)
8 For example 19 or 30ac or 1, 2 or 24d (5)
11 Genus of algae growing in the English Channel commonly known as "dead man's ropes" (6)
15 Mostly limestone plateau noted for its apple brandy (8)
18 Relating to gnomes but not Zurich (6)
19 Small & medium-sized enterprises (4)
20 Ephemeral desert river beds (5)
21 See 30d
24 Home of Berkshire Hathaway (5)
27 A box in a theatre or opera house (4)
29 Direction between S & SE (3)
30/21 As opposed to baddy (5)
31 One-hundredth of a litre (2)

By Bindweed

Solutions July / Across: 1 Busty **3** Peat **7** NHS **9** Calamites **13** Achar **14/18** Eigenvalues **17** Sonar **19** Cha **20** Ore **21** TED **23** Liege **25** Tau **27** Silo **29** Greene **30** Ness **31** DS **Down: 1** Bituminous **2** Tea **4** Anthracite **5** Thea **6/28** Main **8** SSR **9** Creswell **10** Lignite **11** Manriders **12** IC **15** Io **16** EA **22** Eggs **24** Ion **26** And

FROM THE LIBRARY

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Fellows and Candidate Fellows can visit the Library at Burlington House between 9.30am and 5.30pm, Monday to Friday. You'll find comfortable and quiet study space, scanning and copying facilities, free Wi-Fi and all of the latest books and journals. The Library's professional, dedicated staff are on hand to answer any enquiries.

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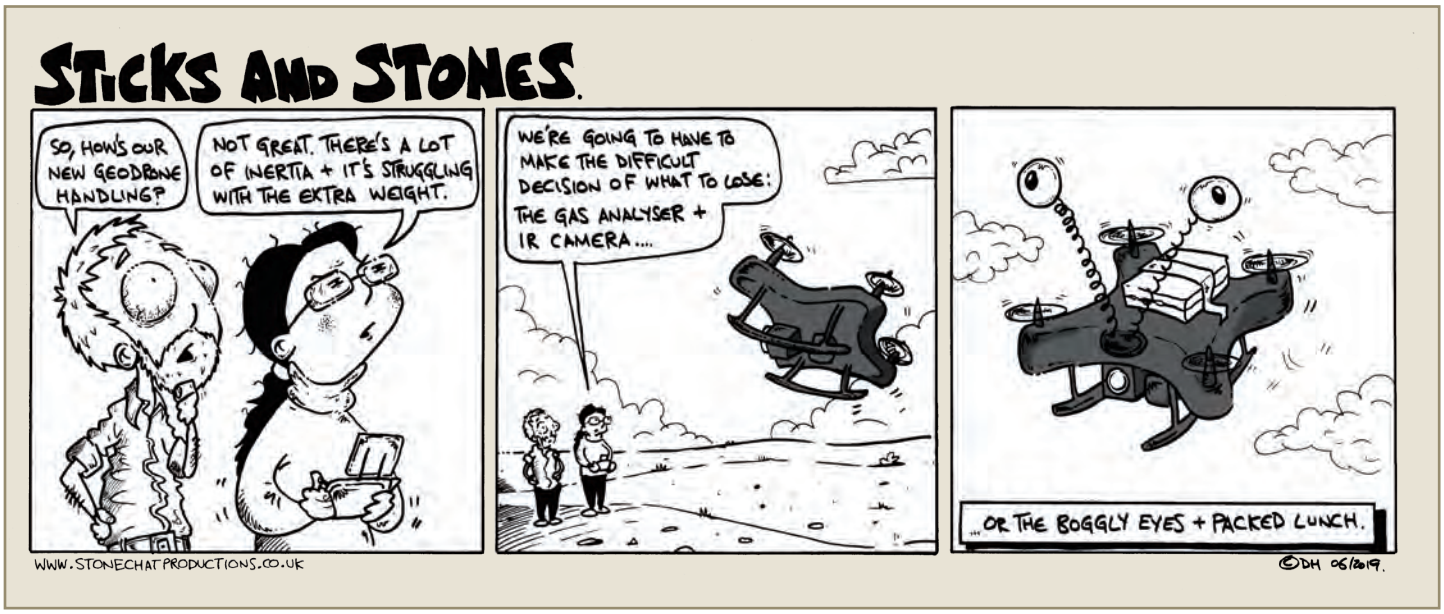
ENDORSED TRAINING/CPD AND EVENTS

MEETING	DATE	VENUE AND DETAILS
Subsidised Introduction to Micromine Course	5-6 Aug	Endorsed CPD course **Venue:** Whitefriars Street, London **W:** https://www.geolsoc.org.uk/Micromine%20Intro%20course%20Aug19
Resource Estimation - UK	7-8 Aug	Endorsed CPD course **Venue:** Whitefriars Street, London **W:** https://www.geolsoc.org.uk/Micromine%20Resource%20estimation%20course%20Aug19
Regional Public Lecture: Diamond windows into the deep Earth	14 Aug	Public lecture **Venue:** North East Futures UTC, Newcastle upon Tyne **W:** https://www.geolsoc.org.uk/GSL-Regional-Lecture-Aug
The Geological Society of Namibia - 50th Anniversary Conference	1-4 Sep	Conference **Venue:** Windhoek, Namibia **W:** https://www.geolsoc.org.uk/GeolsocNamibia-50-Anniversary-Conference
Debris Covered Glaciers	2-4 Sep	Workshop **Venue:** Burlington House, London **W:** https://www.geolsoc.org.uk/GSL-Debris-Covered-Glaciers
Future of Mining EMEA 2019	4-5 Sep	Conference **Venue:** 8 Northumberland Avenue, London, UK **W:** https://www.geolsoc.org.uk/EMEA-Future-of-Mining19
WMRG Chartership Evening	10 Sep	Evening meeting, lecture **Venue:** The Birmingham & Midland Institute **W:** https://www.geolsoc.org.uk/WMRG-Chartership-Evening-2019
Yorkshire: Sub-surface surveys	11 Sep	Lecture **Venue:** The Adelphi Hotel, Leeds **W:** https://www.geolsoc.org.uk/YRGGS-Subsurface-surveys



OBITUARY Keith Westhead (1965-2018)

A runner, piper and British Geological Survey geologist, with Black Country wit

Most *Geoscientist* obituaries focus on scientific achievement; they list publications and professional accomplishments, and include something personal as an added extra. This approach would be a disservice to Keith. His life/work balance was distinctly Scandinavian, perhaps the result of early exposure to Norway. He worked to live, not the other way around. His all-consuming passions were geology, the Great Outdoors, cars (including electric—he was an 'early adopter'), music, cycling, running (11 marathons) and, strangely for a Black Country boy, the bagpipes.

A fine start

Keith came from a polymath Walsall family, with a strong scientific bent, including a biochemist father. His brother Steve recalls fossil hunting as kids, but Keith's passion for geology truly ignited during A-level Geology at Queen Mary's Grammar School. That led to a Geology degree from Leeds and PhD research on Norwegian Palaeozoic rocks (at Liverpool University).

Mystic arts and the BGS

Keith and I joined BGS on the same day in 1990. Mapping training began in Derbyshire. My October 1990 diary entry records '…tedious, gently dipping Coal Measures'. Our trainer, an intimidating type with piercing blue eyes, did his best to enthuse us. It clearly worked; Keith turned his back on Hard Rock and, for the remainder of his career, was a Soft Rock geologist. He joined BGS Exeter and was trained by Roger Bristow in the mystic art of mapping Chalk. Keith adapted brilliantly to Hardy country and 'feature' mapping.

> KEITH CAME FROM A POLYMATH WALSALL FAMILY, WITH A STRONG SCIENTIFIC BENT, INCLUDING A BIOCHEMIST FATHER. HIS BROTHER STEVE RECALLS FOSSIL HUNTING AS KIDS

After Dorchester, he moved to Weymouth and worked on the Purbeck Beds. Rejecting the status quo, his classic paper with Anne Mather on the Purbeck stratigraphy of Dorset is a prime example of original thinking. He then moved to Somerset and mapped Lower-Middle Jurassic strata. Several published BGS maps and memoirs resulted.

In 1994, Keith become Head of Enquires at BGS Keyworth. As an experienced field geologist, he brought a deep understanding of the strengths and weaknesses inherent in geological maps and borehole records. He used these skills, and an early appreciation of the power of digital information systems, to completely overhaul Enquiries. He had a deceptively easy, but organised, way with colleagues and the public. Enquiries became an exemplar for geological and environmental organisations across the world and a huge commercial success for BGS.

Scotland

In 2003 Keith transferred to Edinburgh and joined the Marine Geology Unit, remaining until retirement in August 2018. He was convinced that the subsea geology around the UK was neglected. As part of this work, he returned to his Dorset roots, producing a superb paper and offshore geology map for the Journal of the Geological Society.

Keith embraced his new surroundings and took up piping. He progressed rapidly, ending up as Pipe Major of Stockbridge Grade 4 Pipe Band. He competed in World and European Championships and toured the continent. Jamie, Keith's son, followed in Keith's footsteps, playing bagpipe solos at the Usher Hall in Edinburgh—a great source of pride for his parents.

Keith was funny, modest and gracious; a family man par excellence. He engaged with all his many interests during his final year, even managing to surf. His celebration on the 10th February 2019 was joyous, funny and, given the presence of 30 plus pipers and drummers, very loud. Keith is survived by his wife Helen and his children, Ellie and Jamie.

By Warren Pratt and Keith's BGS colleagues

HELP YOUR OBITUARIST The Society operates a scheme for Fellows to deposit biographical material. The object is to assist obituarists by providing contacts, dates and other information, and thus ensure that Fellows' lives are accorded appropriate and accurate commemoration. Please send your CV and a photograph to Amy Whitchurch at the Society.

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in Natural Resources

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investment in the natural resources sector, we hope to see you at the conference.

For further information please contact:

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