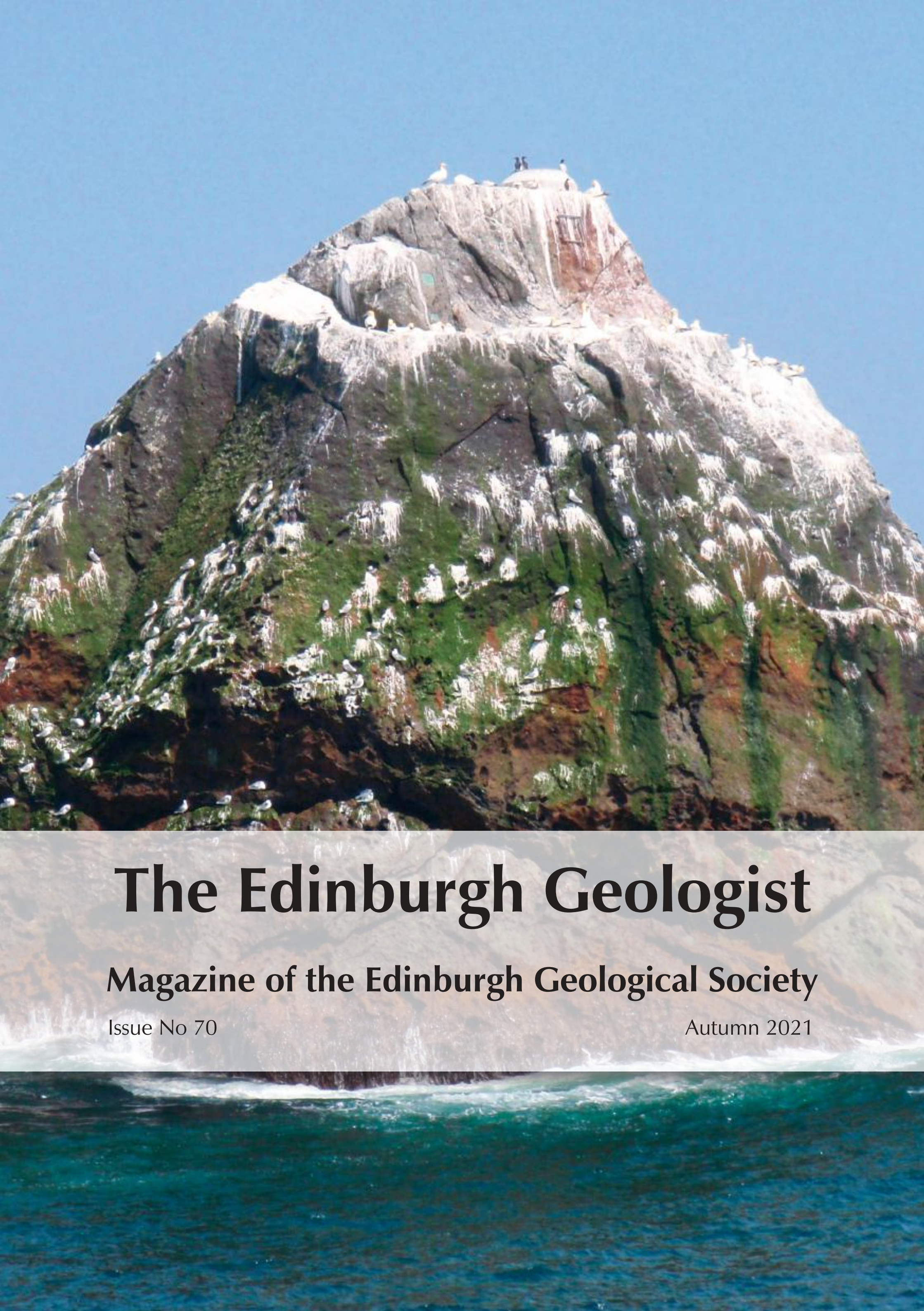

The Edinburgh Geologist

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Rockall Island. Photograph courtesy of Andy Strangeway (www.island-man.co.uk)

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The Edinburgh Geological Society was founded in 1834 with the twin aims of stimulating public interest in geology and advancing geological knowledge. We organise a programme of lectures and excursions and also publish leaflets and excursion guides. For more information about the Society and membership, please visit www.edinburghgeolsoc.org.

Festival Time

By Robert Gatliff

This edition of EG is the last before COP26 and includes a mix of the old (Scotland's first climate scientist) and the new (Tom Wager & Ryan Pereira) with articles on research related to sustainable development and global climate change at the Lyell Centre. Geology teaching and research are changing rapidly in response to the demands of funding agencies and students who want courses relevant to our low carbon future.

Despite the virus, EGS has had a full programme of on-line lectures and a mix of on-line and real field trips with limits on numbers. The 2021/22 lecture programme may also be on-line, but I am optimistic that we can go ahead with a live Public Lecture at Dynamic Earth and the GA/EGS conference at the Surgeon's Hall in October. There will be opportunities to attend a reception on the 15th October at the Playfair Library the conference at the Surgeon's Hall and festival dinner on the 16th October, and a field trip on the Sunday morning.

The conference will mark the end of the second Scottish Geology Festival, put together by the Scottish Geology Trust, with volunteer support from across the country. Angus Miller is the Festival Director, and the programme includes more than 100 in-person and online events hosted by organisations across the country. Do try and attend some of the events—details are on www.scottishgeologytrust.org

EGS, with support from a team of post-graduates, put on a series of discussion walks as part of the Edinburgh Science Festival. These were based on how Edinburgh may adapt to climate change and the move towards net zero. There were some excellent discussions, but surprisingly few EGS members attended. Perhaps it is time for some feedback from members about our future activities. Do please let us know—you can email the editor

Rockall: The tip of a Microcontinent

By Dick Merriman—Willoughby on the Wolds, Leicestershire

Since records began in 1811 fewer than 140 people have landed on Rockall, the tiny Atlantic island best known for offshore weather forecasts. It is now 50 years since the first of two expeditions to Rockall began to throw light on its geological history and significance (Harrison, 1975). Landing is a step onto a piece of the cratonic jigsaw puzzle that was created when the northeast Atlantic Ocean was formed. This lone rock, just over 70 feet high, is the only subaerial part of a submerged microcontinent, the Rockall Plateau, at least the size of Ireland. It once formed part of a vast region of ancient crust extending from Russia to North America. But more than 100 million years ago a massive rift in the earth's crust spread northwards from the south Atlantic, splitting this ancient craton into Europe, Greenland and North America. Some smaller regions of the fragmented craton eventually sank beneath the advancing ocean.

In 1971, I was one of the first two geologists, both from the British Geological Survey (then the Institute of Geological Sciences), to be landed by helicopter on Rockall (Figure 1). We were part of an MOD-supported expedition that included a party of Royal Engineers, Royal Navy helicopters and Royal Marine climbing experts, who were planning to attach a flashing light beacon to the rock. With fellow geologist Dr Jan Hawkes, I was in the first landing party to make a reconnaissance of Hall's Ledge on 9th June. Over the next 6 or 7 days, while Jan and I made a detailed map and sampled the granite, a team of Royal Engineers erected a scaffold on Hall's Ledge. They used this to drill a series of horizontal holes through the top of the rock. On the final day of the expedition these holes were packed with blasting powder and Rockall's tip, the top 5ft of the rock, was neatly blown off, keeling over into the waiting waters of the Atlantic. The almost flat surface produced by the blast was used to attach a light beacon in June 1972.

Apart from Rockall and nearby Helen's Reef, little is known about the rocks that make up Rockall Plateau. A few dredged boulders and scattered drill-core samples suggest it comprises some very

old Lewisian crust, similar to the rocks found in the Outer Hebrides. Younger Tertiary sedimentary rocks are present in the Hatton Basin on the west side of the microcontinent. The granitic composition of Rockall has been known from samples first collected over 200 years ago by Lieutenant Basil Hall RN. Analysis of samples we collected confirmed that Rockall is an unusual granite containing the minerals acmite, aegirine and riebeckite. After completing a petrological analysis of samples collected from the HMS *Vidal* landings in 1955, Sabine (1960) suggested that the granite contains a new mineral species. We subsequently isolated this mineral and were able to confirm it is a new mineral called bazirite, a barium-zirconium-silicate, found only in the Rockall granite. (Young et al., 1978).

Age-dating of the samples we collected show that the granite was emplaced 53 million years ago. The island is almost certainly part of a much larger volcanic complex, perhaps in size and extent resembling the volcanic complex of St Kilda, emplaced some 55 million years ago (Harding et al, 1984). These volcanoes and others in western Scotland and northern Ireland, are all part of a Tertiary volcanic province that has long been associated with the opening of the Atlantic Ocean. However, some other rocks in reefs close to Rockall suggest that the splitting of the crust that allowed the Atlantic to form began much earlier.

Helen's Reef lies about 3.3 km to the east of Rockall, and is named after the brigantine *Helen* that foundered on the reef in 1824 with the loss of 16 lives. In 1972 divers recovered basaltic rock samples from the reef that are completely different from those found on Rockall. The age dates obtained from these rocks are in the range 80–100 million years old, much older than Rockall.

These dates suggest that the Rockall Plateau began to separate from NW Europe in the mid-or late-Cretaceous. Perhaps dinosaurs once roamed freely over the microcontinent before it was submerged by the rising waters of the Atlantic Ocean. It is an interesting thought for the next time we listen to an offshore weather forecast.

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Editor's comments: I was lucky enough to be a geologist on a more recent marine drilling expedition in 1999 when we did indeed core Cretaceous sediments on the western side of the Rockall microcontinent. One issue is the nature of the crust beneath the Rockall Trough which separates Rockall from Ireland and Great Britain. David Smythe suggested a Permian age (a time of few magnetic reversals) for the opening of the Rockall Trough on the basis that there are no magnetic anomaly stripes in the Trough. Irish researchers collected geophysical data that they interpret to show a thinned continental crust beneath the Trough. Dating of Anton Dohrn and Rosemary Bank, two very large seamounts in the Trough indicate a Late Cretaceous age of extension and volcanism (see Hitchen, Johnson & Gatliff (eds, 2013 Geology of the Rockall Basin and adjacent areas, BGS RR 12/03). The politics of Rockall Bank remain complicated with the UK, Faroes and Ireland having competing claims lodged with the UN

James Croll — Joiner. Janitor. Genius

By Mike Robinson, Chief Executive, Royal Scottish Geographical Society

James Croll is one of those characters who has been all but forgotten in Scotland and is virtually unheard of in his home town of Perth, and yet made a fundamental contribution to our current day understanding of science and the ice ages. In this year of the UN Climate COP26 in Glasgow, as the world's attention is on Scotland, this is a great opportunity to raise the profile of Croll as one of the world's first climate scientists.

The James Croll Medal. The highest honour awarded by the Quaternary Research Association (QRA)

His theories in themselves might merit greater attention, but they are all the more remarkable in light of his personal story. How did a man of such modest birth, who was plagued throughout his life with ill health, and who left school after only 3 years, barely able to read and write, become one of the leading scientific thinkers of his day?

James Croll was born 200 years ago, on January 2nd in 1821 to David Croil, a stonemason and crofter, and Janet Ellis, formerly of Elgin, in the crofting hamlet of Little Whitefield, about five miles north of Perth. When he was 3 years old the family croft was cleared by the landowner Lord Willoughby. Some families were encouraged to relocate to Burrel Town, a mile or so east, and others were offered an area of derelict bog-land a mile or so west, in some sort of recompense for being displaced. This latter area became the village of Wolfhill and here James' father David managed to clear between 4 and 5 acres and build their own house. Having previously farmed an area of closer to 20 acres, as Croil's family had for at least the previous 200 years, it was not possible to feed the family from such a small land-holding, so James' father had to revert to his trade as a stonemason and travel regularly away from home (most of the villagers around this time were stonemasons or handloom weavers according to the census). It therefore fell to James to farm the land.

James was afflicted with a pain in his fontanelle which would have required him to wear a hat in class to keep his head from hurting. This was enough to put him off attending school, so up to the age of 8 he was schooled in part by his parents, occasionally by a visiting school teacher, but in main by his elder brother Alexander. Unfortunately his brother, only two years his elder, died at the age of ten, and James was forced to attend school himself from that point onwards. His parents took the death of their eldest son very badly, and had already lost James' younger brother William two years earlier, at only a few months of age. Only his brother David, one year his junior, who suffered from a hunched back, also survived childhood.

James attended school in Guildtown from the age of 9, but found the teacher to be too tyrannical, and did not fare well. When he finally left, aged 13, to help manage the croft, by his own admission he was below the average student. But it was around this time that he stumbled upon the monthly 'Penny Magazine' of the Society for the Diffusion of Useful Knowledge in a shop in Perth and suddenly his intellect was unleashed.

Croll read avidly from this moment forth, and by his late teens felt he had a pretty good grasp of most of the main disciplines in science. *"I remember well that, before I could make headway in physical astronomy,... I had to go back and study the laws of motion and fundamental principles of mechanics. In like manner I studied pneumatics, hydrostatics, light, heat, electricity and magnetism. I obtained assistance from no one. In fact there were none of my acquaintances who knew anything whatever about these subjects."* Ironically geology was one of the few subjects he struggled to find much enthusiasm for.

At the age of 17 James had to go and get a job, and he moved the two miles to Collace, to learn to be a millwright, ultimately journeying around much of the North east of Scotland. After almost six years of what were fairly poor living conditions on the road, he finally tired of the job and was relieved to move back to Wolfhill, where he took himself back to school to learn algebra. As a 22 year old in a class of children he was a novelty, albeit not unique in classrooms of that period, but it is again evidence of his desire to learn.

It was at this time when Croll started as a millwright that a leading Swiss scientist, Agassiz rocked the Swiss Geological community by first reporting his theory of glaciation at a conference in Neuchatel. Up until this time most scientists believed that massive rocks, which had travelled large distances from their source (erratic rocks), had been washed there in the biblical floods that Noah survived, either directly or transported in ice bergs that floated on the flood waters. The idea that glaciers covered larger areas and had deposited rocks there but had now retreated was controversial and widely disputed, but it was Agassiz in 1837 who first formally presented this theory and explained the theory of an ice age being responsible.

Closer to home this was the period of 'disruption' in the Church of Scotland and Croll, as a deeply religious man, worked as a joiner to help build his friend, the Reverend Andrew Bonar's new Kirk at Kinrossie (now the village hall). On completion Croll moved to Glasgow and then Paisley where he continued to work as a joiner for 3 years, until 1846, when his elbow became ossified and he was forced once again to return to Wolfhill.

It was in this year that he made a life long friend through a moment of fate — wandering into Perth to seek work, he was handed a leaflet at Bridgend advertising a new tea and coffee merchants in the High Street. Croll took this as a 'sign', so he walked to the shop and befriended the owner, David Irons. He began working for Irons in Perth for some months, before Irons set him up in business in Elgin with his own shop. (It was David Irons' son, James, who later wrote and compiled Croll's autobiographical sketch and memoirs).

Whilst in Elgin he met and married Isabella MacDonald from Forres who helped him with the shop, but within 3 years, he became ill and unable to work and was forced to sell it and move back to Perth once again. Staunch teetotallers, he and his wife established a Temperance Hotel in the Well Meadow in Blairgowrie, even building their own furniture to save money, but it was perhaps predictably unsuccessful and he once again had to sell up and try his hand at something else. He then worked as an insurance salesman in Dundee, Edinburgh and then Leicester, but, as a retiring and modest man, was never comfortable in the role, despite his seeming success. This time it was his wife who became seriously ill, and they were forced to move back to Glasgow where her sisters could help with care.

Croll took some time at this stage to produce his first book, again reflecting his religious interest, *"The Philosophy of Theism"*, and for the next year and a half, tried his hand as a journalist on a temperance newspaper in Glasgow.

Then finally, at the age of 38, in an age when the average life span was barely mid forties, he finally got the lucky break he needed. He got a job as a janitor at the Anderson College in Glasgow.

Paid £1 a week (equivalent of £3,500 salary today), plus taxes, coal and a house, it was barely enough to sustain him, his wife, and his brother David, who was now forced to live with them after the death of his mother. But James Croll was the happiest in his work that he had ever been. Often his brother would come to work with him and whilst David did the chores, James would sit and read his way through the books in the extensive library, for which he now had the keys.

Fairly quickly he began to develop more and more scientific papers. The theory proposed by Agassiz that glaciers were once much more advanced and their advance and retreat had shaped the landscape, was now much more firmly established.

In 1864 Croll waded into this area of debate and wrote a critical paper for the Philosophical Magazine : *"On the Physical Cause of the Change of Climate During Glacial Epochs"* based on the eccentricity of the earth's orbit and it's effect on the ice ages. He proposed that there were in fact several ice ages and that they were brought about in part by changes in the orbit of the earth round the sun; the tilt of the earth in space, particularly in relation to the different seasons; and by the 'wobble' of the magnetic poles over time. The combination of these factors, exacerbated by 'feedbacks' like changes in the extent of ice and the consequent variation in the earth reflecting sunlight back into space, could explain the regularity and causes of several historical ice ages, and indeed predict future ones.

This began a period in which Croll corresponded regularly with many of the greatest scientific minds of the day, arguing, commenting on and explaining theories about subjects such as the ice ages, ocean currents, evolution and the age of the sun. His regular correspondents included Darwin, Tyndall, Lyell, Wallace, Lord Kelvin, Joseph Hooker and Fridtjof Nansen amongst many others and his reputation grew.

In 1867 he was persuaded by Archibald Geikie to join the Geological Survey of Scotland, despite failing the entrance exam, and Geikie encouraged him in his studies greatly. Unfortunately once again Croll was blighted with increasing head pains which affected his concentration and limited his ability to develop his thinking — something for which he was typically apologetic.

In 1875 he published his most critical work, the distillation of his theory of ice ages and earth's orbit, called "Climate & Time", comprised of 31 chapters which tackled aspects of Croll's astronomical theory of long-term climate change, particularly exploring the cause, behaviour and climatic effect of ocean currents, and attempting to calibrate geological time. In the following year, 1876 his only surviving brother David died. It was also in this year that his work began to receive global recognition. He was made a fellow of the Royal Society, an Honorary Member of the New York Academy of Sciences (amongst others) and he was awarded an Honorary degree by the University of St Andrews.

Forced to retire early, at the age of 59, from the continuing ill health that had so plagued his life, many of Croll's friends

James Croll with colleagues at the Geological Survey of Scotland.

and acquaintances pleaded with the Government of the day to consider him for an enhanced pension, as his few years in service entitled him to very little. This was not successful however, and Croll was forced to move into rented lodgings in North Methven Street in Perth. He was later given a monetary 'gift' by the Geological Society which allowed him to see out his days in a house at 5 Pitcullen Crescent in Perth. In his last years he had returned to the earlier themes of his religious papers, and produced a book called *"The Philosophical Basis of Evolution"* which was rushed to print in order that he saw a copy before he died. Reportedly, in these last few days, he was handed a printed copy and celebrated, despite a life of staunch teetotalism, with a glass of scotch, saying *"I don't think there's much fear of me learning to drink now"*.

James Croll died on December 15th 1890.

In all he produced 92 scientific papers, wrote four books and although elements of his theory were incorrect, he opened the door to an understanding of the links between the sun and the earth's climate, paving the way for Milutin Milankovitch (1879–1958) and others to refine and develop his thinking. Both he and Milankovitch were ahead of their time, however, and the true value of their work was never wholly evident in their own lifetimes. It was not until 1976 when Imbrie, Shackleton, Hayes and others, using a variety of new techniques, gathered the proxy data to support their findings more fully.

James Croll is buried in Cargill churchyard in a grave with several family members, on the banks of the Tay, close to the area in which he grew up. His work is appreciated amongst geologists and other scientists, but he has never had the wider recognition he so richly deserves, despite one or two modern awards being given in his name. Maybe it is time to recognise this man from humble beginnings, whose intellect shone through despite his lack of formal education, misfortune and illnesses. A joiner? Yes, by necessity. A janitor? Yes and a happy man with it. A genius? Maybe. But an inspirational individual? Absolutely.

Editor's Note: The RSGS has published a Penny Magazine to celebrate James Croll and EGS made a contribution to the cost of publication

The Sustainable development, climate crisis, and pandemic: UK science response to a changing world

By Thomas Wagner, The Lyell Centre, HWU

As we emerge from the Covid pandemic, the world is different. Model simulations and common sense suggest that this change will continue, at a faster rate, as we move into a warmer and uncertain future. The challenges associated with tackling the "climate crisis' while finding and implementing the path towards sustainable development for the sake of humanity and natural ecosystems on our unique blue planet are enormous. We are aware that there is no simple answer to address this intractable global challenge, but the nature and urgency of the tasks ahead has sparked a new quality and depth of 'science without borders'.

The UK has traditionally been, and will continue to be, a global player in science and innovation. This article looks at aspects of a rapidly changing landscape and analyses the transition of the science sector into

Figure 1 The 17 goals of the UN Sustainable Development Goals (SDGs), https://sdgs.un.org/goals.

a new quality of cross-disciplinary and cross-sectoral research aiming to mitigate the impacts of climate change through innovative strategies to achieve the UN Sustainable Development goals (SDGs) (Figure 1).

The quality and impact if this new 'science without borders' is breath-taking and exciting and opens unprecedented opportunities for researchers at any phase of their career, students, and stakeholders partnering with universities. This study explores information from the UK, with a focus on Scotland and Heriot-Watt University, and the Lyell Centre, the home of the author.

Roots of a changing research landscape

The issue of global climate change and the urgency for co-ordinated global action is not new. The Intergovernmental Panel on Climate Change (IPCC, https://www.ipc.ch) was established in 1988. Since then, IPCC has become the global authority to analyse and update on the status of Earth's climate and outline possible projections under diverse business and societal scenarios. IPCC is underpinned by the best climate science teams from across the world. The implementation of climate science into politics and society poses however a different and highly complex task.

One critical milestone towards such a global political and social agenda has been the ratification of the United Nations (UN) Millennium Declaration in 2000, committing world leaders to combat poverty, hunger, disease, illiteracy, environmental degradation, and discrimination against women, defined in eight Millennium Development Goals (MDGs; https://www.un.org/milleniumgoals/).

The MDG agenda experienced a major push at two outstanding events at the end of 2015. On 12 December 2015, at the Conference of Parties (COP 21 in Paris), a landmark agreement was reached to combat climate change and to accelerate and intensify actions and investments for a sustainable low carbon future. The 'Paris Agreement' for the first time brings all nations into a common basis to undertake ambitious efforts to combat climate change and adapt, with enhanced support for developing countries. With this scope it entered a new course in the global climate effort. This landmark decision was complemented by the UN Sustainable Development Goals (SDGs), which officially came into force on 1 January 2016. The SDGs are nationally-owned and country-led, wherein each country is given the freedom to establish a national framework in achieving the SDGs.

UK Science and Innovation response to the SDGs

The UK is a world leader in research, with only China and the USA ahead in research output (Universities UK, 2020). This outstanding performance in the UK does not happen just because of brilliant researchers working in universities and other research centres. Remarkably, over 57% of UK publications are the result of international collaboration (Universities UK, 2020). These figures emphasise that universities in the UK not only employ some of the best talents from across the globe but that the national research community heavily relies on and works with international partnerships to create a combined outcome that secures a world-leading position.

The UK government response to address the global challenges of the SDGs has been strong. From 2016 until 2021allocations for Official Development Assistance (ODA) research have massively increased to support of four major funds (Department of International Development, DFID, Department for Business, Energy & Industry Strategy, BEIS GCRF, BEIS Newton Fund, and National Institute for Health research, NIHR Global Health Research). Jointly these programs invested above a staggering one billion pounds between 2020–2021, doubling the resources from 2016–2017 and have resulted in upscaling of science engagement, creating greater impact, and fostering new partnerships, between UK universities and globally.

Flagship programs such as the Global Challenges Research Fund (GCRF) have received £1.5 billion between 2016 and 2021 to support cutting-edge research and innovation that addresses the challenges faced by the developing countries. There are major success stories to report from all ODA research programs, but here we keep the focus on GCRF and the exciting changes this program has enabled.

Since its start in 2016, GCRF has been delivered by 17 UK organisations, including UK Research and Innovation (UKRI), and the UK Research Councils, to support over 800 projects in 126 low-and middle income project partner Countries (LMIC) and over 1,700 organisations with strategic partnerships. Three of the largest programmes supported nearly 2000 researchers in more than 1000 partner organisations in over 100 countries, but none of these numbers can convey the human impact of this investment. At the project level, global health leads the portfolio, with around 240 projects, followed by Cities and Sustainable Infrastructure, Food Security, and

Resilience to Environmental Shocks and Change, each at around 100 projects, followed by Security and Forces Displacement, around 80 projects, and education with around 20 projects.

It is difficult to directly assess how the recent changes in global challenge funding in the UK has changed research intensity and output, and research mentality. Some clues come from the analyses of UK academic contributions to the SDGs recorded by national assessment submissions (Digital Science, 2021). Data from the 2014 Research Excellence Framework (REF) reflect on the state of research for the period 2008-2014 serves as a baseline. Assigning the REF 2014 SDG-related outputs to the SGD goals detects the breadth of integrated research before GCRF and other ODA research funding was introduced, with SDG 16 Peace and Justice, Health and Wellbeing, 13 Climate Action, and 7 Energy leading the field. A different approach concludes that citizen science contributes to 5 SDG indicators and has potential to contribute to another 76 indicators, in total covering around 33% of all SDGs. The largest contribution is with SDG 15 Life on Land, SDG 11 Sustainable Cities and Communities, SDG 3 Health and Wellbeing, and SDG 6 Clean Water and Sanitation.

How will the performance of the UK with regards to SDG related research look like in the current 2015–2021 REF cycle? Scientific publication is one aspect of demonstrating output and impact; other important assets and values are, however, not capture by this variable. Focussing on UK publications from 2020 only, the data suggests that the 2014 REF outcome may be dwarfed compared with REF 2021. If correct, this would further demonstrate the ongoing massive and hopefully irreversible change towards integrated and solution-based research in the UK.

The Covid pandemic

The Covid pandemic has paralysed the world and put most SDG activities to slow progress or even to a halt. The consequences of this standstill are disastrous for the most vulnerable countries in many cases reversing the achievements made in the five years these countries adopted the SDGs. For example, the number of people at risk of starvation have doubled to 270 million, compared to figures before the pandemic. An editorial from Nature from January 2021 therefore asks how science can put SDGs back on track and to conclude some concrete recommendations (Editorial, Nature 2021).

GCRF research in Scotland

GCRF was distributed through a number of 'delivery partners', including UK Research and Innovation (UKRI), the learned societies, such as the Royal Academy of Engineering, and university funders, such as the Scottish Funding Council (SFC). In the five years since 2016, SFC has distributed nearly £42M in GCRF support to Scotland's 18 Higher Education Institutions. This national funding from SFC is part of the GCRF funding secured from the central UK program.

Scotland's performance in SDG science has been excellent. During the first three years more than 800 projects were funded out of Scottish universities in 80 developing countries. Human health and well-being have remained the most significant research themes from the start of the programme, reflecting the countries' well-established heritage of tropical medicine research. However there has also been a steady growth in projects addressing displacement and conflict, clean energy, and communities.

It is important to note that the size of funding does not necessarily translates proportionally into positive impact on the ground in the countries of the global south. In LMICs, the impact of relatively small amounts of funding has been significant and sometimes a game changer. Scottish universities are aware of this situation, and therefore most projects supported through SFC-GCRF were for less than £30,000 and commonly only lasting for a year or less, but the impact on communities and conceptual new ideas has been far-reaching, as is illustrated in the final section, based on project examples from HWU.

GCRF research at HWU

In Heriot-Watt University, GCRF funding was used to preferentially support researchers at the start of their careers to build up international networks and to run small research programmes on topics that they cared deeply about. Out of the 48 projects funded by SFC-GCRF at HWU half were for 'seed' awards (<£20,000), but they 'jump-started' new and highly productive

Figure 2 GCRF project team from Malaysia and Indonesia inspecting aquaculture farm in mangrove forests of Matang in Malaysia.

relationships with international partners (Figure 2)

The GCRF 'seed' and alike ODA research projects have also been a strong catalyst for professional development for academic staff (see Pereira, this volume). The SDG priority areas of the 48 SFC and 18 directly supported projects at HWU up to summer 2021 show a broad spectrum addressing all SDGs (Figure 3), with preferences for SDG 3 Good Health and Wellbeing and SDG 4 Equality and Education, followed by SDG 11 Sustainable Cities and Communities, SDG 1 No Poverty and SDG 5 Gender Equality.

One project uses a novel multi-disciplinary, multi-dimensional approach to socio-ecological system modelling. Focusing on the Colombian Amazon region the team used data analysis together with economic techniques to

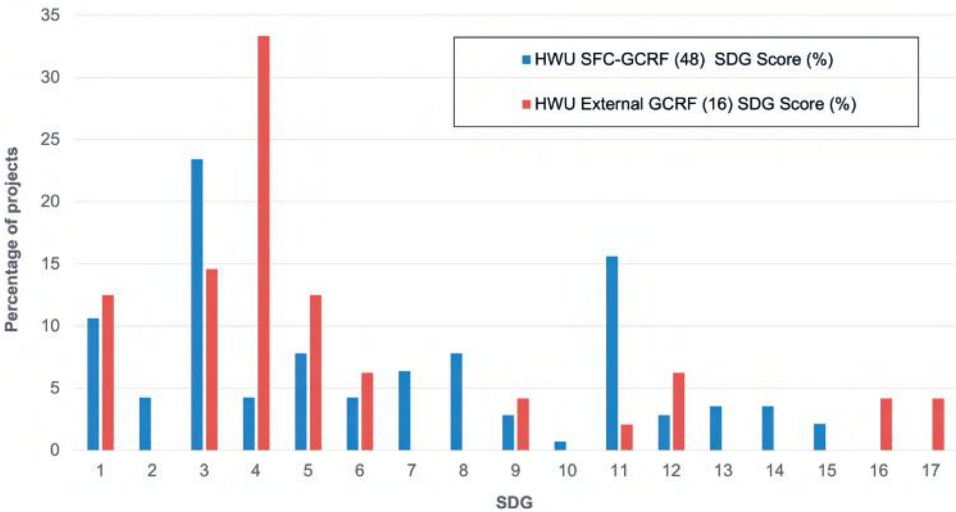

***Figure 3** Assignment of UN SDGs to all GCRF funded project sat HWU. Projects are split between SFC-GCRF projects (48) and GCRF directed projects (18), presented as percentage of both funding sources. Primary and secondary SDG assignments were used for each project, double-weighting the primary SDG compared to the secondary SDG to highlight the core focus of the respective project. Further SDGs, addressed by the projects, are not included in this analysis.*

merge existing environmental, socioeconomic, and agroforestry monitoring datasets from the Amazonian Scientific Research Institute – SINCHI into a new and integrated dataset to facilitate policy evaluation of land use alternatives (Figure 4). Marco Ehrlich, Deputy Director for Science and Technology, SINCHI concluded that this project was a unique opportunity to generate innovative solutions and creative models capable of addressing the many problems and challenges confronting the largest and most biodiverse forest on Earth'. The new socioeconomic model has direct applications to other forest regions, including the coastal Choco region in Colombia. For the full story see *Socio-economic forest model, Colombia*.

***Figure 4* HWU Colombia GCRF team welcomes SINCHI research visitor (right) in the Lyell Centre.**

In another example, one early career researcher with expertise in the use of games for communication, applied her skills to communicating Covid-19 transmission risks with indigenous communities in Colombia. Working with Colombian partners they have helped the community to understand how the pandemic is affecting their lives and to take protective action. Although this was not a large-scale grant, the communities reached out in gratitude for the commitment to support them through these difficult times. For the full story see *Gamification in Colombia*.

***Figure 5* Indigenous women from the Choco region in Colombia studying sample under scientific microscope.**

The impacts of research often take time to be realised, but occasionally timing is perfect. A Heriot-Watt geologist investigated potential tsunami risks from sub-sea landslides in the Makassar Strait off Indonesia in 2019. As his results were emerging, the Government of Indonesia announced plans to shift their capital from Jakarta to Kalimantan, an area indicated to be potentially susceptible to inundation, should such a landslip occur. He and his partners in Indonesia Figure 6), are now working with the government geological services to better understand the risks and make suitable accommodation for this in the planning of the new city. Full story see *Tsunami risk Indonesia*.

Figure 6 Project introduction and concept meeting at our GCRF partner hosts in Indonesia.

Maintaining these impactful research collaborations through a pandemic has been a major challenge that no-one was well prepared for.

Nevertheless, adapting plans, working online across time zones (Figure 7), and responding to constantly changing travel conditions, these partnerships have been strengthened through adversity. Professional friendships are deepened as teams have become more understanding of what is and is not possible. While we know more about the scope for collaborating remotely, we have also come to value the benefits of direct human contact and realise our responsibility to drive these close partnerships further.

Figure 7 Online project meeting with colleagues from HWU-Malaysia and GCRF project partners in Indonesia.

Summary and outlook

This is an exciting time for a new breed of sustainability scientists which take a holistic view at global challenges and use research and innovation to develop and deliver solutions on the ground, shared with and to the benefit of local communities. The UN SDGs provide a broad and highly relevant framework, giving science a new place in society and more direct responsibility to actively lead the agenda. The pandemic has demonstrated the central importance of up-to-date scientific facts driving political and our individual decisions. Delivering the SDG builds on the same foundation, just much greater orders of magnitude.

The research community across the UK and internationally has invested talent and energy into building global partnerships, which are essential for the multiple challenges that we face. That commitment will continue beyond the life of the UK GCRF programme and we will see it's fruits for many years ahead.

Although the UK government has temporarily reduced its commitment to ODA funded research, in 2021–22, the UK science community very much hopes that the continuing benefits of such support will be recognised again and earlier commitments on ODA will be restored as soon as possible.

Acknowledgements
The author thanks Janey Andrews and Catalina Bastidas from the HWU-GCRF team and Ryan Pereira, HWU-Lyell Centre, for their contributions to collate the information and review the draft of this manuscript.

References
A complete list of references and links to web pages will be available with the online version.

Editor's Note: Tom Wagner is a geologist and biogeochemist who has worked at two of Europe's top multi-disciplinary marine science labs (Marum, University of Bremen, and at the Royal Netherlands Institute for Sea Research) before moving to Newcastle University. I first met him at an ocean drilling meeting where he was seeking industry support for a coring project to study the Cretaceous black shales beneath the Atlantic Ocean. He is now Professor of Earth System Science at HWU, Leader of the Biogeochemistry Group and Director International Development at the Lyell Centre. His core scientific expertise lies in assessing the role and functioning of Carbon and nutrients as primary drivers of Ecosystems, Climate Change and Energy Resources. The following article is from Associate Professor of the Biogeochemistry Group, Ryan Pereira, another of the new breed of sustainability geoscientists!

An early career scientist's perspective on the climate crisis, shared stories, and the road ahead to sustainable development

By Dr Ryan Pereira, The Lyell Centre, HWU

They say that success is built on a foundation of failures. This should be viewed positively with optimism that humanity will succeed in a transition to greener economies and environmental sustainability on our journey to a net zero lifestyle. The failures of early adoption to climate adaptation policies and strategies in the last century has created a pressure point now that forces all of us to carefully examine our own role in Earth's changing climate. This offers opportunities for us all to engage, no matter what our background, ability, or interest. While individual actions often feel dwarfed by a challenge that requires changes at a scale that many of us find difficult to grasp, all of us can act as the spark for continued action with each of us having a critical role in keeping the global, regional and local focus of the climate crisis. This new connected and fluid network of people and its focus on sustainable development, I believe, is our greatest strength and the next horizon of humanity. In this article I share my experiences of addressing the climate crisis, the ever-increasing need to incorporate a wide variety of perspectives, the multiple lessons learned, and how shared experiences between people and communities become a common story for positive change.

My story begins in the green heart of a former British colony, Guyana, in South America working with the Iwokrama International Centre for Rainforest Conservation and Management (IIC), with whom we have now worked together for over 15 years. In this time, the country has transformed rapidly as it has begun to utilise its natural riches from tropical rainforest to gold and oil. During this rapid growth, the International Science Committee (ISC) was formed to expand Iwokrama's expertise with international support to better engage with government and international organisations (Figure 1). Guyana is now at a crossroads of unprecedented economic wealth for the country, but the challenge will be to see this translated into societal gain

Figure 1 ***Left Dane Gobin IIC Chief Executive Officer introducing the new 5-year science plan for Iwokrama at the first meeting of the ISC. Right: Second meeting of the ISC where core thematic areas for Iwokrama's mission are developed.***

without long term and irreversible environmental impact.

When I started in Guyana as a PhD student the focus was to unravel the connections between water, carbon and nutrients flowing from the land to the ocean and examine the role of rainforests in climate regulation. The ultimate goal was to investigate whether we could further minimise the impact of logging in Guyana's rainforests. This early work was supported by colleagues at several universities (Newcastle, HWU, Durham and The OU) and required multiple sources of funding from NERC, the Wolfson Foundation, and the Inter-American Development Bank. The road of discovery has yielded unexpected results including the identification of a group of organic compounds in rivers that are largely invisible to commonly deployed remote and in-situ sensing technologies (Pereira et al. 2014). A new research project funded by the European Research Council will look at how organic matter from tropical rivers maybe an important factor in the ocean's ability to store anthropogenically derived greenhouse gases (Pereira et al. 2018).

We make progress but seem to find more unanswered questions than answers, but while blue-skies discovery science is at the heart of research and innovation, it is through the framework of the United Nations Sustainable Development Goals and the UKs Global Challenges Research Fund (GCRF; see article by Wagner in this issue) that the greatest impact

***Figure 2** Left: my first encounter with Dr Isabella Bovolo, now at Durham University, sharing stories of soil and groundwater in the Rupununi with interested school children of Bina Hill; Right: the Lyell Centre CWD team in 2019 (from left Sara Trojahn, Dr Juliane Bischoff, Dr James Spray, and Sevda Norouzi) embarking on their first and life changing expedition to the Iwokrama rainforest.*

of our work in Amazonia can be seen. This work is diverse, founded in environmental conservation and has brought together indigenous Amerindian communities with landowners, and trans-boundary trade and commerce stakeholders. It has also expanded the network of people involved in this work with significant contributions from academic, industrial, governmental, and non-governmental partners based across the globe without whom, none of this would be possible. Together we are designing sustainable development plans for the vulnerable savannah lands of the Rupununi and exploring new ways of preserving the environment while generating new income revenues through the power of virtual and augmented reality technologies (Cole et al. 2021). In our most recent work, we are co-creating a shared understanding of important geographical features, their inter-connections, and how they impact food supply with indigenous communities. Our aim is to empower those that belong to the Rupununi Region to manage their world and have a voice with global reach. This work began through a Scottish Research Council Funded GCRF seed-corn project where a collaboration between HWU and BGS identified a lack of understanding between geographical features and their connections with water (Figure 3). It identified that we needed to create a shared understanding between top-down domain expertise with bottom-up local knowledge. By sharing our stories from our individual and collective perspectives, we began a common narrative that has set us down a path of co-creation in securing our future.

There have been many hiccups along the way. The insecurity and often staggered financial support to continue our work has delayed progress and there have been a multitude of logistical challenges to overcome, from roads flooding, boats breaking miles from anywhere, accidental baths with giant otters, and so many encounters with snakes I have lost count (Figure 2). Of course, this is nothing compared to the disarray caused from the threat of COVID-19 but in many respects, it has focussed our effort and forced all of us to be more resourceful and inventive to work together. As a result, we are now using social media platforms and infographics together with gaming approaches to address key serious challenges in the Rupununi.

Reassuringly, our work in Guyana has drawn parallels with other parts of the world which has expanded the regions where the Carbon-Water Dynamics team at the Lyell Centre now work (www.carbonwaterdynamics.wordpress.com). This allows us to apply generic understanding gained from Amazonia to regions in S.E Asia, and Africa. Intriguingly, the initial involvement with these regions is

Figure 3 Left: Green Labaria snake encountered on a forest trail; Right: Brighid O'Dochartaigh of the BGS explaining groundwater connections in the Rupununi.

typically founded on the CWD team's ability to characterise water and carbon. The immediate next step is to disentangle the interconnections that exist between the natural and human environments and explore options to remove the barriers towards environmental sustainability. This experience, which is not unusual, is ideally suited to GCRF and the Scottish Funding Council's approach to allow Universities to support smaller-scale transformative projects. In fact, the limited budgets, and typically short timelines from design to implementation of seed corn projects force early career researchers to utilise their innate capacity to adapt, act quicky, and be resourceful to address a critical need. This experience has transformed me into a more inventive person. Importantly, while these project outcomes do not typically conform to widely used metrics of success the intangible benefits can be massive. For example, through our GCRF project in Guyana we were able to bring together stakeholders in the Rupununi to begin communications built on trust when previously misinformation and rumour were disrupting potential progress. We can only hope that further co-creation will build more trust so that one day in a future not too distant we are telling shared stories on our road of sustainability to the next generation.

Acknowledgements
The author thanks Thomas Wagner and Juliane Bischoff, HWU-Lyell Centre, for their contributions and review of this manuscript, and to all those involved on this continuing journey of co-creation and discovery.

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The stuff of the land

By Professor Frank Rennie, Lews Castle College University of the Highlands & Islands

In all the intermittent discussions about 'a sense of place' that a locality may, or may not, be perceived to have, it frequently seems to me that a lot is talked about the 'emotions' of a place, rather than what is physically present, even if that may be somewhat difficult to discern. One of the indelible marks of geological training is having the ability (indeed it can be almost an unbidden visceral reaction) to make immediate an appraisal about the character of a place simply by looking at the evidence of the landscape. Wherever we are in the world, whichever rural landscape we look upon, geoscientists subconsciously make an almost instantaneous assessment about the stuff that we are standing on. It is not just the conspicuous, large-scale, features that drive these assessments. Certainly, we often look first at the dominant shapes of the landscape, the crags and valleys that determine the configurations of river catchments, or the large-scale humps such as eskers of sand and gravel or lenticular blobs of boulder-clay that are the signatures of later re-working. It is much more than these obvious features, however, as any consideration will include many subtle hints at the varieties of solid rock that often lie buried beneath our feet, and these will determine the topography, the derived soil, and in some aspects may even reflect the culture of the place.

I will give one small example to illustrate my point. Travelling through my home range of the Outer Hebrides, a very obvious feature of the land can be the mile after mile of dry-stone walls that mark-out the boundaries of villages and individual crofts. To many (most?) people, they are simply a picturesque element, or at best, a functional part of the view. To a geologist, however, there is an instant recognition that the rough, irregular boulders constructing the walls are formed of ancient Lewisian Gneiss.

Even within the apparent sameness of 'undifferentiated gneiss' the practiced eye picks up the pink splash of a pegmatite or the smooth folds of metasediments that will give hints to the tectonic origins of that place. There is an intimate connection between form, function, and environmental history, that conveys a

Figure 1 Lewisian dry stone walls

particular sense of each unique place. True, the geology alone is not the total 'sense of place' but it is often the first impression, and a major modifying fabric of the natural environment that conditions so much else—the landforms, drainage, opportunities for vegetative cover, and so on.

More than that, whenever we move to another part of the world, a different set of geological identifiers will trigger their own cryptic messages. In Caithness, the stone walls are nothing like those in the Hebrides, with the large rectangular slabs of 'flagstone' standing upright on their thin edge, almost like large tiles. On some of the older buildings, particularly large flagstones the size of a family dining table may form elements of a roof, conveying an impressive gravitas and solidity to previous human occupation. If you are especially diligent and also especially lucky, you might find among the accumulated layers of flagstones, thin dark remains of the fossil fish that singularly identify their provenance and convey information on a wealth of Earth history. When we move to Orkney, the field walls are likely to be of red sandstone, while around parts of the Midland Valley, a soft yellow sandstone was favoured for construction. In other areas, like the west of Ireland, the pale local limestone is able to be fashioned into almost-regular blocks that stack solidly with comparative ease. This is a world away from the thrawn, jagged, resilient lumps of Lewisian Gneiss that defy a systematic fracture and will take craft and cunning to fashion into self-standing structures.

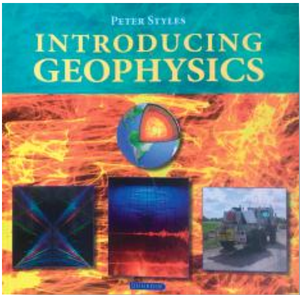
Even in areas where the underlying geology is hidden, where the surface of the land is not partitioned by the walls of natural stone, that landscape speaks to me of its deficits. In the flatlands, or in the regions of the valley floodplains, simply walking alongside a river course is to have the eyes drawn to the shingle, the rolled boulders, and perhaps even some protruding bedrock. Whatever is exposed to your gaze gives an indication of what is still hidden in that landscape. Whether it is the suggestion of loose materials that have been transported from further upstream, or the resistant sliver of a rock-shelf that has been cut by river action, it all has a story to tell about what that place is made of. With a little 'inside knowledge' (pardon the pun!) the details of the three-dimensional terrane is implicit from the superficialities of a briefly observed perspective of the surface terrain. Even a large and incongruous rock-type, carelessly dumped in apparent isolation, might suggest a glacial erratic, whose close examination may provide clues to both its original source area, and perhaps also the direction of the moving ice that once sculpted the region. The fragments of geological evidence that are scattered around on the surface of the land are mentally accumulated by the geologist, frequently subliminally, and are used to create a mental image of the both the deep Earth, and the longitudinal history of why that place looks as it does.

For better or for worse, our interpretations of the geology of a place are integral to our perceptions of a 'sense of place' and consequently to our understanding(s) of that place. Whether we are thinking about the 'cultural landscape' in our collective national psychology, or the very practical details of land ownership and land-use policies, a consideration of geology is an essential component. For some people, that consideration may be superficial or transitory, for others it will be fundamental. Either way, geological knowledge informs us all about how we see a place.

Frank Rennie is Professor of Sustainable Rural Development in Lews Castle College, at the University of the Highlands and Islands and a Fellow of the Edinburgh Geological Society since 1976. His latest book, *The Changing Outer Hebrides: Galson and the meaning of Place* begins with the context provided by the Lewisian Gneiss in its type-locality.

Book review

Introducing Geophysics By Peter Styles, Dunedin Academic Press, Edinburgh. 2021. Paperback. 117 pp. £14.99. ISBN 9781780460802.



"Everything we know about the deep Earth, apart from the superficial pinpricks provided by boreholes, we have learned from geophysics." In this excellent introduction to geophysics, Peter Styles, Past President of The Geological Society, has kept mathematics to a minimum. He explains that geophysics is the physics of the Earth, described by classical physics, including heat, gravity, magnetism, electricity, vibrations and waves. The explanations are beautifully and very carefully illustrated and a pleasure to read. It is clear that Peter enjoys teaching. He wants you to be as thrilled by the wonders of geophysics as he is.

The target readership for this book is not stated. I suggest it be recommended reading at final year of high school, especially for students of physics and geography, students in first year of university studying physics and Earth and environmental sciences, and also to keen amateurs with an interest in the physics of the Earth.

Peter studied Physics at Oxford before embarking on PhD research in Geophysics at Newcastle, where Dr Ron Girdler was his supervisor and Keith Runcorn was the Professor. He has had a very distinguished career as an academic geophysicist in the UK and is currently Professor Emeritus at Keele University. He has taught "the whole of geophysics," but in Chapter 1 he says, "I will make no attempt to be comprehensive."

There are seven chapters: Introduction and scene setting, Heat flow and the driving forces, Seismology and seismic exploration, The Earth's magnetic field and its implications, Electrical properties of the Earth, Gravity: the figure and structure of the Earth, and Geophysics goes to work. I learned something from every chapter. Every chapter is good. The chapter on magnetism is really good.

The book is full of interesting things, while not losing sight of the big picture. For example, Chapter 1 contains a lucid explanation of Euler's theorem for motion of plates on the surface of a sphere, showing mid-ocean ridges, transform faults, subduction and pole of rotation in one easy-to-understand diagram. Chapter 6 shows seismograms from the Sumatra earthquake of Boxing Day (26 December) 2004 at stations to the east, out to Christmas Island, and their relation to wavefronts expanding from the epicentre across the Pacific Ocean and ray paths through the Earth. Chapter 4 describes short-term magnetic polar wandering and shows how the measurement of magnetic reversals led to the Vine-Matthews hypothesis of sea-floor spreading. Chapter 6 includes a straight-line log-log plot of the semi-minor axis of the orbit against the orbital period for the planets in the solar system. It also describes Cavendish's measurement of the gravitational constant G.

The final chapter covers applied geophysics, focusing on the shallow near-surface applications that interest Peter the most, including geotechnical investigations for civil engineering projects, and archaeology, using survey techniques that can be performed with a small group of people. Certain things not mentioned include: 3D seismic surveying with 100,000-channel systems; the worldwide International Monitoring System (IMS), built by the Comprehensive Nuclear Test Ban Treaty Organisation (CTBTO), airborne full tensor gravity gradiometry; high-resolution aeromagnetic surveys with drones.

This is an important book for anyone who wants an easy-to-read introduction to the wonders of geophysics. It will create a desire to know more.

Professor Anton Ziolkowski
University of Edinburgh

Editor's note: Peter and Anton are two of the UK's leading geophysicists and I'd like to endorse Anton's comments on what is a very readable book and thank Peter for writing his book and Anton for his review. To close this edition of EG, Anton was one of the researchers who began the geophysical exploration of the Rockall Bank, finding a major sedimentary basin to the west of Rockall (Roberts et al, 1970).

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