MINING THE BRINE
A NOVEL ROUTE TO A MORE SUSTAINABLE FUTURE?

DIGGING INTO DATA ACCESS
The need for reform

SAFE DISPOSAL
Nuclear waste and the role for geoscience

SOCIETY AWARDS
Trailblazing geoscientists

ANNUAL REVIEW
The Society’s activities in 2021
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Gain the up-to-date knowledge and skills needed to understand and solve challenging water problems applicable to a diverse range of careers or further research in this evolving field.

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Editor's welcome

As summer rolls around, with it comes the most exciting day in the Society’s calendar: President’s Day. The ceremony will again be virtual and, while it is disappointing to miss an opportunity to meet in person (p 23), a virtual gathering will allow Fellows, family and friends from across the globe to join the celebrations.

In this edition of Geoscientist, we provide a section dedicated to the Annual General Meeting, President’s Day and the Awards Ceremony (p 9), featuring interviews with Tanya Atwater (Wollaston Medalist), William (Bill) Ryan (Lyell Medalist) and Anna Joy Drury (Wollaston Fund winner) that provide fascinating insights into the personal histories and scientific journeys of these trailblazing geoscientists.

Tanya and Bill tell passionately engaging stories of a remarkable period in Earth science, at the height of the plate tectonic revolution. Both began their careers in marine geoscience during the 1960s, when the many pieces of the plate tectonic puzzle were falling into place, leading to the acceptance of a theory that has transformed our understanding of the planet. Their words paint an intoxicating picture of discovery, of days filled with marine expeditions, and the opening up of the oceanic realm for detailed exploration. Likewise, Anna Joy highlights how marine data continue to reveal Earth’s great secrets, as well as crucial insights into the future path it may take.

In all of these stories, the critical role for data stands out. Plate tectonic theory was finally accepted because of a data explosion that allowed robust testing of the principle. As Anna Joy notes, it is essential to embrace the FAIR data principles, ensuring that data are Findable, Accessible, Interoperable and Reusable – a point detailed in an article by Alex Dickinson and Mark Ireland (p 32) that underlines some of the challenges associated with accessing archived data in the UK.

Sadly, we only have room to feature interviews with a small number of Medalists and Fund winners in our pages. So please join us for President’s Day when we will celebrate the incredible achievements of all of the awardees.

The AGM will also take place virtually on 8 June, giving Fellows the opportunity to hear about the Society’s activities (as summarised in the Annual Review on page 57), elect new Council members and Officers, and discuss issues. The Society has undergone dramatic change in the past few years and things remain unsettled as our incoming President, Ruth Allington, takes the helm (p 12). Ruth’s priorities include finding a replacement for our Executive Secretary, Richard Hughes, who will retire later this year, and easing uncertainty associated with the Burlington House lease – for which a dedicated (virtual) discussion meeting will take place on 19 May that is open to all Fellows (p 6).

Despite this uncertainty, our out-going President, Mike Daly, notes the positive direction in which the Society heads (p 10), thanks in-part to the strategic review that has focused our efforts, as well as Council’s decision to release finances from the Fermor Endowment Fund (to support minerals research critical to the energy transition) and to create the ‘Geological Society Futures Fund’ (to invest in membership services and activities) – proactive initiatives that signal a bright future.

AMY WHITCHURCH, EXECUTIVE EDITOR
The Pathway to Chartership

Have you been thinking about becoming Chartered, either as a Chartered Geologist (CGeol) or as a Chartered Scientist (CSci)?

Accreditation as a Chartered Geologist or Chartered Scientist is a sign to clients, regulators, employers, and the general public that you are a competent professional who can demonstrate a high level of knowledge, skills and experience, and that you are bound by a strict code of professional conduct.

Geology is becoming increasingly regulated as a profession making it a good idea to gain your Chartership, especially if you are considering working abroad where it is often necessary to have a recognised licence to practice or to sign off reports. The Geological Society is licensed by the European Federation of Geologists to award the title of European Geologist (EurGeol) and has links across the globe with other international regulatory bodies.

**Fellows can take advantage of our Chartership Services**

The dedicated Chartership team at the Geological Society is with you through every stage of your Chartership journey to ensure that your application demonstrates as clearly as possible that you have achieved the required level of competency.

Find out more on our website: www.geolsoc.org.uk/chartership

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**The Chartership Journey**

1. **Check you are eligible for Chartership**
   1) You must be a Fellow of the Society
   2) You must hold appropriate educational qualifications
   3) You need at least four years' relevant work experience

2. **Find your Supporter**
   You need one professionally qualified, and preferably chartered, Supporter who has current, first-hand knowledge of your competencies.
   We have a dedicated LinkedIn group for those who need help finding a Supporter or a Mentor

3. **Begin the validation process**
   The online application is in three parts and takes around three months to complete

4. **Application and Supporter statements submitted**
   Application fee paid

5. **Scrutineers review application**

6. **Recommendation received for interview or postponement**

7. **Validation interview**
   Carried out in person or via video conference call

8. **Chartership status awarded by the Geological Society Council**

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**Further Information**

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Burlington House
Piccadilly
London
W1J 0BG

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E: chartership@geolsoc.org.uk
W: www.geolsoc.org.uk/chartership
FELLOWS WILL BE AWARE that the Geological Society has a long and illustrious history. It was founded in 1807 and in 1825 was granted its Royal Charter of Incorporation, with a supplemental charter granted in 2006. Today it is a registered charity and its instruments of governance include its Royal Charter, its bye-laws and its regulations.

The bye-laws are a key instrument of governance, setting out many of the rules under which the Society operates. The current bye-laws, though, are over 20 years old and in that period much has changed, both within the Society and in the external environment within which it operates.

Council has approved a review of the bye-laws aimed at ensuring that the Society’s key instrument of governance reflects modern organisational standards, and that we have the flexibility needed to operate in a rapidly evolving and unpredictable world. A working group has been formed and its initial work will be to propose revisions that will then be the subject of a Fellowship consultation. This working group will be supported by an advisory group drawn more widely from the Fellowship.

The terms of reference and working group membership can be found at geolsoc.org.uk/About/Governance/Bye-laws/2022-Bye-laws-review. The current bye-laws can be found at geolsoc.org.uk/byelaws and Fellows’ comments on the review or the bye-laws themselves can be sent to byelaws.review@geolsoc.org.uk. If you wish to join the advisory group please contact this same address. Jessica Smith, Council member, Vice-president Regional Groups, Chair of the bye-laws working group.

LIBRARY E-RESOURCE EXPANSION

The Society library is delighted to announce a major expansion of the e-resources available to Fellows for 2022, including new e-journals, e-books and journal archives going back as far as the late 18th century. As well as covering all aspects of geological sciences, this new package will offer users access to some of the latest research on topics such as energy policy, the energy transition, carbon capture and geohazards.

We are also expanding our historical content, with acquisition of the digital archives for Earth and Environmental Science Transactions of the Royal Society of Edinburgh [1788 - ], Geological Magazine [1864 - ] and Proceedings of the Geologists’ Association [1859 - ]. And we regularly add new e-books via the VLeBooks platform.

This means that, as well as the Lyell Collection, Fellows can now access hundreds of thousands of pages of Earth science research from other providers via their computer or mobile device. To access these amazing resources, you will need an OpenAthens account. If you don’t already have one, please email the library (library@geolsoc.org.uk) for more information on how to register.

BURLINGTON HOUSE UPDATE

Fellows are invited to join us on 19 May from 9.30 to 10.30 am BST for a virtual update on the Burlington House lease situation. Submit questions via burlingtonhouse@geolsoc.org.uk

Register at https://us02web.zoom.us/webinar/register/WN_qR2AMOWLSVOgsVcpfuBA
The geoscientific textbooks available to many schools globally are generally moderate, poor or non-existent. So, why not create your own? We want to encourage geoscientists and geoscience teachers across the world to develop a textbook for their own country, region, state or even city.

We have shown the way by developing the book Exploring Geoscience Across the Globe – England. We took the original open-source book, Exploring Geoscience Across the Globe, and five of us worked together to:

• replace 280 of the 500 international photographs with photos from England
• write 40 new ‘interest boxes’ of interesting geological features in England, to add to the 60 international interest boxes – all intended to enhance the core text, which addresses the international geoscience syllabus
• record the time this took us

For the investment of 200 hours of time distributed among five people (i.e. 40 hours each on average – or just one working week), we were able to prepare a geoscience textbook for England. Such a thing has never been done before.


So, wake up, world! You too can have a textbook of your own that helps to educate and enthuse schools, teachers and students across your country.

To create your own textbook, contact Tanja Reinhardt (Reinhardtt2@ukzn.ac.za) for a Word document template to populate. Once finished, we will add a customised cover, unique ISBN number, and post it for free download on the International Geoscience Education Organisation website.

Authors
Chris King with Elizabeth Devon, Peter Kennett, Pete Loader and Maggie Williams

This article was drafted by Chris King shortly before he sadly passed away in February 2022. The wide uptake of this initiative would be part of a wonderful legacy for a truly remarkable man.

The textbook Exploring Geoscience Across the Globe – England and the international geoscience syllabus, as well as a range of other resources, are available at: igeoscied.org
Final Call for Abstracts
Planned session themes now available on the event website.

The new Energy Geoscience Conference (EGC) aims to explore and develop the contribution of geology and geophysics to the energy transition. Abstracts are invited across the breadth of energy-related geosciences and further details are available on the conference website. Talks and posters are sought on themes including oil, gas, H2, helium, lithium, low and high enthalphy geothermal, subsurface storage (gas, H2, compressed air, heat), higher activity radioactive waste disposal and the subsurface aspects of renewable energy.

In person and virtual contributions from the UK, North West Europe and worldwide are sought by the convenors.

Early committed speakers include:
- Dr Mark Bentley, TRACS/Heriot-Watt University
- Prof. Andreas Busch, Heriot-Watt University
- Dr Oliver Duffy, Bureau of Econ. Geol
- Prof. Jon Gluyas, Durham University
- Alice Hall, University of Aberdeen GeoNetZero CDT
- Dr Steve Laubach, University Texas at Austin
- Dr Sophie Nixon, University of Manchester
- Khalil al Rashidi, BP
- Dr Jonathan Turner, Nuclear Waste Services
- Prof. Mark Zoback, Stanford University

Abstract submission deadline: 30 June 2022

Organised by

[Image of The Geological Society logo]

For further information please visit energygeoscienceconf.org

#EGC2023

Registered charity number in England & Wales
PESGB Conferences Ltd - 1086619
The Geological Society of London - 210161
ANNUAL GENERAL MEETING 2022

THE AGM will take place on Wednesday 8 June 11:00 – 12:30 (GMT+1) and will be conducted virtually.

Information on how to register to attend the AGM will be sent to all Fellows for whom we have a registered email address. If you do not receive an email or if you would like further information on how to register, please email christina.marron@geolsoc.org.uk

Agenda
In line with bye-law 9.2, the agenda for the AGM is presented as follows:
• Apologies
• Minutes of the Annual General Meeting held on 25 June 2021
• Appointment of Scrutineers for the ballots for Council and Officers
• Ballot for Council
• Ballot for Officers
• Annual Report and Accounts for 2021
  • President’s Report
  • Secretaries’ Reports
  • Treasurer’s Report
• Comments from Fellows
• Fellowship subscriptions for 2023
• Deaths
• Appointment of Auditors
• Report of Scrutineers on the ballot for Officers (if required)
• Any other business

The Society’s Annual Review 2021 is available on page 57.

ELECTION RESULTS
THE ADVISORY ballot for Council, conducted by Civica Election Services, closed on 31 March 2022. The turnout was 12.9%.

A total of 1,476 valid votes were cast for the six vacancies on Council. Of the nine candidates who took part, the six candidates who received the most votes are:

<table>
<thead>
<tr>
<th>CANDIDATES</th>
<th>NO OF VOTES</th>
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<tbody>
<tr>
<td>Hollie Fisher</td>
<td>900</td>
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<tr>
<td>Mark Anderson</td>
<td>843</td>
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<tr>
<td>Daniel Le Heron</td>
<td>797</td>
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<tr>
<td>Natasha Dowey</td>
<td>768</td>
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<tr>
<td>Anna Bird</td>
<td>732</td>
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<tr>
<td>Ben Lepley</td>
<td>521</td>
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These six candidates will go forward for election as Council members at the AGM. We warmly thank the three other candidates who stood in the preliminary ballot for their interest to serve Council.

Finally, we give whole-hearted thanks to the Council members standing down at the AGM: Dr Michael C. Daly, Dr Kathryn Goodenough, Andrew Moore, Sarah Scott, Jessica Smith and Dr Alex Whittaker.

NOTIFICATION OF OFFICERS FOR 2022/2023
At the AGM, Fellows will be asked to elect the following members of Council as Officers for 2022/23:

President: Ruth Allington
Vice-President: Gemma Sherwood (Regional Groups)
Secretaries: Prof Jennie Gilbert (Science)
Dr Joel Gill (Foreign & External Affairs)
Prof James Griffiths (Professional Matters)
Prof Robin Strachan (Publications)
Treasurer: Dr Keith Myers

FUTURE MEETING DATES
COUNCIL AND ORDINARY GENERAL MEETINGS:
2022: 22 June, 21 September, 23 November
2023: 1 February, 26 April, 28 June, 20 September, 22 November

ANNUAL GENERAL MEETING & PRESIDENT’S DAY:
2023: 14 June
Earth science front and centre

Being at the helm of any organisation during a global pandemic is a daunting challenge, but the Geological Society has achieved much in the past two years, says outgoing President Mike Daly

“PRESIDENTS are around for three years, and the two of those in the President’s seat can be very dangerous.”

Mike Daly, who ends his term as President of the Society in June, has certainly had more to contend with than most in his role. After a year as President Designate, Mike took over in June 2020 just as the first Covid-19 lockdown was drawing to a close, with no visible end to the pandemic in sight. On top of that, the Society’s long-term home at Burlington House continues to be under threat, despite the launch of a public campaign in early 2021.

“To be a focused and thriving Society will be an increasingly big challenge in the 21st century, particularly as the lease issue continues to be a distraction for the Executive leadership.”

Society means company

Despite much of the Society’s work being carried out remotely during his two years at the helm, Mike has made his presence felt.

“I think the Society has changed hugely since I first became a Fellow in the late 1970s,” he says, “and arguably one of the largest periods of change has occurred over the past two to three years.”

The first and most obvious challenge for a Society during a pandemic is communication. As Ted Nield writes in this issue’s Viewpoint section, ‘society means company’. Fulfilling one of the Society’s key roles at a time when gathering in-person has been restricted, if not impossible, hasn’t been easy.

“The Covid pandemic and lockdown made it essential for the Society to instantly move to a virtual format,” Mike recalls – which posed significant issues.

“The IT and communications technology of the Society in Burlington House is not state-of-the-art communication technology. However, we did really well in using what we have.

“I’d recognise two highlights: The ‘Future of Geoscience’ event in June 2020 showed the Society the power and reach of the virtual medium. Then, in 2021, the three Energy Transition seminars showed the impact of bringing diverse and high-quality people together to address the very broad range of issues associated with this growing subject.”

Another major challenge, faced by all organisations during such a long period of remote working, has been staff engagement and retention. Citing “a small number of high-performing early to mid-career employees” as instrumental to the Society’s work during this period, Mike acknowledges that it has been a time of significant change.

“The employee attrition rate is growing,” he says, but adds, “people leaving to work for other prestigious organisations is a positive message about the value the Society adds to its employees.

“The 2021 employee survey results were very positive and a major improvement on earlier years. After the constraints and employee changes during the two Covid years, it seems this was a major vote for the direction the Society is now following.”

Strategic review

That direction has been guided by a strategic review that began during Mike’s time as President Designate. “With the help of an international consultancy firm, we instigated a bottom-up review,” he says, in particular with science strategy and membership trends in mind. Since a peak of around 12,500 Fellows in 2017, membership numbers have declined, with a loss of around 8% between 2017 and 2019.

“Council took a decision to address this decline, and started a process to understand why members have not renewed.”

Various theories have been posited; in an article for Geoscientist in August 2020 (Geoscientist 30(5), 16-19), Mike wrote that, “the rapidly changing global context has raised questions about the relevance of the Society’s membership offering to the 21st century geoscientist”. Of particular concern, he says, “is the difficulty geosciences as a whole, and the Society in particular, has in reflecting the diversity of the UK community”.

It’s early days to judge whether efforts to address the decline are working, but, Mike says, “total numbers have since been broadly
constant at around 11,500 from 2020 through 2022. Membership categories have been restructured, and we now have a strong membership renewal process run by an external organisation to support the internal membership team.

“In addition, Council has decided to release funds from the ‘Fermor Endowment Fund’ and to create the ‘Geological Society Futures Fund’, which will be used to invest in our science programme and membership services. This initiative is a new and proactive direction for the Society and augurs well for the future.”

Remaining relevant
One outcome of the strategic review, Mike says, is that “to remain relevant to active members and young geoscientists, the Society needs to deepen its involvement in five growing strategic science themes”.

These themes – energy transition; geohazards, geoengineering & georesilience; planetary science; and digital geoscience – featured in much of the Society’s activities during the past two years; not least in its outreach and education work, and the hugely successful Year of Space. Amongst a programme of online events and outreach initiatives, this included a major exhibition, *Spacescapes: Postcards from our solar system*, in the Burlington House Courtyard in 2021 that, despite lockdowns, attracted thousands of people. Meanwhile, in a Society first, the policy team secured Non-Governmental Organisation Observer status to attend the COP26 meeting in Glasgow – an opportunity to emphasise the important role of geoscience in the climate change conversation.

Another priority identified by the strategic review was the importance of being ‘dynamic and responsive’ with a ‘strong digital identity’. Communicating with members and other audiences online is key – but here, Mike has some reservations.

“The fertile world of social media has a habit of raising an issue to great importance and then moving on quickly. That speed can make societies like ours appear slow.

“The challenge for the Society is to be dynamic and knowledgeable about what is going on externally, but also to be confident in its own agenda and values that its membership believes in. This takes open discussion and a respect for different views and constant change, but not unthought-out reaction.”

The future
With lockdowns (hopefully) in our past and restrictions lifting, Fellows and staff must be eagerly looking ahead to the return of in-person events and collaboration, and the opportunity to apply more of the lessons learned from the strategic review. What advice would Mike offer to his successor?

“I’d be wary of offering advice, but the experience of the past few years has taught me a number of things. What the Society doesn’t need is another opinion starting lots of initiatives and telling it how to operate. What the Society needs is support and independent insight into their problems, like the future of our science and its community, and support in delivering for those.”

His thoughts on how this can be achieved suggest face-to-face communication and a return to in-person meetings are more important than ever.

“Our council is diverse, and strong and advocative views often drown the quieter and reflective views. The President needs to ensure both are aired and heard. That often means finding the latter away from the Council table, to be fully aware of the breadth of what Council, as a whole, is thinking and what that offers.

“T think the major challenge is to keep the Earth sciences front and centre, and to continue to develop an inclusive and diverse community.”

Prof Mike Daly is the out-going President of the Geological Society, a Non-Executive Board Director and a Visiting Professor at the Earth Sciences Department of the University of Oxford, UK.

Interview by Sarah Day
Challenging perceptions

The Society’s new President, Ruth Allington discusses her career as an engineering geologist and expert mediator, her enthusiasm for working in ‘the borderlands’, and her priorities for the Society’s future.

WHEN RUTH ALLINGTON, who takes over as the Geological Society’s President this month, attended her interview for an undergraduate course at King’s College London, she recalls being asked what, at the time, seemed an odd question.

“Professor John Pugh asked me what I had noticed about the geomorphology of the Strand.

“Of course, at the age of 17, I hadn’t noticed anything about the geomorphology of the Strand. Geomorphology, as far as I was concerned, could only be studied and observed in the countryside – preferably abroad!”

That question, and the thought processes it provoked, made all the difference, she says, in her decision to study at King’s.

“He gave me a glimpse of the excitement of thinking in new ways and challenging perceptions.”

It’s an approach to the science that she has carried throughout her engineering geology career, which has included 38 years at GWP Consultants (formerly the Geoffrey Walton Practice), as well as work as an expert witness and mediator.

“Through working in a small firm and always being a consultant, I have come to realise the irrelevance of artificial boundaries between technical and scientific disciplines, and the futility and destructive nature of the turf wars between them.”

Early influences

Ruth says her interest in the science began at school – “I loved physical geology, especially the field trips” – and, in part, was stimulated by a love of drawing. “I loved drawing the landscape and also the drawings of fossils and rocks in geological books that my grandfather (an industrial chemist, who had studied geology as a subsidiary subject) and my parents had.”

“Mediation, in the mid-1990s, in the course of my work as an expert witness in opencast coal-related contractual disputes that had gone to arbitration”

In particular, she recalls a field trip to Switzerland where, at age 16, her interests in geography, geology and art came together.

“I had a little black sketchbook as a field book and the first of many Rotring pens. It was the most wonderful week of climbing mountains looking at glaciers, landforms and rocks, and stopping frequently to interpret the landscape and the way it had influenced land uses.”

O-Level geology followed, and with it a visit to the engineering geology laboratories at Portsmouth Polytechnic, which Ruth credits with stimulating her interest in that particular field. Unsure about studying pure geology, she applied for a joint honours course in geography and geology, and found herself facing that unexpected interview question.

“The answer, as many will know, is that the Strand is on a river terrace – hence the steep streets and steps that run from the Strand down to the embankment.”

Having initially feared that studying joint honours risked becoming ‘a jack of all trades and master of none’, she says she found it “tremendously exciting to have the opportunity...”
to study two such complementary subjects at the same time, and not be wholly in either camp.”

“I gained an insight into how the mapping, observational, analytical and interpretive skills of geomorphology and geology could be applied in practical engineering situations and I resolved to follow that path.”

Ruth went on to study for an MSc in Engineering Geology at Durham, after which, “with a big dose of accidental good timing and good luck”, she began working at GWP Consultants. There, she designed quarries and other open pits, provided consulting advice in relation to their operation and impacts, and gave expert input to the resolution of disputes. It was this latter work that led to her interest in mediation.

**Facilitative skills**

“I discovered mediation in the mid-1990s, in the course of my work as an expert witness in opencast coal-related contractual disputes that had gone to arbitration.”

She recalls a particular claim by an opencast contractor against one of the successors to British Coal Opencast following privatisation, which had “got bogged down”.

“It was very clear that the arbitration was going to be very lengthy and expensive indeed as the positions of the parties on almost every aspect were very far apart. In a last-ditch effort to avoid an arbitration hearing, mediation was arranged – the parties agreed a way to settle the matter on the day, and signed the agreement and transferred the funds the following day.

“I decided that this was such an amazing process that I’d like to know more and I trained as a mediator in 1997.

“In recent years, I have been lucky enough to participate in intensive training with Maria Arpa at the Centre for Peaceful Solutions and to become a Dialogue Road Map facilitator – this has further extended and deepened my mediation practice and I am one of the directors of the Peaceful Solutions mediation service.

“I have found working as a mediator incredibly fulfilling – it makes a difference to people whose working and/or professional lives have been disrupted by disputes. Often their finances have been adversely impacted, sometimes for many years.”

Ruth describes a “palette of facilitative skills” that she has acquired as a mediator: “skills such as active listening, summarising and re-framing to help parties in a dispute (or meeting or conversation), to de-escalate tension and hear and express each other’s point of view and needs (even if they disagree), and to help them reach a solution they can agree to.

“Of all the professional and technical skills I have acquired over the years, these are the most important to me personally, in consultancy, as an expert witness, and in professional and voluntary leadership roles.

“I do think my facilitative skills and experience will be helpful in my role as President.”

Ruth’s involvement with the Society began with the Engineering Group in 1981, when she attended the group’s annual conference.

“I was nervous but made so welcome, and it wasn’t long before I was on the committee, becoming first Secretary and later Chair. These were enormously enjoyable times, when I first became part of a professional community and learned such a lot from meetings, conferences and field trips, as well as from getting to know more established engineering geologists.

“Being awarded the Engineering Group Award in 1995 and being the Glossop Lecturer in 2012 and receiving the Glossop Medal were huge highlights for me.

“In many ways, the Society has changed beyond recognition since I joined 40 years ago, but what has been a constant for me is my sense of connection to it.”

**Borderlands**

All Presidents arrive with a lengthy to-do list, but Ruth’s will be particularly full – chief among them, the appointment of a new Executive Secretary, and the search for a resolution to the continuing uncertainty over the Society’s future at Burlington House.

“As to wider changes and challenges for the Society, I think the top two priorities are: influencing and supporting the science agenda underpinning the energy transition, responsible supply of critical minerals and responses to climate change; and supporting geoscience education and training at all levels to meet current and future workforce requirements.”

Her experience of working in what she describes as “the overlaps” will doubtless be put to good use in addressing those priorities.

“There is excitement and value in working in the overlaps – the borderlands, as Peter Fookes and Rudolph Glossop have described the areas of common interest to engineers and geologists. This is where I have concentrated in my career.

“Equally important as the interfaces between specialists are those between specialists and non-specialists – particularly the public, but also lawyers, accountants, politicians, regulators and the media.

“I hope to focus on helping the Society successfully navigate the changes and challenges we face, and make the most of the opportunities they present.”

Ms Ruth Allington is an Engineering Geologist and qualified mediator and facilitator, and the incoming President of the Geological Society.

Interview by Sarah Day
Charting the revolution

Tanya Atwater became hooked on Earth science at the height of the plate tectonic revolution, and she has a profound story to tell.

TANYA’S PASSION for wilderness and adventure has deep roots.

“My ancestors were covered-wagon pioneers and seafarers, seeking out adventures and challenges, and my family continued the tradition. Our weekends and vacations were spent camping and hiking and horseback riding and river rafting, often in the wildest, most remote places we could find.”

Catching fire

Tanya originally wanted to be an artist and loved spatial relationships – hogging the maps on family trips and relishing the opportunity to translate between paper and passing countryside.

After experimenting with various majors while studying at the Massachusetts Institute of Technology, it was an almost fortuitous experiment with geology that really made Tanya “catch fire”.

“I attended the Indiana University geology field camp in Montana, just for fun. Geological mapping is primarily a spatial puzzle: the mapper must visualise the geologic structure and geometry, figure out how these shapes are cut by the undulating surface of the present landscape, and then translate all that into lines and symbols on a flat paper map. I was in heaven and hooked on geology.”

Tanya switched to study geophysics at the University of California at Berkeley, taking as many geology courses as she could fit into her schedule.

Sailing the seas

On moving to Scripps Oceanographic Institution in La Jolla, California, in 1967 for graduate school, Tanya found the place in uproar.

“A month before, Fred Vine had given a lecture about marine magnetic anomalies and how they demonstrate that oceanic crust is created by sea-floor spreading. This concept, in turn, validated the theory of continental drift and led to the development of its modern version, the theory of plate tectonics. Furthermore, the magnetic anomalies give us the wherewithal to measure and chart the drift of the plates through time. A great revolution was just starting in the Earth sciences and I had stepped into the middle of it! In the light of the new concepts, all the data collected by generations of geoscientists was in need of re-interpretation. Furthermore, the need for many new measurements and experiments and compilations suddenly became obvious. Dr. H. W. Menard was recompiling the magnetic anomalies that had been measured by ships crossing the northeast Pacific. The resulting map was so exciting, so full of new relationships that I could not stay away from his lab.”

People from all over the world visited Scripps to share their insights.

“It was so exciting, there were so many new connections to explore, so much to be done – I often could not sleep at night.”

The Scripps ‘Deep Tow’ sonar system was about to survey the Gorda Rise, off the coast of northern California, and the ocean-bound expedition team needed a graduate student.

“It would be the first close-up look at a sea-floor spreading centre! I signed on at once and never looked back. By this stroke of luck, I became embroiled for life in the effort to understand the process of sea-floor spreading and the details of the formation and aging of the world’s oceanic crusts. I have never lost my fascination with this subject and have continued to explore it with new technologies as they came along: mapping with various sophisticated sonars, deep-sea cameras, deep-diving submersibles. I have visited and studied the deep ocean floor, 2.5 to 3.5 km deep, on 12 different dives in the small submersible Alvin. It is amazingly different down there.”

Tanya is particularly well known for her reconstructions of plate tectonic interactions in western North America.

“It was clear from the beginning of the plate tectonic revolution that the San Andreas Fault system in California was a major strike-slip plate boundary between the Pacific and North American plates. However, when we examined the magnetic anomalies in the adjacent Pacific Ocean basin, they implied a very different plate configuration for past times. They showed that the ocean floor here was formed by sea-floor...
spreading between the Pacific Plate and another oceanic plate, the Farallon Plate. The Farallon Plate had once lain between the Pacific and North American plates, but had since been completely subducted along much of its length. The subduction of the Farallon Plate allowed the other two (Pacific and North America) to come into contact only rather recently and only then to form the San Andreas Fault. The geologic record in California told a similar story: a long history of subduction and a relatively young origin for the San Andreas system. When the dates of the magnetic reversals were finally established first-hand by the Deep Sea Drilling Project in 1969, the final piece fell in place.

"Much of the definitive data for the plate tectonic revolution came from the oceanic realm. In the 1960s, marine geology was a very small field and most institutions didn’t have anyone on their staffs who specialised in this subject. Thus, when word of the revolution spread, we oceanographic graduate students found ourselves in the unusual situation of having a profound story to tell. I gave seminars to anyone who would listen. It was a heady experience."

Modern relevance
Tanya devotes much of her time to science communication, and feels strongly that a general understanding of science and technology is essential for all.

"Ours is a technological age and one in which the results of our technology are fundamentally altering our planet, our only home. We must understand the consequences of that use. Earth science, in particular, offers a unique, long-term view that all world citizens need to incorporate into their thinking. Earth was here long before we humans evolved and will continue, indifferent to whether we thrive. We now have enough understanding of many geological phenomena to take them into account when planning our structures and activities. We know how to minimise the impacts of many natural disasters, but it won’t happen in a democracy unless the citizens understand what is involved."

And at a fundamental level, Tanya notes that, "it is fun, interesting and empowering to learn the reasons that things are the way they are. The shapes, colours and textures of the countryside tell their own stories to the viewer who is geologically aware. A basic knowledge of geology can enhance every cross-country trip and can deepen every person’s appreciation of the planet and of the back yard. It brings the world map to life."

Professor Tanya Atwater is an Emeritus Professor of Tectonics at the University of California, Santa Barbara, USA and the 2022 recipient of the Society’s Wollaston Medal.

Interview by Amy Whitchurch and based on excerpts taken from “Some ramblings about life and geo-adventures” by Tanya Atwater, with permission.
Geological transformations

Over the past 60 years or so, marine geoscientific discoveries have revolutionised our understanding of Earth processes, and William B.F. Ryan has been at the forefront of these developments.

**BILL WAS INTRODUCED** to geoscience in 1961, during a Woods Hole Oceanographic Institute research expedition that travelled across the Atlantic and into the Mediterranean Sea.

“I was struck by the progressive decrease in sediment thickness away from the continental edge and its absence in the axial rift valley of the mid-ocean ridge. I wondered at that time if new ocean floor was being created in the valley and aged as the two sides moved away from the ridge axis.”

**Epicentre of discovery**

On entering graduate school at Columbia University in 1962, however, Bill discovered that his professors were adamantly against the concept of continental drift.

“My mentor, Bruce Heezen, would only allow a very modest extension by expansion of Earth. This was just enough to create the rift valley discovered by Marie Tharp.”

Heezen, who collaborated with Tharp to map the Mid-Atlantic Ridge, did eventually accept the idea of continental drift and in the following years, Bill witnessed some extraordinary revolutions in geological understanding.

“I was right at the epicentre of the symmetric magnetic anomaly discoveries that gave birth to the paradigms of seafloor spreading and plate tectonics.”

Bill’s own work on the periodic appearance of organic-carbon-rich sediments in the eastern Mediterranean has evolved into the remarkable field of astrochronology, whereby strata are dated via calibration with astronomical cycles.

“My dissertation work was on the floor of the Mediterranean Sea, where suspected convergence between the continents of Africa and Europe was evident in the folds and thrusts that built accretionary ridges seaward of the Hellenic and Calabrian Island Arcs. My modest efforts to find brief excursions in Earth’s past magnetic field in deep-sea sediments has been taken by others to create a high-resolution magnetic-reversal timescale useful for calculating seafloor spreading rates and plate velocities.”

**Salinity crisis**

Much of Bill’s work has centred on the Messinian Salinity Crisis – the extraordinary desiccation of the Mediterranean basin that took place about five-and-a-half million years ago. In 1970, Bill was co-chief scientist (together with Kenneth Hsü) on Leg 13 of the Deep-Sea Drilling Project that cored the Messinian salt deposits, revealing evidence of subaerial exposure of mudflats in the form of gravels, floodplain silts and windblown cross-beds deposited atop the extensive 1.5-km-thick salt.

“Although we knew ahead of Leg 13 that there was evidence of a thick buried layer of salt that had deformed into diapiric intrusions, all previous studies of similar salt giants had envisioned precipitation within deep pools of evaporating brine replenished from an exterior sea. However, when we found beds of anhydrite and gypsum in facies identical to those of coastal sabkhas, as well as wavy laminations that resembled algal stromatolites, we questioned our preconceptions. After recovery in our cores of beds of anhydrite separated by layers of mud with bottom-dwelling diatoms that required sunlight and ostracods that had lived in river mouths or shallow lagoons, we asked, ‘Could the Mediterranean have actually dried out?’ It was an uncomfortable hypothesis until we found desiccation cracks in a salt bed and learned about the huge down-cutting of the Nile and Rhône rivers that fed the Mediterranean basin at that time.”

The core samples also revealed evidence for the subsequent Zanclean Flood that is thought to have occurred when the Strait of Gibraltar opened, allowing water from the Atlantic to refill the Mediterranean basin.

“Fluvial sands immediately draped by deep-sea pelagic oozes could only be explained by a sudden opening of the Gibraltar Strait and a catastrophic flood of saltwater into a mostly-empty Mediterranean lake, filling it in a matter of years.”
Fifty years on, Bill is back working where he started, in the Mediterranean, investigating a new explanation for the formation of its giant salt deposits – an explanation that he hopes to test via future scientific drilling into and through the giant salt layer.

**A shift in emphasis**

While the various ocean drilling and discovery programs are some of the longest running and most fruitful projects in geoscience, Bill suggests that marine geoscience is increasingly heading toward modelling, with much less emphasis on new observations. “I see little interest by students in going on expeditions or into the field or building new instrumentation and more time spent in front of their computer screens.”

A shift away from observational science may be due, in part, to the costs and complexities of sea-going expeditions, which Bill notes are amongst the biggest challenges in marine geoscience today. “Understanding the hazards of mega-earthquakes and tsunami, for example, requires access to regions within the exclusive economic zone of coastal nations. Getting permission ahead of proposal-writing or even departure from port is becoming more and more difficult.”

**Technical developments**

In addition to theoretical revolutions, Bill notes the numerous technical transformations that played a huge role in his research, including accelerator mass spectrometry carbon-14 dating, multi-beam bathymetric and side-looking sonar mapping (a technique that Bill himself helped refine), multichannel seismic reflection profiling, deep-sea drilling, borehole logging, GPS navigation, autonomous underwater vehicles, deep-diving submersibles and the internet.

Bill is also a technical pioneer, devoting considerable time to help develop tools such as GeoMapApp, a map-based application for browsing, visualising and analysing a diverse suite of curated global and regional geoscience data sets. “It came out of a need to get data stored in users’ hard drives that is subject to eventual loss. The app provides users with a variety of methods to view their own data and combine them with public data. We now have a Global Multi-Resolution Topography (GMRT.org) synthesis that is supported by the US National Science Foundation and serves edited multi-beam sonar data collected by scientists and institutions worldwide from more than 1,300 expeditions.”

This innovative application, to which everyone can freely contribute and access, is now widely used by schoolchildren, students, researchers and industry professionals across the globe.

Professor William B.F. Ryan is Special Research Scientist, Marine Geology and Geophysics, at Lamont-Doherty Earth Observatory, Columbia University, USA, and the 2022 recipient of the Society’s Lyell Medal.

*Interview by Amy Whitchurch*
Palaeoclimate complexities

When it comes to palaeoclimate, Anna Joy Drury notes that there is so much to be explored, from developing new methods, to reconstructing aspects of Earth’s past climate, to trying to understand how the Earth system functioned during different time periods.

As a child, potent images of Earth’s natural power and its effect on people’s lives, such as those depicting the aftermath of the eruption of Vesuvius that destroyed Pompeii, made a strong impression on Anna Joy. Her interest in Earth’s past climates, however, was initiated during her undergraduate study at University College Utrecht, the Netherlands, with the realisation that she could combine her love of Earth science, chemistry and history in one topic. A research internship at the Royal Dutch Meteorological Society was followed by an MSc, a PhD and post-doctoral research that spans palaeoceanography, stratigraphy and geochemistry.

Ocean expeditions

Currently, Anna Joy is investigating the driving forces behind potentially long-lasting El Niño-like conditions during the late Miocene and the consequences that the prolonged warmth of such an enduring El Niño-like state may have on global climate. This project uses material recovered during an ocean drilling expedition on which Anna Joy was involved.

“The expedition was run by the International Ocean Discovery Program (IODP), a brilliant international research programme that has been going in one form or another for over 50 years. The programme offers amazing opportunities for international collaboration and recovers marine archives relevant to a host of Earth science topics, including plate tectonic processes, geohazards and past climate research. The recovered sediment cores are essential to my work as they provide archives that capture the history of Earth’s oceans and climates during the Mesozoic and Cenozoic.”

Highly accurate time constraints are required to interpret these records and Anna Joy uses an integrated stratigraphical approach that brings together diverse datasets.

Much of Anna Joy’s research looks at Earth’s climatic response to astronomical forcing.

“The energy that Earth gets from the Sun is controlled by semi-periodic changes in astronomical parameters, such as the eccentricity of Earth’s orbit, as well as the tilt (obliquity) and wobble (precession) of Earth on its axis. Each parameter has its own unique rhythm and they come together to control the amount of solar energy that the planet receives, which in turn influences Earth’s climate dynamics.

“I am interested in the influence of these astronomical cycles on Earth’s climate during the past 66 million years. The imprint of these cycles is often excellent in the marine archives recovered by the IODP, and I use proxies such as stable oxygen and carbon isotopes in foraminifera, as well as geochemical analysis of the sediments using X-ray fluorescence, to reconstruct changes in global ice volume, temperature and the carbon cycle.”

Anna Joy Drury standing in front of the JOIDES Resolution research vessel, which is part of the International Ocean Discovery Program.

Pulling apart the secrets hidden in these data has been fascinating and very rewarding. We are just starting to grasp how different components of the Earth System respond individually to astronomical forcing.”
“Where possible, I make sure that the records I work on are underpinned by astrochronology, which is an approach using the imprint of astronomical forcing as a chronometer.”

Deciphering the details
Anna Joy and her colleagues have made great progress in deciphering the finer details of Earth’s climate change record for the Cenozoic.

“I’ve recently been involved in several projects looking at the changing imprint of astronomical forcing on Earth’s climate. I was one of the leads in the CENOGRID (Cenozoic global reference benthic carbon and oxygen isotope dataset) Project, which provides the most accurate record of Cenozoic climate to date. We showed that Earth experienced four climatic states since the dinosaurs went extinct, classified as ‘Hothouse’, ‘Warmhouse’, ‘Coolhouse’ and ‘Icehouse’. Each state has a characteristic climate variability pattern driven by a combination of atmospheric greenhouse gas concentrations and polar ice volumes.

“I was also involved in the Carbon Megasplice project, looking at the complex relationship between the carbon cycle and wider climate system over the past 35 million years. For much of this time, the carbon cycle varied in tandem with the amount of Antarctic sea ice, but this relationship turned on its head about six million years ago due to the increasing influence of high-latitude climate processes in the northern hemisphere. Additionally, I led a study showing that carbonate deposition in the Atlantic Ocean occurred in three distinct patterns in response to astronomical forcing, with switches between patterns corresponding to major warming and cooling events over the last 30 million years. “Pulling apart the secrets hidden in these data has been fascinating and very rewarding. We are just starting to grasp how different components of the Earth System respond individually to astronomical forcing. The next step will be to understand how these components interact as a complex whole to drive our climate in the past.”

Global – regional interplay
The rate of present-day climate change is unprecedented on geological timescales. As Anna Joy notes, Earth science is essential for improving our understanding of climate change, the processes and feedbacks that drive it, and the consequences of extreme and unpredictable events.

“Some of the biggest challenges are to decipher: how different feedback mechanisms work to drive climate change on short and long timescales; how quickly the climate system can recover from major perturbations, such as the dramatic increase in carbon dioxide that we are currently experiencing; what equilibrium states Earth can exist in and what the thresholds are between these states; and what the frequency of extreme climate events are, as well as the warning signs for these.”

Recent advances in our understanding of palaeoclimate have provided detailed insights into the long-term trends and short-term variability of global climate. However, Anna Joy emphasises that we now need to better understand how regional climate is influenced by global patterns.

“Future anthropogenic climate change will be felt in different ways in different regions, so it is essential to understand the interplay between regional and global climate trends. “CENOGRID was a great step forward in providing a continuous, highly accurate view of global climate trends and it provides a framework from which we can start to understand the regional complexities of climate.

“Additionally, the next phase of scientific oceanic drilling can hopefully capitalise on existing and ongoing technological and methodological advances and really push the boundaries of what we can get out of these expeditions.”

Anna Joy is a passionate advocate of collaborative science and open data, and helped develop the Code for Ocean Drilling Data – an open-source code for the synthesis and analysis of the diverse data that come from ocean cores.

“In addressing these challenges, we must embrace the FAIR Data Principles (Findable, Accessible, Interoperable, and Reusable), as well as open access for all. It is also crucial to ensure that our science is international and collaborative. It would be wonderful if we could develop more mechanisms to fund intercontinental teams to answer complex questions in ways that individual groups cannot do alone.”

Dr Anna Joy Drury is a Marie Curie Research Fellow at University College London, UK and recipient of the Geological Society’s Wollaston Fund for 2022

Interview by Amy Whitchurch.
The search for a low-risk permanent disposal site for spent nuclear fuel remains one of the great challenges of our age and probably the one with the greatest public resistance. England and Wales are currently exploring the option of deep geological disposal, whilst Finland is in the final stages of commissioning tunnels in what may be the world’s first spent fuel disposal facility. Yet, the country with the most nuclear power plants, the US, is at a social and political impasse concerning any plan for spent nuclear fuel.

Until 2009, the US was on its way to achieving a national nuclear waste disposal site at Yucca Mountain, Nevada. However, progress halted largely because of political and social objections. This cautionary tale from the US exemplifies the geological and social complexities involved for any high-level nuclear waste disposal site, and may help concentrate the minds of those involved in the UK’s disposal effort.

The plan was to place the waste in specially designed canisters, install these by rail in tunnels excavated in the mountain, and to leave the mountain without a permanent seal for at least a century (a "pre-closure phase") and to seal it permanently thereafter. Thus, the repository would start as a monitored repository and then become a sealed-and-forget type.

Characterisation of the site involved a thorough vetting of every geological phenomenon, past and present, within a 100-km radius of the proposed repository. Whatever hazards that could be anticipated in the pre-closure and post-closure phases of operation were considered, including groundwater infiltration, earthquake damage, and volcanic intrusion (e.g. Stuckless & Levich, 2007).

The investigation proceeded slowly, partly due to bureaucracy and partly because of the exceptional care and detail required for a never-before-achieved goal of safety and longevity. The main constraint on time was quality assurance, a system of protocols designed to ensure that every step of the work was documented and each collected sample was retrievable, accurately located, and precisely measured.

This approach was meant to guarantee the safety and longevity of the repository. The US plan was to leave the mountain without a permanent seal for at least a century, then to seal it permanently. However, the project faced significant challenges, including political and social objections.

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The demand for the reduced use of fossil fuels has stimulated calls for increased nuclear power. However, that enthusiasm does not extend to managing the growing volume of spent nuclear fuel – the inevitable result of generating carbon-free nuclear energy.

Nuclear challenges

Public opinion is the greatest barrier to finding a long-term solution for spent nuclear fuel, argue Max Dobson and Dennis O’Leary

The search for a low-risk permanent disposal site for spent nuclear fuel remains one of the great challenges of our age and probably the one with the greatest public resistance. England and Wales are currently exploring the option of deep geological disposal, whilst Finland is in the final stages of commissioning tunnels in what may be the world’s first spent fuel disposal facility. Yet, the country with the most nuclear power plants, the US, is at a social and political impasse concerning any plan for spent nuclear fuel.

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to ensure a transparent path of accountability and data quality, with no shortcuts or untraceable work. Independent staff continually reviewed the protocols, and revised the technical definitions and work procedures. Detailed study plans for every aspect of research were essential. Geologists were required to carry up-to-date documents in the field and prepare for field audits to ensure they followed the correct procedures and document retention. This was science in the regulatory environment.

In practice, the documentation associated with site work threatened to overwhelm actual results. Most notably, in 2004, a one-million-year outlook became a court-ordered licence requirement. The original timeline for repository performance was for a 10,000-year outlook. How could a geologist confidently predict what might happen a million years on, when meaningful prediction depended on the extrapolation of a highly varied, 15-million-year geological history?

Another impediment to progress was public opinion. The primary concern was that surface water would infiltrate the repository, shorten the life of the waste canisters, and release radioisotopes to the ‘accessible environment’.

From the geological viewpoint, we argue that Yucca Mountain is as acceptable a site for radioactive waste disposal in the US as is likely to be found – the potentially adverse aspects are well understood and constrained by sound science. The cost of characterising and developing an alternative underground repository site in the US would take decades and cost billions of dollars. However, despite a proposed trillion-dollar US Infrastructure Law (The Bipartisan Infrastructure Law, 2021) that lists extensive support for more nuclear power, there is no mention of a national mined repository, so this seems out of the question.

The 2021 Blue Ribbon Commission on America’s Nuclear Future that dismissed Yucca Mountain as a repository site recommended deep borehole disposal as an alternative. However, they stipulated that any progress required cooperation and permission from residents in the affected areas. The commission was keen not to repeat the Yucca Mountain debacle; public buy-in would be essential. In countries including Canada, Finland, Spain and Sweden, instituted procedures ensure that local communities consent to the location of a nuclear waste facility. A consent-based approach may be feasible in Western Europe, where the populace typically has a relatively high regard for societal cooperation. In the US, however, concern for private property rights and suspicion of the federal government would likely defeat such an approach.

In reviewing the history and travails of obtaining a geological repository for nuclear waste in the US, we see that science – geology – faces a barrier that wasn’t properly considered in the decades of planning and research: public opinion. No amount of analysis, modelling and research can overcome this resistance, and scientists are poorly prepared to deal with it. Public attitude remains the last and most important barrier to finding a long-term solution to the problem of nuclear waste. This presents an astonishing irony, as public acceptance of nuclear power is counterweighed by the public’s refusal to deal with the residue of creating that power. Perhaps the situation is analogous to the pollution of the Thames during the 1850s – if it gets bad enough, a remedy will be found. Unfortunately, one cannot smell gamma radiation.

The full version of this article is available at Geoscientist.Online

MAXWELL DOBSON
Professor Maxwell Dobson was Head of Geology at Aberystwyth University (1988 – 1993) and Head of Geology at Sultan Qaboos University, Oman (1999 – 2001). Now retired, Max is a long-time collaborator with Dennis O’Leary.

DENNIS O’LEARY
Dr Dennis O’Leary was a Senior Geologist with the US Geological Survey working on the Yucca Mountain Project. As part of the project, he was tasked with assessing the geological stability of the mountain and its surroundings, including hazards posed by earthquakes, faults near the mountain, and volcanic eruptions. Dennis passed away in October 2021.
Modern geoscience publishing

Olivier Pourret and the EarthArXiv Team on how preprints can help bring the geosciences into the 21st century

The preprint is the initial version of a research article, often (but not always) before submission to a journal and before formal peer-review. Preprints help modernise geoscience by removing barriers that inhibit broad participation in the scientific process, and which are slowing progress towards a more open and transparent research culture.

Preprints are not new; they have been around since the 1960s. In August 1991, a centralised web network, arXiv (arxiv.org/, pronounced "är kiv", from the Greek letter "chi"), was established to share physics preprints. arXiv has supported the fields of physics, mathematics and computer science for over 30 years, during which time the pace of dissemination of scientific information has quickened. In recent years, more disciplines – including the geosciences, via EarthArXiv (eartharxiv.org/; Narock et al., 2019) and ESSOAr (essoar.org) – have started to take advantage of preprints.

Preprints have many well-documented benefits for both researchers and the public (e.g., Bourne et al., 2017; Sarabipour et al., 2019; Pourret et al., 2020). For example, preprints enable:

- Rapid sharing of research results, which can be critical for time-sensitive studies (such as after disasters), as well as for early career researchers applying for jobs, or any academic applying for grants or a promotion, given that journal-led peer review can take many months to years;
- Greater visibility and accessibility for research outputs, given there is no charge for posting or reading a preprint, especially for those who do not have access to pay-walled journals, or limited access due to remote working (such as during lockdowns);
- Additional peer feedback beyond that provided by journal-led peer review, enhancing the possibility of collaboration via community input and discussion;
- Researchers to establish priority (or a precedent) on their results, mitigating the chance of being ‘scooped’;
- Breakdown of the silos that traditional journals uphold, by exposing us to broader research than we might encounter otherwise, and giving a home to works that do not have a clear destination in a traditional publication;
- Research to be more open and transparent, with the intention of improving the overall quality, integrity, and reproducibility of results.

During the pandemic, the medical and broader scientific community, as well as the public, have seen the role for preprints in accelerating the scientific process for the benefit of humanity (Besançon et al., 2021). Preprints are now an established part of the scientific publication process, and are here to stay (Lanati et al., 2021).

Preprints are helping to modernise the geosciences by removing structural barriers that make science and knowledge less accessible to those who often fund knowledge-creation — taxpayers — as well as making research results quickly available to all who might benefit from it.

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And the EarthArXiv Team

FURTHER READING
A full list is available at geoscientist.online.
Society means company

DEAR EDITORS,
I was more than usually delighted by the spring issue of Geoscientist, when I noticed that I was personally acquainted with several of this year’s Award winners. My delight was swiftly extinguished, however, by discovering that President’s Day, the Society’s annual gala event in June, has been downgraded to a virtual one, just as restrictions are lifting. President’s Day has always had to be subsidised; I fear that the opportunity to save money has proved too tempting, and that it will soon have gone the same way as good sausages after rationing was lifted. Meeting friends and colleagues face-to-face for work and pleasure is 90% of what any Society should be about. Society means company.

DR TED NIELD

On behalf of the Society, the Editorial Team write in response: Ted Nield is right to point out the significance of in-person meetings. Indeed, the community is the heart of our Society. Planning for President’s Day 2022 began many months ago, when pandemic-related restrictions in the UK and internationally were indefinite and advice from global governments was rapidly changing in the face of new variants. While borne from the need to reduce uncertainty, a virtual President’s Day is also more inclusive, allowing Fellows, medallists and awardees (as well as their families and colleagues) not just from across the UK, but from across the globe to participate in the celebrations.

We share Ted’s view that ‘Society means community’ and are pleased to now see the resumption of in-person events. However, given the additional benefits of virtual meetings, we will continue to offer hybrid options for many Society events going forward.

Geology erased?

DEAR EDITOR,
I was surprised and concerned to notice the word ‘geology’ appears nowhere in the recently published statement of our Society’s Mission, Vision, Value and Purpose, redefined (Geoscientist, spring 2022). These statements could apply to many Earth Scientists, such as meteorologists and botanists, so what distinguishes us from them? Consider those outside our geological circle, in government and positions of influence elsewhere, who seek professional geologists to bring geology to their table. If they do not turn to us, because we do not claim geology is what we “do”, then others will quickly fill the space we appear to be casually vacating.

Further, such a stance to outsiders can hardly support our occupancy of Burlington House if, despite the name over the door, the word geology is not seen fit to be mentioned in the Society’s own summary of its raison d’être.

The article concludes with an expression of hope that we agree with these redefinitions. I do not, not because I disagree with the general sentiments expressed, but because they fail to assert that, above all, geology is the subject the Geological Society protects and fosters, and the discipline its Fellows practise. For these reasons I hope the statements will be amended.

DR MICHAEL DE FREITAS,
Emeritus Reader in Engineering Geology, Imperial College London, UK

On behalf of the Society, the Editorial Team write in response: Michael De Freitas raises an important point and one that was the subject of considerable discussion by the ‘task and finish’ group convened to redefine the statements, as well as amongst the Society’s staff, Trustees, Regional and Specialist Groups. Ultimately it was decided that the term ‘Earth Science’ was more broadly inclusive and effectively encapsulated the work of the entire Fellowship, while also reflecting the increasingly collaborative and multidisciplinary work we do with those engaged in fields outside of the immediate profession.

John Faithfull
@FaithfulJohn
I did not know that there were pure hydrogen natural gas wells, and that a village in Mali has been powered by natural hydrogen for nearly a decade – amazing!

James Pembroke Media
@JPMediaLtd
Just landed! The latest issue of Geoscientist features a report from COP26 and why graphite is vital for our low-carbon future @geoscientistmag @geolsoc #climatechange #cop26 #energytransition #magazines #design

Lucy Blennerhassett
@CoolPlanet_Lucy
I’m now a contributor for @geoscientistmag Check out my ‘In-brief’ article communicating the research of @ThomasJAubry and team! Learn about how a warming climate might impact the effect of volcanic aerosols in our atmosphere & more in this spring issue geoscientist.online
The transition to net zero is creating unprecedented demand for metals. Olivia Hogg and Jon Blundy discuss the role for volcanoes as a novel route to a more sustainable future.
The era of fossil fuel-derived energy is drawing to a close. Electricity generation via renewable sources is a promising candidate to bridge the gap to a low-carbon future (Fig. 1), but it has created and will continue to generate an unprecedented demand for metals, such as copper, lithium and nickel.

A global-scale transition to an electric economy comes with pervasive socio-political and environmental implications. Conventional mining practices are energy intensive and leave indelible scars on the environment, yet they currently represent the only effective way to supply enough metals to meet rising demand. We cannot halt the growth of economies, and therefore cannot escape the need to secure more metals, but using conventional approaches risks devaluing many of the benefits of the energy transition itself.

To satisfy our continued need for energy, we must change how we mine and what we mine. New research indicates that metalliferous magmatic brines, which are found worldwide beneath dormant volcanoes and above granites, together with co-recovery of geothermal power, may provide a more sustainable solution to the global shortage of key metals.

Growing incentives
The Industrial Revolution saw development and growth of steam power, using coal and later petroleum, to fuel industries such as textiles, transport and mining. Fossil fuels quickly became central to richer economies;
supplying energy to power electricity networks, internal combustion engines for railway locomotives, road vehicles and ships to trade resources more quickly. Ready access to fossil fuels became synonymous with economic growth. After 1950, the intensive use of fossil fuels spread to economies globally, simultaneously adding to their rapid and ongoing depletion, as well as propagation of a global climate crisis – something that could not have been envisaged 200 years ago.

Renewable energy sources, such as wind, hydroelectric, geothermal and solar, paired with energy storage in batteries, as well as nuclear power are preferred alternatives, and offer a means to alleviate many of the adverse environmental consequences of the use and extraction fossil fuels. However, existing renewable energy infrastructures and technologies are not yet fit for the anticipated global energy transition.

The UK Government’s Net Zero Strategy (BEIS, 2021) addresses the imperative to develop more low-carbon technologies by 2030 by committing £350 million to the Automotive Transformation Fund, which aims to accelerate electric vehicle use, and £1 billion to offshore wind infrastructure. To meet the associated production goals, a dramatic increase in metal supply is critical. Yet, the UK imports most of its metals, and demand for global supplies is rising, while the security of supply, particularly given recent global political uncertainty, is a grave issue. Is it possible to increase metal supply and sustain a low-carbon approach? Recent environmental opposition to new mines for copper in Ecuador and lithium in Serbia are harbingers of the complex times ahead for a mining industry that is often subject to the same public mistrust as fossil fuel industries.

Meeting metal demands
How can we secure enough metals to keep up with the resource transition? The reuse of metals from pre-existing manufactured objects will not meet the predicted growth in demand. For example, a report from the World Bank (Arrobas et al., 2017) showed that even an entirely circular economy could not surmount the growing demand for copper. A more practical way to meet rising demand is through mining, yet there are caveats associated with expanding this industry on the requisite scale. By 2050, lithium demand is set to increase by 965%, cobalt by 585%, copper by 7% and silver by 60% compared with current production levels (Arrobas et al., 2017), and yet existing mining operations are extracting ever lower-grade ores and new reserves are harder to find. In recent years, the mining industry has made low-carbon operations a core facet of its identity. However, can we expect the industry to meet rising global demands, whilst simultaneously maintaining a net-zero approach?

Mining giants BHP and Rio Tinto intend to reduce carbon emissions at their own operations by 30% and 15% respectively by 2030, with targets to become entirely carbon-neutral by 2050 (McKinsey Report, 2021). Anglo American has committed to carbon-neutral operations by 2040 through improved precision mining and reductions in water usage. In 2020, Anglo American drew 33% of its global electricity from renewable sources and by 2023 the company aims...
to increase this to 56% (Anglo American, 2021). Use of electric vehicles on mining sites is increasing: Anglo American attribute 10 – 15% of their operational emissions to mine-site trucks (Anglo American, 2021), so replacing them with fuel cell electric vehicles will significantly reduce emissions. With resource demands set to soar, the mining industry will need to ‘scale-up’ whilst maintaining low emissions.

The reality is that the current infrastructure is insufficient for the required increased level of global production. Europe aspires to roll out low-carbon technologies, such as electric vehicles, but is ill placed to meet the resource needs. Historically, many of the key resources needed for such technologies, including copper, nickel, cobalt and lithium, were mined across Europe. However, proposals to open new, large conventional mines within Europe may face insurmountable environmental opposition. One solution is to look to supplies outside of Europe, with the attendant risk of creating a business-as-usual growth that has unacceptably large environmental impacts. Thus, gains made in Europe will be offset by activities elsewhere, not least in resource-rich countries hungry for foreign income.

Concerns regarding metal security are leading mining companies to contemplate virgin territory in the deep sea, with some Pacific and European states exploring seafloor mining—presenting new challenges and new environmental risks. In 1972, the Clarion-Clipperton Zone, an abyssal plain between Hawaii and Mexico, was found to host considerable untapped deposits of metals including copper, nickel and manganese (Heffernan, 2019). Thirty years on, such environments are being considered for their mining prospects. Data are scarce, but there is widespread concern that deep-sea mining may impose irreversible damage to poorly understood marine ecosystems and ocean chemistry. Seabed scars from the 1972 field campaign persist today, a portent of the damage that global-scale marine mining projects may inflict.

An unsung source

There is a pressing need to reinvent mining as we know it. The majority of the non-ferrous metals that we extract are ultimately linked to magma. The same processes that create magma in Earth’s crust and mantle, and transport it to the surface as volcanoes, also deliver prodigious quantities of metals dissolved in hot volcanic gases and brines. These processes initiate at depths greater than 5 km within the crust, as magmas begin exsolving volatiles in the form of saline, metal-rich aqueous fluids. Their metal endowment is a veritable who’s who of the Periodic Table, and includes many metals that are critical to the net-zero transition, including copper, lithium and silver.

Figure 2: Compositions of magmatic brines and volcanic gases for representative sodium chloride contents of 50 wt% in brine and 1 wt% in volcanic gas. Metal abundance plotted in wt%. Metals along the x-axis are ordered by increasing abundance in volcanic gases. Boxes mark interquartile ranges and median abundance for a given metal; whiskers denote maximum and minimum ranges; outliers are represented as dots. Across the broad suite of metals, brines show the most enriched metal signatures, up to three orders of magnitude higher than volcanic gases. (Figure based on data compiled from 25 references by O.R. Hogg and available on request from the author.)
impractical. However, a much more concentrated metal resource underlies volcanoes. At depths of around 2 km, hot brines separate out from the ascending magmatic fluids. Metal enrichment scales with fluid salinity, and magmatic brines have salt contents reaching 70 wt% sodium chloride (Bodnar and Sanchez, 2014), compared to just 3 wt% sodium chloride in seawater (Kesler, 2005). Consequently, the brines sequester metals, becoming enriched by more than two orders of magnitude in almost all metals relative to their parent magmatic fluid (Fig. 2). An indication of the potential metal resource associated with volcanoes can be gleaned by comparing their global metal output to that from conventional mining (Fig. 3).

Harvesting the bounty
Conventional mining practices utilise ancient volcanic systems, where magmatic activity has long since ceased and brines have deposited their metal load as solid ores. Time and erosion bring these ore bodies closer to the surface where they can be extracted in giant open or underground pits (Fig. 4). The ore grades are typically so low that more than 99% of the rock extracted in this way is waste, resulting in huge tailings piles left at the surface. A promising disruptive concept involves directly mining brines from hot magmatic rocks, such as those beneath dormant volcanic systems or above young granite intrusions. ‘Brine mining’ affords unparalleled advantages compared to conventional methods, because metals are extracted from a concentrated solution, rather than solid rock. Brine mining would eradicate the need for several energy-intensive processes associated with hard-rock ore body refinement, and, if geothermal power is recovered alongside the metals, represents a potentially carbon-neutral method of metal recovery.

Lithium, as an example, is largely mined from hard-rock sources in Australia, by exploiting spodumene minerals hosted in pegmatite deposits. Lithium is also sourced from salar brines in South America, where ancient waters have interacted with and leached lithium from surrounding volcanic deposits. However, the rapid increase in demand for lithium is seeing previously unexplored sources being considered for exploitation. For example, the company Cornish Lithium is actively seeking to co-produce lithium, heat, and water from geothermal waters in Cornwall, UK, in a low-carbon way. Lithium is selectively removed from geothermal waters via Direct Lithium Extraction — a method that, according to Dr Rebecca Paisley, Lead Geochemist at Cornish Lithium, repurposes existing technology that is traditionally used to treat contaminated water and enables lithium extraction in a low-carbon manner, using only a fraction of the water, land and reagent consumption involved in hard-rock or salar brine lithium mining. In

**Figure 3:** Metals produced globally via mining compared to the total atmospheric flux from arc volcanoes (in kg/day). Vertical bars represent the standard error of the mean global volcanic flux. Solid black 1:1 line is plotted. Data lying above this line infer that metals are more enriched in volcanic gas plumes whereas those lying below the 1:1 line indicate that metal production from mines is greater than the amount fluxed from volcanoes. A notable exception is iron, the bulk of whose production derives from non-magmatic sources. Volcanic flux data from Edmonds et al. (2018) and Shinohara et al. (2013). Mined metal production data from Mineral Commodity Summaries 2019, USGS.
Getting fluids to flow through rocks at supercritical conditions is an issue for both geothermal power and brine mining. At high temperatures within Earth, rocks behave in a ductile, rather than brittle, fashion, inhibiting the formation of fractures and reducing permeability. One solution to this problem is reservoir stimulation, a process at the heart of enhanced geothermal systems. This approach typically entails injecting fluids into the reservoir to promote fractures and permeability development, but at rates too low to trigger seismicity. Encouragingly, recent research from Japan shows how stimulated ductile reservoirs tend to form ‘cloud-fracture networks’ consisting of many tiny, permeability-enhancing microcracks, rather than large seismogenic fault-like cracks (Watanabe et al., 2019). Whether the critical point of water (~374 °C) are extracted from depth to the surface. With over 3 million joules per kilogram of fluid extracted, supercritical fluids have over three times the energy of conventional geothermal fluids. Supercritical geothermal power is an area of active research in Iceland, New Zealand, Japan, USA, Italy and Mexico.

Although supercritical geothermal power faces some obvious technical challenges, this is not uncharted territory; more than 25 years ago Japan drilled a 3.7-km-deep geothermal well into a hot, 90,000-year-old granite at Kakkonda (Fig. 6), where they recovered small quantities of unusually metal-rich, 520 °C brine (Saito et al., 1998). Since then technology has advanced, with new developments in drill bits, drilling muds, well-bore casings and well-head equipment. At Larderello (Tuscany, Italy), for example, the Venelle-2 Well recently reached 2.9 km depth, penetrating fluid-bearing rocks at over 500 °C (Petty et al., 2020). Technological advances are reducing the costs of drilling deep, hot wells, which in turn impacts the economics of geothermal energy as a source of baseload green power.
dense brines can be recovered in this way, alongside lower-density supercritical fluids, remains to be seen.

The next challenge for brine mining is recovering solute-rich fluids to the surface without extensive scaling of the wells themselves because the solutes precipitate during ascent. In the geothermal industry, scaling is a serious impediment to efficient fluid extraction that can impact the longevity of a power plant. Conversely, to the miner, scales represent unusually high-grade ‘ore’ of a type rarely encountered in nature. For example at Kakkonda, well-bore scales contain up to 13% per cent weight of copper, 20% zinc and 20 ppm gold, not to mention a wealth of other valuable metals. Ensuring that this polymetallic bounty is brought to the surface, rather than precipitating en route is crucial. Designing novel materials that can sequester metals from hot fluids at the bottom of the well, and development of well-casing materials that inhibit scale nucleation, are just two possibilities under consideration.

In conventional mining, so-called ‘behemoth’ deposits, with more than 60 million tonnes of copper, have dominated the global raw materials supply chain for decades. There is increasing recognition that some smaller, high-grade deposits may be economically viable (and commercially ‘agile’), while many

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**FURTHER READING**

- Bewick, D. (2021) Big miners’ capital discipline is good news for investors. The Economist
- Bodnar, R.J. et al. (2014) Treatise on Geochemistry (2nd Ed) Elsevier, 119, 142
- Green Alliance. (2021) Critical point: Securing the raw materials needed for the UK’s green transition
- Petty, S. et al. (2020) Path to Superhot Geothermal Energy Development. GRC Annual Meeting 2020
critical metals are found as by-products of mines targeting more abundant metals. Behemoth deposits hold considerably more metal than is likely to be hosted beneath a single volcano, but whereas behemoth deposits are exceedingly rare and hard to find, volcanoes are abundant and easy to spot. Around 2,000 volcanoes globally have the potential to become future brine mines. Interestingly, of the 44 European states, at least 15 have active or dormant volcanoes under their jurisdiction that would be potentially suitable for the simultaneous extraction of metals and geothermal power.

A unique perspective
We cannot eradicate the demand for energy and metals because they are, and continue to be, the means for economies to develop and prosper. It would be hypocritical to demonise mining, whilst relishing the economic benefits that it delivers. And yet, that is commonly the case, not least because metal extraction and consumption are usually decoupled geographically – a legacy in many ways of colonial times and the Industrial Revolution. As with so much of what we consume, it is vital to acknowledge the link between resources and their supply chain.

We propose that one solution to the rapidly emerging energy crisis may be to mine metals in an unconventional way that offers a less environmentally impactful and potentially carbon-zero approach. There is a growing awareness that magmatic brines have the potential to resolve the resource paradigm in which we find ourselves. Investing time in technological development and broadening our understanding of volcanic systems, including drilling into them, is central to evaluating how we can simultaneously harness geothermal power and metals, and so better equip us for the energy transition. In many ways, the storage of magmatic fluids in underground porous rock resembles oil-and-gas reservoirs, meaning that existing hydrocarbon expertise could be readily repurposed in the hunt for brine reservoirs.

As Earth scientists, we have a unique perspective that allows us to address the critical resources challenges ahead. This includes improved strategies for finding resources, and the development of cleaner and more efficient extractive and refinement processes, while at the same time considering mutual global ambitions to deliver carbon-negative energy and building resilience across Europe towards the ever-changing nature of our supply chain.

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Digging into data access: The need for reform

Challenges in accessing archived geoscience data could hinder the UK’s adoption of new low-carbon technologies. Alex Dickinson and Mark Ireland suggest that a centralised archival system could help
GEOSCIENCE TECHNOLOGIES will play a vital role in realising net-zero ambitions. Subsurface reservoirs can store hydrogen fuel, lock away radioactive waste, and sequester carbon dioxide. Ground-source heat pumps and deep geothermal aquifers support decarbonisation of heating systems, whilst increased extraction of critical minerals will be key to building low-carbon infrastructure.

To develop these technologies, geoscientists need a reliable understanding of how heat and fluids move through the subsurface. This understanding is derived from the analysis of extensive empirical datasets. Geoscientists drill boreholes to characterise the composition of soils and rocks at depth, to measure variables such as subsurface temperature, and to sample the chemistry of groundwater in aquifers. They use remote-sensing methods, including magnetic surveying and seismic imaging, to reveal the three-dimensional geometry of subsurface structures and to track the movement of fluids.

Acquiring these datasets can be costly. Drilling a 1.5-km-deep onshore borehole, for instance, may cost £2 million. Such costs are often not justified during the initial development of technologies with unproven economic returns. As a result, nearly all nascent low-carbon projects make use of existing datasets. The UK has a rich trove of such datasets, most of which have been acquired in the past century to support the extractive and construction industries. However, barriers to data access threaten to slow the development of new technologies, hindering our ability to meet net-zero targets.

What data are needed?
In the past, geoscientists commonly worked with observational datasets acquired in a small geographical area. They became familiar with the quirks of each dataset, which they often analysed by making subjective judgements. Today, geoscientists are making increasing use of open-source software that can automate data analysis and make the results more reliable. Using such software, they develop tools that help policymakers and investors find promising locations for low-carbon technologies and identify regions in which acquisition of further data would be worthwhile (see box ‘Heat under Holland’ on page 36).

Efficient analysis using open-source software requires access to trustworthy datasets that are stored in consistently structured computer-readable formats. Geoscientists can no longer rely on picking out quirks by eye. Unfortunately, many of the UK’s existing geoscience data are archived in inconsistent formats and are hard to obtain.

Current data access
Researchers hoping to access UK geoscience data are confronted by an array of websites maintained by various organisations. Each organisation has a different approach to archiving and data sharing, and ease of data access is highly variable. To illustrate this variation, we consider five kinds of data that are most
UK geoscience datasets (white boxes) will be key to developing low-carbon geoscience technologies. 3D geological frameworks = three-dimensional representations of regional geology constructed from seismic data and borehole stratigraphic interpretations; borehole digital logs = computer-readable records of quantitative measurements made within boreholes; potential fields = gravity, magnetic and electromagnetic surveys; prestack/poststack seismic reflection records = seismic data before/after processing to make an image of the subsurface. Blue boxes = offshore data; green boxes = onshore data; solid arrows = publicly available for free download directly from website of relevant organisation (coloured central lozenges); dashed arrows = unavailable for free, direct download. Black lozenges show other possible sources of data (data release agents are commercial organisations that profit from reselling historical data). BGS = British Geological Survey; EA = Environment Agency; MDE = Marine Data Exchange; OGA (NDR) = Oil and Gas Authority (National Data Repository); UKOGL = UK Onshore Geophysical Library.
Due to the complexities of ownership and confidentiality, few BGS datasets can be downloaded. Many datasets lack detailed metadata, so lengthy correspondence is needed to establish what data exist and whether their confidentiality period has expired. Due to the extensive nature of the BGS holdings, mechanisms for accessing data can be unclear to researchers who are not well acquainted with the structure of the archives (see the online version of the article for an example concerning borehole data).

When onshore data can be made publicly available, they are archived using a range of physical and digital media. Due to variety in the quality of archiving, the cost of data retrieval can be high and users must often manually convert data to computer-readable formats. As a result of the cost and effort of accessing and formatting onshore data, geoscientists at companies, universities and research institutes often decide to develop and maintain their own databases of publicly available records. This approach leads to two problems. First, databases may not be shared with other members of the geoscience community due to concerns over ownership. Second, the use of independently maintained databases in geoscience studies may reduce confidence in the accuracy and trustworthiness of results.

**Improving data access**

Improving access to onshore and offshore geoscience data requires work in three areas:

1) **Reviewing the legal status of datasets:** Compilation of a comprehensive summary of ownership and availability of all existing datasets would help geoscientists identify information that is readily accessible. Where the ownership of historical records is unclear, their legal status should be reviewed to ensure that as much data as possible is publicly available. The UK must also ensure that data acquired in future are appropriately reported and archived. Data-reporting requirements for the majority of established industries are well defined. However, preservation of near-surface data acquired by the construction industry is currently voluntary, and the requirements for nascent industries, such as geothermal power, are not always clear. To avoid the loss of valuable information, regulators should review data-reporting mechanisms for growing industries and plan for the emergence of new industries. There must be continued focus on the requirements for publicly funded research projects to publish open-source data.

2) **Curating standardised digital datasets:** Ideally, data from all existing print and digital sources would be converted into simple, widely used open-source formats. Archived physical specimens would be detailed in easily searchable databases, and all datasets and databases would be accompanied by comprehensive descriptive metadata. Wherever possible, metadata for subjective interpretations (such as three-dimensional models of geological structure) would provide exhaustive links to the underlying observational data on which they are based. To aid planning of future projects, descriptions of confidential datasets would clearly indicate when the confidentiality period expires. If datasets cannot be made publicly available, the metadata should explain why.

3) **Building a single online platform:** Delivery of all open-source digital geoscience data through a single platform would dramatically reduce the time that geoscientists spend tracking down and requesting data. Ideally, the platform would be underpinned by an intuitively structured database that can be easily searched using text strings. Datasets with geographical information would also be displayed on a single interactive map. Each database entry would provide clear links to all associated data, metadata, and reports. Wherever possible, data would be free to download or to access using tools such as Application Programming Interfaces. These tools remove the need for researchers to maintain personal archives of data on local computers. Instead, they can analyse consistent, regularly updated datasets that are remotely hosted in the cloud.

**Figure 2: Custodial organisations draw funding from many different sources.** Licensing fees describe income acquired through issuing and terminating of licences and permits. Industry levy describes annual charges billed to all holders of hydrocarbon licences. Note that the column for the Environment Agency (EA) is plotted against the right-hand y-axis; all other columns are plotted against the left-hand y-axis. We could not find figures for the Marine Data Exchange, which is funded by the Crown Estate. BGS = British Geological Survey; OGA = Oil and Gas Authority (funder of the National Data Repository); UKOGL = UK Onshore Geophysical Library. A list of data sources is available as Supplementary Information at doi.org/10.6084/m9.figshare.c.5939299
Thanks to the explosion of digital technologies in the past decade, now is an excellent time to build the digital services and infrastructure that will underpin curation and delivery of standardised datasets. Scanned records can be automatically digitised, whilst petabytes of data can now be easily shared using cloud-based systems. Once a standardised digital archive has been established, it will be simple to update it to accommodate new storage formats, delivery tools, and data acquired by future projects.

The necessary infrastructure might be best developed in partnership with a dedicated cloud service provider. For instance, NASA has established partnerships with Amazon Web Services and Google to make a projected 250 petabytes of open-source data available through cloud-based services by 2025. Aside from commercial partnerships, collaboration with data custodians in other countries could drive efficient and mutually beneficial improvements to data access.

### Who will improve access?

Data custodians are aware of the need to improve access to their resources, and have already begun several excellent initiatives. For instance, NASA has recently published its first digital strategy (The British Geological Survey, 2020), and has set up Application Programming Interfaces for several of its datasets. However, similar strategies and tools are often independently developed by each custodial organisation. For example, the Marine Data Exchange, the NDR and the UK Onshore Geophysical Library all maintain online platforms that help geoscientists find and download seismic data. This duplication of data-management initiatives is inefficient.

Reducing these inefficiencies by coordinating efforts across custodial organisations would be challenging, not least because each organisation relies on different sources of funding. The British Geological Survey (BGS) draws on many sources, whereas the Marine Data Exchange, the NDR and the UK Onshore Geophysical Library each rely on a single source or donor. All three organisations have no responsibilities other than data management and data preservation.

In contrast, both the Environment Agency and the BGS receive funding from multiple sources and undertake many vital roles beyond data archiving. For example, the Marine Data Exchange, the NDR and the UK Onshore Geophysical Library all maintain

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**Table 1:** Volumes of data held by each custodial organisation. Note that figures are highly approximate. Different organisations often report different statistics for the same type of data (e.g. number of seismic surveys versus total length of seismic lines), and so direct comparison is difficult.

<table>
<thead>
<tr>
<th>Custodian</th>
<th>Data</th>
<th>Source</th>
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<tbody>
<tr>
<td><strong>Total data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BGS</td>
<td>Digital data</td>
<td>1,240 terabytes</td>
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<tr>
<td></td>
<td>Paper records</td>
<td>&gt; 11 km shelving</td>
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<td>Digital data</td>
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<td>Digital data currently in NDR</td>
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<tr>
<td>Non-NDR OGA data</td>
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<td>NDR 2026</td>
<td>Proposed size of NDR in 2026</td>
<td>~5,000 terabytes</td>
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<td><strong>Borehole</strong></td>
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<tr>
<td>BGS</td>
<td>Onshore boreholes</td>
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<td></td>
<td>Boreholes with digital logs</td>
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<td></td>
<td>of which non-confidential</td>
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<td></td>
<td>Non-confidential digital logs</td>
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<td>Boreholes with paper logs</td>
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<td>Length of core</td>
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<td>Physical samples</td>
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<td></td>
<td>Scanned reports</td>
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<td>Total length of 2D seismic lines</td>
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<td>UKOGL</td>
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<tr>
<td></td>
<td>Total area of 3D seismic surveys</td>
<td>2,400 km²</td>
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</tbody>
</table>

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Britannica entries include both records maintained by the BGS proper and records maintained by the National Geological Repository and the National Geoscience Data Centre. NDR 2026 = planned size of the National Data Repository (NDR) in 2026. The bar chart at the right-hand side compares the total volumes of digital data held by each organisation. We could not find information for the National Geoscience Data Centre. The BGS has constructed several onshore geological frameworks. Estimated total size of current Oil and Gas Authority (OGA) digital archives includes both NDR and non-NDR data. Aside from the Coal Authority archive, the BGS maintains further seismic datasets of unstated size. The UK Onshore Geophysical Library (UKOGL) also provides access to seismic data maintained by the BGS. MDE = Marine Data Exchange. A list of data sources is available as Supplementary Information at doi.org/10.6084/m9.figshare.c.5939299
funding, it derives a third of its income from sale of data and from licensing of activities such as fishing and waste disposal. The BGS receives more than half of its income from Government funding, with the remainder made up from commercial consultancy, research grants, and data sales. These competing incentives, and often a lack of funding, mean improvements to data access cannot always be prioritised.

We suggest that the inefficiencies of the current system could be overcome by establishing a centralised organisation dedicated to the preservation and management of all onshore and offshore geoscience data. This organisation would focus on reviewing the legal status of historical records and overseeing the development of digital infrastructure for the curation and delivery of standardised datasets. It would have responsibility, where appropriate, for setting charges associated with data delivery. It could also work with regulators towards efficient enforcement of data reporting.

Establishing this new model for geoscience data management would likely cost tens of millions of pounds. Much of the initial cost would cover development of digital infrastructure, followed by digitisation of print media and reformatting of compiled data into standardised datasets. The digital infrastructure might be most easily created by expanding or mimicking the cloud-based systems that host the Marine Data Exchange and the NDR. Once established, cloud-based infrastructure could reduce annual data-storage costs by up to £400,000 per petabyte (Net Zero Technology Centre, 2021).

Long-term maintenance costs could be met through levies on the hydrocarbon and renewable-energy industries. The overall cost of data preservation will almost certainly reduce due to elimination of duplicate initiatives. Establishment of a centralised organisation for data delivery may also require changes to the business model of the BGS, which receives around 7% of its income from data sales (The British Geological Survey, 2021) (Fig. 2).

However the costs are met, overhauling management of the UK’s geoscience data will cost only a fraction of the estimated annual investment of £50 billion needed for decarbonisation (The Climate Change Committee, 2020). This small investment seems highly worthwhile. Improved data access will help researchers, engineers and policymakers make decisions that are fully informed by all existing data, and will encourage development of low-carbon industries. By exporting these industries, the UK can profit from the projected global investment in clean-energy technology of £3 trillion per year by 2030 (The International Energy Agency, 2021).

Aside from the economic benefits, transparent sharing of data and decision-making will help foster public support for low-carbon technologies that could otherwise be portrayed as dangerous. Standardised datasets will facilitate changes to university geoscience courses, and will encourage the teaching of highly valued analytical skills such as data science. On the level of fundamental research, reanalysis of comprehensive datasets using modern computational tools could revolutionise our understanding of British geology.

Data-archiving experts may disagree that establishment of a centralised body is the best way to realise the full potential of the UK’s geoscience data. We acknowledge that our suggestions are based on our perspective as end users of data, and that insights from those with expertise in data architecture are vital. Many of the organisations mentioned here are already doing excellent and often unrecognised work to improve data access. By providing an end-user viewpoint, we hope that this article will prompt discussion about the best way to build on their efforts and maximise the value of the UK’s rich data trove.

**HEAT UNDER HOLLAND**

The Netherlands Organisation for Applied Scientific Research has constructed nationwide, three-dimensional predictive models of subsurface temperature and the economic potential of future geothermal systems. These models are available online (thermogis.nl/en). Due to this modelling initiative, over 90% of drilled geothermal projects have been successful, and installed geothermal power expanded by a factor of ten between 2010 and 2018 (Ministry of Economic Affairs and Climate Policy, 2020).

These models are underpinned by a repository of data from all boreholes drilled by the hydrocarbon industry. Anyone can freely access these data. Imagine, for instance, that a Dutch geoscientist is investigating the potential for a geothermal heating system near Utrecht. They want to download digital logs for a certain borehole, which they find using an interactive map. Clicking on the borehole, they learn that six types of log are available. Within ten minutes, they have downloaded all these logs and 87 associated reports for no cost. These files have a total size of 380 megabytes.

**Acknowledgments**

We thank employees at the British Geological Survey, the National Data Repository, and the Oil and Gas Authority (now the North Sea Transition Authority) for their help in finding information for this article. The full version of this article, including references and additional figures and tables, is available at Geoscientist.Online. Supplementary information is available at doi.org/10.6084/m9.figshare.c.595299

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Between 1604 and 1914, various Enclosure Acts restricted public access to large swathes of common land in England. Much of the Pennine uplands was reserved for grouse breeding, with exclusive access for shooting parties, and the Dark Peak of the Peak District became largely inaccessible to walkers wanting a brief escape from nearby industrial cities, such as Manchester and Sheffield.

Protest
In an act of protest, on Sunday 24 April 1932, more than 400 people participated in a mass trespass onto Kinder Scout, a moorland gritstone plateau and, at heights of up to 636 m above sea level, the highest terrain in the Peak District. The main group, from Manchester, set off from the rallying point at Bowden Bridge Quarry in Hayfield, Derbyshire, scrambling up the William Clough route towards the Kinder Plateau.

Eventually, gamekeepers confronted the group en route, and scuffles ensued. Eventually the party broke through, reaching Ashop Head where they met a smaller group of walkers from Sheffield who had accessed Kinder Scout from the other side at Edale, Derbyshire, via Jacob’s Ladder. Both groups then retraced their steps back to their starting points. Upon return of the Manchester group, some arrests were made relating to unlawful assembly and breach of the peace. However, the arrests simply increased publicity for the cause and the long-term goal of establishing some form of rights to roam the open country.

Initiating change
This event, known as the Mass Trespass of Kinder Scout, was pivotal in initiating important changes in the UK. The trespass is often credited as having led to: legislation to establish the National Parks, with the Peak District designated as the first National Park in the UK, in 1951; the opening up of long-distance footpaths (and, in particular, the Pennine Way, which opened in 1965 – appropriately on 24 April, the same date as the Mass Trespass – and starts in Edale and crosses Kinder Scout); and the Countryside Rights of Way Act in 2000, which formalised the right to roam over swathes of land mapped as ‘open country’ or registered as common land in England and Wales.

The Pennine Way crosses the river Kinder above the Kinder Downfall, a 30-m-high waterfall on the edge of Kinder Scout. The characteristics of the waterfall change with the seasons and weather; during strong westerly winds the water flow is blown back on itself creating a cloud of spray that can be seen from miles around. In dry weather, the cascade at Kinder Downfall is replaced by a staircase of Carboniferous Kinderscout Grit; in hard winter months the waterfall can sometimes freeze over, attracting ice climbers.

In 1982, a commemorative plaque was erected in Bowden Bridge Quarry (now a National Trust car park for walkers) to mark the 50th anniversary of the Mass Trespass. On this the 90th anniversary year, we should reflect on the significant role this event, and notably the pioneering spirit of the group of working class trespassers, played in facilitating both the open public access to the countryside that we enjoy today and our protected landscapes.
What’s cooking?

Nina Morgan explores culinary secrets in the Buckland household

WILLIAM BUCKLAND [1784 – 1856], the first Reader in Geology at the University of Oxford, was notorious for his catholic tastes in the culinary department, as well as the ambition he shared with his eldest son, Frank [1826 – 1880], to eat his way through the animal kingdom.

Guests at Buckland’s table in Christ Church College, Oxford, recall many memorable meals. As the scientist, Liberal politician and, for a short time, Postmaster General, Baron Lyon Playfair [1818 – 1898] recounted to Buckland’s daughter and biographer, Elizabeth Oke Buckland Gordon [1837 – 1919], “The hedgehog was a successful experiment, and both Liebig and I thought it good and tender.” But, not all dishes were so successful. Crocodile, Playford recalled, “was an utter failure.”

Meat and potatoes

In England, roast meats are traditionally accompanied by carbohydrate-rich vegetables such as potatoes. But, to accompany these exotic meals, the Bucklands may have turned to something different, such as white rice, a grain that was becoming popular in the mid-19th century. Writing to Buckland on 19 June 1831, the widely travelled British naval officer, Basil Hall [1788 – 1844], son of the Scottish geologist Sir James Hall [1761 – 1832], provided Buckland with detailed instructions for its preparation:

“I forgot to mention to you [in discussing] the method of boiling rice, that after the water is poured off, it must on no account be stirred, but be allowed to steam in quiet.

“My cook is in the habit of pouring the whole mass, water[,] rice and all into a cullender, & allowing the water to run quite off, then returning the rice to the dry pot. I have no doubt that by a little patience, & close attention to the directions you will succeed in getting good rice…”

And adds this helpful hint:

“Recollect that it is far easier to boil Bengal Rice well, than it is to boil Carolina rice – so that you should practice [sic] your cook first in the Bengal & then promote her talents to a trial of the Carolina.”

Chemistry in the kitchen

Whether Buckland busied himself in the kitchen is not certain. But, his wife, Mary Buckland [née Morland, 1797 – 1857] certainly did. The chemist and physicist William Hyde Wollaston [1766 – 1828] – he of the Wollaston Medal, the highest award granted by the Geological Society of London – was one of the recipients of her efforts, and applied his chemistry skills to analyse her gift of some jelly.

Writing to Mary on 2 October 1828, Wollaston comments on the taste of her ‘amethystine produce’:

“If I answer as a Chemist I can surely reply that the colour appears to be vegetable. If you ask me as a Botanist, what vegetable, I reply… it is not very easy to guess which may give it… As a man of taste I should suspect the colour to be given by some kind of fruit & if I were to rely on taste alone I should say some kind of plum. As a cook – I suspect you would not get that colour without a good jelly bag.”

Mary’s jelly stirred into some perfectly cooked white rice must have made a delicious pudding and a splendid end to an exotic meal.

Acknowledgements:

I thank Matthew Barton, Digital Archivist at the Oxford University Museum of Natural History (OUMNH) for drawing my attention to the letter from Basil Hall to William Buckland, and the archivists and librarian at the OUMNH for permission to quote from it. I also thank Peter Lincoln for drawing my attention to the letter from William Wollaston to Mary Buckland, and Roderick Gordon for permission to quote from it.

Sources:

• The Wikipedia entry for Basil Hall: en.wikipedia.org/wiki/Basil_Hall

NINA MORGAN
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Asian climate, tectonics and biodiversity

Hybrid Conference

How do tectonics and climate force surface processes and the evolution of biodiversity in Asia?

This meeting will examine this long-standing question by unraveling coupled geodynamic and Earth surface processes that impact environmental conditions and the biosphere across different spatial and temporal scales.

With ongoing human alteration of the Earth’s ecosystems and rapid global warming, there is an urgent need to understand the response of biotic communities and environmental change. Examining how past climate change influenced biological diversity around topographically complex and tectonically active systems provides unique information about their ability to adapt to changing environmental conditions.

Specific insight on how rapid climate and landscape changes impacted ancient life will shed light on the origins and governing factors of biodiversity hotspots and thus inform conservation efforts. Eventually, this information can guide policy decisions under projections for a rapidly warming climate to ensure that we preserve biodiversity of our ecosystems into the future, which is essential to global economic, social and cultural prosperity.

Convenors
Dr Guillaume Dupont-Nivet (CNRS - Géosciences Rennes, France)
Dr Tara Jonell (University of Glasgow)
Dr René Dommain (University of Potsdam, Germany)
Prof Peter Clift (Louisiana State University, USA)

Keynote Speakers
Prof Oliver Jagoutz (Massachusetts Institute of Technology, USA)
Prof Carina Hoorn (University of Amsterdam, Netherlands)
Robert A Spicer (The Open University, UK)
Dr Thomas von Rintelen (Natural History Museum, Leibniz-Institute for Evolution and Biodiversity Research, Germany)
Prof Robert Morley (Palynova)

Further Information
View the full programme or register now www.geolsoc.org.uk/asianclimate2021
The safe and secure disposal of radioactive waste is a pressing global issue. Mike Bowman and colleagues discuss the role for geoscience in this endeavour. A long-term solution for higher-activity radioactive waste disposal in the UK is needed. To discuss the critical role played by the geosphere in the deep geological disposal of radioactive waste, in September 2021 the Yorkshire Geological Society partnered with Radioactive Waste Management UK (now Nuclear Waste Services, NWS) and the British Geological Survey (BGS) to convene a meeting entitled ‘Deep geological disposal of radioactive waste: The role of geoscience.’ In the UK, radioactive waste disposal is a devolved responsibility. Scottish policy requires that long-term management of higher-activity waste should be in near-surface facilities located as close as possible to the sources of the waste. However, in common with most other countries, English and Welsh governments favour deep geological disposal, between 200 and 1,000 m below surface, as the safest way of containing and isolating the waste for the long-term, such that it cannot harm people or the environment. A site-selection process in England and Wales seeks to engage communities interested in hosting a geological disposal facility (GDF) in their local area, onshore or inshore (the area within UK territorial waters, 22.2 km from low-water tide mark). The GDF programme is a major environmental protection project where geoscience skills play a key part in its success. The selection of suitable sites is led by NWS, a publicly funded organisation planning for delivery of a GDF in which the UK’s higher-activity radioactive waste inventory will be disposed.

The two-day virtual event comprised a series of invited talks, which provided summary updates on the UK’s GDF programme and the main European radioactive waste disposal programmes. These were supplemented by short films from early career geoscientists working on GDF-related technology that highlighted the impact of their...
work on a future GDF. It is clear from the talks, discussions and films that the GDF programme is a major infrastructure project with many career opportunities for subsurface geoscientists with skillsets that might formerly have been engaged in oil-and-gas industry activities.

**Technical focus**
The first day of the meeting had a broadly technical focus. Jonathan Turner, Chief Geologist at NWS, described a GDF in terms of a highly engineered, bespoke facility. The long-term containment and isolation of radionuclides is provided by the multi-barrier concept in which engineered barriers work together with the natural geosphere barrier. Jonathan introduced the three principal rock-type categories, subdivided based on their fluid flow and engineering properties: higher-strength rocks, such as slates; lower-strength sedimentary rocks, such as Jurassic-Cretaceous claystones; and evaporites, such as Triassic deposits mined in Cheshire.

Jonathan used the 1.3-billion-year-old Cigar Lake uranium ore deposit in northern Saskatchewan, Canada, as a natural analogue for a GDF (Geoscientist 30 (8), 10-15, 2020). This uranium ore lies ~400 m beneath the surface, yet despite its age, there is no sign of radioactive contamination at the surface or in the overburden.

Subsequent talks offered insight into ongoing GDF programmes in Sweden, Switzerland and Germany. Kaj Ahlbom (SKB, Sweden) was head of site investigation at Forsmark, on the east coast at Uppland, where a GDF will be constructed in Archaean granites. Kaj outlined the analyses undertaken to assure the inherent safety and security of the site selected for the repository, providing regulators and local communities with confidence in both site selection and repository design. In Sweden, the properties of the granitoid host rock means that SKB were reliant on non-seismic geophysical methods, such as gravity and magnetics, to image the subsurface before borehole drilling.

Tim Vietor (Nagra, Switzerland) described the nationwide screening and technical assessment that enabled selection of the Middle Jurassic Opalinus Clay as the most suitable host rock for a Swiss GDF. He reviewed the long-term isolation arguments and repository design challenges for a location in the north Swiss foreland basin, away from active uplift and erosion in the Alps. Nagra is in the final phases of a deep drilling campaign as part of the last stage in the Swiss Sectoral Plan leading to a recommendation of their favoured site to host a repository. The subsurface evaluation focuses upon four candidate sites using the knowledge gained from high-resolution 3D seismic data, long-term flow tests and recent drilling to directly sample the Opalinus Clay.

Since 2016, Germany has been engaged in developing rules, criteria and requirements enabling identification of a site that will deliver the best possible long-term safety. Lukas Poliok and Nicole Schubarth-Engelschall (BGR, Germany) reviewed ongoing investigations that focus on halite, particularly Germany’s extensive Permian evaporite successions, as a potential host rock for higher-activity waste.

A panel discussion chaired by Jen Roberts (University of Strathclyde, UK) and comprising Julie West (West Consult, UK), Tom Berry (Yorkshire Geological Society and Jacobs, UK), Fiona McEvoy (Environment Agency, formerly BGS, UK) and Cherry Tweed (NWS) examined how geoscience can help engage, inform, and enrol communities who might be willing to host a GDF. They discussed the short- and long-term focus of the required geological and engineering work, how subsurface characterisation can be used to inform and energise conversations with communities, and touched on the exciting potential of new techniques, such as artificial intelligence, virtual and augmented reality, machine learning, modelling and surveillance – all of which will be key to the delivery of a GDF.

**Geopolitics and sociology**
The second day of the meeting examined how geoscience can be used to help engage with a community and influence the siting of a GDF. Jon Gluyas (University of Durham, UK) presented a broad-ranging talk on Earth resources, geostorage (contrasting this with permanent disposal) and sustainability. Placed in the context of today’s environmental and climate challenges, Jon emphasised the importance of understanding the subsurface. Fiona McEvoy and David Schofield (BGS) reviewed the longer-term climatic considerations, stressing the need for very long-term stability of the geosphere barrier and highlighting the impact of climatic processes, such as continental glaciations, on the integrity of a GDF.

Neil Chapman (University of Sheffield, UK) reviewed the history of deep geological disposal of radioactive waste...
since its inception in the United States in the 1950s. The longevity of the system must be factored into the conceptual framework for a GDF, the safety system and the engineering approach. The fundamental objective of a GDF is to provide a passively safe system that will contain and isolate the waste at depth without human interference for hundreds of thousands of years. However, the facility should be designed such that it is sufficiently flexible to accommodate future developments in the nuclear fuel cycle.

Major infrastructure projects have a transformational impact on host communities. Here, Penny Harvey, Professor of Social Anthropology at the University of Manchester, UK, described her experiences from studying the sociological impact of major resources projects, particularly in South America. Among the approaches she discussed was the way in which the wonders of geoscience can be used to inspire and engage communities.

A panel composed of Andrew Bloodworth (BGS), Mike Daly (University of Oxford, UK, and President of the Geological Society), Neil Chapman and Penny Harvey discussed the need to obtain and retain a ‘licence to operate’ among the communities affected by a GDF. Given the long timeframes for GDFs, it is essential to engage young people who will be involved in many key decisions.

The complex technical messages required to understand GDF safety must be conveyed clearly and it will be critically important to deliver upon commitments made to communities. A sense of pride in enabling the delivery of a first-of-a-kind major infrastructure project can help a community to ‘own’ a GDF in their area. The panel agreed that major infrastructure programmes like GDF have the potential to create a plethora of career opportunities for geoscience and subsurface professionals.

Penny Harvey discussed the way in which the wonders of geoscience can be used to inspire and engage communities.

MIKE BOWMAN
Yorkshire Geological Society and University of Manchester, UK

TOM BERRY
Yorkshire Geological Society and Jacobs, UK

FIONA MCEVOY
Environment Agency and Visiting Research Associate, BGS, UK

JONATHAN TURNER
Nuclear Waste Services, UK
New in the Journal of the Geological Society

A new stratigraphic framework for the early Neoproterozoic successions of Scotland

By Maarten Krabbendam, Rob Strachan and Tony Prave

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https://jgs.lyellcollection.org/content/179/2/jgs2021-054

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Key to the past

ABOUT 56 MILLION years ago, Earth experienced an extraordinary episode of global environmental change. Over a geological instant, surface temperatures soared by 6 °C, ecosystems, both terrestrial and marine, evolved dramatically, and tremendous quantities of carbon dioxide entered the ocean and atmosphere. The event, now called the Paleocene-Eocene Thermal Maximum (PETM), likely represents our best past analogue for understanding the effects of current climate change associated with anthropogenic fossil fuel emissions. As highlighted by three recent studies, the PETM also forces our broad geoscience community to contemplate a commonly taught axiom: the present is the key to the past.

The first study by Sev Kender (at the University of Exeter, UK and the British Geological Survey) and colleagues reconstructs mercury (Hg) records from sediment cores that span the PETM and come from the North Sea. The records reveal that Hg accumulation increased significantly but sporadically before and during the PETM. Assuming most sedimentary Hg derives from volcanoes, the authors conclude that pulsed volcanism, particularly in the North Atlantic Igneous Province, drove the PETM, including a substantial portion of the carbon emissions. This general idea was pushed to the forefront nearly two decades ago with the discovery of numerous buried craters on the Norwegian continental margin, which apparently contain sediment deposited during the PETM. In the recent paper, though, sedimentary Hg contents are relatively low at the onset of the PETM, precisely when stable carbon isotope records suggest massive carbon emissions were occurring. The authors therefore suggest volcanism triggered additional carbon release from other sources.

A recurring and fascinating find is that, along continental margins, the PETM manifests as an expanded horizon of terrestrially derived material. A second study by Simin Jin at the China University of Geosciences and colleagues...
spectacularly shows this aspect for cores from the North Sea. Indeed, the onset and main phase of the PETM, which lasted less than 200,000 years, corresponds to 140 metres of stratigraphic thickness in one of the cores. Moreover, this record displays cycles in sedimentary components with an apparent beat to Earth’s precession. Consistent with results from general circulation models for Earth’s future, the authors argue that greatly enhanced rainfall seasonality characterised the PETM, and this led to immense sedimentary discharge from rivers to continental margins.

The third paper, which comes from Maodian Liu at Peking University, China, never mentions the PETM. Indeed, it entirely omits reference to the geological past. Instead, it is a remarkable and comprehensive examination of Hg riverine discharge to modern continental margins. The team shows convincingly, and in contrast to dogma, that most Hg on modern continental margins derives from rivers rather than from atmospheric sources, such as emitted by volcanoes. Crucially, they also suggest that rivers disproportionately add Hg during events of extreme discharge.

Individually, the three papers represent interesting works, each of which moves a disparate field forward. Read collectively, they exemplify how we might misread the sedimentary record during times of extraordinary change. For example, it seems that sedimentary filling of craters along the Norwegian margin and Hg anomalies in the North Sea could potentially represent an underappreciated and perhaps unprecedented delivery of fluvially derived components to continental margins, rather than near instantaneous and voluminous volcanism. For the PETM, a better axiom might be: the future is the key to the past.

JERRY DICKENS

**Electrifying plumes**

Volcanic eruption plumes sometimes develop lightning storms. The detection of radio waves generated by these storms can help warn of hazardous ash, yet little is known about how volcanic plumes become electrified. Using the 2020 Taal eruption in the Philippines as a case study, Alexa Van Eaton of the US Geological Survey and colleagues developed a conceptual model for how plumes with high water content can become electrified.

The eruption of Taal volcano on 12 January 2020 was phreatomagmatic, meaning there was interaction between magma and water. In this case, a large water-rich ash plume rose 17 km above sea level and spread out as an umbrella-shaped cloud. The team used a combination of satellite imagery, time-lapse photography and a global dataset of radio waves generated by lightning to investigate volcanic-lightning production.

Their results show that lightning was only detected globally once the plume reached >10 km above sea level, where the lightning flash rate increased to over 70 flashes per minute as the plume expanded vertically and laterally. The authors suggest that at these higher altitudes, water freezes within the plume, leading to intense electrification, like regular thunderstorms. Ground-based photos showed hundreds of tiny flashes and blue-coloured ‘streamers’ at the umbrella cloud base. The team propose that enhanced electrical activity occurs in this region because the flow changes from vertical to lateral movement, which helps separate different regions of charge. Their model suggests that initial electrification occurs by collisions of ash particles near the volcanic vent, but lightning here is not globally detectable, contrary to the higher altitude ‘thunderstorm-like’ lightning. The 2022 eruption of Hunga submarine volcano in Tonga produced a record level of lightning, which this conceptual model may now help to understand.

Taal produced many plume-to-ground lightning strikes within 20-
30 km from the volcano – a region inhabited by over 1.2 million people. Therefore, this research not only helps to inform the different processes of lightning formation in water-rich eruptions, but also emphasises the hazard of volcanic lightning in densely populated areas.

LUCY BLENNERHASSETT

Alpine flooding
Nature Geoscience 15, 118–123 (2022); doi.org/10.1038/s41561-021-00878-y

Flooding is a significant natural hazard that affects many people worldwide every year. Understanding flood frequency and severity is critical to minimising the human and economic costs, but climate change is likely to alter flooding patterns, making risk management more complicated.

Bruno Wilhelm at the Université Grenoble Alpes, France and colleagues compiled and analysed palaeoflood and temperature records from the European Alps over the past 10,000 years to assess whether there is a relationship between changing temperature and the frequency and magnitude of floods. The team chose the European Alps because mountainous areas are particularly prone to flooding and this densely populated region is already experiencing a high warming rate that may be leading to more frequent heavy rainfall events.

Interestingly, the researchers find that past warming tended to coincide with a decrease in flood events. Specifically, warming of 0.5 to 2 °C coincides with a 25–50% decrease in the frequency of large flood events (those that typically have a recurrence interval greater than ten years). The team suggest that floods are more frequent during colder periods because the soil moisture content is high and precipitation increases due to the prevailing westerly winds and incoming storm track. However, there is some evidence that past warming is linked to an increase in extreme flood events (those with a recurrence interval of greater than 100 years) in small alpine catchments, with these events triggered by localised but intense convective storms.

The work highlights the value of palaeoflood data and the need for records covering at least 200 years, so that robust flood patterns can be detected.

While the analysis is limited to the Alps, and research in different environments and locations is crucial to improve our understanding of flood risk, the results illustrate the complexities of flood responses to changing climate.

STEPHEN MCHUGH

Negative-relief traps
Petroleum Geoscience 28 (2022); doi.org/10.1144/petgeo2021-074

When CO₂ is dissolved in water or brine, the resulting solution is denser than the original CO₂-free fluid. Given the negative buoyancy of CO₂-rich brines, it should be possible to use negative-relief trapping configurations for CO₂ sequestration – the opposite of what is typically considered a conventional structural trap for hydrocarbon accumulations or indeed positively buoyant, pure CO₂. Negative relief structures, synforms for example, can be identified using existing hydrocarbon subsurface data sets.

By analysing such data from basins globally, Simon Stewart at Saudi Aramco, Saudi Arabia, has highlighted the opportunity of considering systematic differences between typical hydrocarbon traps and geological storage options for CO₂-rich brines.

Stewart’s analysis highlights that a trap’s spatial scale is an important consideration. In flexural sedimentary basins, synformal traps can be very large, with some reaching sizes approaching the basin scale. In this
case, the traps will form the upper end of a multiscale geometry that may include a population of smaller structures. For conventional oil-and-gas exploration targets, the entire basin is rarely mapped in sufficient detail, or with the required data quality, to fully evaluate the population of negative-relief traps. Therefore, the use of existing hydrocarbon exploration data to quantify the storage potential of a basin in negative-relief traps comes with great uncertainty, which must be factored into risk analyses of volumetric assessments.

Despite this uncertainty, the work highlights the potential to store large volumes of CO$_2$ in the subsurface via an additional mechanism (that is, in addition to the more conventional positive-buoyancy traps for immiscible pure CO$_2$) supporting the CO$_2$-sequestration aspect of the energy transition. Stewart’s approach exemplifies the innovation required to meet the challenge of net-zero efforts and may prompt review of data acquired through decades of hydrocarbon exploration and production activities, and repurposing of the data to open alternative means of CO$_2$ sequestration.

To help empower engineering geologists to communicate their value more confidently, and thereby enhance their influence and impact, Richard Lagesse at Arup, in Los Angeles, USA, and colleagues from Arup and the British Geological Survey, carry out a mapping exercise using the published literature and project case studies from a range of different geographies, organisations and development contexts. They review all the 169 targets that make up the 17 SDGs against typical engineering geology knowledge, skills and activities, to understand how engineering geologists currently contribute to the SDGs and identify areas where contributions could be increased. The methodology used identifies direct dependencies between engineering geology and some of the SDGs, in addition to indirect dependencies of all other SDGs.

The results show that engineering geologists can contribute to all the SDGs, with their skills directly relevant to 82 of the 169 targets, and indirectly relevant to a further 25 targets. The primary areas of impact are through infrastructure development, building resilience and disaster risk reduction, as well as environmental protection. Secondary contributions include the development of equitable and effective communities, and the creation of collaborative and strong partnerships. The study goes further by articulating the strength of the contributions of engineering geologists to each target, thereby highlighting opportunities to maximise and extend their impact. For example, the authors suggest that engineering geologists should look to extend their influence in policy-making, and have greater consideration of the impact of climate change at various stages in their projects.

SADE AGARD

**Engineers contribute to the SDGs via infrastructure development, amongst other contributions.**

**Engineering geologists** have unique skills that make their role in delivering the United Nations Sustainable Development Goals (SGDs) an important one. It is essential for engineering geologists to communicate their value in this endeavour yet they often lack the practical holistic information, specific to engineering geology, that enables them to clearly understand how they can, or already do, contribute to sustainable development.
THE PEAK DISTRICT: LANDSCAPE AND GEOLOGY

DETAILS

REVIEWED BY COLIN J SERRIDGE
This publication is welcome and timely. 2021 marked the 70th anniversary of the Peak District National Park, the first of the designated national parks in the UK, and 2022 is the 90th anniversary of the Kinder Mass Trespass, which led to much greater accessibility to the Peak District for walkers, particularly from the industrial towns and cities surrounding this unique part of the British landscape.

The book provides fascinating insight into the landscape and geology of the Peak District. The author’s long association with and in-depth knowledge of the area, which extends over many years, combined with his enthusiasm for its geology and landscape evolution, together with its modification through anthropogenic activity, is clear in the content, style and delivery of the publication. The book is written in a fluent and understandable manner that will appeal to a wide audience and is supported by a wealth of fascinating photographs (many drawn from the author’s own personal collection), together with very useful and informative maps, sketch profiles and cross sections.

An introductory chapter sets the scene, describing the contrast between the White Peak (characterised by Carboniferous limestones) and the Dark Peak (characterised by Carboniferous gritstones), which defines the Peak District geology. The remainder of the book is split into three main sections: the first, Starting with the Rocks, contains chapters that cover the White Peak limestone, the Dark Peak gritstone and the Derbyshire dome. The second section, Creating the Landscape, contains chapters that capture the shaping of the Peak District – the impact of the ice ages, the limestone country that includes karst and underground caves, as well as the contrasting moorland associated with the Dark Peak and the ‘sheepwalk’ grassland of the White Peak.

The third section, Impact of Mankind, covers the mineral riches of the Peak District and the stone industry (quarrying and the use of stone commercially), including how stone has been used in construction, giving the villages, towns and historic buildings within the region their distinctive character, together with an interesting section on dams and reservoirs.

Humankind has also helped to shape the landscape for our enjoyment, and suggestions for walks and places to visit are provided, giving the reader the opportunity to appreciate the best of the National Park’s landforms, perhaps inspiring a visit to a location not previously visited.

The author is to be congratulated for providing such a wealth of information and illustrations in a book of its size.

A HISTORY OF THE UNIVERSE IN 21 STARS (AND 3 IMPOSTERS)

DETAILS

REVIEWED BY LARS BACKSTROM
Each chapter in ‘A History of the Universe in 21 Stars (and 3 Imposters)’ covers one celestial object, including where and when during the year to locate it, why the object is important to our understanding of the universe, the history of its discovery and the effort that went into unravelling its secrets.

Most, if not all, of the objects described will be familiar to anyone with an interest in astronomy. Some are obvious choices, like Betelgeuse and Sirius B, while the importance of others, like Polaris and Mizar, are not obvious – at least not to me – until reading on. The selection becomes even more impressive as all of them, except for S2, are either visible to the naked eye or through a small telescope, meaning that after reading a chapter it is possible to go out and observe the actual object – location and time of year permitting.

The book does a very good job of covering our present understanding of the universe using non-technical language. What I found impressive is that the author also gives a comprehensive history of the field of astronomy itself, including important contributions from unrecognised female pioneers and scientists from non-Western cultures.

Two minor issues that I had at the beginning were the lack of photos and the use of hand-drawn star-charts. I realised later, however, that the charts really do a good job as aids for locating the objects in question because of their clarity and exclusion of irrelevant details. A big issue that I have, however, is the lack of an index, which made for a fiddly process of trying to remember where I had come across the names of people and objects that recur throughout the text and which I found interesting for cross-checking.

The book also inexplicably lacks an author biography: I had to find Giles Sparrow’s website to ascertain his credentials.

He studied Astronomy and Science Communication at UCL and Imperial College London and therefore has a thorough understanding of his subject.

Whatever the book’s issues, I would still recommend it to anyone who has even the slightest interest in astronomy as it is a very rewarding read; the colloquial language makes it an excellent gift to budding young amateur astronomers. I wish I had had such a great overview as this during my amateur astronomer days, so many years ago now.
A CURIOUS BOY – THE MAKING OF A SCIENTIST

DETAILS
PRICE: £20.00 harpercollins.co.uk

REVIEWED BY TED NEILD
We all (should) know Richard Fortey FRS, President in the Geological Society’s Bicentenary Year (2007), distinguished palaeontologist and writer. And I am sure that Collins are banking that many more people do too, because nobody buys autobiographies of people they’ve never heard of, which is why so many celebrity chefs write them. What sells such books is being known to ‘people who are interested in people’ (which is most people).

In 1976, on the 15th anniversary of his autobiographical poem of youth, Summoned by Bells, Sir John Betjeman told Radio Times: “People’s lives are interesting only up until they’re 21. It’s one’s first humiliations and struggles that are very interesting.” Fortey duly stops his own compelling and delightful memoir when the Natural History Museum, his career home, accepts him. The ‘making of a scientist’ was done.

Unsurprisingly, poets and writers excel at youthful memoirs. The landscapes of youth possess a magic that no other landscapes ever can – except, perhaps, the imagined ones of deep time – the realm of the geologist. Like them they are, inevitably, reconstructions at a distance. Reimaginings. Data are missing. But sensation is strong.

Each chapter in A Curious Boy takes an object as its springboard – a trout, a bird’s egg collection, his first ammonite specimen. Fortey is interested to know what led him down his path (towards trilobites and away from poetry). The headmaster of Ealing Grammar helped him choose by asking whether he was more interested in people or things. Young Fortey’s life flashed before his eyes – chemistry, fossils, flowers, butterflies, fungi – “Things, Sir”. And so it was settled.

But he is not just interested in things. His portraits of his parents, especially his father, who ran two fishing shops largely without the knowledge of the Inland Revenue, are vivid and moving. Nor shall I forget the tragedy that deprived young Richard of his father and might well have deprived us all of geology’s most persuasive writer.

I hope Fortey’s faithful readers do not fall too far on the ‘things’ side. The book contains no shortage of objects, but how many readers of ‘popular science’ are actually only interested in the curator’s white gloves? They would miss so much.

APPLICATION OF ANALYTICAL TECHNIQUES TO PETROLEUM SYSTEMS

DETAILS
BY: Patrick J Dowey, Mark Osborne & Herbert Volk (Eds.) (2020). The Geological Society of London. 346 pp. (hbk)
ISBN: 9781786204066
PRICE: £100.00 geolsoc.org.uk

REVIEWED BY RICHARD DAWE
A petroleum system consists of a number of components, including a mature source rock, a migration pathway, reservoir rock and fluids, a trap and seal. Each component must be studied at all scales, from nanometres to kilometres. Such studies begin with samples of outcrop rocks, core and drill cuttings and fluid samples from seeps or wells. This multitude of physical property data is then placed in a geological framework of space and time and ‘interpreted’ to unravel the complexities of the hydrocarbon accumulation. Much laboratory detective work has to be undertaken to gather all the geological evidence that can identify this petroleum system. A broad range of analytical instruments and interpretation approaches are essential and this book discusses many of the new technologies that can be used to gain this knowledge.

This 346-page volume is a wide-ranging exposé of modern analytical techniques, bringing together topics and case studies and written by leading authorities in internationally recognised laboratories. The 17 papers explore fluid and isotope geochemistry, organic geochemistry, imaging and sediment provenance. Each paper covers a different data collection method using complex and often expensive kit: there are no detailed descriptions of the actual instruments, though, as these are found in instruction booklets.

Cutting-edge techniques and innovations in analytical approaches are emphasised, and how they can be applied to benefit the defining of the appropriate parts of the petroleum system. For example: mud gas isotopes to distinguish connected from disconnected reservoirs and the monitoring of gradual fluid movements; fluid inclusion petrography coupled with Raman spectroscopy to investigate the charge history of gas fields; and molecular and isotopic geochemistry of fluids to predict the occurrence and quality of oil and gas and its generation source. There are also chapters on: imaging using modern electron microscope systems by focused ion beam; SEM secondary ionisation MS to identify thermal maturity effects caused by compaction, cementation and secondary infilling; isotopic dating techniques; sophisticated gas chromatographic procedures to develop ideas on bitumen generation; and sediment provenance through sediment reworking.

Application of Analytical Techniques to Petroleum Systems illustrates how the current state-of-the-art instruments give results/interpretations to address the challenges of defining the petroleum system. The examples are presented in excellent, clear, relevant figures and this volume continues the high standards of the Geological Society Special Publication series. It should be in the library of any practising geoscientist who is developing geological models in new(ish) prospects.
JOHN RAMSAY  
(1931 – 2021)  

One of the finest and most influential structural geologists of modern times

BY JOHN DEWEY

JOHN WAS born and raised in north London. He excelled in mathematics and chemistry, and developed great abilities in running, cycling, rock climbing and mountaineering, as well as a great interest in music, learning to play the cello. John came to love the natural world. He won a State Scholarship and was accepted by Imperial College London to read geology.

Mapping

John’s undergraduate mapping of the Tryfan Syncine is a masterpiece and was a harbinger of the field skills for which he would become famous. John graduated with first class honours, then completed his PhD, in two years, on the Loch Monar district, producing his second brilliant map. In Monar, John showed how sections through polyphase folds can generate very complicated patterns, and how outcrop structures may be used to determine the large-scale structures.

A short post-doctoral period was followed by two years of military service. John then returned to Imperial College London as a lecturer and developed a Masters course in structural geology, attended by many who were to become distinguished researchers, such as Mike Coward. During a sabbatical leave at the University of the Witwatersrand, John made superb detailed maps of the metasediments of the central Barberton Mountain Land and of the Chinamora Batholith and its margins.

John later moved to a Chair in Leeds in 1973, when he continued mapping the whole Glenelg region, showing the enormous extent of the pre-Moine basement and its unconformity. In 1977, John moved to a Chair at the ETH in Zurich, Switzerland where he and his wife Dorothee mapped in the Helvetic Alps, and demonstrated that most of the nappes are cylindroidal.

John’s six-inch field sheets were masterworks of the finest detail and clarity, comparable with those of C. T. Clough in the Scottish Highlands during the late 1800s. His maps and field photographs were beautiful works of art; he also painted in oils superbly. He combined this with a powerful three-dimensional ability, and a thorough mathematical and engineering approach.

John published Folding and Fracturing of Rocks in 1967, and more recently, with co-authors Richard Lisle and Martin Huber, The Techniques of Modern Structural Geology. From microscope to outcrop and region, John was able to convey much of his love and understanding of rocks to his students and colleagues.

Retirement

In retirement in the idyllic Ardeche, France, John grew olives, fruit and vegetables, composed music and poetry, and ran music schools. He continued with geology, albeit at a lesser pace, with conferences, field trips, and mapping in Glenelg.

John was a quiet, modest, undemonstrative, and thoughtful man, with an intense love of beauty in everything from rocks to music, painting, and landscapes. He was kind and ready to help anyone, always had time to discuss and explain the finer points of a structural problem, sought the opinion of others, avoided confrontation, and was non-judgemental.

John was showered with many honours, medals including the Wollaston Medal, and honorary degrees. He was appointed CBE, and elected to national academies including the Royal Society and the US National Academy of Sciences. His sixtieth birthday was celebrated by a conference in Zurich and an Alpine field trip. His 80th birthday involved a smaller Alpine field trip.

John will be remembered as a great scientist, internationalist, and human being.

The full version of this obituary appears online.
JOHN MURRAY was born in London in 1937, but evacuated to Bury during World War II, and the family subsequently moved to Worthing in 1953.

John showed an early enthusiasm for microscopy and natural science, and in 1956 went to Imperial College of Science & Technology, University of London, to read for a BSc Geology. At that time, Imperial had many strengths, not including palaeontology. However, taught by the late David Carter, John was introduced to fossil foraminifera as an undergraduate. Even more radically, John remained at Imperial with David Carter to research the ecology of living foraminifera of Christchurch Harbour, southern England. Foraminifera were valued as biostratigraphical tools, but little was known about their modern ecology for reliable palaeoecological interpretation.

Foraminifera

After a brief postdoctoral period at the Marine Laboratory, Plymouth, John was appointed to a lectureship at the University of Bristol, where he remained from 1962 to 1975. The Bristol period was very productive involving work on foraminifera from modern environments, including Abu Dhabi and the English Channel. The latter work arose from W.F. Whittard’s project mapping the floor of the English Channel, which led to publications on the Paleogene foraminifera of the Hampshire Basin, as well as living material from the Channel. The pattern of studying both living and fossil material was a characteristic of John’s career. During this period, the influential book *Distribution and Ecology of Living Benthic Foraminiferids* (1973) was published.

From 1975 until 1989, John was Professor of Geology and Head of the Department of Geology at Exeter University, until the department was closed. He then moved to the National Oceanographic Centre, Southampton (a product of the merger of Southampton University Geology with the Institute of Oceanographic Sciences) and, following retirement in 2003, continued research there as Emeritus Professor.

Global scale

John’s scientific production is impressive. He studied and synthesized information about living benthic foraminifera and their environments on a global scale ranging from marshes to the deep sea, from the tropics to the subarctic. He also sought to apply knowledge of present environments to the interpretation of the past. His second book *Ecology and Palaeoecology of Benthic Foraminifera* (1991) and his third on *Ecology and Applications of Benthic Foraminifera* (2006) remain of international importance. Other aspects of his research included studies of benthic foraminiferal population dynamics, organic matter palaeofluxes, cement mineralogy in agglutinated forms, taphonomic experiments, environmental variability vs change, the significance of rare species; all fundamental contributions to our understanding of benthic foraminiferal ecology and the implications for palaeoecological interpretations.

Service and awards

During his long career, John served on many professional bodies, was President of the Palaeontological Association and The Micropalaeontological Society, and was a Secretary of the Geological Society. Amongst many awards were the Coke Medal of the Geological Society and the inaugural Brady Medal of The Micropalaeontological Society (both 2007).

John died on 23 October 2021 in Southampton. His wife Jeanne predeceased him and he is survived by sons Richard and Rob, and four grandchildren.
OBITUARIES | CELEBRATING COLLEAGUES

GEORGE BENNISON, who died on 14 April 2020 aged 97, was a stratigrapher, palaeontologist and sedimentary petrologist who spent all his professional life as a university teacher.

Education and army service
Born in Nottingham on 11 July 1922, George lived in Chesterfield, Derbyshire until he went to Bede College, Durham University in 1940. There he met Gwen, his future wife. They were both keen rowers, and George represented Durham in other sports too.

George was called up into the army in 1942, where he worked mainly on Radar. He also played the trumpet in the Army dance band. George was demobbed in November 1945 and returned to Bede College to finish his degree, obtaining 1st Class Honours in Geology in 1948. It was during his time in the army that he married Gwen, on his 21st birthday in 1943.

After a brief appointment as an assistant lecturer at Glasgow, George moved to Aberdeen’s Geology Department, where he began his research on the relationship between the lamellibranch fauna and sedimentology in the Calciferous Sandstone of Ayrshire, for which he was awarded an MSc by Durham University in 1953. Further work on the same formation in Fife led to a PhD from the University of Aberdeen in 1960.

Publications
In 1960, George moved to the University of Birmingham Geology Department. There he taught stratigraphy and geological map interpretation, and geology to civil engineering students. In 1964, he published Introduction to Geological Structures and Maps, which was a huge success, running to multiple editions.

After George retired in 1986, Birmingham alumni Keith Moseley and then Paul Olver assisted in the revision. In the upcoming 9th edition, Prof. John Tellam will provide hydrogeological map exercises to replace some of those that were suitable for coal mining students, a change George saw as necessary due to the changing nature of the jobs market.

George’s second major contribution to education came in 1969 when he published The Geological History of the British Isles, with two chapters contributed by Alan Wright. This became a standard stratigraphy textbook for many UK universities and a reference work for the many foreign scholars who visit the areas of classic geology in the British Isles. It stands as a starting point for new research into their plate tectonic evolution.

George spent several summer vacations in the United States, visiting swamp areas similar to the conditions where coal is laid down as a sedimentary rock, visiting coal mines and undertaking consultancy work on coal reserve calculation for coal companies. He incorporated these experiences into subsequent editions of his undergraduate book of geological map exercises.

Supportive and generous
George was a member of the International Association of Mathematical Geology, and a Fellow, then Senior Fellow of the Geological Society of London. He looked forward to the arrival of Geoscientist magazine to the last. His daughter summed up his character as cheerful, encouraging, supportive and generous to everyone. This is also how his students and colleagues will remember him.

Contact
If you would like to contribute an obituary, please email the editor geoscientist@geolsoc.org.uk

Roll of Honour
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
OBITUARIES | CELEBRATING COLLEAGUES

WILLIAM GEOFFREY TOWNSON 1947 – 2020

A highly skilled oil geologist, geological communicator and artist

BY JAMES ROSE

Pictured, above: Geoff continued to contribute to the field of geology after his retirement from Shell.

IN MEMORY OF...

The Society notes with sadness the passing of:

• Aylward, Gordon*
• Baldwin, Stuart Arnold
• Burgess, Iain*
• Carr, Andrew*
• Chinner, Graham Alan*
• Floyd, Peter
• Harrison, Chris
• Hasan, Syed Manzurul
• Hide, Robert Timothy*
• Johnstone, Alan
• King, Christopher John Henry
• Knight, Roger*
• Lavers, Brian A*
• Marinos, Paul (Pavlos)
• Maurenbrecher, Pieter Michiel
• McAdam, Archibald*
• Myers, John
• Olver, Paul *
• Price, Gerald*
• Raybould, John Garth*
• Sims, Peter*
• Smith, Alexander Gordon*
• Standing, Anthony*
• Stringer, Peter
• Taylor, Christopher*
• Walker, Peter*
• Walters, Steven*
• Warden, Arthur*
• Whittaker, Alfred

(Bold, recent additions to the list; * Fellows for whom no obituarist has been commissioned)

GEORGE TOWNSON grew-up in Worthing, Sussex. He took a BSc degree in Geology at King's College, London (1965 – 68) and a DPhil at the University of Oxford, where he studied the Portland Beds of England and northern France under the supervision of Prof. Tony Hallam [1968 – 1971]. Whilst at Oxford, Geoff met Jane, a member of the secretarial staff in the Geology Department, whom he married in 1971, prior to taking up his career with Shell, in the Netherlands.

Oil geologist

Following training in the Netherlands, Geoff returned to the UK as an oil geologist working on the North Sea — indeed, he worked on the second exploration well of the Brent Oil-and-Gas Field where he cut the first cores! He was also involved in the discovery of the Cormorant and several other oilfields in the Northern and Central North Sea.

In 1976, appointment as Exploration Geologist at Shell Brunei took Geoff to Borneo, where he carried out onshore fieldwork and offshore interpretation. Geoff’s next move, in 1980, was to Perth, Western Australia, where he was Chief Geologist at Shell Australia and his tenure contributed to discoveries in the Bass Strait.

From 1985 onwards, he moved into management and was based in The Hague and London as Shell International Area Geologist, UK Business Development Manager and Business Development Coordinator Oil, as part of the International Senior Management team.

Charmouth

After retiring from Shell, Geoff and Jane moved to Charmouth, Dorset on the Jurassic Coast, and back to the territory of Geoff’s DPhil research. In Charmouth, Geoff became something of an institution. Firstly, he contributed as a volunteer to the Geological Society’s R.H. Worth award-winning Charmouth Heritage Coast Centre geological charity. He began a series of courses for the local University of the Third Age (U3A) that explained geological concepts through the regional geology. These courses proved to be outstandingly successful and indeed many joined the Heritage Coast U3A just to be able to take Geoff’s course. Reputation has it that they were far from a ‘light-touch’, but very enjoyable.

In Charmouth, Geoff also developed his artistic skills, exhibiting his paintings at local galleries and contributing to local social events. Using his artistic skills, he also contributed a Drawing Tutor course at the U3A and within the community. His paintings are of geological topics and recognition of his skill in depicting landslides is acknowledged by Professor Dave Petley in his Landslide Blog as an ‘ability to capture the drama of the landscape’.

Publishing

Over his career, Geoff published a number of papers on the topic of this DPhil research and his research findings whilst in the oil industry. His final publication was in Geoscientist in 2017. Entitled ‘On seeing the most rocks’, his article reviewed the significance of the Geological Society’s field trips funded by the oil industry.

Geoff Townson died of an untreatable form of cancer and will be greatly missed by his wife Jane, sons and their families, as well as the community to which he contributed so much over his career and retirement.
Earthworks: engineering geology in design and construction practice
Virtual Training

This course is for practicing ground and materials engineers who want to learn more about current earthworks practice, explore the principles and application of design, and understand the demands and opportunities during construction. The course covers new build earthworks, in principal rail, road, and developments, but not existing earthworks and their asset management.

**Course modules**

**Module 1  Introduction and Design Fundamentals | 8 November**
- Earthworks types, descriptions, and purpose
- Data management for earthworks in a UK regional geological setting
- Earthworks planning process
- CDM

**Module 2  Design Implementation | 15 November**
- Design principles
- Designing for construction and maximising use of materials
- Earthworks contract documents, standards, guidance and advice
- Understanding material classes and typical performance

**Module 3  Strategy and Construction Controls | 22 November**
- Establishing an earthworks / materials strategy
- Managing variability of materials, control and change during construction
- Understanding test methods and controls for mitigating risk

**Module 4  Planning and Managing Risks and Opportunities | 29 November**
- Case history on Planning earthworks support from:
  - Soil improvement and stabilisation
  - Environmental controls and Climate Change

The course will put an emphasis on team working between designer and constructor. This approach is particularly necessary in earthworks linear projects where the geology can be highly variable.

**Registration**
We can offer bespoke discounts on group registrations of 5 or more.

There are a limited number of student places at a special rate.

**Further Information**
For further information about the conference please contact:
W1J 0BG
T: 0207 434 9944
E: training@geolsoc.org.uk
W: www.geolsoc.org.uk/11-earthworks

Join the conversation on Twitter: #GSLTraining
A YEAR ago, my letter focused on the Society’s resilience and laying new foundations for its future. The 2020 strategic options project underpinned those foundations and drove the impactful 2021 Energy Transition seminar series and briefing on Geoscience and the Hydrogen Economy. It also gave context for the spectacular Spacescapes exhibition in the Burlington House Courtyard, which is now exhibited at the Harwell Science and Innovation campus. The new Geoscientist magazine format is bold and supported by an interesting new website, geoscientist.online. And the Society’s membership count has remained stable for the past three years. In summary, 2021 has been a busy and successful year of delivery for the Society and the executive team. Which brings me to the Burlington House lease.

In August 2020, growing financial pressure and falling income led Council to renew its efforts to secure the Geological Society’s future. Council decided to pursue two directions. Firstly, together with the Royal Astronomical Society, Linnean Society, and Society of Antiquaries, a lobbying effort was undertaken to persuade the UK Government to support our continued presence in Burlington House. Secondly, a working group was established to assess the needs of the Society in the 21st century, and develop options for the Society’s relocation from, or restructuring within, Burlington House.

The lobbying achieved many successes. Fellows wrote to their MPs, and MP Tim Laughton raised a Westminster Hall debate on 8 June 2021. Over 120 Conservative, Labour and Plaid Cymru MPs supported us, and several spoke about the Courtyard Societies’ collective value and encouraged Government to seek a mutually beneficial arrangement for our continued occupation of Burlington House. In addition, a letter from Sir David Attenborough to the Prime Minister and an interview with broadcaster and astronomer Professor Brian Cox on the BBC Today programme argued our case. Despite these and other efforts, no fundamental progress was made. This has left the Courtyard Societies with no sense that a solution with the present Government was possible.

Meanwhile, the working group was in action, led by past-President David Shilston and comprising a diverse group of Fellows. After exploring several options thoroughly, the working group presented the results of its work to Council in February of this year. Their recommended option to Council in the event of a relocation is to move to premises within central London. They also recommended reducing the amount of occupied space and creating a community home for the Society with modern IT capability able to embrace the world. Council unanimously supported these recommendations. The effort and time required to complete such a move should not be underestimated. However, such a move would provide an opportunity to equip the Society technologically and financially for a sustained and aspirational future.

Finally, I would like to acknowledge the success of the Society’s engagement on the world stage of the 26th UN Climate Change Conference of the Parties, held in Glasgow. The Society attended with observer status, led by the Energy Transition Theme Leader. COP itself was a mixed success, with business taking the event seriously for the first time, but serious divisions emerged as India, China and other coal-dependent nations, rejected the “phase out” of coal-fired power, demanding a more open-ended “phasing down” of coal usage. This schism heralded a much bigger uncertainty that is now upon us as I write. The tragic and saddening invasion of the sovereign state of Ukraine is a humanitarian disaster on an unfathomable scale. The world’s energy security is a casualty of this event, bringing even greater uncertainty to the velocity and outcome of an energy transition.

Within this context, the Geological Society is in good health and I wish my successor, Ruth Allington, much success as she takes on what will be another interesting two years. Finally, I would like to thank the Society’s Council, Executive Secretary, staff and membership for all the support, correspondence and calls I have received while in this role, and for the privilege of serving the Society.

DR MICHAEL DALY
Council is the trustee body of the Society. The following named persons were trustees of the charity on the date this report was approved:

**Honorary Officers**
- **President:** Dr Michael Daly
- **Vice President:** Miss Jessica Smith
- **Secretaries:** Prof James Griffiths, Dr Joel Gill, Prof Robin Strachan, Prof James Griffiths, Dr Joel Gill, Prof Robin Strachan, Dr Alexander Whittaker
- **Treasurer:** Dr Keith Myers

**Other members of Council**
- Ms Joanna Alexander, Prof Mark Allen, Ruth Allington (President Designate), Dr Neil Frewin, Dr Jennie Gilbert, Dr Kathryn Goodenough, Mr Andrew Moore, Dr Amanda Owen, Dr John Perry, Mrs Sarah Scott, Ms Gemma Sherwood, Miss Lucy Thomas and Mrs Lucy Williams.

The following named persons also served on Council as trustees during the financial year to which this report relates but stepped down prior to the date this report was approved:
- Mr Thomas Backhouse, Mr John Booth, Mr Andrew Bloodworth, Mr Graham Goffey, Prof Chris King, Prof Bryne Ngwenya, Dr Helen Smyth

CONTINUED DISRUPTION caused by the Covid-19 pandemic delayed a return to normal, in-person operations in early 2021. The Society continued to embrace the new opportunities offered by virtual and hybrid operations, and with great success. Public lectures continued online, with an added series on the geology of the solar system as part of our 2021 Year of Space programme. The online format enabled record attendances, with over 2,500 live viewers and 29,000 more watching on demand via our YouTube channel – a 15-fold increase on viewership in previous years. The Society also hosted its first hybrid meetings in October, and plans to provide a hybrid approach for all meetings going forward.

Virtual connectivity also enabled the launch of a new series of Continuing Professional Development (CPD) courses, marking a step change in the services we provide to support the Fellowship. We will continue to expand the range of courses on offer in the coming years to help support not only professional development, but also career changes.

The Society’s new Fellowship categories structure, rolled out in late 2021, is designed to be more inclusive and equitable. The previous, age-based fee structure has been replaced by a simpler career-stage structure and has been welcomed across the Fellowship. I am very pleased to report that total Fellowship numbers stabilised, with the declines of recent years arrested.

2021 was another very successful year for publishing, with the new journal *Earth Science, Systems and Society* launched in January. The superb, new format, quarterly *Geoscientist* magazine, with strengthened science content, has been extremely well received by the readership.

The first major Geological Society exhibition staged in the Burlington House Courtyard was greeted with much acclaim. Thanks to generous sponsorship, the Spacescapes exhibition enabled several thousand visitors to explore the geology of our solar system through a series of stunning images. The eight plinths towered over visitors from August to October, and played host to several school groups.

The year saw significant progress with the implementation of the recommendations of the 2020 strategic options review. Leaders were appointed for new science themes including the Energy Transition, Geohazards, Geoengineering & Georesilience, and Climate & Ecology. A successful series of Energy Transition workshops was held in the spring and summer, and a conference on Climate Change in the Geological Record in May. The Society’s purpose, mission, vision and values statements were overhauled and will be rolled out to the Fellowship in 2022.

This is my last annual report contribution as I will retire towards the end of 2022. It has been a great privilege to serve the Society as Executive Secretary, and I pay tribute to all those who give their own time so generously to improve the Society. Above all, I offer my sincere thanks to the Society’s staff, who work tirelessly and with great dedication in pursuit of our vision of being ‘An inclusive and thriving Earth science community, advancing knowledge, addressing global challenges, and inspiring future generations’.

**Dr Richard Hughes**
LAST YEAR marked a limited return to Burlington House, but nevertheless saw a wealth of activities designed to support members in their career development, build a more diverse and inclusive geoscience community, and explore the important role Earth science will play in securing a more sustainable future. It was also a year of firsts for the Society, including the first exhibition in the Burlington House Courtyard and the Society’s first attendance at the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow as an observer organisation.

Supporting professional development
In January, the Society launched a new series of events dedicated to supporting continuing professional development (CPD). The first course consisted of 14 sessions exploring the most common geohazards found in the UK, and was attended by over 100 professionals and students. Subsequent courses covered the use of remote sensing and advances in Earthworks. The Society’s new Training Course Committee is working to broaden the range of events on offer, and has already added courses in mining and raw materials for 2022. These courses count towards CPD requirements for Chartered Geologists, of which there are currently 2,749 and Chartered Scientists, who number 255.

Remote Library services continued throughout the year, even during periods of restrictive measures. The use of online resources such as e-books and online journal access through Open Athens remained strong as the Library reopened safely for visitors in late spring. The number of appointments available for visitors grew steadily throughout the year.

The Society’s Publishing House continued to work to disseminate research findings from industry and academia alike. To support a sustainable transition towards open access, the Society is offering transformative Read and Publish agreements that combine access to...
Several thousand visitors viewed the exhibition during the seven weeks it was in the Courtyard.

The books programme again produced a number of important volumes for both specialist and broad-interest audiences in 2021. Highlights include *A Guide to Forensic Geology and Geoethics: Status and Future Perspectives*, both collaborations with IUGS, and a Special Publication entitled *Celebrating 100 Years of Female Fellowship of the Geological Society*.

The review of the degree accreditation scheme concluded at the end of the year, with a final period of consultation in early 2022. The revised scheme offers a streamlined process for departments applying for initial accreditation, and a more straightforward process for re-accreditation. The scheme focuses on ensuring that students are able to attain the behavioural and learning objectives required for entering the workforce or pursuing further study, and is aligned with the revised QAA Subject Benchmark Statement for Earth science, environmental science and environmental studies (ES³).

The requirements also recognise the importance of inclusive and accessible field-based teaching and independent study, and require students to have a sufficient amount of fieldwork to develop competence in field techniques and the ability to operate as a field scientist.

**Year of Space**

On 18 August, eight pillars were erected in the Burlington House Courtyard. The two tallest pillars reached two metres, and all displayed scenes from our solar system. This exhibit explored the many ways that mountains, lakes, geysers, impact craters and other features can form, whether on rocky planets or icy moons. Several thousand visitors viewed the exhibition during the seven weeks it remained in the Courtyard, and nearly a thousand more accessed a virtual tour. The exhibition was designed with pro bono support from Rogers Stirk Harbour and Partners and sponsored by Bluewater Energy. Additional funding was provided by UK Space Agency, SRK Consulting, Imperial College London, the Michael Davies Charitable Settlement, the Open University and Virgin Galactic.

The funding also allowed the Society to run a programme of outreach aimed at visitors and the wider community. During weekends and school holidays, a team of staff and volunteers crewed an outreach table that introduced young people to the concept of geology, and allowed them to interact with rock samples, including the Society’s own meteorite. Members of the scientific team that consulted on the exhibition, including Professor Sanjeev Gupta, also offered guided tours of the installation, including insights into the missions that helped to chart the geology of our planetary neighbours.

To allow those who couldn’t make it to London to engage with the exhibition, the Society developed a virtual tour with supporting information. In addition, the education team partnered with The Felix Project to deliver educational materials to students through local London food banks. And over 22,000 people from across the UK and beyond watched a series of ten lectures on the geology of the inner and outer solar system, with a slight preview of exoplanets as well. Planetary science also featured heavily in the winter issue of the new-look *Geoscientist* magazine, which looked at tectonics on Pluto and the latest findings on Mars and other terrestrial bodies.

**Strategic science themes**

The Society’s receipt of observer status and attendance at COP26 was one highlight of a series of events and resources aimed at demonstrating the importance of the Earth sciences in meeting net zero targets. The Society released a briefing note on *Geoscience and the Hydrogen Economy* in April, which was subsequently translated into French and Spanish in collaboration with the European Federation of Geologists. The hydrogen economy was also the subject of a joint event organised between the Society, European Federation of Geologists and the University of Glasgow, and held during the second week of COP26.
The Society hosted three webinars in the spring and summer looking at the range of geoscience contributions to decarbonisation, as well as an in-person event in conjunction with the Critical Minerals Association looking specifically at the rapidly growing need for key minerals.

A virtual conference based on the Society’s statement on Climate Change in the Geological Record had over 200 attendees, and featured expert keynotes, early career talks, and flash talks, followed by a breakout poster session over Zoom. The conference was convened by Professor Dan Lunt, who later took on the role of theme leader for the Climate and Ecology theme.

History of geoscience
The Library continued to explore both the history of the Society and the history of the science, including a popular programme of activities on the work and legacy of Mary Anning. An online exhibition featured a retrospective of her most notable discoveries, as well as an exploration of the impacts her work had on geologists active at the time. The Library also hosted a virtual event on Mary Anning, featuring Tom Sharpe FGS, author of *The Fossil Woman: A Life of Mary Anning*.

Ongoing work in the collections uncovered a number of notable items, including a life-size lithograph of an ichthyosaur skull found in Banz, Germany circa 1843 by Carl Theodori (1788 – 1857). The lithograph came from *Beschreibung des kolossalen Ichthyosaurus trigonodon in der Lokal Petrefakten-Sammlung zu Banz* (1854) by Carl Theodori, a part of the Society’s collection of rare books.

And the Society was pleased to serve as a partner on three bids to the Hidden Histories joint funding call from the Natural Environment Research Council and the Arts and Humanities Research Council. Two of these proposals were awarded funding, and the Society will be working to support historical research through its archives and to disseminate the findings to the broader geoscience community.
2021 WAS another challenging year for the Society, with the Covid-19 pandemic continuing to impact activity. Income for the year was £4.87m (2020: £5.30m) and expenditure was £4.78m* (2020: £5.51m). The impact of the cost savings made in 2020 meant that the Society was able to deliver a small operating surplus in 2021 of £0.09m (2020: -£0.21m) despite lower revenues. The Society’s investment portfolio and foreign exchange gains of £0.71m meant that overall net income for the year taken to reserves was £0.33m after the IT impairment charge (see discussion below).

Fellowship income declined only slightly to £1.9m (2020: £2.0m) and was significantly ahead of budget with proactive chasing of Fellowship renewals delivering positive results. Fellowship revenues have proved more resilient than expected, having peaked at £2.1m in 2018/19. The number of Fellows at end 2021 was 11,620 (2020: 11,691). With the revised Fellowship categories implemented in 2021, along with the compelling new strategy for the Society, there is every hope that Fellowship income will continue to be stable with the potential for modest growth into the future.

The Publishing House income was £2.45m (2020: £2.75m) with 2021 the first year that Covid pandemic-related library budget cuts in academic institutions were felt. This led to some churn in Lyell Collection subscription renewals and quickened the decline in individual journal subscriptions. Costs at the Publishing House fell broadly in line with income, resulting in a better-than-anticipated outcome. Significant progress was made in the negotiation of transformative read and publish agreements in key markets through 2021, which migrate subscription revenue to publishing revenue. The transition to open access has quickened in Europe and these are important steps to ensure future sustainability in an increasingly open landscape.

Income from the events programme increased to £0.30m (2020: £0.16) as a limited programme of online and hybrid events recommenced. The delivery of four new CPD courses demonstrated the potential of CPD training as an income growth area for the Society. A business plan is being developed to grow this income stream. Expenditure of the Science and Education programme was £0.99m, excluding an exceptional IT impairment charge of £0.5m (2020: £1.08m). Science and education spending was supplemented by sponsorship income, as well as pro bono support. Securing further sponsorship income will be a priority for 2022 and onwards.

In 2021, the Society commenced three major IT projects as part of its new digital strategy – a new CRM system to improve efficiency and deliver better Fellowship services, a new lower cost and more flexible online publishing platform for the Publishing House, and a new website for the Society. Capital investment, driven by the IT projects, is planned to increase from £0.25m in 2021 to £0.6m in 2022. After accepting that the current CRM system was not sufficiently suitable to meet future requirements, Council sanctioned a replacement system. Consequently, a non-cash impairment charge of £0.5m will be taken to write off the booked cost of the current CRM system on the balance sheet. Lessons have been learnt and steps have been taken to strengthen IT governance.

There is every hope that Fellowship income will continue to be stable with potential for modest growth in the future.

Looking at longer-term trends, the Society’s annual income in 2021 was £1.1 million (17%) lower that its peak in 2018. Forty-three per cent of this fall has been due to lower publishing income and 19% due to reduced Fellowship income. The Society has responded by cutting annual operating expenditure, which has fallen by £1.2 million (21%) since 2018. Whilst the Society has in most years been able to deliver a small operating surplus, £670k of capital spending means an overall draw on cash of -£0.6 million in last three years. Meanwhile, growth in the investment portfolio value means financial assets increased by £1.3 million since end-2018 to £11.2 million at end-2021. So, the Society has been shrinking in terms of charitable income and expenditure, while at the same time growing in terms of its financial assets. Looking forward, the Society continues to face a challenge
of declining income and it will have no choice but to keep expenditure in check if it is to maintain a cash-neutral budget policy. It does, however, have the cushion of considerable financial reserves and is financially robust. The Finance and Planning Committee and Council have reviewed the Society’s free reserves policy in the light of the potential need to fund a Burlington House move and also to invest in the Society’s charitable activities to sustain future charitable income flows.

Despite global uncertainty, the Society is financially robust, and the 2022 budget is targeting a modest increase in income

The standard measure used by charities to measure financial flexibility is in ‘free reserves’, defined as the proportion of its unrestricted funds that a charity is free to spend on it charitable activities. At the end of 2021, the Society’s free reserves stood at £5.53m (2020: £4.39m) with an additional £1.62m held in a designated Burlington House Fund. So, the Society had £7.15m of its reserves that it could freely spend on any of its charitable activities, including a move from Burlington House. All charities are, however, expected to hold sufficient reserves to provide for unforeseen loss of income or unforeseen expenditure. A risked-based method has been used to calculate an appropriate free-reserves target to cover both an unforeseen operational deficit and capital commitments to the end of 2024. For 2022, this is calculated at £2.57m, which leaves £4.59m of reserves at end 2021 free to fund both future Burlington House moving costs and discretionary investment. The free reserves target will now be set annually using a risked-based approach.

The Society has decided to release funds from reserves (initially £0.25m per year) into a Futures Fund primarily focused on investing in membership services and activity that will deliver future income. In addition, Council has decided that £0.5m will be released annually over a three-year period from the £2.2m Fermor Endowment Fund to fund minerals research critical to the energy transition. The Fermor Fund does not count towards free reserves as it is an endowment. These are highly positive decisions that will allow the Society to both invest in its future and increase its impact in academic research.

Despite current global uncertainty, the Society is financially robust, and the 2022 budget is targeting a modest increase in income to around £5m and a small operational surplus. I would like to thank my predecessor Graham Goffey and all the FPC, Audit and Investment committee members for their sterling efforts.

**DR KEITH MYERS**

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**Figure 1:** The Society’s income and expenditure for 2020 and 2021

**Figure 2:** The Society’s unrestricted, restricted and endowment funds for 2020 and 2021 in £000s
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Tell us about your work
I work in sustainable geoscience, which integrates the unique skills of geoscientists in a way that contributes to positive sustainable development. Geoscientists are well placed to identify opportunities to alleviate issues such as global poverty and inequality.

What drew you to geoscience?
I studied geology because of a love for nature, but brought a background in Modern World History, a curiosity for human affairs and a desire to play a role in civic life. Studying geoscience helped me gain a sense of the beauty and yet vulnerability of life on Earth, and made me think beyond my own individual human experience. It also gave me a more comprehensive understanding of the impacts of climate change.

What are you currently working on?
Whilst studying and working in petroleum geoscience and engineering geology, I gained insights into the links between social and economic development, and the management of natural resources. However, all the projects I worked on were based in developed communities. Rather than providing geotechnical information for say, a luxurious basement, I wanted to use my expertise to improve the lives of those in more vulnerable situations. So, I set up the Area Code Foundation – a Registered Scottish Charitable Incorporated Organisation. My role is to integrate geological knowledge into our projects to help drive social and economic growth, and ultimately alleviate poverty in developing communities.

Tell us about the Area Code Foundation
Learning about carbon capture and storage technologies challenged me to think about the ethics of aiming for net-zero carbon emissions for developing communities. Senegal, for example, relies on fossil fuels for economic and social growth, and it may not be practical or ethical for Senegal to aim for net zero in the same timeframe as developed nations. The Area Code Foundation aims to support developing communities through the energy transition.

Currently, we are working in Bambilor, a village near Dakar, Senegal. Their biggest issue is climate change-induced drought. The Sahara Desert is expanding at an unprecedented rate, threatening the security of people in Bambilor, whose livelihoods depend on agriculture. We take a community-led approach, for example, helping to connect community leaders with geophysicists who can carry out groundwater surveys, or with local university geoscience departments that can supply data on the regional geology.

Last year, we began regeneration of a local school, Gorom 3, installing electricity and toilets, and creating a garden. Many people do not appreciate how geology underpins much of what they rely on in their everyday lives or for their country’s economic development. We’re helping to build awareness by introducing a geology course to the curriculum at Gorom 3.

Our long-term vision is to connect with more developing communities. For example, sea-level rise and coastal erosion in Dakar threatens nearby homes, and we aim to provide geotechnical advice that can help create more resilient infrastructure.

What advice would you give to someone hoping to work in your field?
Philanthropic work requires cross-cultural awareness and communication skills that are rarely taught in geoscientific courses. Collaboration with a range of industry professionals is key. Geoscientists are vital to achieving the UN’s Sustainable Development Goals, and it is important that we clearly express our role and value for reaching these targets.
NEW TITLE ALERT
Large Igneous Provinces and their Plumbing Systems

Edited by
R. K. Srivastava, R. E. Ernst, K. L. Buchan, M. De Kock

Identification of large-volume, short-duration mafic magmatic events of intraplate affinity in both continental and oceanic settings on the Earth and other planets provides invaluable clues for understanding several vital geological issues of current concern. Of particular importance is understanding the assembly and dispersal of supercontinents through Earth's history, dramatic climate change events including mass extinctions, and processes that have produced a wide range of large igneous province (LIP)-related resources, such as Ni–Cu–PGE, Au, U, base metals and petroleum. This volume comprises 21 contributions on the latest developments and new information on LIPS and their plumbing systems and presents methodical studies on different components of LIP plumbing systems. These articles are especially helpful in understanding continental break-up events, regional domal uplift and a variety of metallogenic systems, as well as the temporal and spatial distribution of LIPS, their origin and their likely links to mantle plumes/superplumes.

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