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AGU ADVANCING EARTH AND SPACE SCIENCE

Geoscience in Action

ADVANCING SUSTAINABLE DEVELOPMENT

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Cover photo: Students studying vein arrays on the limb of a Variscan fold in Loughshinny, Co. Dublin, Ireland. These folds were generated by the Variscan orogeny, which led to the formation of the supercontinent Pangea. © Science Foundation Ireland Research Centre in Applied Geosciences (iCRAG).

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SHORT SUMMARY

Geoscience will play a vital role in solving the challenges we face

It is estimated that more than 400,000 people work globally as geoscientists. The profession is, nevertheless, going through an identity crisis. University enrollment in geology courses is declining in many countries. There is a sense that the profession needs to find a new purpose that is more in tune with evolving societal needs and the expectations of budding scientists.

Consequently, appointments to academic posts in sustainability geoscience are becoming more common, traditional petroleum geology courses are being rebranded as geo-energy courses and many mining geology courses are now encompassing natural resource management. In industry, fossil-fuel and mining companies are beginning to extend their renewable energy and new minerals portfolios and to reskill their staff in sustainability thinking.

Written by leading geoscientists from across the globe, *Geoscience in Action: Advancing Sustainable Development* seeks to inspire geoscientists everywhere to give more focus to advancing sustainability by showcasing case studies of how geoscience is already addressing climate change and other global challenges. In Delhi, India, for instance, geoscientists worked with regional civil servants to alleviate a water crisis by utilizing overflow from floodplains, becoming a model for other riverine cities.

More than 1 billion people in the world live close to an active volcano

Educators can use these case studies as manuals to show students the myriad ways in which they can make an impact with a geoscience degree. Scientists wishing to offer their expertise to find sustainable solutions can use this report to find organizations with which to partner.

We need more geoscientists in our society to be part of the decisions shaping our future. *Geoscience in Action* not only explains why—it shows us how.

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"Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed"

Geoscience in Action

ADVANCING SUSTAINABLE DEVELOPMENT

Maria Angela Capello, Emer Caslin, Iain S. Stewart, Denise M. Cox,
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Ludivine Wouters, Miriam S. Winsten, Vimal Singh and Kombada Mhopjeni

This work is dedicated to present and future geoscientists.

Much of this image consists of the Reserva de la Biosfera Pantanos de Centla, a biosphere reserve in southern Mexico that protects wetlands in the area. The water bodies, mangroves, and forests are a sanctuary for a great variety of wildlife. Sediment carried away by the Grijalva River appears as a sweeping light blue brushstroke flowing into the Gulf of Mexico at the top of the image. © unsplash.com/@usgs.

ACKNOWLEDGMENTS

This report would not have been possible without the valuable contributions, support and encouragement of numerous people and institutions.

We would like to acknowledge the role of UNESCO and the American Geophysical Union (AGU) and their leadership in transforming our dream of communicating loudly and widely how geoscientists advance and support each of the United Nations' 17 Sustainable Development Goals (SDGs). We are grateful to many individuals, divisions and units at UNESCO headquarters, notably in the International Geoscience Programme (IGCP), and especially Özlem Adiyaman, who endorsed this project from the beginning and opened UNESCO doors for collaboration in the work. Jenny Lunn, Melissa Goodwin, Victoria Thompson, J. Henry Pereira and many other staff of AGU were instrumental in administering and carrying out production of the report, and we appreciate their professionalism and commitment to the project.

We profusely extend special thanks to the organizations that provided financial support for publication of the report, namely AGU, the Society of Exploration Geophysicists (SEG), the American Geosciences Institute (AGI), UNESCO IGCP and the University of California, Davis. We are honoured by their encouragement as well as their material support. We also are thankful to the many organizations that endorsed this work.

We thank the many individuals and organizations who provided examples that demonstrate the contribution of geoscience to sustainable development. We also are thankful for our families, who supported us during more than a year of work in developing this publication.

ENDORSEMENTS

At the time of publication, the contents of this report have been endorsed by the following organizations:

- American Association of Petroleum Geologists
- American Geosciences Institute
- Coordinación de Plataformas Oceanográficas, Coordinación de la Investigación Científica, Universidad Nacional Autónoma de México
- EuroGeoSurveys
- European Association of Geoscientists and Engineers
- European Federation of Geologists
- GeoLatinas
- Geological Society of Africa
- Geological Society of America
- Geological Society of Australia
- GeoScienceWorld
- International Association for Promoting Geoethics
- International Association of Volcanology and Chemistry of the Earth's Interior
- International Union of Geological Sciences
- International Women in Mining
- Mineralogical Society of the United Kingdom and Ireland
- Oklahoma State University Boone Pickens School of Geology
- Responsible Raw Materials
- Science Foundation Ireland Research Centre in Applied Geosciences
- Society of Exploration Geophysicists
- Society of Petroleum Engineers Gaia Sustainability Program and Sustainability Technical Section
- Université de Liège, Urban and Environmental Engineering
- University of California, Davis
- Women in Earth & Environmental Sciences Australasia

PREFACE

Geoscience in Action was inspired by the mapping exercise conducted for creation of the Geophysical Sustainability Atlas, written by three of the authors of the current work and published in the Society of Exploration Geophysicists' journal *The Leading Edge* in January 2021 (Capello et al., 2021). That article provided a framework for understanding the value that geophysics brings to advancement of the United Nations' Sustainable Development Goals (SDGs) by mapping geophysical activity to each of the SDGs. Upon that work's publication, many practitioners of applied geophysics found it grounding and inspirational. The need to produce a similar yet expanded work to cover all geosciences soon became apparent.

The primary audience for this report is geoscientists. We aim to provide educators, researchers, administrators and front-line practitioners of all geoscience disciplines the opportunity to see themselves through the lens of the value they bring to society on local, national, regional and global scales, and how they can deliver more value. We focus this work on the need for geoscientists to enhance their skills in relationship building, ethics, policy development, and a suite of other social-scientific dimensions, through an equity-and-inclusion lens, to maximize their contributions in physical realms. Our primary goal is to empower geoscientists by providing an engaging way to communicate the value of geoscience.

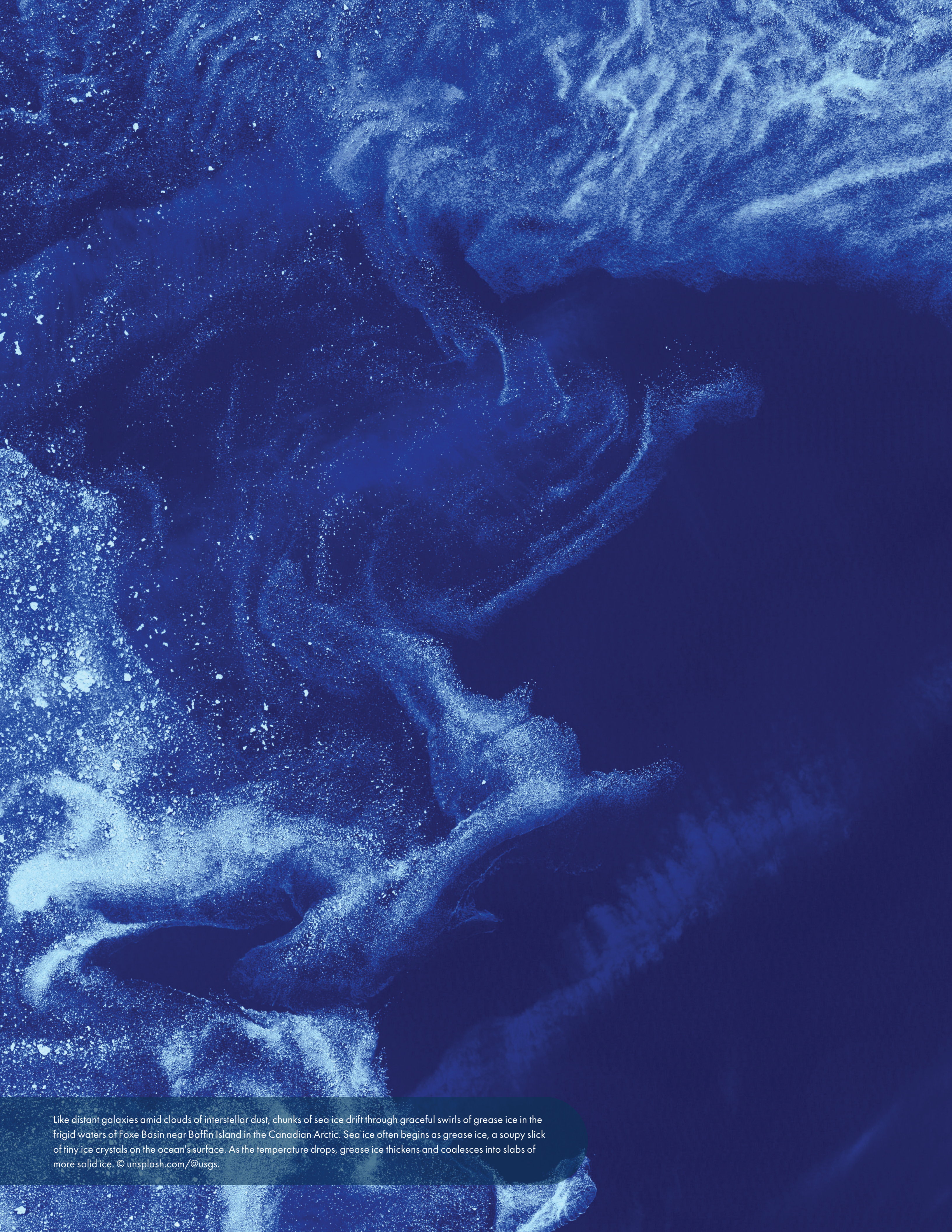
We also developed this work with the goal of reaching an audience beyond the geoscience community. Our purposes include showing policy-makers, physical and social scientists in other disciplines, corporate and academic leaders, leaders of governmental entities and non-government organizations, media representatives, and the public at large how they can engage and collaborate with geoscientists in pursuit of the SDGs, highlighting the important role geoscience can and does play in progressing towards SDG achievement.

We assembled a multicultural, multipractitioner, multisector team to create this work. We gained support from the geoscience community at large through a social media call for examples of geoscience-involved SDG activity and from several leading geoscience professional organizations. Our work has been enriched by the suggestions and encouragement we received.

This report is a product of remarkably global and enthusiastic teamwork. We encouraged each other through the large and small tasks involved in mapping geoscience as applied to sustainable development and presenting a compendium of examples. Our greatest hope is that this work will inspire future generations of geoscientists and their collaborators who, no doubt, will do more than us to protect, enhance and responsibly live in our diverse geologic settings.

CONTENTS

CONTENTS



Like distant galaxies amid clouds of interstellar dust, chunks of sea ice drift through graceful swirls of grease ice in the frigid waters of Foxe Basin near Baffin Island in the Canadian Arctic. Sea ice often begins as grease ice, a soupy slick of tiny ice crystals on the ocean's surface. As the temperature drops, grease ice thickens and coalesces into slabs of more solid ice. © unsplash.com/@usgs.

FOREWORD

As children, standing in the present and looking back at the past can be like standing on the edge of a precipice. We discover that life on Earth has existed for an incredible span of time. We learn about the age of dinosaurs; we delve into the mysteries of nature. This sense of awe and wonder is intuitive. This also what gave rise to geoscience.

Geoscience tells a tale of the past, while charting a path for our future. It is not only about minerals, fossils and rocks. It also encompasses fields such as Earth resources and hydrogeology – essential in a world affected by a climate disruption. That is why geoscience is so important for us here at UNESCO – where science is the 'S' in our name. We advance this discipline in a number of ways.

Firstly, we preserve geological landscapes of international significance through our network of 177 UNESCO Global Geoparks in 46 countries. In these areas, we combine protection with education and sustainable development – from the island of Qeshm, in Iran, where women drive geotourism activities, to the Basque Coast, in Spain, where the geological history of the planet can be read like an open book.

Secondly, UNESCO works to raise awareness of the importance of the geosciences, notably through International Geodiversity Day, which celebrates the close relationship between biodiversity, geodiversity, culture and history, every year on 6 October.

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Thirdly, UNESCO supports the production of knowledge by fostering international cooperation in this field. For the past 50 years, our International Geoscience Programme has brought together geoscientists from across the globe – including early career scientists, women, and scientists from the Global South – to ask essential questions and offer illuminating answers.

Originally created to make a geological correlation between the different parts of the world, the Programme is also shaping the future of geoscience – contributing, for instance, to the creation of new disciplines such as medical geology, which seeks to understand the impact of the natural environment on health. Today, the Programme is turning its attention to new collaborative projects, always with one goal in mind: to benefit society.

This report on *Geoscience in Action* is one such example. Developed as part of the collaborative project "Geology for Sustainable Development", this report is a call to action, advocating for the important role that geoscience can play in efforts to advance the Sustainable Development Goals. At a time when there is a looming shortage of about half of the 90 natural elements in the Periodic Table, it offers examples and insights, showing how geoscientists can realign their research to support policy-makers and society at large.

I encourage readers to share the examples contained in this report with your colleagues, with your friends and especially with your children. We need more geoscientists – particularly women – so that they, too, can be part of the decisions shaping our future. Let there be no doubt: the geosciences will be critical meeting the challenges of our times. We need the geosciences and the geosciences need us.

Audrey Azoulay
Director-General of UNESCO

EXECUTIVE SUMMARY

There is an urgent need to address the sustainability challenges facing our planet and people – from the rise of global poverty to the acceleration of climate change and its consequences (flooding, soil degradation, ocean acidification, natural hazards, etc.) and the resulting threats to health and social justice.

In September 2015, the United Nations General Assembly defined the 2030 Agenda for Sustainable Development, which was adopted by all United Nations Member States. There were 17 Sustainable Development Goals (SDGs) identified to address social inclusion, environmental protection, and economic growth in all parts of the globe. The goals call on all stakeholders, acting in collaborative partnership, to take bold and transformative steps to shift the world onto a sustainable and resilient path.

Geoscientists possess a holistic understanding of Earth, studying the physical, chemical and biological components that shape our planet through multiple scales and dimensions, including time. Our ability to understand this fourth dimension allows us to look to the past to help forge a sustainable future through management of our natural resources, conservation of our environment, and protection of our citizens from natural hazards.

One way to highlight the clear value geoscientists contribute to a sustainable future is by mapping geoscience disciplines, methods and tools to the SDGs. Geoscientists can lead global and local efforts in sustainable development through projects, initiatives, advocacy, knowledge sharing and monitoring of progress towards the 2030 Agenda.

This mapping exercise was carried out by an international team of geoscientists representing academia, industry and government from multiple geoscience sectors and disciplines. The broader geoscience community was instrumental in sharing case studies that mapped to the SDGs.

The purpose of this report is to showcase how geoscience can be applied to deliver value to the world and confirm the discipline's significance to the 2030 Agenda. The report aims to foster collaboration within the geoscience community as well as enhance geoscientists' collaboration with other experts and decision-makers and their communities. In addition, it aims to highlight the diversity of contributions that geoscience makes in sustainable development and inspire the next generation of geoscientists. This is done by defining the competencies most associated with geoscience and illustrating how geoscience and geoscientists contribute to the SDGs. The most important part of this report is the chapter describing a diverse set of projects that show how the application of geoscience contributes to the SDGs. These examples ideally will resonate with all readers, within the geoscience community as well as outside of it, and we hope they will inspire the initiation of a multitude of new projects.

Geoscience activity in support of SDG advancement was organized under three dimensions: people (positive impact on individuals), planet (positive impact on physical systems), and prosperity (positive impact on socioeconomic systems). This classification provides a better means to measure progress than tracking the 17 SDGs alone. It illustrates how the SDGs are part of an interconnected framework within which progress to achieve social, environmental and economic change is greatest when the goals are advanced simultaneously.

There is no universal definition of the dimensions, so a major undertaking of the project was to identify and map the contributions of geoscience and geoscientists within each dimension. This task was achieved through the following steps:

1) identification of geoscience disciplines, methods and tools relevant to the 169 individual targets and 231 unique indicators of the 17 SDGs

2) classification and assignment of the SDGs towards which geoscience and geoscientists contribute within the dimensions of people, planet and prosperity

3) establishment of the dominant SDGs per dimension for geoscience

The SDGs of peace (SDG 16) and partnerships (SDG 17) were considered an integral part of all three dimensions.

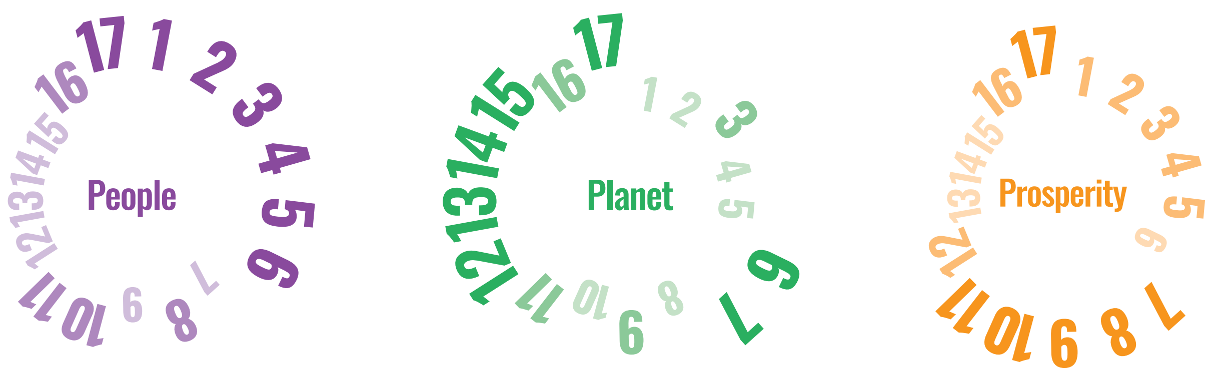


Figure 1. The three dimensions of people, planet and prosperity with the dominant SDGs for geoscience highlighted within each dimension. Interlinkages across dimensions provide opportunities for collaboration among geoscience disciplines. The examples associated with each dimension highlight the breadth of geoscience contributions to global sustainable development.

Examples demonstrating how geoscientists are contributing to achievement of the goals were obtained through a public call to the global geoscience community via social media and professional platforms.

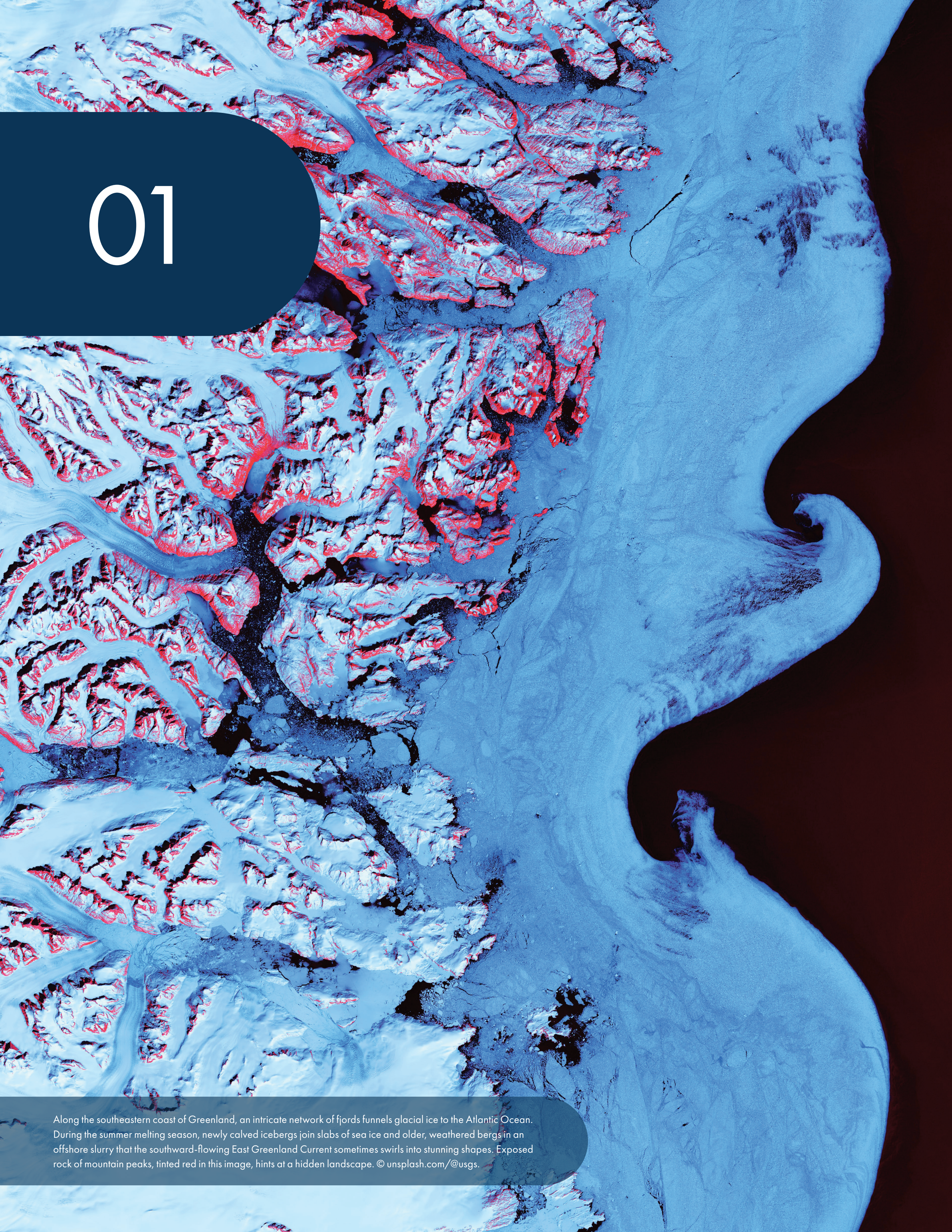
Six examples were selected per dimension – for a total of 18 – to showcase geoscience initiatives at the individual, group and organizational levels, with different scopes that address the dimensions of people, planet and prosperity (Figure 1), covering a wide geographic distribution.

The examples capture the diversity of initiatives in which geoscientists are engaged across the sustainability spectrum, from water resource management, reducing natural hazard risk, and accelerating decarbonization to confronting gender inequities and discrimination.

An important contribution of this report is the recognition that geoscientists need to embrace skills beyond those typically associated with their core areas of inquiry and practice. Addressing sustainable development challenges requires work at the boundaries of disciplines and sectors. In addition to effectively using geoscience tools and methods, geoscientists also need to effectively communicate with engineers, environmentalists, policy-makers and community leaders. Those who can apply these additional skills will be instrumental in accelerating the pace of SDG advancement.

Geoscientists have an opportunity to contribute much more towards the achievement of strong sustainable development solutions to many of the world's greatest social, economic and environmental problems. Yet society at large and even geoscientists underappreciate how they can apply their talents and skills towards those ends. We offer a framework with examples for understanding the wide range of geoscience activity through which sustainable systems are being established and maintained and how this activity can grow with more participation and focus.

The sustainability of geoscience itself relies on assessment, understanding and communication of the value the various subdisciplines deliver. *Geoscience in Action* offers a value proposition we think will help inspire many in forthcoming generations to pursue careers in geoscience and motivate current geoscientists to redirect their research and practice to new, transformative endeavours that would improve their long-term employability or entrepreneurship ambitions while expanding their social contributions.



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Along the southeastern coast of Greenland, an intricate network of fjords funnels glacial ice to the Atlantic Ocean. During the summer melting season, newly calved icebergs join slabs of sea ice and older, weathered bergs in an offshore slurry that the southward-flowing East Greenland Current sometimes swirls into stunning shapes. Exposed rock of mountain peaks, tinted red in this image, hints at a hidden landscape. © unsplash.com/@usgs.

MAPPING GEOSCIENCE CONTRIBUTIONS

1.1. Maximizing integration of geoscience in sustainable development initiatives

This report examines what geoscience contributes to sustainability in the context of the United Nations' 17 Sustainable Development Goals (SDGs). We mapped our daily activities, goals and suppositions in geoscience practice, along with those of thousands of our colleagues around the world, to the SDGs to create a platform for understanding how they align. Here we offer a lens through which all geoscientists, regardless of disciplinary focus, may see themselves and their activities framed in the current flow of global objectives related to sustainable development.

A fundamental premise is that geoscientists need a compelling story to support their connection with and inclusion in collaborative efforts pertinent to the SDGs, with attention to the goals' interdependent components tuned to social, economic and environmental systems. While seeking to bring geoscientists a proud sense of belonging in the global pursuit of the goals, we highlight how they can maximize the impact of their technical expertise by enhancing their skills in communication and administration. In comparison with other disciplines, geoscientists are surprisingly under-represented in sustainability endeavours relative to their potential contributions.

A central challenge, therefore, is how to ignite a positive response from all stakeholders in geoscience around a common vision about value creation in all components of the profession, including research, technology, business, academia and humanitarian outreach. We offer our mapping of geoscience activities to the SDGs and the people, planet and prosperity dimensions, summarized in the clocks for each dimension and in the geoscience sustainability clock (see Chapter 2). This mapping is demonstrated in a collection of illustrative, inspiring examples that we present in Chapter 4.

Our hope is that this work will positively impact future geoscientists in the application of their talent and skills and lead to greater integration of the geosciences into global sustainable development initiatives.

1.2. Earth toolkit

Geoscientists are Earth scientists. Our principal concern is our amazing planet – its history, how it works, and what those aspects of it mean for those living on it. The science of the planet is a tricky business. Earth, after all, is an experiment that has been conducted only once and has lasted 4.5 billion years. It requires unique scientific perspectives, methods and insights – a metaphorical toolkit. Although that toolkit has been designed to understand Earth's enigmatic past, it equally can be applied to studying its uncertain future. Key attributes of geoscience that can be directed to sustainability issues are that it is:

- interdisciplinary: blending physics, chemistry and biology and drawing from engineering and mathematics

- interpretative: deciphering clues in the rock record or the deep subsurface to shed light on Earth processes
- observational: formulating and testing new ideas and theories, thereby making geoscience a data-driven endeavour
- historical: using observations of present-day phenomena and environments to infer conditions in the past (and future!)
- systems based: recognizing the dynamic interconnections between the solid earth (lithosphere) and the other 'spheres' (atmo, hydro, cryo and bio) that maintain a habitable planet

Geoscientists understand that Earth is complex and complicated. It is complex in that it is a system characterized by feedback between processes and among component parts that can lead to strong effects in unanticipated places. It is complicated because physical, chemical and biological processes all interact with human processes, often at the same time and place. The recent exploration of space, with the robots investigating Mars, has shown us the tremendous relevance of geoscience in the understanding of a planet.

Although geoscientists are not the only scientists who work with complicated, complex systems, their ability to apply a systems-thinking approach to understanding the planet and their capacity to visualize in three dimensions and communicate time-lapse effects of processes in simple terms are valuable in identifying and presenting grand societal challenges in sustainable development.

1.3. The 17 SDGs

The United Nations World Commission on Environment and Development report *Our Common Future* (1987), also referred to as the Brundtland Report, defined sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' This definition remains widely accepted, although it is often debated (Purvis et al., 2019). The narrative of integrating economic, social and environmental aspects of sustainable development developed from there.

On 25 September 2015 the United Nations General Assembly adopted Resolution 70/1, defining the 2030 Agenda for Sustainable Development (United Nations Department of Economic and Social Affairs, Division for Sustainable Development, 2015). This ambitious action plan aims to strengthen universal peace and calls on all stakeholders, acting in collaborative partnership, to take bold and transformative steps to shift the world onto a sustainable and resilient path. Global in nature and universally applicable, the 2030 Agenda integrates the three dimensions of sustainable development: social inclusion, environmental protection and economic growth. Never before its adoption had world leaders pledged common action across such a broad policy agenda, expanding and reinforcing the dynamics of the Millennium Development Goals, which started a global effort in 2000 to tackle the indignity of poverty (United Nations, 2015*a*).

The 2030 Agenda hinges on 17 SDGs (United Nations, 2015*b*) and focuses on implementation, with 169 targets and 247 progress indicators (United Nations, 2022*b*) tuned synchronously to improving the quality of life for all the world's inhabitants. This transformative framework (Figure 2) of interlinked and indivisible parameters calls upon the initiative of all people, individually and collectively. Governments, civil society champions and organizations, the private sector, and all other stakeholders share responsibility for the realization of these important, world-changing objectives for people, planet and prosperity.

The SDGs provide 'the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice' (United Nations, 2022*c*).

The stakes are high for everyone (United Nations, 2022*a*). Making significant progress towards achievement will require widespread understanding of the SDG framework to guide decision-making, action, and assessment of impact, and it will entail collaboration at all levels and across borders, functions and disciplines, including natural sciences (UNESCO, 2022). Geoscientists participate in projects, initiatives, advocacy, knowledge sharing and monitoring of progress towards the 2030 Agenda, yet they can play a much more prominent role.

SDG 1
No Poverty

End poverty in all its forms everywhere.

SDG 2
Zero Hunger

End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

SDG 3
Good Health and Well-Being

Ensure healthy lives and promote well-being for all at all ages.

SDG 4
Quality Education

Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

SDG 5
Gender Equality

Achieve gender equality and empower all women and girls.

SDS 6
Clean Water and Sanitation

Ensure availability and sustainable management of water and sanitation for all.

SDG 7
Affordable and Clean Energy

Ensure access to affordable, reliable, sustainable and modern energy for all.

SDG 8
Decent Work and Economic Growth

Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

SDG 9
Industry, Innovation and Infrastructure

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

SDG 10
Reduced Inequalities

Reduce inequality within and among countries.

SDG 11
Sustainable Cities and Communities

Make cities and human settlements inclusive, safe, resilient and sustainable.

SDG 12
Responsible Consumption and Production

Ensure sustainable consumption and production patterns.

SDG 13
Climate Action

Take urgent action to combat climate change and its impacts.

SDG 14
Life Below Water

Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

SDG 15
Life on Land

Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

SDG 16
Peace, Justice and Strong Institutions

Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

SDG 17
Partnerships for the Goals

Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Figure 2. The United Nations' 17 SDGs for 2030 (United Nations, 2015).

We have noticed that many professionals working in sectors in which geoscientists are usually employed, including energy, only recently have gained significant awareness of and knowledge about the SDGs. Even the best communication campaign, anchored in the most noble causes, may require years to percolate to the day-to-day activities and interests of individuals.

We are energized, rather than deterred, by this observation. With this report, we offer a route to understanding and engagement not only for individual geoscientists but also for their institutions and society at large. The report includes a review of the competencies most associated with geoscience and the social dynamics that can make them more useful in progress towards SDG achievement. Our aims include helping experts and decision-makers not trained in geoscience to better appreciate the value geoscientists deliver to the world and inspiring more multidisciplinary, multisector collaboration.

Global call to action

'What we are announcing today – an Agenda for global action for the next 15 years – is a charter for people and planet in the twenty-first century. Children and young women and men are critical agents of change and will find in the new Goals a platform to channel their infinite capacities for activism into the creation of a better world.

'"We the peoples" are the celebrated opening words of the Charter of the United Nations. It is "we the peoples" who are embarking today on the road to 2030. Our journey will involve Governments as well as parliaments, the United Nations system and other international institutions, local authorities, indigenous peoples, civil society, business and the private sector, the scientific and academic community – and all people. Millions have already engaged with, and will own, this Agenda. It is an Agenda of the people, by the people and for the people – and this, we believe, will ensure its success.

'The future of humanity and of our planet lies in our hands. It lies also in the hands of today's younger generation who will pass the torch to future generations. We have mapped the road to sustainable development; it will be for all of us to ensure that the journey is successful and its gains irreversible.'

—UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 70/1

> ‘Social sustainability (people) considers alleviating poverty; economic sustainability (prosperity) is related to the long-run sustainability of both renewable and non-renewable resources so that they are put into the system of production and make long-run economic revenue; and environmental sustainability (planet) is linked to the protection and conservation of life forms existing on earth.’
>
> **—SUSTAINABLE RESOURCE MANAGEMENT, HUSSAIN AND VELASCO-MUÑOZ (2021)**

1.4. Time for action

With fewer than 10 years to go and despite some progress, action to achieve the SDGs is not yet advancing at the speed or scale required (United Nations, 2022*d*). In September 2019, United Nations Secretary-General António Guterres called on all sectors of society to mobilize for a Decade of Action (United Nations, 2020) to accelerate sustainable solutions to the world’s biggest challenges via:

- global action to secure greater leadership, more resources, and smarter solutions for the SDGs
- local action embedding the needed transitions in the policies, budgets, institutions and regulatory frameworks of governments, cities and local authorities
- individual action to generate an unstoppable movement pushing for the required transformations

To maintain and increase the necessary momentum of action and impact, the United Nations has called for a transformative recovery of economic and societal well-being. Geoscientists are key actors in this change, and we encourage them to mobilize globally for a better tomorrow.

The timeline of the SDGs is challenging. This report describes geoscience-specific actions and examples of small steps pertinent to the discipline that can and do contribute to progress in achieving sustainability.

1.5. Organizing and measuring by dimensions

At the heart of the 2030 Agenda are five critical dimensions: the traditional people, planet and prosperity are complemented by partnership (SDG 17) and peace (SDG 16) to give the concept of sustainable development deeper meaning (United Nations System Staff College, 2017). The United Nations sees these dimensions as useful to understanding how the SDGs are interrelated to one another, leading to conscious choices in terms of trade-offs, synergies and spin-offs.

In a United Nations Foundation blog post, Brown and Rasmussen (2019) highlight the use of dimensions in assessments: ‘One way to measure progress is to focus on the “5 Ps” that shape the SDGs: People, Planet, Prosperity, Peace, and Partnerships. The 5 Ps highlight how the SDGs are an intertwined framework instead of a group of siloed goals. Progress on one P must balance and support progress on another.’

Importantly, there is no universal definition of these dimensions: each organization, depending on its focus and agenda, will include and spotlight different factors. This is how we consider the SDGs for the purposes of this *Geoscience in Action* report, factoring in interconnections and mapping geoscientific contributions to each dimension.

In our mapping and in assembling our examples, we have organized our work around the people, planet and prosperity dimensions and regard the SDGs of peace (SDG 16) and partnerships (SDG 17) as integral parts of all three dimensions.

02

No water. No vegetation. No oases. Known as the "Land of Terror," the Tanezrouft Basin in Algeria is one of the most desolate parts of the Sahara Desert. Sand dunes, which appear in yellow, streak down the left side of the image, and sandstone formations carved by relentless wind erosion make concentric loops, much like the grain seen in a piece of wood. © unsplash.com/@usgs.

GEOSCIENCE AND SUSTAINABILITY: PEOPLE, PLANET AND PROSPERITY

2.1. Building a framework for geoscience and sustainability

Geoscience and geoscientists contribute unique skills and competencies to initiatives of the 2030 Agenda for Sustainable Development. To map these contributions, we:

- classified the SDGs according to the widely accepted definitions of people, planet and prosperity under the 2030 Agenda (United Nations Department of Economic and Social Affairs, Division for Sustainable Development, 2015). This grouping reinforces how the SDGs are an intertwined framework rather than of a group of siloed goals. Progress on one dimension can lead to progress on another.
- assessed the 169 targets and 231 unique indicators for the SDGs to understand the spectrum of contributions made by geoscience and geoscientists to each of the dimensions.
- established the dominant (primary) and secondary SDGs for each dimension. Defining primary and secondary SDGs for a target and dimension does not exclude consideration of the other SDGs. The interlinked nature of the SDGs is critical to their advancement.

The resulting classification is one interpretation of the people, planet and prosperity dimensions in relation to geoscience and geoscientists; it is neither absolute nor exclusive. We acknowledge that SDGs identified as dominant in a dimension pursuant to our methodology may not appear so in other mappings. We celebrate a variety of approaches leading to constructive engagement and positive outcomes. To that end, we encourage all readers to build on this proposal and explore the SDGs, including targets, indicators, publications, initiatives and events, on the United Nations Industrial Development Organization (2022) Knowledge Hub.

> 'By performing an SDG mapping exercise, an organization, an industry, a scientific sector, or a segment of society can better identify its opportunities, strengths, and weaknesses as a potential contributor to the achievement of these goals. The results also will empower individual geophysicists to identify opportunities to contribute toward advancing the SDGs in their own spheres of influence and expertise. Mapping exercises are a way to build individual and organizational strategies for a new era, creating a buy-in toward the SDGs.'
>
> **—GEOPHYSICAL SUSTAINABILITY ATLAS, CAPELLO ET AL. (2021)**

2.2. People dimension: positive impact on individuals

Traditionally focused primarily on poverty alleviation and employment, the social dimension of sustainable development is perhaps less defined than the others and now extends to encompass wider and less measurable factors such as quality of life, social interactions, gender equity, culture, and integrated governance, including human rights (United Nations Department of Economic and Social Affairs, 2022). The COVID-19 pandemic and ensuing socioeconomic crisis have further heightened the focus on this aspect of sustainability, with a renewed drive to curb social and health inequities.

> 'We are determined to end poverty and hunger, in all their forms and dimensions, and to ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment.'
>
> **—UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 70/1**

To identify avenues and options for geoscience and geoscientists to contribute in this dimension, we considered mainly the potential for direct positive impact, at an individual level, of geoscientific knowledge informing better decision-making and reversing misconceptions about sustainability stakes. Primary targets and indicators of progress for each target are identified for each SDG (United Nations, 2015*b*), and those towards which we envisage geoscience contributions – shortened to highlight aspects most relevant to geoscience – include:

- **Supporting Goal 1: No poverty —** End poverty in all its forms everywhere
  - **1.4** Ensure all have equal rights to natural resources and appropriate new technology
  - **1.5** Build the resilience of those in vulnerable situations to climate-related extreme events and other environmental shocks and disasters

- **Supporting Goal 2: Zero hunger —** End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
  - **2.3** Double agricultural productivity through knowledge
  - **2.4** Ensure sustainable food production systems and implement resilient agricultural practices

- **Supporting Goal 3: Good health and well-being —** Ensure healthy lives and promote well-being for all at all ages
  - **3.9** Reduce deaths and illness from air, water and soil pollution and contamination

- **Supporting Goal 4: Quality education —** Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
  - **4.7** Ensure all learners acquire the knowledge and skills needed to promote sustainable development
  - **4.b** Expand scholarships for technical, engineering and scientific programmes

- **Supporting Goal 5: Gender equality —** Achieve gender equality and empower all women and girls
  - **5.5** Ensure women's full and effective participation and equal opportunities in economic life
  - **5.b** Enhance the use of enabling technology to promote the empowerment of women

- **Supporting Goal 6: Clean water and sanitation —** Ensure availability and sustainable management of water and sanitation for all
  - **6.1** Achieve universal and equitable access to safe and affordable drinking water
  - **6.b** Support participation of local communities in improving water and sanitation management

- **Supporting Goal 17: Partnerships for the goals —** Strengthen the means of implementation and revitalize the global partnership for sustainable development
  - **17.6** Enhance international cooperation on and access to science, technology and innovation
  - **17.7** Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries
  - **17.19** Develop measurements of progress on sustainable development

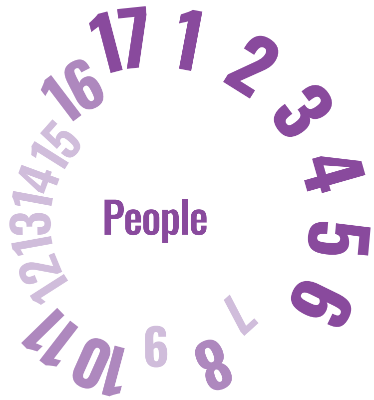


Figure 3. The geoscience people dimension showcases the main SDGs tapped by geoscientists for elements related to human well-being and quality of life: 1, 2, 3, 4, 5, 6 and 17. Identified as important and related at a secondary level are SDGs 8, 10 and 11.

Indicators for assessing progress towards achieving SDG targets and goals are provided in the UN Statistics Wiki: E-Handbook on SDG Indicators (United Nations, 2022*b*). Figure 3 illustrates the primary and secondary SDGs that geoscience addresses in the people dimension.

This report's people dimension examples involve economic, social and physical cartography; soil geochemistry and nutrients; geologically based indoor-radon potential hazard mapping; geoscience awareness raising through radio programming; geoscience gender equity initiatives; and securing potable water.

2.3. Planet dimension: positive impact on physical systems

Perhaps the most widely agreed on and understood dimension of sustainability, and a predominant consideration in the emergence of the notion of sustainable development, is the set of environmental factors that is central to the global challenges that the 2030 Agenda seeks to address. This planet dimension is sometimes restricted to current factors of environmentally conditioned welfare and health, including air quality, noise, and water quality; the more widely accepted view of the dimension encompasses all conditions of long-term development through critical natural resources, ecosystems, waste management and climate stability.

> 'We are determined to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations.'
>
> **—UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 70/1**

To identify avenues and options for geoscience and geoscientists to contribute in this dimension, we considered mainly the potential for direct positive impact on physical systems and geoscientists' capacity to direct principles-based action for sustainable outcomes. Primary SDG-supporting targets (United Nations, 2015*b*) for which we envisage such contributions (Figure 4) include:

- **Supporting SDG 6: Clean water and sanitation —** Ensure availability and sustainable management of water and sanitation for all
  - **6.1** Achieve universal and equitable access to safe and affordable drinking water for all
  - **6.2** Implement integrated water resources management at all levels

- **Supporting SDG 7: Affordable and clean energy —** Ensure access to affordable, reliable, sustainable, and modern energy for all
  - **7.2** Increase substantially the share of renewable energy in the global energy mix
  - **7.a** Facilitate access to clean energy research, including cleaner fossil-fuel technology

- **Supporting SDG 12: Responsible consumption and production —** Ensure sustainable consumption and production patterns
  - **12.2** Achieve the sustainable management and efficient use of natural resources
  - **12.4** Achieve the environmentally sound management of chemicals and all wastes
  - **12.8** Ensure that people everywhere have awareness for sustainable development

- **Supporting SDG 13: Climate action —** Take urgent action to combat climate change and its impacts
  - **13.1** Strengthen resilience to climate-related hazards and natural disasters
  - **13.2** Integrate climate change measures into national policies, strategies and planning
  - **13.3** Improve institutional capacity on climate change mitigation and impact reduction

- **Supporting SDG 14: Life below water —** Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
  - **14.2** Sustainably manage and protect marine and coastal ecosystems, including restoration
  - **14.3** Minimize and address ocean acidification, including through scientific cooperation

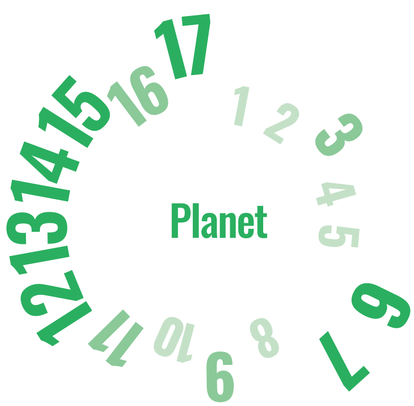


Figure 4. The geoscience planet dimension showcases the main SDGs tapped by geoscientists for elements related to the planet and its ecosystems: 6, 7, 12, 13, 14, 15 and 17. Identified as important and related at a secondary level are SDGs 3, 9, 11 and 16.

- **Supporting SDG 15: Life on land —** Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
  - **15.1** Ensure the conservation, restoration and sustainable use of freshwater ecosystems
  - **15.9** Integrate ecosystem and biodiversity values into national and local planning

- **Supporting SDG 17: Partnerships for the goals —** Strengthen the means of implementation and revitalize the global partnership for sustainable development
  - **17.6** Enhance international cooperation and access to science, technology and innovation
  - **17.7** Promote the dissemination of environmentally sound technologies to developing countries
  - **17.19** measurements of progress on sustainable development

This report's planet dimension examples cover citizen science applied to water quality monitoring, geothermal energy, biodiversity protection in UNESCO Global Geoparks, carbon capture and storage, fish habitat monitoring, and assessing forest ecosystem health.

2.4. Prosperity dimension: positive impact on socioeconomic systems

The global economy acts as both enabler and primary risk to the other two dimensions, people and planet (Brown and Rasmussen, 2019). Sustainable development entails reorganization of economic systems to balance growth with other goals and yield wider economic benefit. Systemic solutions are required to reduce increasing inequities, yet trends towards achieving shared prosperity have mostly stalled, and vast, systemic inequities that limit prosperity in terms of decent work, economic mobility, equity, access to energy, diversity and inclusion remain. Limiting and reversing climate change are increasingly considered both a constraint and an opportunity for sustainable growth as economies transition to innovative technologies for cleaner energy and more reasoned impact on ecosystems.

To identify avenues and options for geoscience and geoscientists to contribute to the prosperity dimension, we considered mainly the potential for direct positive impact on socioeconomic systems, leveraging geoscience's exploration of options enabling sound outcomes and geoscientists' inherently multidisciplinary approach. Primary SDG-supporting targets (United Nations, 2015*b*) for which we envisage such contributions are indicated in large bold letters in Figure 5 and include:

Figure 5. The geoscience prosperity dimension showcases the main SDGs tapped by geoscientists for elements related to the prosperity of human beings: 7, 8, 9, 10, 11 and 17. Identified as important and related at a secondary level are SDGs 1, 2, 3, 4, 5, 12 and 16.

- **Supporting SDG 7: Affordable and clean energy —** Ensure access to affordable, reliable, sustainable, and modern energy for all
  - **7.2** Increase substantially the share of renewable energy in the global energy mix
  - **7.a** Facilitate access to clean energy research, including cleaner fossil-fuel technology

- **Supporting SDG 8: Decent work and economic growth —** Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all
  - **8.2** Achieve higher levels of economic productivity through diversification and innovation
  - **8.5** Achieve full and productive employment and decent work and payment for all

- **Supporting SDG 9: Industry innovation and infrastructure —** Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
  - **9.1** Develop quality, reliable, sustainable and resilient infrastructure
  - **9.4** Upgrade and retrofit industries to make them sustainable with clean technologies

- **Supporting SDG 10: Reduced inequalities —** Reduce inequality within and among countries
  - **10.2** Empower and promote the economic inclusion of all
  - **10.4** Adopt policies, especially social protection policies, to achieve greater equality

- **Supporting SDG 11: Sustainable cities and communities —** Make cities and human settlements inclusive, safe, resilient, and sustainable
  - **11.3** Enhance sustainable urbanization and human settlement planning and management
  - **11.4** Protect and safeguard cultural and natural heritage
  - **11.5** Anticipate and reduce disaster impact

> ‘We are determined to ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature.’
>
> **—UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 70/1**

- **Supporting SDG 16: Peace, justice and strong institutions —** Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels
  - **16.10** Ensure public access to information
  - **16.a** Strengthen relevant national institutions for building capacity at all levels
  - **16.b** Promote and enforce policies for sustainable development

- **Supporting SDG 17: Partnerships for the goals —** Strengthen the means of implementation and revitalize the global partnership for sustainable development
  - **17.6** Enhance international cooperation and access to science, technology and innovation
  - **17.7** Promote the dissemination of environmentally sound technologies to developing countries
  - **17.19** Develop measurements of progress on sustainable development

This report’s prosperity dimension examples involve standards for resource extraction and reporting, geoethics, earthquake hazard mitigation, action towards equity in geoscience, forecasting volcanic activity and risks, and using geoscience in heritage site investigation.

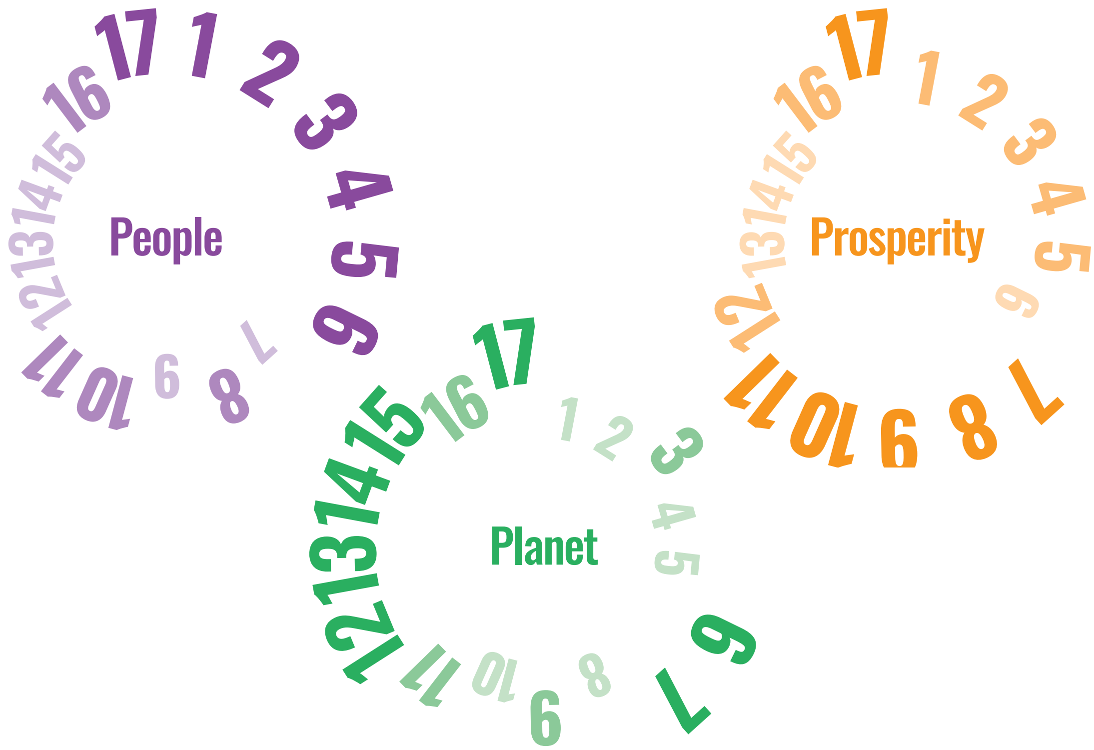


Figure 6. Graphic illustration of the interconnection among the three geoscience dimensions.

2.5. Interlinkages among the dimensions: opportunities for cooperation on multiple fronts

The interconnection and interlinkages among the three dimensions are better understood when we analyse the specificities of each one of the SDGs. It is, by definition, impossible to consider each one separate from others, especially when mapping from the perspective of disciplines or knowledge areas. Hence, some of the SDGs that are considered primary for one dimension may be found repeated in another. For example, SDG 17 and SDG 16 appear as primary or secondary for the three dimensions.

These interlinkages unleash important opportunities for practitioners of geoscience disciplines to emerge from their silos and collaborate with practitioners of other professions and disciplines to advance sustainability initiatives. Our selection of examples aims to illustrate how geoscience contributes to advancement in each of the dimensions (Figure 6), in part to facilitate application of this report to new projects and initiatives.

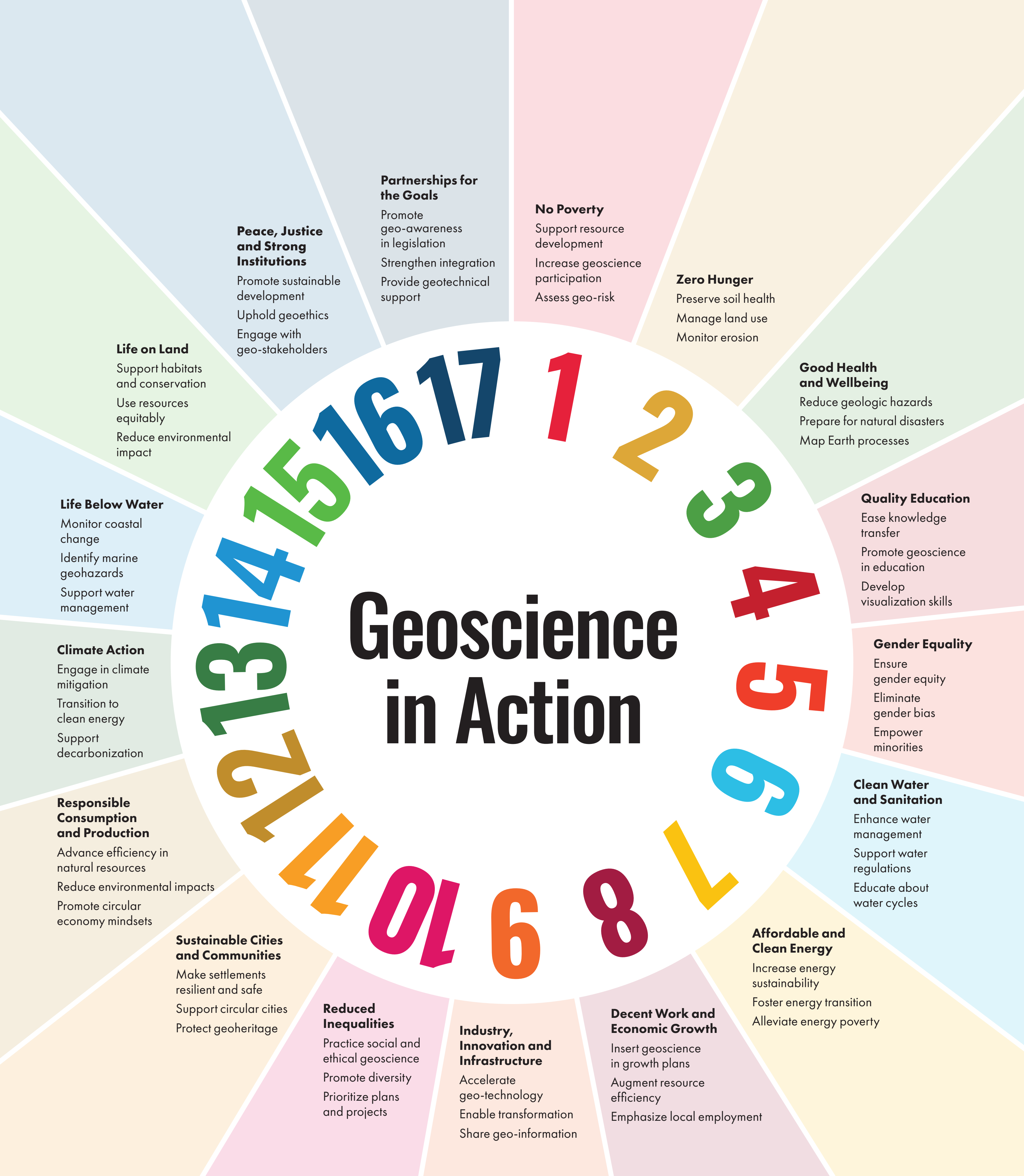


Figure 7. The geoscience sustainability clock. Geoscience tools, methods and approaches are mapped to each one of the 17 SDGs.

2.6. A clock to summarize how geoscience advances the 17 SDGs

Following the work done to map geophysics tools, knowledge and techniques to the 17 SDGs, we expanded the approach to cover and consider all geosciences.

The result is an expanded perspective that encompasses a full spectrum of geosciences – from volcanology to hydrogeophysics and from geochemistry to satellite monitoring. The challenge was to determine how to put into evidence the vast variety of disciplines, applications, and segments of life, industry and economy in which geoscientists work for sustainable purposes. A decision was made to work with case studies, mapping those to the three selected dimensions – people, planet and prosperity – as well as to the SDGs.

Inspired by a strategy that was used in creation of the Geophysical Sustainability Atlas (Capello et al., 2021), we concentrated the SDG mapping in a single infographic we call the geoscience sustainability clock (Figure 7).

03

The so-called Richat Structure is a geological formation in the Maur Adrar Desert in the African country of Mauritania. Although it resembles an impact crater, the Richat Structure formed when a volcanic dome hardened and gradually eroded, exposing the onion-like layers of rock. © unsplash.com/@usgs.

GEOSCIENCE COMPETENCIES

Across this report, we address how geoscience research and professional practice are central to sustainability and delivering the SDGs. The geosciences are fundamental to the exploration, development and management of natural resources; to investigating and alleviating environmental concerns; and to the mitigation of natural hazards. The American Geosciences Institute has examined the essential geoscientific skillset in *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education* (Mosher and Keane, 2021). Here we highlight the key technical, conceptual and social competencies of the modern geoscientist.

3.1. Geoscience technical competencies

Geoscientists are Earth scientists, meaning that their core concern is the fundamental working of the planet. Geoscience is a multidisciplinary science that integrates physics, chemistry and biology; draws from engineering, computing and mathematics; and spills over into the geographical and environmental sciences, as depicted in Figure 8. Blending and balancing these disparate disciplines lead to high-level technical expertise across a broad portfolio of subdisciplines, notably:

- geophysics: deploying a wide array of techniques that image inside the planet's depths, monitor the action of earthquakes (seismology) and volcanoes (volcanology), and explore for subterranean mineral, energy and water resources
- geochemistry: forensically characterizing the materials, minerals and rocks that make up our physical world (mineralogy and petrology) using the tools and principles of low-temperature aqueous geochemistry for environmental problem solving
- geobiology: revealing the intimate relationships between environments and ecosystems, past and present, and charting the evolution of life as preserved in the rock record (palaeontology)
- engineering geology: using our understanding of soil and rock properties to solve practical problems for infrastructure and the built environment (whereas hydrogeology examines the flow of groundwater in the subsurface)
- geodata science: using probability and statistics to measure Earth variables over time and space and high-level mathematical modelling and computation tools alongside artificial intelligence and machine learning systems to solve and visualize complex systems

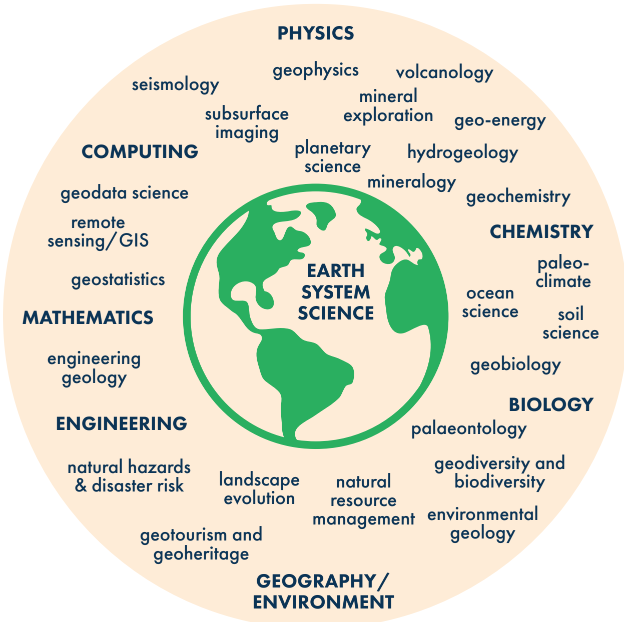


Figure 8. The multidisciplinary nature of geoscience, integrating physics, chemistry and biology and drawing from engineering, mathematics and geography.

3.2. Geoscience conceptual competencies

The human mind is arguably the geoscientist's most important tool. It is the geoscience mind that converts colours and textures of dirt or blotches on a satellite image or wiggles on a seismogram into explanatory narratives about the formation and migration of oil, the rise and fall of mountain ranges, and the opening and closing of oceans (Kastens et al., 2009). Geoscientists take a long view of time, appreciating the relative brevity of human history within the vastness of the age of Earth. Business, politics and the media tend to operate on short time-frames, on the order of days to years, but the geologic view of deep time can provide a crucial counterweight and support decision-making with a time horizon of decades to centuries. In this role as *time travellers*, geoscientists can envision Earth in states drastically different from the planet they personally have experienced. They do so because of their command of key conceptual skillsets.

- Comprehension of the planet as a holistic unit is pivotal to engage in strategic planning and think beyond regional and national barriers to identify collaborative solutions.
- Field-based learning is fundamental for geoscientists to observe and develop a feel for Earth processes and a sense of scale. It strengthens their ability to integrate fragmentary information, reason spatially and temporally, and critique the quality of observational data.
- Multiscalar levels of inquiry, from the nano to the planetary and from seconds to millions of years, are key to understanding how Earth processes work.
- Three- and four-dimensional thinking that requires considerable intellectual flexibility, imagination and creativity is needed for geoscientists to visualize and solve problems in three dimensions and across geologic time.
- Interdisciplinary problem-solving skills address problems in the context of an open and dynamic system of interacting parts and processes.
- Management of subjectivity, uncertainty, and risk is integral to all geoscience interpretations.
- Geoscience reasoning and synthesis are crucial to tackle geoscience problems that have no clear, unambiguous answers. Geoscientists work by analogy and inference to make predictions about the future and to draw conclusions about the past with limited data and to test potential solutions against real observational data.

3.3. Social competencies of geoscientists

Geoscientists often conduct initial assessments for new mineral prospects or major environmental and Earth-engineering projects and frequently are the experts that the public first encounters in related planning and decision-making. Securing the *social license to operate* from local communities means geoscientists need to be economically, socially and culturally aware and communicate empathetically and diplomatically. Whether working within their organizations, interacting with other technical specialists and other professionals, or engaging with non-scientists outside their organizations, geoscientists create stories that translate data and observations into compelling narratives about the planet's past, present and future that link to far-seeing environmentally and societally responsible decision-making.

Geoscientists have a community of practice; they are not merely individuals who know about the planet, but a global community that has been shaped by and embodies a distinctive suite of experiences, approaches, perspectives and values, including:

- multidisciplinary and multicultural teamwork, including negotiation, conflict resolution, mentoring operations, and project management

Technical competencies

Geophysics

Geobiology

Geochemistry

Engineering geology

Geodata

Structural geology

Other branches of geoscience

Conceptual competencies

Field-based learning

Multiscalar levels of inquiry

3D and 4D thinking

Interdisciplinary problem solving

Geoscience reasoning and synthesis

Management of subjectivity and uncertainty

Other branches of geoscience

Social competencies

Multidisciplinary teamwork

Negotiation

Mentoring

Understanding societal relevance

Preparing communities for geohazards

Ability to sell ideas

Storytelling

Cultural literacy

Figure 9. Technical, conceptual and social competencies of geoscientists.

- the ability to convey abstract ideas and create compelling stories
- leadership and influence and the ability to inspire others
- application of technology to real-world problems
- utilization of analogs, enhancing collaborative approaches across country borders
- business management
- social learning, cultural literacy, and understanding of societal relevance

None of these attributes, taken individually, is unique to the geosciences, nor does every individual geoscientist have every one of these skillsets, subscribe to every perspective, and utilize every approach. Indeed, it is fair to say that although our technical competencies are well developed, geoscience conceptual competencies are often not fully realized, even by ourselves, geoscientists. Perhaps more importantly, however, many key aspects of our potential social skillsets remain underdeveloped. Geoscience educators have a public role not only as the planet's storytellers but also as the inspirers of the next generation of twenty-first-century Earth scientists and decision-makers.

An important contribution of this report is to recognize where skills need to be improved in future geoscience training (Figure 9). Addressing sustainable development challenges requires work at the boundaries of disciplines and sectors. To work effectively at these interfaces, geoscientists need to develop into *science diplomats*, strengthening their latent skills in stakeholder mapping, negotiation, ethics, partnership development, and policy shaping. The interface between geoscience and the human sciences (sociology, psychology, political science, economics) is another critical space that needs to be developed if geoscientific knowledge and understanding are to translate into wise planetary stewardship.

04

The deep purple in the lower right spreads out into a few channels before fading into a multitude of colors. These channels are remnants of an ancient drainage network in Kenya. The beauty of the colors actually hides a stark reality for hundreds of thousands of people. The dark spots at the top center of the image are refugee camps. © unsplash.com/@usgs.

HOW GEOSCIENCE ADVANCES THE SDGS: SOME EXAMPLES

4.1. Call for examples

The authors of this report engaged in a campaign to obtain global examples demonstrating geoscientists advancing the SDGs. Posts made on social media and professional platforms, such as LinkedIn, Instagram and Twitter, triggered an overwhelming response.

Eighteen examples – six per dimension – were selected from the many submissions adhering to a range of criteria.

Examples were selected on the basis of the quality of the content and whether they helped ensure that collectively they mapped to all SDGs.

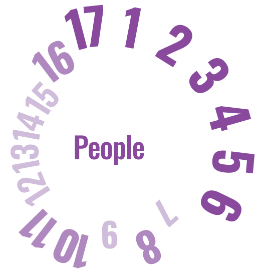
The selection process also involved considering relevance, impact, global distribution and noncommercialism. Further, we ensured that the examples would cover initiatives at the individual, group and organizational levels, with different scopes that address the dimensions people, planet and prosperity. Care also was taken to ensure that the collection included examples from a range of geoscience sectors and practices. In some cases, case histories related by topic were clustered as a single example.

Enhancement and expansion paths are proposed for each example, with the intention of inspiring readers to think similarly about the sustainability potential of projects with which they might be involved.

Our hope is these examples will help geoscientists acquire new perspectives and provide them with a framework within which to apply their skills and expertise to meet the needs of the present and the future.

We received more high-quality examples than we could include in this report, and some of those not published here will be shared on the *Geoscience in Action* website (2022) and in campaigns to raise awareness about this mapping initiative.

4.2. Examples for the people dimension



	People dimension examples mapped to the SDGs	Primary SDGs	Secondary SDGs
4.2.1.	Geoscientific data for policy decisions: economic, social and physical cartography of an invisible city – São Leopoldo Municipality, southern Brazil	1	2 3 6 10 11
4.2.2.	Supporting agriculture and health policies: understanding soil geochemistry and micronutrients; Africa capacity-strengthening initiative – Malawi, Zambia and Kenya	2	3 12
4.2.3.	Geologic mapping to identify health risks: geologically based indoor-radon potential hazard map – Kentucky, United States of America	3	4 11
4.2.4.	Creating awareness of geoscience in society: *The Geoscience Corner* radio talk show – Namibia	4	3 9 10 11
4.2.5.	Towards gender equity in geoscience: GeoLatinas (Latin America), Indigenous Women in Mining and Resources Australia, and Girls into Geoscience (United Kingdom and Ireland)	5	4 7 8 16
4.2.6.	Access to water: Delhi water crisis; the Palla Project – India	6	2 3 9 11
	SDGs mapped to the people dimension: positive impact on individuals	1 2 3 4 5 6	5 8 10 11 16

Table 1. Examples that show how geoscience supports the people dimension and how the examples map to the SDGs. A few examples include secondary SDGs that are not among SDG assignments for the dimension, reflecting that many examples of geoscience activity invoke multiple dimensions.

4.2.1.

Geoscientific data for policy decisions: economic, social and physical cartography of an invisible city – São Leopoldo Municipality, southern Brazil

Synopsis

Social cartography of an *invisible city* is a multidisciplinary and transdisciplinary project that addresses communities living in occupied areas of the São Leopoldo Municipality, southern Brazil. The project includes teachers, employees, students and volunteers from different organizations. The invisibility of these communities in terms of social, economic and educational public policies generated a severe social vulnerability aggravated by the Brazilian political crisis and the impacts of the COVID-19 pandemic. After evaluating the scenario, a solidarity network (Rede Solidária São Leo) was structured to provide judicial assistance for land regulation, guarantee food and health security, and promote employment generation and income. More recently, geoscience was included in the project´s scope because most of the occupied areas in the municipality are part of environmentally sensitive and geologically hazardous areas for flood inundations. Funding for this project would improve the number of people collecting field data and accelerate the diagnostics and mapping of the environmental and geologic hazard area.

Challenges, opportunities and objectives

- The main purpose of the project is to integrate social and physical georeferenced data into a geographic information system (GIS)-based system to support decision-making for public policies.
- This work will demarcate the environmentally sensitive and hazardous areas for inundations in the flood plain of the Sinos River, where some of the communities are located.

Project profile

The project involves about 35 teachers, students, municipal employees and secretaries, and community leaders. At the time of this publication, the project had no significant financial support; therefore, everyone paid for their own expenses when working in the communities. Individuals and organizations donated some funds that were used exclusively for food, toiletries and cleaning supplies.

A mobile application was developed to record data during interviews with the residents. The health, education and economic information necessary to understand the community's social vulnerability and the *invisibility* of the community were analysed with data analysis techniques for appropriate statistical treatment and data representation. Without a valid address, residents were *invisible* to health agents who might help address problems of basic sanitation, water and electric power.

A project based on GIS mapping was structured to identify and demarcate all the occupied areas. A zonation of the Sinos River flood plain based on declivity will demarcate areas that will potentially flood during extreme rainfall events. Uncrewed aerial vehicle (UAV) surveys will provide high-resolution three-dimensional (3D) models of the areas of interest and large-scale cartographic products useful for land regulation and demarcation of the environmentally protected area. Geophysical surveys will also be used to investigate a polder (low-lying reclaimed land) located at the margin of the Sinos River beside one of the occupied areas.

Few similar methods and approaches appear in the scientific literature. Social cartography based on GIS, remote sensing, and data analysis seems to be a novelty and might be useful worldwide.

Project leadership

The project was led by Unisinos University.

There is not a formal hierarchy in the Rede Solidária São Leo. Key leaders are Prof Marilene Maia and Prof Isamara Allegretti (social service, senior leaders and managers), Prof Francisco Tognoli (geology, geoscience leader), and Prof Adriane Thum and Prof Patricia Nerbas (engineering/architecture, urban planning leaders). Additional leaders include the São Leopoldo municipal secretaries for social development, public security, housing, health, education, and human rights; Housing National Movement; and Missionárias de Cristo Ressuscitado Human Rights State Council and Human Rights Defense Center.

Outcomes and impact

- The project addresses 15 occupied areas and about 10,000 families in the municipality.
- Phase I data were acquired in only two areas because of personnel and cost limitations. This phase directly impacted 350 families, or 1,400 people, living in the occupied areas located in a neighbourhood that is included in the geologic hazard area for flood inundations.
- More than 17,000 people are estimated to be impacted by the geoscientific approach of the project in this first phase.
- The results of this project can be used in public policy formulation and urban planning.

KEYWORDS AND HASHTAGS

#Cartography #FloodZones #InvisibleCities #SocialVulnerability #Brazil #Flooding #Rainfall #Amazon #Pluviometry #SDG1

PRIMARY AND SECONDARY SDGS

1 2 3 6 10 11

Key geoscience skills

- **Technical:** GIS mapping, remote sensing, 3D modelling, UAV data collection
- **Conceptual:** field-based learning, multiscalar levels of inquiry, 3D and 4D thinking, interdisciplinary problem solving
- **Social:** multidisciplinary teamwork, application of technology to real-world problems, understanding of societal relevance

Upscaling and accelerating actions

This project includes 15 communities in the São Leopoldo Municipality. The next steps are to include more communities in the database and to continue to monitor and update the data for the previous communities. The results obtained in this initial approach will support searching for funds, which is crucial to increase the research staff and accelerate data acquisition.

Where to find out more

City of São Leopoldo, Brazil. 2021*a*. Social cartography of urban occupations in São Leopoldo starts this Friday. [In Portuguese: Cartografia social das ocupações urbanas de São Leopoldo inicia nesta sexta-feira.] https://www.saoleopoldo.rs.gov.br/?titulo=&template=conteudo&categoria=&codigoCategoria=&idConteudo=&idNoticia=25925&tipoConteudo=INCLUDE_MOSTRA_NOTICIAS (Accessed 28 December 2022.)

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4.2.2.

Supporting agriculture and health policies: understanding soil geochemistry and micronutrients; Africa capacity-strengthening initiative – Malawi, Zambia and Kenya

Synopsis

Soil occupies the heart of SDG 2, 'Zero Hunger', because, to a great extent, crop yield is determined by soil fertility. What most people do not understand is the *hidden hunger* from mineral deficiencies (British Geological Survey Science Facilities, Centre for Environmental Geochemistry, 2022) and that poor soils can lead to malnutrition and serious health issues. To address the issue, the University of Nottingham and the British Geological Survey (BGS), through a new Royal Society-Department for International Development (DFID) Africa Capacity Strengthening Initiative, started a project to understand soil geochemical processes that could support policies in agriculture and public health.

In a parallel study, the Centre for Environmental Geochemistry of the BGS, in collaboration with the International Agency for Research on Cancer and Moi University and the University of Eldoret, both in Kenya, initiated environmental and human biomonitoring sampling in Kenya to provide a measure of environmental and dietary factors along with other factors leading to oesophageal cancer. Cancer is an emerging health problem in Africa, and oesophageal cancer is one of the most prevalent cancers in East Africa (Hamdi et al., 2021). In this study, the aim is to examine the link between geochemistry and crop data with areas of high-frequency cases of oesophageal cancer (Watts et al., 2016).

Challenges, opportunities and objectives

- The role of geochemistry in the origin of several diseases, including cancers, through malnutrition is not understood fully.
- Geochemical mapping of soil, water and crops was carried out to understand the distribution of essential micronutrients (e.g. selenium and zinc) and investigate any potential linkage of these micronutrients with prevalent health issues.
- Data generated through these investigations can help to carry out appropriate interventions to prevent the diseases caused by malnutrition and increase crop production.
- Providing training to local scientists and public health officers was another important aspect of the project for local capacity building.

Project leadership

BGS (Centre for Environmental Geochemistry) and the University of Nottingham led the project. Partner institutes included Lilongwe University of Agriculture and Natural Resources and the Department of Agricultural Research in Malawi; the University of Zambia, the Zambian Agricultural Research Institute, and Copperbelt University in Zambia, the Chemistry and Soils Research Institute in Zimbabwe; and Moi University and the University of Eldoret in Kenya.

Project profile

The multidisciplinary aspect of the project is evident in that it brings together geochemists, farmers, health practitioners, biostatisticians and epidemiologists. Round 1 of the project started in about 2015 with the aim to bring understanding about the geochemical processes in soil that could help in formulating agriculture and health policies. Experts from the United Kingdom, Malawi, Zambia and Zimbabwe collaborated in this effort, with plans to extend it to Kenya.

A soil prediction map of 56 chemical elements, pH, and organic matter was developed with machine learning analysis using several layers of information such as element concentrations in soil samples, major landforms, average rainfalls, dominant parent materials, major waterbodies, etc. (Figure 10).

An understanding of soil geochemistry and associated micronutrients supplies the data needed for policy-makers to provide area-specific interventions for food fortification and assessment of geogenic health risks.

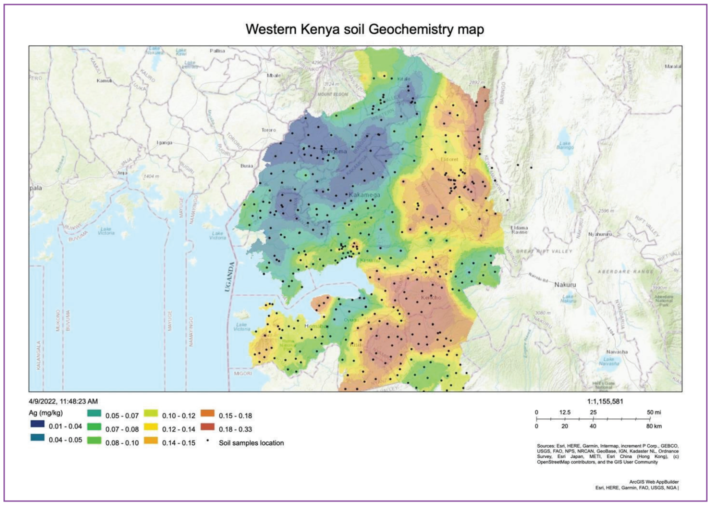

Figure 10. Soil geochemistry map of western Kenya developed by the British Geological Survey (2022).

KEYWORDS AND HASHTAGS

#Geochemistry #Soil #Micronutrients #Malnutrition #OesophagealCancer #Food #Kenya #SDG2

PRIMARY AND SECONDARY SDGS

2 3 12

Outcomes and impact

- Knowledge of soil geochemistry can assist in investigating the impact and influence of measured parameters on health conditions such as micronutrient deficiency and oesophageal cancer.
- The geochemical studies also will help in providing information to local stakeholders about their exposure to potentially harmful geogenic metals that have chronic health implications (Humphrey, 2021).
- An understanding of soil geochemistry can help policy-makers provide area-specific interventions for food fortification.

Key geoscience skills

- **Technical:** analytical geochemistry, geospatial analysis, machine learning
- **Conceptual:** field-based learning, geoscience reasoning and synthesis
- **Social:** multidisciplinary teamwork, application of technology to real-world problems, understanding of societal relevance

Upscaling and accelerating actions

With a growing population, the demand for food is increasing. Meeting the demand requires various means to increase crop yield. However, beyond crop fertility and yield, not much attention is given to the micronutrients in soil that are essential for human well-being. There is an urgent need to initiate soil geochemistry and micronutrient programmes, especially in developing countries, to understand the link between environmental factors and human well-being.

Where to find out more

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4.2.3.

Geologic mapping to identify health risks: geologically based indoor-radon potential hazard map – Kentucky, United States of America

Synopsis

Kentucky Geological Survey and University of Kentucky College of Nursing Bridging Research Efforts and Advocacy Toward Healthy Environments (BREATHE) programme scientists combined more than 70,000 home radon test kit results with Kentucky's digital geologic map coverage to produce the most detailed statewide indoor-radon potential risk map in the United States of America. The map is web-based and searchable and merges detailed geologic mapping, radon home test kits, and colour-coded hazard values to help residents understand their risk to the clear, odourless, tasteless gas. The information can be used to bring awareness to the health risks of radon, encourage testing, and implement technology to reduce high radon levels.

Challenges, opportunities and objectives

- Radon is the second-leading cause of lung cancer in the United States of America.
- Kentucky has one of the highest smoking rates in the United States of America, and the effects of radon are exacerbated by cigarette smoke.
- The geology-based indoor-radon potential risk map of Kentucky is an ongoing public health advocacy programme that will help communicate the health risks of radon (Figure 11).

Project leadership

The Kentucky Geological Survey and the University of Kentucky College of Nursing BREATHE programme led the project.

Project profile

Radon is derived from the decomposition of uranium in rock and surrounding soil and is found in every region in the United States of America. Individual geologic rock units and structural features have varying concentrations of uranium and produce different amounts of radon, thus the importance of mapping residential radon concentrations by geologic and geographic area. Black shale and phosphatic limestones are the common uranium-bearing, high-radon-potential rock types in Kentucky.

The project received funding through a National Institute of Environmental Health Sciences research centre grant to purchase a gamma spectrometer for a Kentucky Geological Survey drone. The drone collects airborne data, allowing the survey to better understand the effects of geologic features such as lithologic changes, faults and sinkholes on soil radon levels. The goal is to use the detailed data collected to construct potential radon microzonation maps.

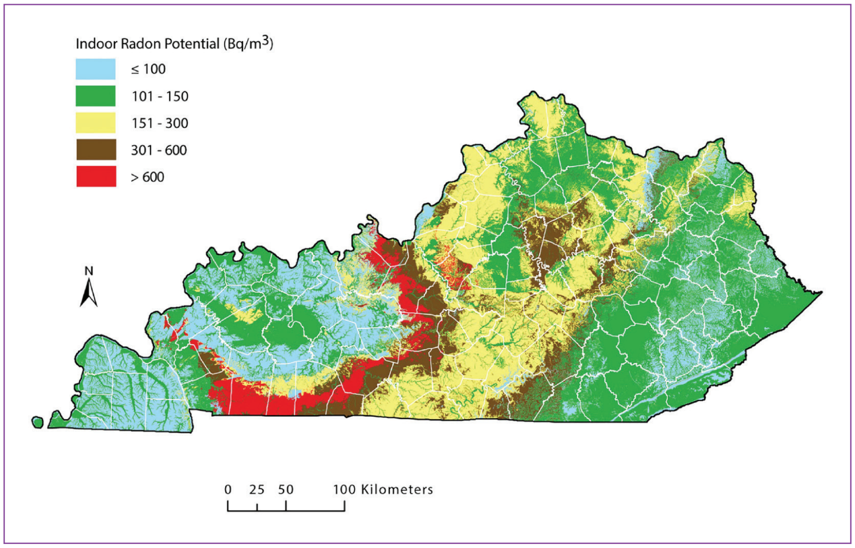

Figure 11. Map of Kentucky showing indoor radon potential [Bq/m3] (Hanneberg et al., 2020).

KEYWORDS AND HASHTAGS

#Radon #LungCancer #BREATHE #Kentucky #hazards #SDG3

PRIMARY AND SECONDARY SDGS

3 4 11

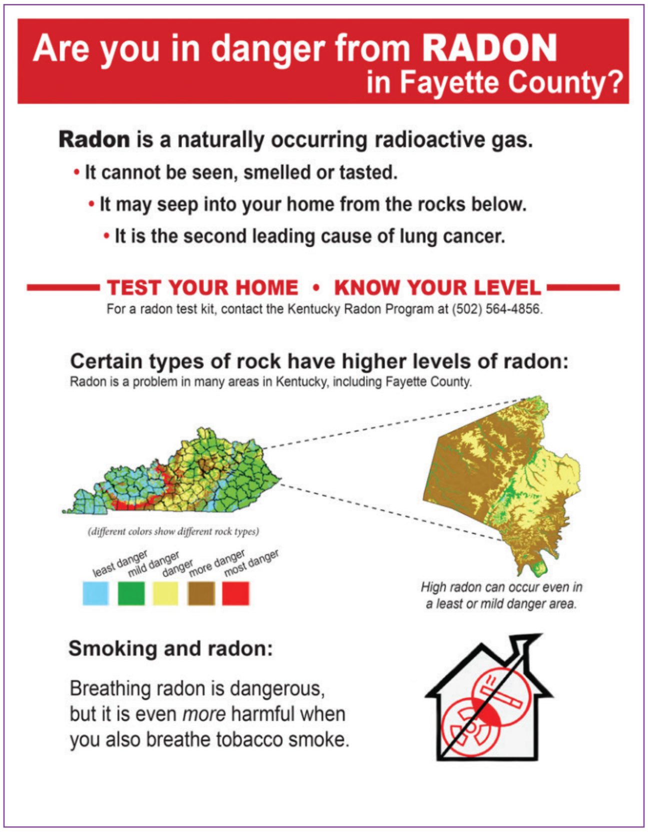

Figure 12. A notice about radon dangers in Fayette County, Kentucky (Derouin, 2021).

Outcomes and impact

- The specific project addresses the State of Kentucky's population and produced the most detailed statewide indoor-radon potential risk map in the United States of America.
- The information can be used to bring awareness to the health risks of radon, encourage testing, and implement technology to reduce high radon levels. See example of public-awareness notice in Figure 12.
- The technology and methods can be applied to high-uranium lithologies and structural features globally.

Key geoscience skills

- **Technical:** geophysical methods, UAV data collection
- **Conceptual:** field-based learning, managing subjectivity and uncertainty
- **Social:** application of technology to real-world problems

Upscaling and accelerating actions

- Sharing geologic information and risk assessment analysis with the community proved useful in this example, so expanding awareness of this case could be beneficial to elevate the knowledge and readiness of society about geohazards in other countries and regions.
- Expanding on workshops and training activities for society at large about geologic hazards can improve public health and safety.
- Including geology courses in high school curricular programmes can establish a base of understanding at a global scale about the different kinds of geohazards.

Where to find out more

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4.2.4.

Creating awareness of geoscience in society: *The Geoscience Corner* radio talk show – Namibia

Synopsis

The Geoscience Corner is a nationwide outreach initiative for geoscience awareness carried out by the Geoscience Council of Namibia (GSCN) in cooperation with the Namibian Broadcasting Corporation (NBC). This project produced radio talk shows on eight themes: hydrogeology, minerals and rock materials, agrogeology, engineering geology, geohazards, geoheritage and geotourism, energy, and climate change. The radio talk shows were broadcast on 11 Namibian Broadcasting Corporation FM stations in nine vernacular languages. The Namibian national radio stations have an approximate audience of 1.6 million out of a total Namibian population of 2.6 million.

Before the commencement of *The Geoscience Corner*, GSCN hosted an engagement workshop in October 2021 with key media practitioners from Namibian Broadcasting Corporation radio services, public relations officers, and scientists and geoscientists from various disciplines and institutions.

Challenges, opportunities and objectives

- *The Geoscience Corner* aims to provide enhanced knowledge and understanding of the many aspects of geoscience and its application to socioeconomic development.
- The show aims to foster participatory engagement and dialogue between geoscientists and wider audiences. Geoscientists from various disciplines and institutions (government ministries, mining and petroleum industries, parastatal organizations, universities, and local authorities) have been taking part in this initiative, and their continuous volunteerism is highly appreciated.

Project leadership

GSCN and NBC led the project.

- The topics are selected to broaden society's knowledge of practical geology in everyday life.
- The programme aims to enhance the knowledge of Namibian Broadcasting Corporation media practitioners on geoscience and geoscientists' issues.
- The programme aims to enlighten society about geoscience services available in the country in easy-to-understand layperson's language.
- The programme aims to provide opportunities to expose youth to geoscience career opportunities.

Project profile

The nationwide outreach initiative for geoscience awareness has two phases.

Phase 1 started with a workshop in October 2021, 'Bringing NBC Media Practitioners to the World of Geoscience', attended by 83 people, including 33 Namibian Broadcasting Corporation media practitioners, from 12 organizations and groups involved. (Figure 13 is a photo of the participants.) The following entities were represented: Ministry of Mines and Energy; Ministry of Agriculture, Water and Land Reform; City of Windhoek; Namibia Water Corporation; Ministry of Environment, Forestry and Tourism; geoscience consultants; National Petroleum Corporation of

Figure 13. Participants in the 'Bringing NBC Media Practitioners to the World of Geoscience' workshop visit one of the injection and discharge wells in the Windhoek aquifer. Windhoek is an aquifer artificially recharged using surface water from dams. © Anna Nguno.

KEYWORDS AND HASHTAGS

#Geosciencecommunication, #PublicEngagement, #MediaEngagement, #SDG4, #Namibia

PRIMARY AND SECONDARY SDGS

4 3 9 10 11

Namibia; QKR Namibia Navachab Gold Mine; University of Namibia Geology Department; Uranium Institution of Namibia; UNESCO-Windhoek; and Namibian Broadcasting Corporation. The workshop had 12 sessions, including field site and mine visits.

Phase 2 is *The Geoscience Corner* radio talk show hosted on the Namibian Broadcasting Corporation's 11 multilingual radio channels. Every month since February 2022 there have been several themed geoscience talks given by local Earth scientists. In February, the radio show theme was hydrogeology, followed by minerals and rock materials in March and agrogeology–medical geology in April; it concluded in December 2022. From February to August 2022, about 128 Earth scientists, 44% of whom were women, participated in the radio talk shows.

The envisaged Namibian Broadcasting Corporation FM target audience is 61.5% of the Namibian population. All 11 of the FM stations received positive feedback. This initiative cost less than 1 million Namibia dollars plus in-kind contributions of geoscientists and the organizations involved.

Outcomes and impact

- Participants in the workshop 'Bringing NBC Media Practitioners to the World of Geoscience', with the assistance of geoscientists, will be able to interpret, translate and communicate geoinformation to the public in an understandable and relatable manner.
- Improved public geoscience literacy is helping individuals understand and influence national decisions.
- Enhanced awareness and access to the geoscience knowledge base and expertise are further empowering the public.
- Enhanced participatory engagement and dialogue between geoscientists and the public at large are having a similar positive effect.
- Awareness and understanding of societal issues that geoscientists address are being elevated.

Month	Theme[1]
February	Hydrogeology and contaminant geology
March	Minerals and rock materials
April	Agrogeology (rock to crop) and medical geology
May	Engineering geology
June	Geohazzards
July	Geoheritage and geotourism
August	Energy
September	Climate change

[1] Each theme addresses the scope and application of a particular aspect of geoscience, and different topics related to the theme are covered in weekly programs.

Table 2. Geoscientific themes covered by *The Geoscience Corner* in 2022.

KEYWORDS AND HASHTAGS
#Geosciencecommunication, #PublicEngagement, #MediaEngagement, #SDG4, #Namibia

PRIMARY AND SECONDARY SDGS
4 3 9 10 11

Key geoscience skills

- **Technical:** hydrogeology, agrogeology, geochemistry, engineering geology, geohazards, palaeontology
- **Conceptual:** interdisciplinary problem solving, field-based learning
- **Social:** multidisciplinary teamwork, business management and leadership

Upscaling and accelerating actions

The purpose of *The Geoscience Corner* is to achieve the following:

- education of geoscientists in communicating skills for the public
- training of local talent for radio talk shows, podcasts and similar initiatives
- inclusion of geoscience communication in layperson courses
- efficient embrace of social media platforms by participating organizations and audiences

Where to find out more

Geoscience Council of Namibia. (2022). Geoscience Corner radio talk show. https://geocouncil.org.na/news/7/GEOSCIENCE-THE-BEDROCK-OF-MODERN-DAY-LIFE (Accessed 29 December 2022.)

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4.2.5.

Towards gender equity in geoscience: GeoLatinas (Latin America), Indigenous Women in Mining and Resources Australia, and Girls into Geoscience (United Kingdom and Ireland)

Project leadership

The highlighted initiatives providing leadership in increasing gender equity are GeoLatinas (Latin America), Indigenous Women in Mining and Resources Australia, and Girls into Geoscience (United Kingdom and Ireland).

Synopsis

Geoscience plays an invaluable role in reducing inequities both within the geoscience workforce and within communities. Women-led geoscience networks and educational initiatives for girls provide role models, mentoring and peer support. They improve the participation and engagement of girls in geoscience and the retention of women in geoscience careers. Women-led geoscience networks range from individual local organizations to international networks with members in academia, government, industry and non-governmental organizations. Here we highlight the efforts and achievements of three national and international geoscience initiatives working to increase gender equity in the geosciences.

Challenges, opportunities and objectives

- Women represent about half the world's population but rank lower than men on every critical indicator, and it is estimated that it will take more than 100 years to reach gender parity.
- Women remain under-represented in geoscience careers in academia, industry and government.
- Gender equity-focused networks help with the recognition and removal of systemic barriers promulgated in workplace structure and culture, conscious and unconscious bias, and stereotypes.
- Women-led geoscience networks provide access to mentors and role models who can help improve the hiring and retention of women in geoscience careers.

Project profiles

GeoLatinas

GeoLatinas' mission is to embrace, empower and inspire Latinas to pursue and thrive in careers in the Earth and planetary sciences while providing a platform for other marginalized groups to feel validated and empowered as well. The international network was founded in 2019 and currently serves more than 1,000 members in all work sectors across 45 countries. GeoLatinas works in English, Spanish and Portuguese and has chapters in Bolivarian Republic of Venezuela, Peru, Mexico, Colombia, Chile, Brazil and the United States of America.

The network aims to improve gender equity in the geosciences and planetary sciences by (1) promoting, welcoming and empowering the work and research of Latina women; (2) closing the cultural and linguistic gap that exists between Latin Americans and career opportunities; (3) providing tools to help GeoLatinas succeed at all stages of their careers; and (4) inspiring future generations of Latin Americans to pursue science careers.

Indigenous Women in Mining and Resources Australia (IWIMRA)

IWIMRA was founded in 2017 to create a stronger connection among Indigenous women in Australia's mining and resource sector. Through lived experiences and narratives of Indigenous intersectionality, it is IWIMRA's priority to ensure the visibility, voice and quality participation of Indigenous women.

IWIMRA partners with industry to continually raise the profile of Aboriginal and Torres Strait Islander women to build solutions-driven, influential, cross-cultural relationships that will continue to contribute towards a sustainable future.

Girls into Geoscience (GiG)

GiG aims to promote diversity and equity and provide crucial role models for aspiring female scientists across the Earth science spectrum through in-person events and blog posts. It is an initiative to introduce female-identifying students from schools and universities to the Earth sciences and demonstrate the world of careers open to geoscience graduates today.

GiG is an outreach initiative primarily based around an annual two-day event that comprises a field trip, talks and workshops. The first day consists of an optional field trip to show that fieldwork is fun and not a barrier to female participation in the Earth sciences. The second day is in the format of an academic conference with in-person and virtual talks.

Outcomes and impact

GeoLatinas

Since its founding in 2019, the organization has been empowering and inspiring Latinas to pursue and thrive in careers in geoscience and planetary science in three ways. (1) The GeoLatinas Leadership

KEYWORDS AND HASHTAGS

#GenderEquity, #EDI #RoleModels, #FemaleLeaders #SDG5

PRIMARY AND SECONDARY SDGS

5 4 7 8 16

Council team works on specific projects in professional and personal development, education, and outreach; geocommunity support; sustainability; task management; and visibility and branding. (2) GeoLatinas Local Teams work on specific needs based on local issues. (3) GeoLatinas Ambassadors represent specific regions, help identify needs and issues in their communities, organize local events, and more.

IWIMRA

The organization provides formal safe spaces for Indigenous people to have a yarn and talk about issues. It has identified more than 35 groups in locations throughout Australia that are resources for Indigenous women. In August 2021, IWIMRA achieved an Australian first when it was welcomed as a First Nations Partner.

GiG

Since 2014, more than 250 pupils from schools across the United Kingdom have taken part. In 2016, 75% of those attending said at the end of the event that they were more likely to consider studying geology. A year later, 78% of those responding to a follow-up survey said they were off to study geoscience or related courses at university, with 100% of those saying they would recommend GiG to others. The original UK programme expanded to Girls into Geoscience Ireland.

Key geoscience skills

- **Technical:** leadership, mining, field geology
- **Conceptual:** managing subjectivity and uncertainty, field-based learning
- **Social:** multidisciplinary teamwork, business management and leadership

Upscaling and accelerating actions

These three initiatives demonstrate that professional self-empowerment is attainable through collaboration and peer support. Upscaling of these initiatives could then be achieved by following the best practices and methods utilized by these three initiatives, that is, using the initiatives as models for other geoscience gender equity programmes.

The initiatives here presented are examples of work in different cultural contexts and across geoscience disciplines. They likely are scalable to other regions, countries, or under-represented groups in geoscience.

Where to find out more

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Researcher Luisa Andrade of the Science Foundation Ireland Research Centre in Applied Geosciences (iCRAG) holds a fossilized ammonite at a sustainable geoscience research showcase. © iCRAG.

4.2.6.

Access to water: Delhi water crisis; the Palla Project – India

Project leadership

CGWB of India and the Delhi Jal Board led the Palla Project.

Synopsis

The Palla Project is a successful application of geoscience by the Central Ground Water Board (CGWB) of India to alleviate the water crisis of the National Capital Region (Delhi NCR). The objective was to use water supplies from aquifers and floodplains of the Yamuna River, a solution that was several orders of magnitude more economical than the current practice of rerouting water supply from nearby regions and various sources to Delhi by engineering projects. This project brings hope for other growing cities located on the banks of perennial rivers in India and could be a model for other countries and regions with severe water crises.

Challenges, opportunities and objectives

- About 85% of the water utilized by Delhi, the capital city of India, is imported, much of it via canals and pipelines, drawn from Himalayan rivers such as the Ganga and Sutlej.
- Groundwater levels in India are declining at rapid rates, India's glaciers are melting fast, and rivers are polluted to extreme levels.
- Conventionally, water management practices in India are largely overseen by civil engineers, with geoscientists occasionally having a peripheral role.
- Massive, engineered, surface water rerouting projects in India are the norm, resulting in huge water loss due to evaporation and percolation, generating huge costs for the city, the region and the country.
- India's national groundwater resources have not been considered or even known as a first-hand resource and as such are usually absent from the usual civil engineering practices. Geoscience experience is needed for groundwater systems to be evaluated, accessed and sustainably managed.

Project profile

In India, water shortage crises threaten millions of lives and livelihoods. About 600 million Indians potentially are facing high to extreme water scarcity conditions as the demand for water is increasing due to population and economic growth (Chakraborti et al., 2019). Water shortages and water sharing have been the cause of conflicts between states in India, a situation that is forecast to worsen with time. By 2050, water demand is projected to exceed availability in the country (National Commission for Integrated Water Resources Development, 1999).

Geoscientists have offered a solution in the peak floodwater-harvesting project at Palla in the Yamuna floodplain of Delhi, India. The Palla Project sustains the extraction of about 30 MGD (49 million m^3/day) of

Geoscience helps address water resources challenges in India. © shutterstock.com/pradeepgaurs.

KEYWORDS AND HASHTAGS

Hydrology #WaterCrisis #WaterManagement #India #Potable #WaterScarcity #Humanitarian #SDG6

PRIMARY AND SECONDARY SDGS

6 2 3 9 11

groundwater (worth 7,500 million rupees /year) from about 100 wells for drinking purposes (Rao et al., 2007; Soni et al., 2018). A paradigm shift for sustainable water management practices in India established by this project also builds resilience to possible climate change scenarios. The Palla model of water management for floodplains of large monsoon-regime perennial rivers has the potential to serve as a sustainable source of drinking water for the cities along their banks, and the approach also has potential to be replicated in similar areas (Soni et al., 2018).

Outcomes and impact

- Use of floodplains for groundwater extraction is becoming a successful scheme for Delhi, providing a sustainable water supply to millions of people. The strength of this technique is the perennial recharge and storage of natural groundwater reservoirs. In addition, it has an economic benefit that helps generate revenue for the Delhi Government.
- At present, extraction of groundwater from the floodplains in Delhi helps to fill around 17% of the water deficit. Plans to scale up the project will alleviate nearly 30% of the water deficit. As several large cities in the world are located close to riversides, this scheme provides a practical solution to help meet the water needs of densely populated areas.
- This project showcased the ability of geoscientists to understand the complex interactions of the surface and subsurface water regimes. It demonstrates how geoscientists can provide alternative and cost-effective solutions for access to water, a crucial resource problem for the city and a source of conflict with nearby regions.

Key geoscience skills

- **Technical:** hydrology, geomorphology, groundwater modelling, hydrochemistry
- **Conceptual:** interdisciplinary problem solving, geoscience reasoning and synthesis
- **Social:** multidisciplinary teamwork, ability to sell ideas, application of technology to real-world problems

Upscaling and accelerating actions

The achievements of the Palla Project can be expanded in the following ways:

- implementation of policies that require geoscientists' participation in the technical studies related to water supply and groundwater management
- education of geoscientists in local universities with interdisciplinary skills
- inclusion of basic geoscience courses in civil, chemical, electrical and other engineering careers pertinent to infrastructure development, as well as in careers such as social studies, politics, energy management, and economics
- creation of local community enterprises to support workforce training and development that include geoscience

Where to find out more

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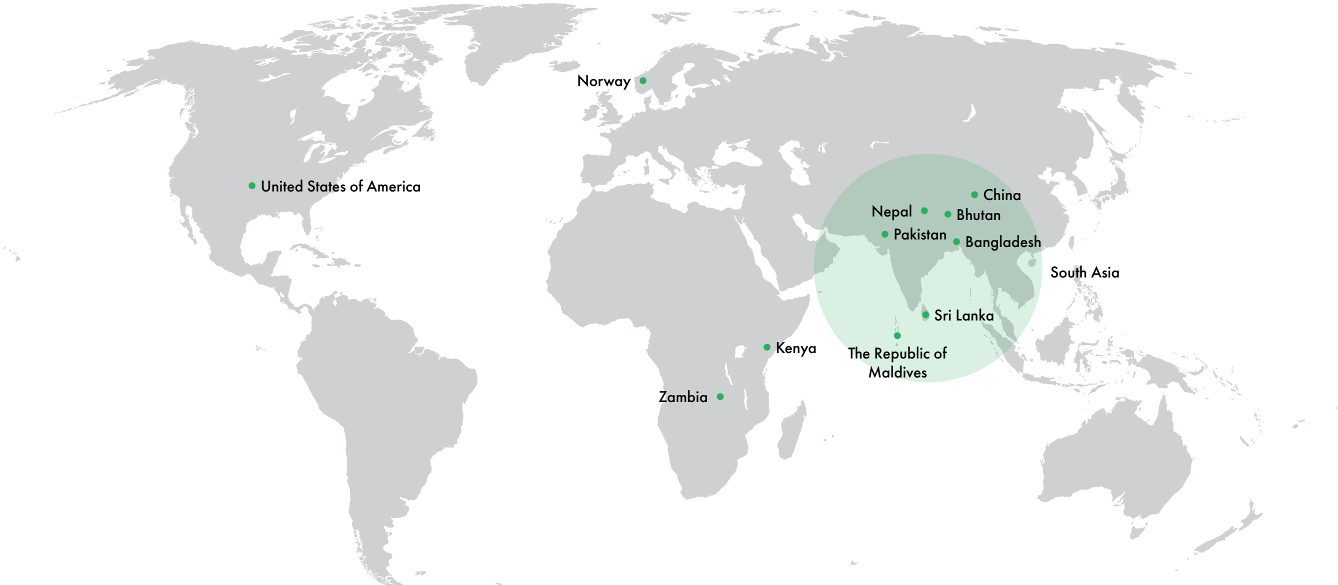
4.3. Examples for the planet dimension



	Planet dimension examples mapped to the SDGs	Primary SDGs	Secondary SDGs
4.3.1.	Monitoring water quality and infrastructure development: citizen science data collection to bridge the science-policy gap – Oklahoma, United States of America	6	3 9 11
4.3.2.	Affordable and clean energy: geothermal energy from the Great Rift Valley – Kenya	7	9 12 13
4.3.3.	Protecting geodiversity and biodiversity with responsible production and consumption: UNESCO Global Geoparks – Magma Geopark, Norway, and Zigong Geopark, China	12	2 4 11 15
4.3.4.	Accelerating decarbonization: Northern Lights carbon capture and storage – Norway	13	4 7 9 11 12
4.3.5.	Understanding resource and health of water environments: geophysical and immunological mapping of fish habitat – Lake Tanganyika, Zambia	14	1 2 4 8 12
4.3.6.	Assessing forest ecosystem health: remote sensing monitoring of threatened and protected lands – South Asia	15	2 8 10 11
	SDGs mapped to the planet dimension: positive impact on physical systems	6 7 12 13 14 15	3 9 11 16

Table 3. Examples that show how geoscience supports the planet dimension and how the examples map to the SDGs. A few examples include secondary SDGs that are not among SDG assignments for the dimension, reflecting that many examples of geoscience activity invoke multiple dimensions.

4.3.1.

Monitoring water quality and infrastructure development: citizen science data collection to bridge the science-policy gap – Oklahoma, United States of America

Project leadership

This initiative was led by the Boone Pickens School of Geology (BPSoG) at OSU, the Oklahoma Department of Environmental Quality, and the Oklahoma Water Resources Board.

Synopsis

Infrastructure projects such as dams, diversions, and hydroelectric structures all impact water quality. Water quality is not necessarily good or bad but rather is evaluated depending on the type of use, for example, drinking water versus recreational water use. More than 50% of Oklahoma's water systems are labelled as impaired by the U.S. Environmental Protection Agency (EPA). The impairments include physiochemical parameters, bacteria, metals, fish bioassessments, and/or a combination of the four. The effect of the impairments ranges from being unsafe for recreation to detrimental to aquatic life, including impacts on fishing, to harmful to human and animal digestion.

The Oklahoma State University (OSU) citizen science water quality initiative was started to educate the public and communicate with legislators about water quality and its relationship to infrastructure. Short on-site field sessions provide an experiential environment for teaching sample collection and analysis. These hands-on experiences improve the public's understanding of water quality issues and the value of science in policy action. A background in geoscience and specific knowledge of geochemistry have been integral components of the project to understand the geologic and infrastructure sources of water impairments that could be occurring.

Challenges, opportunities and objectives

- Infrastructure projects such as dams, diversions, and hydroelectric structures all impact water quality.
- More than 50% of Oklahoma's water systems are labelled as impaired by the EPA (Figure 14).
- Trained citizen scientists can sample and analyse water data for use by the EPA to further understanding of how infrastructure affects water quality.
- Field experiences that include a discussion of sampling methods and the results improve the public's understanding of water quality issues and the value of science in policy action.

Project profile

The citizen science water quality initiative was started at the BPSoG at OSU by doctoral student Lauren Haygood to break down the current science jargon barriers and empower the community to get more involved in water quality and policy.

The project involves short on-site field sessions for sample collection and analysis followed by a discussion of what the results mean in terms of EPA criteria. The parameters tested, driven by the interests of the community, focus on physiochemical parameters such as salinity, dissolved oxygen, conductivity, turbidity, concentration of bacteria, and levels of pesticides

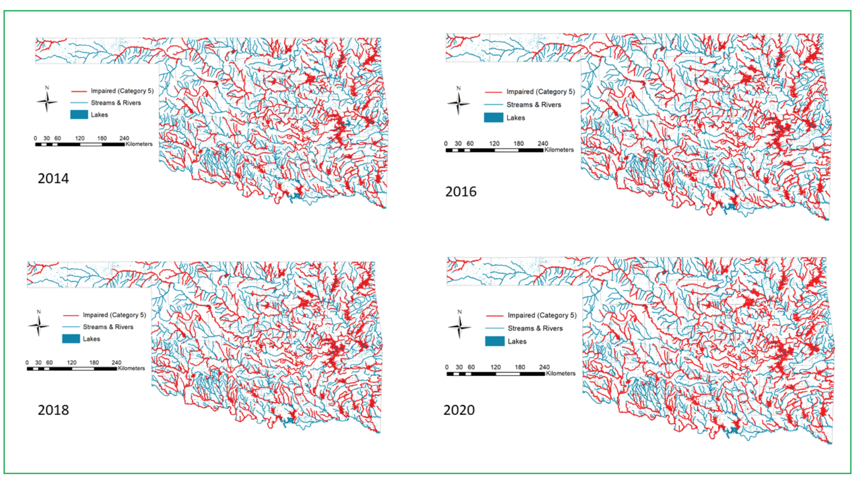


Figure 14. Oklahoma water quality assessments over time based on data sourced from the Oklahoma Department of Environmental Quality and the Oklahoma Water Resources Board.

Lauren Haygood examines water quality test kits with citizen scientists. © Lauren Haygood.

KEYWORDS AND HASHTAGS

#Geochemistry #Hydrology #WaterImpairment #Infrastructure #CitizenScience #Oklahoma #Citizens #Water Quality #wellBeing #PotableWater #SDG6

PRIMARY AND SECONDARY SDGS

6 3 9 11

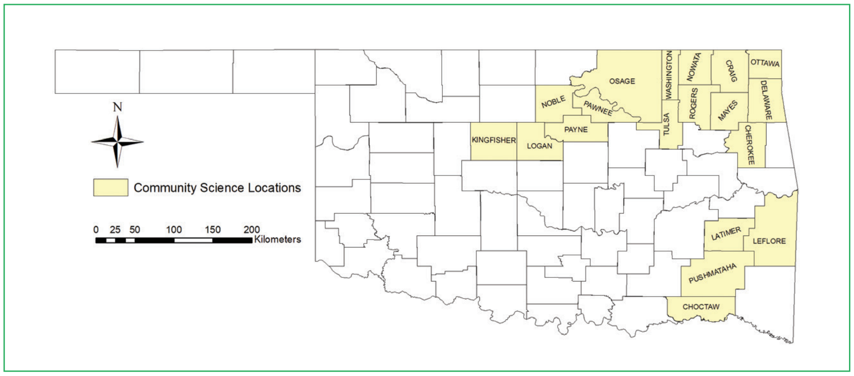


Figure 15. Counties with water systems studied in the Oklahoma State University citizen science water quality initiative.

and metals. The analytical testing equipment includes photometric analysis tools, test strips, and probes with methods to set the appropriate standards for each parameter. Participants in the on-site field sessions receive handouts with information on water quality and how to engage with legislators.

The project initially focused on the Arkansas River in Tulsa County because of ongoing water infrastructure projects and has since grown to include other counties (Figure 15). The water systems to study are selected on the basis of public concern as well as thorough analysis of the publicly available data from the Oklahoma Integrated Reports for waterbodies.

Outcomes and impact

- This project provides citizen science-collected water quality data that can be used by the Oklahoma Department of Environmental Quality for the watershed planning Integrated Report.
- This project highlights the importance of engaging with the community to understand interest in scientific research and policy, including water sustainability, aquatic life, safe drinking water, water management practices, and instream flow.
- Meeting community members at their level and working with them builds trust needed for effective science communication and science policy.

Lauren Haygood leads a group of citizens in data collection to assess water quality in Oklahoma. © Lauren Haygood.

KEYWORDS AND HASHTAGS

#Geochemistry #Hydrology #WaterImpairment #Infrastructure #CitizenScience #Oklahoma #Citizens #Water Quality #WellBeing #PotableWater #SDG6

PRIMARY AND SECONDARY SDGS

6 3 9 11

Key geoscience skills

- **Technical:** geochemistry, biogeochemistry, hydrology, field methods
- **Conceptual:** field-based learning, geoscience reasoning and synthesis
- **Social:** application of technology to real-world problems, understanding of societal relevance, ability to sell ideas

Upscaling and accelerating actions

Funding was received in August 2020, and the first event was held shortly thereafter. The project grew rapidly, with individuals testing water in their free time and a few teachers incorporating the project into their classrooms, including having their students write to legislators about their on-site data collection. More than 500 people have been involved over a one-year time-frame. The initiative continues to evolve, expanding to a focus on teaching and using data collected in the first phase for policy engagement.

Where to find out more

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Lauren Haygood leads a group of citizens in data collection to assess water quality in Oklahoma. © Lauren Haygood.

4.3.2.

Affordable and clean energy: geothermal energy from the Great Rift Valley – Kenya

Synopsis

In 2010 fewer than one in five Kenyans had electricity; now some 60% do, thanks mostly to geothermal power from the East African Rift (EAR). Geothermal is one of the most exciting renewable energy sources for geoscientists because it relates to the active subsurface processes of our planet.

Geothermal energy uses heat from the inner planet that can reach the surface as lava flows, geysers, hot springs, fumaroles, and friction along continental margin contacts. Geothermal energy traditionally has been developed in areas where the heat gradient is very high, but it is now becoming increasingly efficient and accessible in almost all regions, including next-generation deep geothermal drilling that can reach 20 km.

The first geothermal electric generation occurred in Larderello, Italy, in 1904, becoming commercial in 1913. Later, geothermal plants were commissioned in New Zealand in 1958 and in the United States of America in 1960. Today, almost all countries are advancing projects to explore their geothermal capacity, potential and feasibility as part of their clean and renewable energy plans.

Project leadership

The Kenya Electricity Generating Company, a 74% state-owned organization, has built three of the geothermal plants.

The Geothermal Development Company (GDC) is responsible for the exploration of geothermal wells in Kenya as well as the sale of geothermal steam for the purpose of electricity generation to the Kenya Electricity Generating Company and independent companies.

Kenya includes the Great Rift Valley, a complex intracontinental ridge system in East Africa that expands from north to south in the country and is dotted with numerous lakes and volcanoes. Well known as a cradle of humanity, with remarkable fossil discoveries of our ancestors, the valley is now becoming known for its enormous geothermal potential, estimated to have the capacity to generate 10,000 MW of electricity from more than 20 prospective areas. Kenya was the first African country to rely on geothermal energy for electricity, and it is the largest producer of geothermal energy in Africa and the seventh largest in the world.

In a country where demand for energy outstrips the supply, geothermal energy is literally the hotspot for development.

Detail of hot springs at Lake Bogoria, a saline lake that lies in a volcanic half-graben region in the Kenya's Great Rift Valley. It is famous for the geysers and hot springs along its banks and in the lake, with eruptions that have reached up to 5 m high. © shutterstock.com/industryandtravel.

KEYWORDS AND HASHTAGS

#Geothermal, #HeatFlow #StructuralGeology, #Rift, #PlateTectonics #Massai #Tribal #SDG7

PRIMARY AND SECONDARY SDGS

7 9 12 13

Challenges, opportunities and objectives

- Kenya has the ambition to expand its geothermal base and has issued a National Appropriate Mitigation Action Plan to include the private sector in the development plans, creating opportunities for local and international organizations.
- A lesson learned was the need to align the geothermal sector with the transformation of the entire energy sector of the country.
- Geothermal developments have been quick to progress in Kenya and can be expanded rapidly because the size of the geothermal plants is small, they are easy to relocate, and they have the additional benefit of a minimal carbon footprint.
- Kenya's geothermal plans started early, even with scarce resources and moderate confidence by external investors, because Kenyans believed in their own understanding of their national geothermal resources with technical support from geoscience experts.
- The Kenyan Government faces the continuous challenges of raising awareness to gain the buy-in of stakeholders, securing investment partners, ensuring financial transparency, and dealing with questions about monopolies in energy.
- The presence of geothermal potential in what is also a global bird sanctuary and the home of 'Hell's Gate', one of the world's most spectacular national parks, poses a debate on how to balance competing interests of biodiversity and energy demands.
- Although a single well for geothermal energy may be small, having 300 wells in an area interconnected with surface pipelines, transmission lines, roads, and injection pools makes it difficult for the Indigenous population of Masai warriors to work their lands as pastoralists. Coexistence presents a real challenge.
- Geothermal projects have inherent risks, not subject to any insurance or guarantees, such as the social impact if the on-site communities oppose the development, and regulatory risk, in which non-discriminatory law changes following political instability may affect established contracts.

Project profile

The Kenya geothermal electrification project has a long history. Exploration for geothermal energy in Kenya was initiated in 1960, with surface exploration and the drilling of two wells. In the 1970s, geophysical and geologic studies were undertaken near the Olkaria sites and provided a basis to drill a new deep exploration well by 1973 funded by the United Nations Development Programme (UNDP).

Kenya was initially dependent on hydroelectricity, but the unpredictable level of rainfall patterns made hydroelectricity unreliable. With a marked reduction in electricity output during 2003–2006, the country shifted its interest in electricity generation from hydroelectric to geothermal, founding the GDC in 2008.

Kenya's 2019 geothermal capacity was 690 MW from five Olkaria plants. The demand for electricity in Kenya continued to grow, and on 24 May 2022, it hit a new peak of 2,051 MW. By 2030, Kenya is planning to make geothermal its largest source of clean and renewable energy, reaching 5,530 MW of installed geothermal power for 51% of total country capacity.

In 2019, the Olkaria geothermal plant had 1,250 employees, of which only 50 were Masai. To make way for Olkaria's expansions, 1,181 Masai were relocated from 155 households to a 1,700-acre stretch of land outfitted with houses, community services and schools. The Olkaria geothermal plants highlight the delicate balance of energy supply and demand with respect to the required surface footprint and Indigenous populations.

KEYWORDS AND HASHTAGS

#Geothermal, #HeatFlow #StructuralGeology, #Rift, #PlateTectonics #Massai #Tribal #SDG7

PRIMARY AND SECONDARY SDGS

7 9 12 13

Outcomes and impact

- This project has led to the employment of local talent for geothermal activities.
- The project also led to the participation of the private sector of local entrepreneurs in geothermal energy development.
- Technical teams have effectively collaborated with society at large, in particular with tribes that rely on ancient pastoral techniques.
- Awareness about unconventional national resources in Kenya, as derived from a geologic analysis, has increased.
- This project provides a replicable example of how to advance geothermal projects at large scale, with collaborative approaches.

Key geoscience skills

- **Technical:** structural geology, seismic interpretation, reservoir modelling
- **Conceptual:** multiscalar levels of inquiry, 3D and 4D thinking, interdisciplinary problem solving, geoscience reasoning and synthesis
- **Social:** application of technology to real-world problems, cultural literacy

Upscaling and accelerating actions

Kenya's leadership and experience in geothermal energy can be expanded to sites with geologic features similar to those of the EAR, especially its western branch, as well as to other regions of the world with rift structures.

Energy initiatives will benefit from the enactment of legislation and policy specific to geothermal projects, such as feed-in tariffs, tax exemptions, financial support, regional tax/customs exemptions, and, importantly, considerations of regional corridor distribution lines.

Streamlining the regulatory framework through transparent, clear and, especially, predictable licensing and administrative processes would attract more developers and investors to geothermal projects. Initiatives are in place to drill deeper for geothermal development as well as to pursue shallower, low-temperature geothermal projects, which have smaller outputs.

Best practices developed in the EAR may serve as a model for other countries in relation to:

- activating the necessary society-industry dialogue about energy demand and supply decisions
- realizing the feasibility of geothermal acceleration by appointing specialized governmental agencies such as the GDC in Kenya and/or by participating in private-sector activities in Ethiopia
- connecting off-grid areas with small geothermal projects

Direct use of the Kenyan geothermal potential (low enthalpy) could further enhance tourism and recreational industries, with swimming, bathing, balneology and residential uses.

Where to find out more

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4.3.3.

Protecting geodiversity and biodiversity with responsible production and consumption: UNESCO Global Geoparks – Magma Geopark, Norway, and Zigong Geopark, China

Synopsis

Our planet is enriched with an extraordinary ecological diversity of fauna and flora, but the accelerating destruction of natural habitat and species due to human interventions means that biodiversity loss is on everyone's lips. Yet beneath biodiversity is its hidden, silent partner: geodiversity. The basis of every ecosystem is composed of the non-living elements of nature: rocks, minerals and soils, landforms and landscapes, mountains, gorges, rivers, and coasts. Geodiversity has its own intrinsic value worthy of protection, for it is the foundation for the human planet. It literally provides the building stones for our towns and cities and the wider resource base for our economic and social development. So, as well as underpinning biodiversity, geodiversity is the natural capital that strengthens human diversity and sustainable local economy production loops.

Two examples – Magma Geopark, Norway, and Zigong Geopark, China – illustrate the breadth of the UNESCO programme and its importance to both geoscience and humanity. Magma Geopark features biodiversity through a compelling story about sustainable entrepreneurship initiatives via their brand GEOfood. Zigong Geopark is grander on every scale, from geographic location in China to the geodiversity that encapsulates the numerous and extraordinarily well-preserved dinosaur bones. Both geoparks support the local communities' economies with unique approaches related to entrepreneurism and geotourism.

Challenges, opportunities and objectives

- UNESCO's challenge has been to build a workable and collaborative global network of interconnected geoparks.
- Since the creation of its Global Geopark label in 2015, UNESCO has designated 177 formal sites and landscapes scattered across 46 countries.
- The country with by far the most geoparks – 22 as of 2021 – is China.
- With a bottom-up approach, geoparks function through the operation of regional networks that promote collaboration.
- Many geoparks focus on geologic features themselves (Zigong), whereas others encourage the sustainable use of the geologic environment or resources for community awareness, engagement and entrepreneurial ideas (Magma).

Project leadership

The Earth Sciences Division of UNESCO provides leadership for this programme, along with Sara Gentilini at Magma Geopark and Xiaohong Yuan and Zhiguang Zhang at Zigong Geopark.

Project profile

The realization that geology is the bedrock of our cultural identity led the Division of Ecological and Earth Sciences of UNESCO to launch the Global Geoparks initiative. Geoparks are about reconnecting human society at all levels to the planet we all call home and celebrating how our planet and its 4.6-billion-year history has shaped every aspect of our lives. Geoparks are internationally recognized places in which a unique geologic heritage is used to support the sustainable development of local communities. By raising awareness of the modern importance of an area's geologic history and how to responsibly derive well-being from it, UNESCO Global Geoparks give local people a sense of pride in their region, enable sustainable economic activities that support the well-being of their inhabitants, and strengthen their inhabitants' identification with the area.

Magma UNESCO Global Geopark and GEOfood, Norway

Magma Geopark is a network of 46 locations of geologic interest in the southern region of Rogaland, Norway. It is named for its origin as molten rock – magma – that crystallized into anorthosite, the same rock type found on the moon! Magma Geopark is a non-profit organization that covers 2,326 km^2 of relatively barren landscape. Magma Geopark works in collaboration with local municipalities to educate the population about the geologic heritage in Norway, foster tourism, and encourage local entrepreneurship. There is a reliable commitment to reduce CO_2 emissions, and visitors are requested to arrive by public transportation and use electric vehicles or bikes inside the park.

GEO FOOD ®

KEYWORDS AND HASHTAGS

#Geoparks #Preservation #Heritage #Dinosaurs #Zigong #SustainableFood #FoodWaste #LocalFood #Dino #Fossils #SlowFood #GEOfood #ExperienceMagma #TasteMagma #SDG12

PRIMARY AND SECONDARY SDGS

12 2 4 11 15

Magma Geopark launched the brand GEOfood in 2013, two years before the issuing of the SDGs in 2015. GEOfood supports environmentally friendly food enterprises located within UNESCO Global Geoparks territories. The products and restaurants developed under this brand are based on local traditional production knowledge, sharing of ancient culinary techniques, and a unique approach to the geologic heritage of the sites.

A variety of small- and medium-sized businesses have helped expand GEOfood to countries beyond Norway. Thirty-four UNESCO Global Geoparks in Portugal, Spain, Italy, Canada, Argentina, Finland, Iceland, Malaysia, the Republic of Korea, Croatia, Slovenia, Hungary, Slovakia, Ireland, Romania, Uruguay, Chile and Brasil are now part of the GEOfood network. The brand can be used only by organizations that meet sustainability and environmental standards and focus on promoting biodiversity and geodiversity, the correct use of the soil, and respect for the geologic and cultural heritage of their areas.

GEOfood's symbiotic connection to the land helps educate communities and visitors about food waste, healthy diets, recycling of raw materials, and responsible consumption and the connection between geology and food. GEOfood intends to continue to expand its outreach throughout UNESCO Global Geoparks, establishing educational programmes and innovative research projects and tools, focusing on local food producers, restaurants, incentives to use the kilometre-zero food chain, and utilization of local, traditional, regional food.

Zigong UNESCO Global Geopark, China

One of the gems in China's array of geoparks is Zigong. Spanning 1,600 km^2 of Sichuan Province in southwestern China, it was one of the first national geoparks in China and in 2015 was officially endorsed as the country's 19th UNESCO Global Geopark and the second one in Sichuan.

A decade after opening, it attracts more than 2 million visitors annually and generates a tourist income of USD 3 million. Part of its popular attraction is Salt Industry Park, displaying the well-preserved workings of 2,000 years of salt production. But the main attraction is not salt, but bones, for Zigong is dinosaur country. At Dinosaur Park and Qinglongshan Park, 160 dinosaur sites have been discovered among hundreds of ancient vertebrate fossil sites. These form the basis of a remarkable museum, opened in 1987, as well as Dinosaur Kingdom Scenic Area, with a dinosaur restoration area and amusement area. This is where the first relatively well-preserved large Sauropoda Marsh dinosaur fossil skeleton was unearthed. Alongside dinosaur remains are examples of almost all forms of terrestrial vertebrates and nearly 20,000 plant and tree relics, all from the Jurassic period, when extensive lowland plains of rivers and lakes were buried rapidly by sediment and preserved.

Zigong is a true fossilized Jurassic Park. It is no surprise that this location is planned to be the site of Fantawild Dinosaur Kingdom, the first large-scale high-tech modern industrial park with the theme of dinosaur culture in China. But Zigong Global Geopark is more than just a giant

Zigong Geopark in China has numerous and extraordinarily well-preserved dinosaur bones.

geologic theme park. In recent years, it has successively become the National Youth Science and Technology Education Base and the China Paleontology Science Education Base and has cooperated with China University of Geosciences, Chengdu University of Technology, and other universities to carry out practical activities for college students. In 2014, Zigong Global Geopark launched a special activity for the recruitment and training of young science communicators to popularize scientific knowledge for children and provide public audiences with accessible geologic explanations. The following year it established the Salt Expo Classroom to popularize salt culture knowledge, featuring popular science education activities, including Chinese studies, tie-dyeing, paper cutting, calligraphy, fine arts, and other traditional and folk cultures. Zigong is a spectacular nature-based classroom conveying how the ancient geologic past continues to shape the world of today.

Outcomes and impact

- Embracing good practices for increasing citizen awareness about climate change and related issues is ingrained at a geopark, where the visitors and local communities see and experience sustainability practices. They realize sustainability is feasible.
- Field tours of a geopark, with professional guidance on the geologic features, are conceived to motivate more generations to become interested in geoscience.
- Geoparks empower local communities with direct engagement in educational activities related to the geologic sites and their significance for the preservation of traditional ways of living, cooking, and relating to an evergreen ecosystem.
- Geoparks take advantage of their specific geologic sites to expand use of those sites beyond the traditional approach to raw materials to create sustainable productivity loops.
- Geoparks support the valourization of local food products in association with the unique geologic settings of their areas, which shape crops, materials, and, as a result, cooking methods, pastoring, and harvesting, among other activities.

Key geoscience skills

- **Technical:** structural geology, volcanology, soils analysis, igneous rocks, palaeontology, field geology (outcrop analysis)
- **Conceptual:** field-based learning, multiscalar levels of inquiry, 3D and 4D thinking
- **Social:** social learning, cultural literacy and understanding of societal relevance, business management and leadership

Children engaging in geoscience. © Science Foundation Ireland Research Centre in Applied Geosciences (iCRAG).

Upscaling and acceleration actions

- UNESCO Global Geoparks are probably the only territories in the world to cover almost all of the SDGs; they are pioneers of sustainable development. Geoparks are thus natural role models for the application of sustainability principles.
- Expansion of geoparks to all countries will help preserve the countries' geologic and biological diversity and enhance dialogue about the coexistence of humans with nature.
- Dinosaurs are the centre of attraction everywhere. Using these fossilized giant creatures in Zigong Geopark has led to regional development, with an important influx of tourism from within China and elsewhere around the world. This model can be replicated.
- Magma Geopark has expanded the outreach of sustainable practices in food production from Norway to more than 15 countries, with much more potential to explore.
- There is a continued need to raise awareness about UNESCO Global Geoparks, their available educational materials, and their knowledge-sharing repositories.

Where to find out more

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4.3.4.

Accelerating decarbonization: Northern Lights carbon capture and storage – Norway

Synopsis

Carbon capture and storage (CCS) involves capturing carbon dioxide at emission sources, transporting it, and then storing it, typically in saline aquifers or mature hydrocarbon reservoirs as exemplified in Figure 16. CCS is a proven and safe technology vital to achieving net-zero emissions by mid-century and mitigating climate change. CCS is required by Intergovernmental Panel on Climate Change (IPCC) climate models to limit global warming to 1.5 °C.

A huge gap between today's deployment of CCS and what is required to reduce global anthropogenic emissions to net zero remains. Limiting global warming to 2 °C requires installed CCS capacity to increase from around 40 million tonnes per annum (Mtpa) today to more than 5,600 Mtpa by 2050 (Global CCS Institute, 2021*a*). Barriers to scale up this technology are commercial, political, technical and social.

Geoscience subsurface knowledge is key to identifying suitable storage sites and pivotal to the acceleration of deployment. Numerous sites globally have been identified for future storage potential. In this section, the geological CO_2 potential of the Northern Lights project, located under the Norwegian North Sea, is highlighted as a long-term storage complex. With more than 25 years of experience with CO_2 storage in prior projects, Norway is in a strong position to demonstrate CCS at scale.

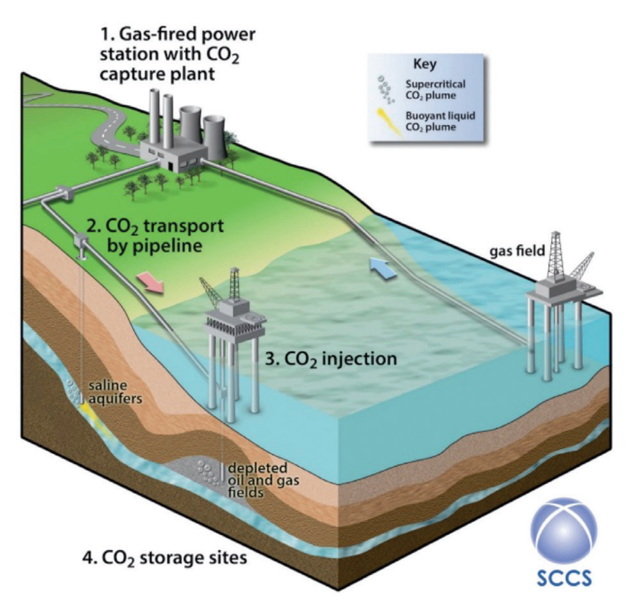

Figure 16. Schematic of the capture of CO_2 and transfer to an offshore storage site in the geologic layers located beneath the seabed. CO_2 can be injected, stored and contained for geologic time periods in depleted oil and gas fields and saline aquifers, for example. © Stanford Center for Carbon Storage.

Project leadership

The project is operated by the Northern Lights Joint Venture (Equinor, Total Energies, Shell) as part of the Norwegian Government's full-scale CCS project.

Challenges, opportunities and objectives

Even though the world has agreed on ambitious climate targets and there is growing consensus among international bodies that carbon storage is needed to achieve them, CCS has made only limited progress, mainly because of lack of financing. The Northern Lights project aims to help overcome these challenges by:

- stimulating a pathway towards commercialization of CCS by developing the world's first open-source CO_2 transport and storage infrastructure, which will provide carbon storage as a service to help emitters get new capture projects started
- demonstrating how enhanced cooperation between the private and public sectors can help overcome market hurdles to increase investment in CCS
- demonstrating and scaling up use of the storage potential of offshore Norway, where oil and gas have been trapped under sealing rock formations for millions of years

The project will also help to reduce and quantify project risks. For example, estimating storage capacity, developing site-monitoring methods, and addressing safety concerns are among the key challenges for geoscientists to address.

Project profile

Emissions must fall dramatically in the next decades if the goals of the Paris Agreement are to be achieved. The International Energy Agency (IEA) (2022) states that 'looking at the crucial 2021–2023 period, measures to date could mobilise around USD 400 billion a year in clean energy and sustainable recovery investment. However, this would still only represent 40% of the investment needed in the IEA's Sustainable Recovery Plan, which is aligned with a pathway towards reaching net zero emissions by 2050 globally.' So more actions are needed to reach the United Nations' climate goals.

KEYWORDS AND HASHTAGS

#CarbonCapture #CCS #CCUS #Decarbonization #NetZero #NorthernLights #CO2 #NetZero #decarb #EnergyTransition #Norway #future #SDG13

PRIMARY AND SECONDARY SDGS

13 4 7 9 11 12

The Norwegian state is presently leading a full-scale CCS project, named Northern Lights, aimed at capturing CO_2 from industrial sources and storing it beneath the North Sea. The Northern Lights site, which lies to the south of the giant Troll hydrocarbon field, will be the third CO_2 storage site to be developed offshore Norway. This site represents a prime location for the geologic storage of CO_2, 2.7 km below the seafloor. CO_2 can be trapped in microscopic rock pores by the same process that has trapped natural gas for millions of years. Geoscientists are responsible for characterizing these reservoirs, quantifying storage capacity, and employing seismic monitoring to demonstrate the CO_2 is safely stored in the intended reservoir unit.

Since the first successful large-scale demonstration of CO_2 storage in the 1990s, the Norwegian Government, industry and academia have continued to collaborate to develop CCS in multiple ways. These projects were stimulated by the CO_2 emissions tax in Norway and assisted by financing from research programmes aimed at developing a better understanding of CO_2 storage concepts.

Northern Lights will deliver CO_2 storage as a service, enabling the decarbonization of industrial emissions in Europe and facilitating the removal of CO_2 from the air.

Outcomes and impact

The Northern Lights project 'can be the first CO_2 storage for Norwegian and European industries, and can support goals to reduce net greenhouse gas emissions to zero by 2050' (Equinor, 2020). The project leadership is in discussions with potential customers representing 48 Mtpa of CO_2, more than the total current annual storage worldwide (Global CCS Institute, 2021*a*).

- In the short term, the objective is to demonstrate that the technical, regulatory and commercial aspects of CCS can be implemented as a climate mitigation tool.
- The project also will demonstrate that CCS is safe by monitoring injection wells and by avoiding emissions from the capture site. The long track record of CO_2 storage offshore Norway has been important for building the case for acceptably safe storage of CO_2.
- The Norwegian Petroleum Directorate has developed CO_2 storage atlases for the Norwegian Continental Shelf (NCS). These publications indicate that there is potential for long-term storage of many gigatons of CO_2 in saline aquifers and mature hydrocarbon fields of the NCS.

Aurora borealis is a common phenomenon in high latitude areas such as Norway, host of the Northern Lights CCS Project. © shutterstock.com/denisbelitsky.

KEYWORDS AND HASHTAGS

#CarbonCapture #CCS #CCUS #Decarbonization #NetZero #NorthernLights #CO2 #NetZero #decarb #EnergyTransition #Norway #future #SDG13

PRIMARY AND SECONDARY SDGS

13 4 7 9 11 12

Key geoscience skills

- **Technical:** reservoir characterization, geophysical monitoring, seismic interpretation, reservoir modelling and simulation
- **Conceptual:** multiscalar levels of inquiry, 3D and 4D thinking, interdisciplinary problem solving, managing subjectivity and uncertainty
- **Social:** multidisciplinary teamwork, application of technology to real-world problems

Upscaling and accelerating actions

CCS has been proven to be technically viable in several existing projects around the world. There are large-scale carbon capture projects already in operation, such as Equinor's Sleipner CCS project, Norway; SaskPower's Boundary Dam CCS project, Canada; and Shell's Quest CCS project, Canada.

What is needed to reach the levels of CCS deployment required to meet climate targets is to:

- reduce investment barriers for business and develop sustainable value-creation opportunities
- continue to support CCS demonstration projects to prove that it is viable
- build open-access CO_2 infrastructure and develop public–private cooperation

Carbon capture projects have the potential to reduce overall mitigation costs and increase flexibility in achieving greenhouse gas emission reductions. Northern Lights will serve as a CCS platform for further innovation in technology, business models, regulations and policy.

Where to find out more

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4.3.5.

Understanding resource and health of water environments: geophysical and immunological mapping of fish habitat – Lake Tanganyika, Zambia

Project leadership

Leadership for this project was provided by the SEG GWB programme; University of Kentucky, United States of America; University of Oklahoma, United States of America; University of Wisconsin, United States of America; University of Arizona, United States of America; Tanzania Fisheries Research Institute, Kigoma Station; and The Nature Conservancy Tuungane Project staff.

Synopsis

Lake Tanganyika (sub-Saharan eastern Africa) provides fish for high-protein sustenance and cash income to impoverished communities living along its shores. Destructive fishing practices, siltation (sediment pollution of nearshore spawning grounds from slash-and-burn deforestation), and climate change pose severe threats to Lake Tanganyika's fisheries. Population growth and an influx of refugees into the region are accelerating the threats to this important resource for food and income.

The Lake Tanganyika geophysical habitat mapping and sediment pollution studies, carried out between 2015 and 2017, were funded by the Society of Exploration Geophysicists' (SEG) Geoscientists without Borders (GWB) programme. The goal of the project was to employ marine geophysical and immunological tools to map Lake Tanganyika's littoral zone and benthic habitat to understand and protect fish-spawning grounds to ensure the continued health and productivity of this important food resource. (Figure 17 diagrams the zonation of lakes.)

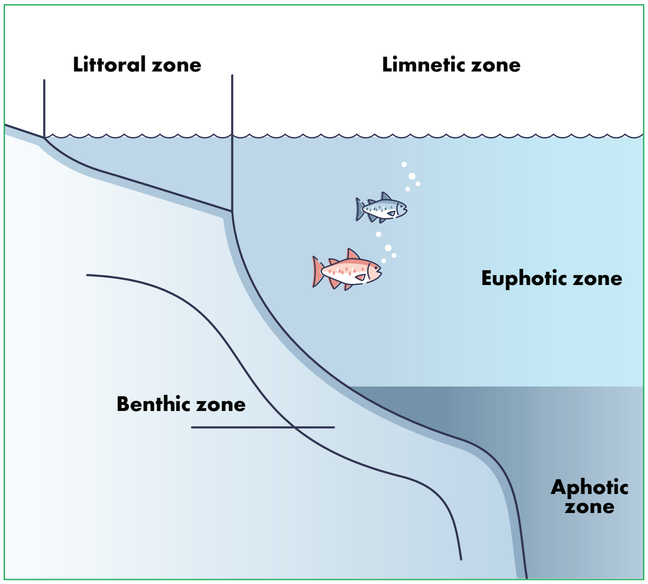

Figure 17. Benthic zone in relation to other lake zones.

Challenges, opportunities and objectives

- Reductions in fish productivity yield are a significant challenge in the tropics.
- This challenge exists for parts of Lake Tanganyika where open-water pelagic fish represent a key food source and cash income for local communities.
- Years of studying freshwater lakes and limnological monitoring suggest that a conservation strategy focused on small-scale protected zones can be vital to fish breeding and rearing.
- The use of acoustic geophysical data and information about sediment mixing and accumulation rates can form a framework for defining protected zones that can secure the health and productivity of the littoral fishery and improve the life of lakeshore villagers.

Project profile

The collapse of Lake Tanganyika's fisheries represents a looming humanitarian and ecological disaster that is widely acknowledged. However, few coordinated efforts have been undertaken to protect food security and safeguard the health and wellness of the people who rely on fish for their nutrition. This project is aimed towards improving the productivity of Lake Tanganyika's fishery in Zambia, securing food resources, and improving the health of thousands of villagers in the vicinity of the Nsumbu Tanganyika Conservation Project co-management area.

The team used detailed echo sounder surveying to produce deepwater benthic maps and to define the depth below the surface of the critical 30 m isobath. Side-scan sonar was used to assess benthic habitats and substrate types (see Figure 18 for an example scan collected in Kungwe Bay), whereas repeatable-signal compressed high intensity radiated pulse (CHIRP) sub-bottom surveys were used to assess the evolution of the delta system. In addition, sediment studies using surface samples and cores were used to provide a geologic framework and to understand recent sedimentation.

KEYWORDS AND HASHTAGS

#BenthicHabitat #Sidescansonar #Siltation #SmallScaleFisheries #Ecosystems #Marine #Benthic #SeaBottom #Tanganika #SDG14

PRIMARY AND SECONDARY SDGS

14 1 2 4 8 12

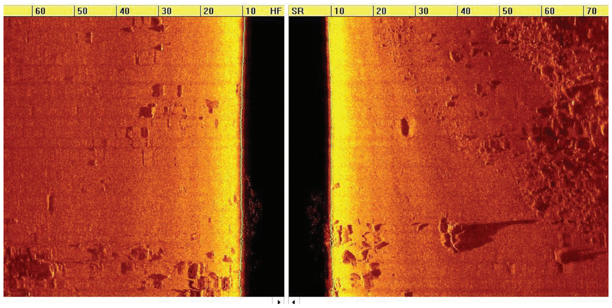

Figure 18. An example of a side-scan sonar image collected in Kungwe Bay. The panel illustrates the presence of bedrock and bedrock cobbles on the lake floor, which form a critical habitat for pelagic fish that swim inshore to spawn. © Geoscientists without Borders' Benthic Habitat for Humanity project team.

Outcomes and impact

- The project demonstrated that high-resolution geophysical data can help locate areas suitable for fish breeding and rearing.
- The geophysical and geological data will be used to create protected zones for small-scale fisheries that will allow fish stocks to recover and safeguard biodiversity.
- The geophysical habitat mapping will help communicate the importance of protected zones and ensure a continued supply of fish as food and a source of income for local communities around Lake Tanganyika.

Key geoscience skills

- **Technical:** geospatial technologies, remote sensing, modelling
- **Conceptual:** multiscalar levels of inquiry, 3D and 4D thinking, geoscience reasoning and synthesis, managing subjectivity and uncertainty
- **Social:** multidisciplinary teamwork, ability to sell ideas, application of technology to real-world problems

Upscaling and accelerating actions

Similar studies to identify no-catch areas to provide habitats for fish breeding and rearing could be identified all along Lake Tanganyika. The echo-sounding and side-scan sonar equipment was donated to the local Tanzania Fisheries Research Institute Kigoma Station and will be used to identify additional areas suitable for fish breeding. This study will provide lakeshore villagers information they can use to continue to fish productively and generate sustainable income.

Where to find out more

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4.3.6.

Assessing forest ecosystem health: remote sensing monitoring of threatened and protected lands – South Asia

Project leadership

University of Delaware, United States of America, and New York University, United States of America, provided leadership for this project.

Synopsis

Rapidly growing populations and development in many parts of the world come at the expense of protected land areas, biodiversity, and soil fertility, compromising forest ecosystem health and services. The pressures on landscape and forested areas often are exacerbated by variability in climate change factors such as rainfall and drought.

In this project, multiple scales of freely available remote sensing data, including Landsat and Sentinel satellite data, the random forest algorithm, and the Google Earth Engine platform, are used to document the status of forest degradation and to provide an easy-to-implement reporting framework for forest ecosystems in six South Asian countries (Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka). Although large swathes of coarse satellite data may be effective for assessing a country's forest health, the study recommends using finer-scale data to assess smaller targeted protected areas.

Challenges, opportunities and objectives

- SDG indicator 15.1.1 is 'forest area as a proportion of total land area', which will help achieve SDG 15: 'protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss' (United Nations, 2022).
- Forest 'area' can provide useful information for long-term monitoring, especially in landscapes with a high rate of deforestation – a process of forest being converted to non-forest.
- Forest degradation is prevalent in many landscapes across South Asia, where there is a reduction in the ecological capacities provided by forests over time.
- Despite the advancements in the field of geospatial technologies, capturing forest degradation has remained elusive.
- The project documents changes in forest cover due to rainfall variability since 2000 in six South Asian countries and determines the appropriate scale for reporting forest degradation due to natural or anthropogenic activities using multiscale remote sensing data sets.

Project profile

The project uses modern technology to monitor key parameters related to deforestation such as rainfall trends, vegetation indexes, and annual rain use efficiency, among others. These measurements are taken in Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka.

The analysis of these parameters year over year enables early detection of vulnerable and jeopardized areas, empowering communities, legislators, inhabitants and landowners to activate preventive or remediation measures to preserve the vegetation layers and soil characteristics necessary for the ecosystem to be resilient and perdure.

The constant monitoring of vegetation and rainfall data is done alongside historical comparisons of parameters during relatively long periods of time (some are 16-year comparisons, 2000–2016). This vision empowers these countries to understand the degradation of their forest areas (Figure 19) and provide powerful visual images that eliminate doubts about the data, motivating remediation actions.

Figure 19. An example of a tree that has died because of environmental factors leading to widespread deforestation. © Pinki Mondal, University of Delaware.

KEYWORDS AND HASHTAGS

#ForestDegradation #Desertification #EcoSystemHealth #RemoteSensing #SatelliteData #SDG15

PRIMARY AND SECONDARY SDGS

15 2 8 10 11

Some of the equipment and methods used are:

- Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) rainfall trends
- annual rain use efficiency (RUE) data set with a spatial resolution of 1 km (RUE is the ratio between the annual sum of vegetation productivity and the annual rainfall, i.e. normalized difference vegetation index, or NDVI, per unit rainfall)
- three sensor-band combinations, leveraging Landsat and Sentinel satellite data
- the random forest algorithm and the Google Earth Engine platform to investigate forest cover status at a finer spatial scale
- two test cases in India and Sri Lanka

Outcomes and impact

- The analyses of the data suggest that certain regions might be experiencing finer-scale degradation processes that cannot be captured by a broad-brush approach involving coarse-scale satellite data.
- The main conclusion is that policy-makers should not rely on reporting the overall vegetation trend at the national level, such as greening or browning, and should consider a multiscale approach to accurately report forest conditions.
- Considering only a broad-brush approach might be misleading, rendering achievement of SDG targets more challenging.
- This project provides landscape managers, policy-makers, academics (faculty, students), and boundary organizations with effective tools to assess and monitor forest health and degradation.

Key geoscience skills

- **Technical:** geospatial technologies, remote sensing, modelling
- **Conceptual:** multiscalar levels of inquiry, 3D and 4D thinking, geoscience reasoning and synthesis, managing subjectivity and uncertainty
- **Social:** multidisciplinary teamwork, ability to sell ideas, application of technology to real-world problems

Upscaling and accelerating actions

- This work provides a systematic reporting framework for policy-makers that considers overall national-level vegetation trends in the context of climate variability.
- The project will document the status of forest degradation within critical protected-area landscapes in support of SDG 15.
- Freely available global satellite data along with the framework defined in this study can be implemented in other regions of the world.

Where to find out more

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Network for Conserving Central India. 2022. Central India Data-Collab. https://www.centralindia-datacollab.org (Accessed 30 December 2022.)

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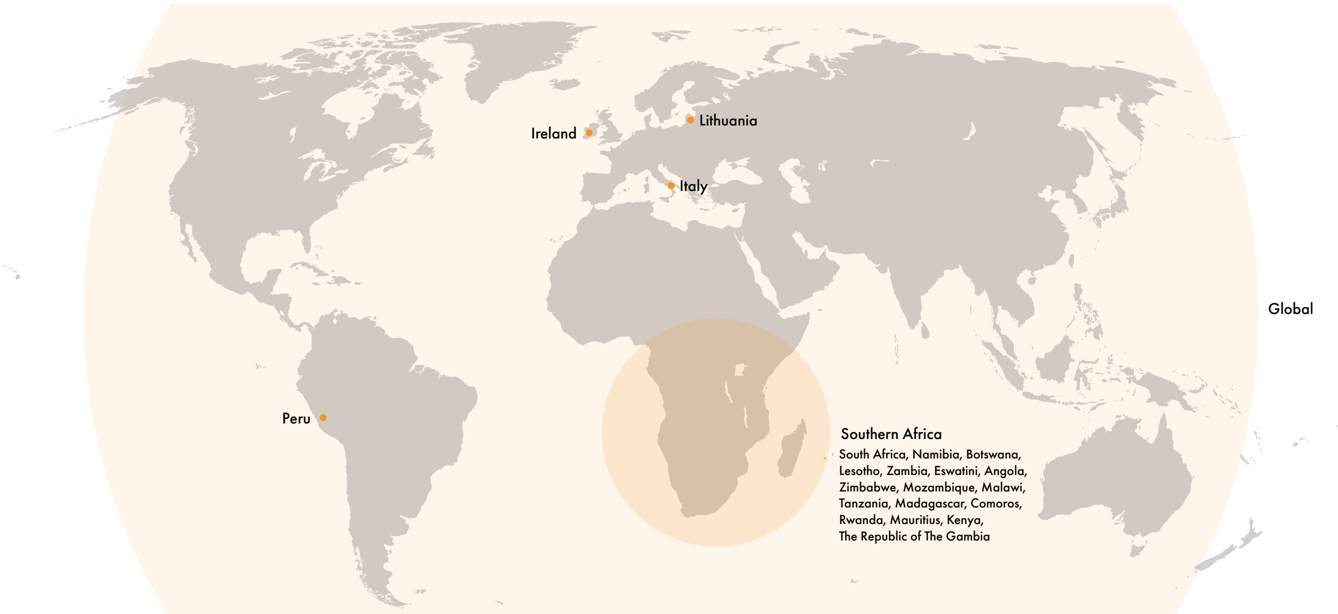
4.4. Examples for the prosperity dimension



	Prosperity dimension examples mapped to the SDGs	Primary SDGs	Secondary SDGs
4.4.1.	Setting standards for resource extraction and reporting: guidelines for environmental, social and governance parameters – southern Africa countries	7	3, 8, 12, 16
4.4.2.	Geoethics and accountability: International Association for Promoting Geoethics – Peru, global	8	4, 10, 12, 16
4.4.3.	Building resilience to geoenvironmental hazards: Global Earthquake Hazard and Risk Model – global	9	3, 10, 11
4.4.4.	Addressing discrimination in all forms: Equity, Diversity, and Inclusion in Geoscience project – Ireland, global	10	4, 5
4.4.5.	Forecasting volcanic activity and risks: World Organization of Volcano Observatories database (WOVOdat) – global	11	3, 9, 10
4.4.6.	Heritage site preservation: identification and reconstruction of Second World War Holocaust sites – Vilnius, Lithuania	16	4, 8, 10, 11
	SDGs mapped to the prosperity dimension: positive impact on socioeconomic systems	7, 8, 9, 10, 11, 16	1, 2, 3, 4, 5, 12

Table 4. Examples that show how geoscience supports the prosperity dimension and how the examples map to the SDGs. A few examples include secondary SDGs that are not among SDG assignments for the dimension, reflecting that many examples of geoscience activity invoke multiple dimensions.

4.4.1.

Setting standards for resource extraction and reporting: guidelines for environmental, social and governance parameters – southern Africa countries

Project leadership

Leadership for this project was provided by the SAMCODES Standards Committee (SSC), which operates under the joint auspices and funding of the Southern African Institute of Mining and Metallurgy and the Geological Society of South Africa.

Synopsis

Many countries need mining to survive. Raw materials are indispensable to support the future of humankind. It is then imperative that countries and other entities find ways to develop new approaches and collaborative outlooks to ensure sustainability aims of their own.

Geoscientists have a great contribution to offer to the mining industry and need to be part of mineral extraction leadership discussions to ingrain sustainability and responsible consumption in the individuals and organizations involved.

South Africa has always relied on mining as an integral part of its economy. The set of South African guidelines for the reporting of environmental, social and governance (ESG) parameters within the solid minerals and oil and gas industries (SAMESG) is leading the establishment of best practices, guidelines and standards for ESG reporting and compliance in a sector that requires more clarity and action on all these elements.

U.S. Geological Survey (USGS) scientist takes an oriented sample of folded, crenulated and metamorphosed banded siltite, exposed in the Blackbird cobalt-copper mine, in the Salmon River Mountains of east-central Idaho, USA. Cobalt is always found in a chemically combined form, and it is primarily used for lithium-ion batteries and for the manufacture of wear-resistant, high-strength alloys. © USGS.

Challenges, opportunities and objectives

Challenges, opportunities and objectives of the SAMESG project include the following:

- enable standardization of ESG reporting for the mining sector, aligned with international standards
- educate the organizations and workers in the mining sector on the importance of periodic, accurate and reliable reporting to enhance self-evaluation processes
- establish a platform of understanding for all involved internal and external stakeholders, whether they are regional, national or local
- increase the participation level of geoscientists in the formulation of South African Mineral Reporting Codes (SAMCODES), especially for mining and oil and gas

Project profile

Professionals worldwide, over the past three decades in particular, have adopted high standards for mineral reporting to contribute to investor, regulator and stakeholder confidence in extractive projects. Leading standards align with the global Committee for Mineral Reserves International Reporting Standards (CRIRSCO) template. Among these are the SAMCODES. Recognizing that ESG aspects of projects are often technically complex and span the entirety of the project value chain, the SSC anticipated the necessity for stringent disclosure standards regarding ESG parameters.

The resulting set of South African guidelines for the reporting of SAMESG was released in 2016. Although initially compiled as a technical guideline for regulated Competent Persons Reports, it has evolved to provide direction on ESG reporting requirements for public reporting. The guidelines apply the 'If not, why not?' principle: to the extent that any one of the nine reportable ESG items does not apply to a reporting entity and its operations or is not material, the reason must be explained and justified.

KEYWORDS AND HASHTAGS

#ESG #SustainableDevelopment #Uncertainty #SDG7

PRIMARY AND SECONDARY SDGS

7 3 8 12 16

Outcomes and impact

- SAMESG provides guidance on the technical supporting information required when compiling compliance documents for frameworks such as the Equator Principles, the United Nations Principles for Responsible Investment, and the Global Reporting Initiative.
- These frameworks encourage collaborative engagement towards more inclusive and transparent analysis of ESG matters, which in turn influence decision-making and project development practices.
- In 2019, SAMESG was recognized by the United Nations with the ISAR Honours Award (2019), raising awareness of national and international best practices on sustainability and SDG reporting, for its outstanding contribution to SDG 12 (indicator target 12.6): 'encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting.'

Key geoscience skills

- **Technical:** resource assessment, reserve valuation, risk assessment
- **Conceptual:** managing subjectivity and uncertainty
- **Social:** business management and leadership, ability to sell ideas, understanding of societal relevance

Upscaling and accelerating actions

SAMESG was compiled through a collaborative effort from 2013 to 2015 among various technical specialists. They shared a common understanding that a key driver for organizations to adopt ESG reporting is that more investors are incorporating ESG criteria into their valuations and investment strategies.

SAMESG has been a market-leading initiative, inspiring a global trend of review of other CRIRSCO-aligned mineral-reporting codes to better integrate ESG parameters.

Where to find out more

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Advancing Responsible Mining

'SAMESG draws extensively on existing international best-practice ESG guidance such as Agenda 21, the U.N. Global Compact, Equator Principles, the World Bank and IFC, and GRI guidelines and standards to name but a few. This was done intentionally to reduce reporting burdens and ensure comprehensive identification of core Triple Bottom Line interest areas and critical reporting indicators.'

–SAMESG COMMITTEE STATEMENT

4.4.2.

Geoethics and responsibility: International Association for Promoting Geoethics – Peru, global

Project leadership

IAPG was formed in 2012 as a multidisciplinary scientific platform for widening the discussion and creating awareness about problems of geoethics and ethics applied to the geosciences.

Synopsis

The International Association for Promoting Geoethics (IAPG) has advanced the ethical practice of geoscience globally during the past decade. IAPG's Peruvian chapter is a strong example of how the organization pursues its mission in a particular country or region.

Project profile

The purpose of IAPG is to help geoscientists across disciplines and geographies become more conscious of their social role and responsibilities and to raise and influence awareness of problems related to georesources and the geoenvironment. The aim is to address vital queries concerning the articulation of preservation and economic development of the Earth system, especially in low-income countries, and the creation of value in relationships among geoscientists, the media, politicians and citizens, particularly in the defence against natural hazards.

Junior geologist in the Altai Mountains, a mountain range in Central and East Asia, where Russia, China, Mongolia and Kazakhstan converge. The preservation of outcrops with good practices of geologic sampling is an integral part of geoethics, to preserve the access of future generations of geoscientists to key outcrops and geological sites. This topic is particularly important in a time of increased pressures on natural systems, decreased accessibility to field sites, degradation of irreplaceable geologic resources, and raised international awareness of the importance of geoheritage, geodiversity, and geoconservation. © Alexandr Frolov, republished under its Creative Commons Attribution-ShareAlike (CC BY-SA) 4.0 International licence.

Geoethics consists of research and reflection on the values that underpin appropriate behaviours and practices wherever human activities interact with the Earth system, providing a point of intersection for geoscience, sociology, philosophy and economics. To foster the dissemination of geoethics, IAPG promotes publication of scientific papers, organizes meetings and conferences, encourages the establishment of regional chapters and specialty groups, and cooperates with other like-minded organizations. IAPG actions have included the establishment of a School on Geoethics and Natural Issues in 2019 to publicize geoethics through webinars, articles, short courses, and participation in scientific projects.

IAPG provides a reference and guidelines to address concrete problems by trying to find socioeconomic solutions compatible with a respect for the environment and the protection of nature and land, encouraging critical analysis of the use and management of georesources.

IAPG Peru

The Peruvian chapter of IAPG was founded in 2014 with the aim to (1) organize and promote conferences and study days on geoethics and geoscientific culture in national scientific events; (2) encourage the formation of study groups focused on geoethics and related topics such as the sustainable use of georesources, application of geoethical values in the management of geologic risks, and education in geoscience; (3) foster interaction among geoscientists, the media and the public regarding the protection of the geologic environment and other geoethics matters; (4) increase the production and quality of publications on geoethics and geoscience in Peru; (5) promote the inclusion of geoethics in educational programmes; (6) promote the improvement of the quality of education in geoscience in the national curriculum; (7) cooperate with national and international organizations in the development of research topics related to geoethics; and (8) facilitate the exchange of geoscientific information and interaction among its members.

KEYWORDS AND HASHTAGS

#GeoEthics #Ethics #GeoHeritage #Values #Earth #Collaboration

PRIMARY AND SECONDARY SDGS

8 4 10 12 16

Outcomes and impact

In March 2022, IAPG supported the creation and launch of the *Journal of Geoethics and Social Geosciences* with the Istituto Nazionale di Geofisica e Vulcanologia (the Italian National Institute of Geophysics and Volcanology) as an open-access journal, without publication costs for authors, open to contributions from human and social sciences experts to provide a multidisciplinary perspective.

Achievement of the IAPG objectives will strengthen the scientific research base on geoethics, facilitate its more effective application, and promote the notion of a shared geoheritage that has cultural, educational and scientific value in addition to being an economic resource.

IAPG Peru activities include:

- organization of an annual minerals exhibition, MinerLima, since 2015, comprising talks, crash courses, workshops and geotours aimed at sharing geoscience knowledge and attracting future geoscientists
- creation of an IAPG Peru Student Group to increase interaction between students and the network and student participation in projects of the IAPG Peru community
- collaboration to produce the book *Geoethics in Peru: A Pathway for Latin America*
- creation of the Georisk Management Task Group to seek unified actions on georisk management and provide guidance on disaster prevention by applying geological engineering solutions and ensuring geological aspects are considered in urban planning
- establishment of a roundtable on geoethics in Peru to extend discussion on the importance of developing geoscience activities with an ethical approach
- organization of the first Peruvian Earth Science Olympiad in 2022 to promote and raise the level of geoscience in schools (In this activity, the focus is on the importance of geoscience education in sustainable development.)

IAPG brings together 3,000 members in 128 countries on five continents and can count on a network of 35 national sections to promote geoethics worldwide. All geoscientific disciplines are represented, and collaboration with disciplines in social sciences and humanities occurs.

Key geoscience skills

- **Technical:** geologic field trips for outcrop interpretation, geologic stress analysis, earthquake risk assessment, seismic interpretation, magnetometry and gravimetry data acquisition, processing and interpretation, sedimentology, mineralogy, reservoir modeling, subsurface mapping
- **Conceptual:** multiscalar levels of inquiry, 3D and 4D thinking, geoscience reasoning and synthesis, managing subjectivity and uncertainty, risk assessment, communication and awareness campaigns planning
- **Social:** understanding of social relevance, community leadership, collaboration, multidisciplinary teamwork, ability to sell ideas, empathy, science communication, conflict resolution

Upscaling and accelerating actions

IAPG has sponsored and facilitated numerous sessions on geoethics at the European Geosciences Union General Assembly since 2013 and at many other scientific congresses with the aim of discussing concepts relevant to the geoscience community and society as a whole such as responsibility, sustainability, prevention, adaptation, geoeducation and geoliteracy. One of the aims was to recentre global sustainability strategies around Earth systems knowledge and services required to support the SDGs and address the lack of geoscience in the SDG debate. Further expansion of these initiatives will include the growth of the regional chapter network and, naturally, should be grounded in the collaboration efforts among professional societies related to geoscience.

KEYWORDS AND HASHTAGS

#GeoEthics #Ethics #GeoHeritage #Values #Earth #Collaboration

PRIMARY AND SECONDARY SDGS

8 4 10 12 16

Where to find out more

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4.4.3.

Building resilience to geoenvironmental hazards: Global Earthquake Hazard and Risk Model – global

Project leadership

The Global Earthquake Model (GEM) Foundation provided leadership for this project.

Synopsis

A major contribution to ending poverty, in all its forms, everywhere (SDG 1) will be to build the resilience of poor and marginalized people living in vulnerable situations and reduce their exposure and susceptibility to both climate-related extreme events and other environmental shocks and disasters. Creating a world that is resilient to geoenvironmental hazards such as earthquakes, volcanic eruptions, tsunamis, landslides and floods is a major societal challenge that closely involves geoscientists.

Challenges, opportunities and objectives

- Between 2000 and 2010 more than half a million people died as a result of earthquakes and tsunamis. Most of these fatalities were in the developing world, where risks increase because of rapid population growth and urbanization.
- These geophysical shocks are not bolts from the blue. By and large, they occur and reoccur in the same geologically active regions, along lethal surface fault lines and tectonic boundaries that have been mapped by geologists and where anticipated ground effects can be modelled by seismologists.
- Despite this wealth of geoscientific knowledge, in many earthquake-prone regions, disaster risk models either do not exist or are inaccessible. Better risk awareness can reduce the toll that earthquakes take on populations by promoting better construction of buildings, greater access to insurance, and improved emergency response.
- That is why, in 2009, a not-for-profit foundation, the Global Earthquake Model, was set up. Based in Pavia, Italy, the foundation brings together a global partnership of geoscientists from more than 30 public, private, academic and non-governmental organizations worldwide. The mission of the GEM Foundation is simple in concept but technically challenging: establish a common global framework for earthquake risk reduction.

Project profile

Improving earthquake safety worldwide is hampered by numerous technical challenges. These include a lack of standardized data, analysis tools, local expertise, international collaboration, and scientific solutions.

To address these challenges, GEM has put together a global network of collaborators to develop and disseminate a complete set of earthquake information for a comprehensive worldwide assessment of seismic risk. It has also developed and freely disseminated hazard and risk analysis software (OpenQuake) to train educators, researchers and risk management professionals worldwide.

Students practice an earthquake drill at Jana Bikash Secondary School, Matatirtha, in Nepal. Preparedness for geo-risks, especially earthquakes and tsunamis, benefits from including geoscientists, who can offer technical information on vulnerable areas, tectonic activity and historical events. © Jim Holmes for Australian Aid of the Australian Department of Foreign Affairs and Trade, republished under its Creative Commons Attribution (CC BY) 2.0 licence.

KEYWORDS AND HASHTAGS

#Earthquakes #Seismology #NaturalHazards #DisasterRiskReduction #Vulnerability #Exposure #SDG9

PRIMARY AND SECONDARY SDGS

9 3 10 11

Geoscientists (seismologists, geologists and geodesists) develop the earthquake hazard models and maps, which require historical information on past earthquake locations, magnitudes, and shaking intensity; earthquake faults; and movement of tectonic plates.

Structural/risk engineers, remote sensing scientists, and geospatial information specialists develop information on human and building vulnerability. Together with mathematicians and computer scientists, this multidisciplinary team builds computer models to simulate potential earthquake impacts and damage.

Outcomes and impact

- A major outcome of the GEM endeavour has been the creation of the Global Earthquake Hazard and Risk Model, a compilation of national and regional earthquake data and models that provides a comprehensive global assessment of earthquake risk.
- GEM also has developed and freely disseminated its OpenQuake hazard and risk analysis software and models, which are being used by thousands of scientists, engineers, risk managers, and planners from more than 100 countries to reduce earthquake risk through real-time warnings, national building codes, critical infrastructure design and regulation, urban planning, corporate asset management, and insurance.
- To date, as many as 1,000 scientists from more than 100 countries have received training on the use of the OpenQuake engine to produce earthquake scenarios and run risk calculations.
- As an example, Prof Ana Beatriz Acevedo has worked closely with GEM to develop a risk model in Colombia for Bogota, Medellin and Cali. Her work has identified vulnerable urban building stock, leading to public initiatives to retrofit local houses and provide education on seismic preparedness for the local community.

Key geoscience skills

- **Technical:** structural geology, seismology, seismotectonics, remote sensing, geospatial information systems, seismic hazard modelling
- **Conceptual:** 3D and 4D thinking, ability to sell ideas, managing subjectivity and uncertainty
- **Social:** multidisciplinary teamwork, application of technology to real-world problems, understanding of societal relevance

Upscaling and accelerating actions

GEM has fundamentally changed the world of earthquake risk assessment and application through its open, collaborative framework for knowledge sharing and capacity building. With the development of its software, databases and hazard/risk models, it has brought geoscientific knowledge to a multidisciplinary and cross-sectoral community of hundreds of scientists and engineers worldwide.

GEM's strategic plan for the next decade (2021–2030) includes:

- more collaboration in multihazard risk assessments, including future risks and climate change impact
- assessment of secondary hazards (e.g. tsunamis, landslides, liquefaction) and cascading and systemic risks (e.g. failure of infrastructure, business interruption, disaster recovery)
- more city-scale and urban applications
- improved modelling of risk solutions leading to resilient communities

Where to find out more

Global Earthquake Model. 2022. Our partners. https://www.globalquakemodel.org/partners (Accessed 2 January 2023.)

4.4.4.

Addressing discrimination in all forms: Equity, Diversity, and Inclusion in Geoscience project – Ireland, global

Project leadership

EDIG is led by director Aileen Doran and co-director Anna Bidgood, with iCRAG as the founding partner.

The initial phase of the EDIG project was facilitated by iCRAG in collaboration with geoscientists and other experts from several external institutes and organizations, and EDIG has since expanded outwards, establishing a more global volunteer base. EDIG currently has more than 30 volunteers from more than 11 countries, and it is growing outwards continuously to become more inclusive and representative.

Synopsis

The Equity, Diversity, and Inclusion in Geoscience (EDIG) project is a global, virtually based initiative started by several geoscientists and other specialists, including social scientists, working together to better understand the impact of EDI-related issues within the larger geoscience community.

The idea for the project grew from conversations within the EDI Committee of the Science Foundation Ireland Research Centre in Applied Geosciences (iCRAG) that recognized significant EDI-related challenges in the geoscience community. As the conversations grew, so did the project, leading to the formation of EDIG as it expanded outwards from iCRAG's EDI Committee to open itself up to new volunteers from any background, sector or location. This evolution aimed to help form a more representative, long-running initiative, intended at providing a platform, open to all, to facilitate conversation and progressive action towards more inclusive and equitable geoscience. A long-term strategy for the project is under development to ensure effective, sustainable running with several planned goals, including the compilation of resources from other groups and initiatives accessible to all.

Challenges, opportunities and objectives

- EDIG was formed in response to the experiences of geoscientists with EDI-related challenges.
- It was designed as a stand-alone virtual conference (2020) to provide a platform for participants to listen, learn and act.
- The EDIG conference was set up to include as diverse a programme as possible, with new voices, not focusing on any single minority or challenge.
- To help design this event, a global survey was launched to help better understand the impact of EDI-related challenges within geoscience. The results were used to help structure and plan the conference, focusing on where we have come from, where we are now, and where we are going in terms of EDI in geoscience.
- The conference highlighted the continued need for action to make geoscience more inclusive and accessible. Subsequently, the EDIG project evolved into a larger volunteer-led initiative, working towards addressing discrimination in all forms (including unconscious biases) within geoscience.
- The second EDIG conference is being planned and will focus on EDI data (its uses, purpose, methods of collection), awareness of overarching challenges, and a global EDI action plan (Is it possible? Should it be considered?).

Attendees of the Science Foundation Ireland Research Centre in Applied Geosciences (iCRAG) Researching Social Theories, Resources, and Environmental (ReSToRE) International Summer School. The school brings together early-career geoscientists and social scientists from 50 developing and developed nations to examine the sustainable use of Earth resources. © iCRAG.

KEYWORDS AND HASHTAGS

#DEI #Equity #Diversity #Inclusion, #Representation #Accessibility #Gender #Ageism #CulturalIssues #Underrepresentation #Outsiders #SDG10

PRIMARY AND SECONDARY SDGS

10 4 5

Project profile

The first phase of the EDIG project (survey and conference) was implemented by 17 volunteers from several institutes. There were 708 participants in the survey, and the conference had a similar number of registrants.

The conference was sponsored by 14 supporting partners that shared EDIG's activities with their networks, including other EDI groups, geoscience organizations, and institutes.

In early 2021, the second phase of the EDIG project was undertaken. It involved restructuring the project and opening the team to new volunteers. Currently, the project has more than 30 volunteers working across the project to help promote a more inclusive and equitable geoscience.

The EDIG project is currently made up of three committees: Executive, General and Advisory Board. The Executive Committee is composed of the remaining original founding members of the project, whereas the General Committee is made up of volunteers in charge of the day-to-day running of the project. The General Committee is composed of five working groups: events, resources, research, social media and network.

Although initially designed as a two-day event, the EDIG project aims to run a conference, host other events (e.g. discussion workshops), share resources, and connect to a wide network to promote action to make geoscience more accessible and inclusive.

Outcomes and impact

- The EDIG survey was administered in the summer of 2020, with 708 participants from 58 countries, through interdisciplinary research in collaboration with several social scientists.
- In collaboration with several social scientists, survey results were analysed and used to inform the 2020 conference structure and topics discussed, including how diversity has changed, intersectionality, unconscious bias, the leaky pipeline, and how to make fieldwork more inclusive.
- As part of planning and preparations for the EDIG conference, the project has developed a wide and diverse network of organizations that help share activities with their memberships.
- EDIG representatives have presented at several conferences and have been invited to several companies for lunchtime talks about lessons learned, helping to facilitate EDI discussions.
- EDIG is working on a website to act as a virtual platform, hosting several resources, to facilitate learning about EDI challenges in geoscience and guide action to make geoscience more inclusive, accessible and equitable.
- With regard to its impact, the EDIG project aims to harness the collective power of the geoscience community to enact change, promoting and improving the equity, diversity and inclusivity of geoscience for the benefit of all.
- EDIG also aims to connect geoscientists from traditionally under-represented backgrounds to those in the majority and to raise awareness of the challenges and barriers experienced by minority and marginalized geoscientists.

Key geoscience skills

- **Technical:** leadership, social science, data analysis, event planning/project management
- **Conceptual:** interdisciplinary problem solving, managing subjectivity and uncertainty, understanding cultural, ethnic, regional, national and individual characteristics or preferences
- **Social:** multidisciplinary teamwork, social learning and cultural literacy

Upscaling and accelerating actions

EDIG will work to:

- provide a platform for people to come together and learn about EDI-related challenges and how to take action
- provide EDI data to contribute to initiatives working towards increased inclusion, accessibility and representation, and to help promote effective change
- design discussion-based workshops and develop resources in collaboration with other groups

Where to find out more

iCRAG (SFI Research Centre in Applied Geosciences). 2022. Equity, diversity, and inclusion in geoscience. https://www.icrag-centre.org/edig/ (Accessed 2 January 2023.)

@iCRAGcentre, @EDIinGeo

4.4.5.

Forecasting volcanic activity and risks: World Organization of Volcano Observatories database (WOVOdat) – global

Synopsis

More than 1 billion people live close to active volcanoes, and with the ever-increasing global population, more and more people are living at risk from volcanic hazards. During volcanic crises, scientists face the challenging task of making a spot-on decision for the timely implementation of actions to mitigate the impact of any volcanic manifestation. This is typically done by interpretation of real-time monitoring data and comprehensive knowledge of past activities of the volcano. But it is not an easy task, as there is a large variety of information and a large variety of volcanic behaviour. The World Organization of Volcano Observatories database (WOVOdat) project aims at freely and openly exchanging data and experiences of past eruptions at a global level to improve the management of volcanic crises and mitigate the risk of volcanic hazards.

The project is based on partnerships between global volcano monitoring observatories within the World Organization of Volcano Observatories (WOVO) and scientists to build an open-access database of volcanic unrest. The project translates and compiles the myriad volcanic monitoring data into common formats with the goal of making them freely web accessible for reference during volcanic crises, comparative studies, and basic research on pre-eruptive processes.

WOVOdat is currently hosted by the Earth Observatory of Singapore (Nanyang Technological University, Singapore) with project primary investigator Benoit Taisne and co-investigator Fidel Costa (at Institut de Physique du Globe de Paris, Université Paris Cité, France).

Project leadership

WOVOdat was initiated by Chris Newhall and is a partnership project of WOVO, a commission of the International Association of Volcanology and Chemistry of the Earth's Interior.

Challenges, opportunities and objectives

- The goal of the WOVOdat project is creating ready access to the most comprehensive and authoritative global unrest database as a resource to improve eruption forecasts, hazard evaluation, and mitigation actions for better decision-making during volcanic crises. WOVOdat aims to be a database for volcanology similar to epidemiological databases that currently exist for medicine.
- The ever-growing data and advancement in volcano monitoring techniques and methods, including evolution in space-based remote sensing monitoring capabilities that cover both spatial and temporal

Lunch with a view of Ngaurahoe volcano during an undergraduate field trip to study the active Tongariro Volcanic Complex, New Zealand. © Heather K. Handley.

parameters, have created challenges in data standardization, integration and management.

- Another challenge is for observatories from different countries that have different data policies to be able to share freely and openly and to have the human and infrastructure resources required to compile, standardize, and effectively contribute their data to the database.
- The WOVOdat online interface (WOVOdat, 2022) already allows interactive data analysis and data visualization and provides the opportunity for comparison between volcanoes and eruption styles, which is needed during volcanic crises.
- The standardization of large amounts of data in WOVOdat opens the opportunity for the application of artificial intelligence and machine learning tools that may be able to provide better and more accurate eruption forecasts than have been possible so far.

Project profile

WOVOdat is a global initiative of the volcano community, mainly the WOVO members. The project is managed and operated by five people, including two project investigators, a co-ordinator, an IT programmer, and a data analyst. WOVOdat is hosted at the Earth Observatory of Singapore of Nanyang Technological University. The volcano observatories that actively contribute to WOVOdat are based in Asia Oceania, specifically in Papua New Guinea, Indonesia, the Philippines, Japan and New Zealand, although historical data in the database come from worldwide volcanoes. The main data contributors are the Smithsonian Institution's Global Volcanism Program, the Global Volcano Model, Japan Meteorological Agency, the National Research Institute for Earth Science and Disaster Resilience, the U.S. Geological Survey (USGS) Volcano Disaster Assistance Program (the USGS Volcano Hazards Program), GeoNet (geological hazard information for New Zealand), UNVACO, the Philippine Institute of Volcanology and Seismology, the Indonesian Center for Volcanology and Geological Hazard Mitigation, Instituto Geográfico Nacional of Spain, and Cornell University. Links to these contributors are available in the footer of the WOVOdat site (WOVOdat, 2022).

Outcomes and impact

- WOVOdat builds global partnerships and collaborations to help reduce societal risk from volcanic hazards.
- WOVOdat builds a comprehensive global database of volcanic unrest as a source of reference for making decisions during crisis response, finding precursory patterns, conducting comparative studies, and understanding eruption processes.
- Following the FAIR (Findability, Accessibility, Interoperability, and Reuse) guiding principles for data, WOVOdat is creating a systematic database structure with a standardized data format of multiparameter volcano monitoring, integrated with metadata, both in space and time, allowing data interoperability between various instrumental monitoring techniques, different processing methods, and observational data.
- WOVOdat also developed a stand-alone local host monitoring database system that is open source and freely available to observatories and is currently adopted and developed at volcano observatories (WOVOdat, 2022).
- WOVOdat coordinates data on volcano monitoring infrastructure through the Global Volcano Monitoring Infrastructure Database to improve the understanding of the current capabilities and limits of volcano monitoring from the ground and space.
- It has organized and led several international workshops to foster collaboration, data sharing, and partnerships within the global volcano monitoring community.
- WOVOdat uses data to help drive policy to address systemic risk in disaster prevention and management.
- It fosters international collaboration by freely exchanging data and best practices among the volcanological community.

KEYWORDS AND HASHTAGS

#VolcanicHazards #EruptionForecasts #VolcanicCrises #Lava #Volcano #GeoHazard #Hazards #Risk #Mountains #Readiness #Collaboration #SDG11

PRIMARY AND SECONDARY SDGS

11 3 9 10

Key geoscience skills

- **Technical:** field methods, database construction, artificial intelligence, machine learning
- **Conceptual:** geoscience reasoning and synthesis, managing subjectivity and uncertainty
- **Social:** multidisciplinary teamwork, application of technology to real-world problems, understanding of societal relevance

Upscaling and accelerating actions

- A major barrier to collaboration and building the WOVOdat database is time, particularly when observatories are operating in crisis mode. Greater funding and resource support would allow additional analysts to work with individual observatories to advance the construction of the global database.
- Increased discussion and agreement between scientists about data standardization, formatting and sharing at the international level would allow faster progress of data incorporation.
- Volcano hazard forecasts could be improved by accessible and well-designed volcanic monitoring infrastructure. The development of central and globally coordinated infrastructure in volcano monitoring would facilitate ease of comparison of data and expansion of the database. With more data, better models could be built, leading to greater accuracy in forecasts.

Where to find out more

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WOVOdat. 2022. Online interface. World Organization of Volcano Observatories database. https://wovodat.org (Accessed 2 January 2023.)

4.4.6.

Heritage site preservation: identification and reconstruction of Second World War Holocaust sites – Vilnius, Lithuania

Synopsis

Protecting key Holocaust sites is important for the preservation of Jewish history and contributes to human well-being both spiritually and economically. This study uses lidar, digital elevation models, ground-penetrating radar (GPR), and electrical resistivity tomography (ERT) to investigate unmarked mass graves at the Ponary extermination site, Lithuania, where ~100,000 people, including 70,000 Jews, were killed and buried between 1941 and 1944. The site also hosts a hand-dug escape tunnel that was used by Jewish prisoners.

The GPR and ERT surveys successfully mapped the unmarked mass graves and delineated a segment of the escape tunnel. Results from this type of study can provide important missing data needed for the reconstruction of historical events, excavation of key sites, and opportunities for memorialization.

Challenges, opportunities and objectives

- Holocaust mass grave sites in Eastern Europe are difficult to locate because of limited, incomplete and poor historical records.
- The overall goal of this project was to explore the use of minimally invasive geophysical methods to identify and delineate unmarked mass grave sites and the remains of a 1944 escape tunnel at the Ponary extermination site in Lithuania.
- Identification of these grave sites and the tunnel are critical to fill gaps in the historical records, reconstruct the site history, help bring closure to Holocaust victims and their families, and protect and safeguard these historic sites.

Project leadership

Leadership for this project was provided by Christopher Newport University, United States of America; Israel Antiquities Authority, Israel; University of Wisconsin–Eau Claire, United States of America; Duquesne University, United States of America; KMB Architects, United States of America; and Lithuanian Institute of History, Lithuania.

Project profile

Between 1941 and 1944 approximately 100,000 people may have been murdered at the Ponary (Paneriai) extermination site in Lithuania. The location of some of the mass grave sites remains unknown, including site details such as the existence of an escape tunnel that was dug during this period by enslaved laborers.

This project complements part of a larger project funded by Geoscientists without Borders, administered by the Society of Exploration Geophysicists, that was undertaken at the request of the Vilna Gaon State Jewish Museum in Lithuania in preparation for the construction of a proposed new information centre. Funding was also provided by several organizations, including BGC Engineering Inc., the U.S. Commission for the Preservation of America's Heritage Abroad, the U.S. Embassy in Lithuania, the University of Hartford, the University of Wisconsin–Eau Claire, Duquesne University, the Antiquities Authority of Israel, sponsors of the PBS show *NOVA*, and the Jewish Community of Lithuania.

The project team included geophysicists, university professors and students, archaeologists, and historians and required consultation with Holocaust survivors and museum staff in Poland and in Lithuania. The field investigations were completed between 8 and 30 June 2016 at the Ponary extermination site in the Vilnius region of Lithuania. ERT and GPR surveys were carried out to provide images of the subsurface in the region of suspected pits and an escape tunnel. Lidar data acquired in 2015 provided details on the digital elevation over the site. A UAV was also used to provide aerial images of the site.

KEYWORDS AND HASHTAGS

#Holocaust #MassGraves #ArchaeologicalSites, #LiDAR #ERT #GPR #Shoa #Geoethics #Ethics #Archeology #SDG16

PRIMARY AND SECONDARY SDGS

16 4 8 10 11

Outcomes and impact

- The lidar digital elevation model provided details of the Ponary site surface topography, and ERT and GPR delineated a large, unmarked mass grave and portions of an escape tunnel constructed by the prisoners in 1944. The circular pit was estimated to be 25 m in diameter and ~4 m in depth. Although the ERT and GPR surveys were not able to determine the contents of the pit conclusively, ERT did show a significant contrast in electrical resistivity between the pit and background soils, suggesting an infilled pit.
- The entrance to the escape tunnel and portions of the tunnel were clearly imaged by the resistivity data and characterized by high-conductivity anomalies (see Figure 20) due to the higher moisture content within the tunnel. The results of the ERT and GPR surveys will be used to optimize the demarcation of the areas of suspected mass graves and the escape tunnel so they can be better protected and memorialized.

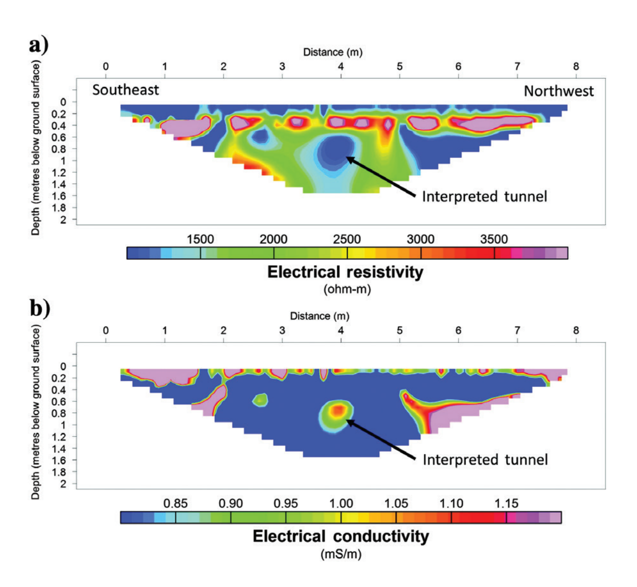


Figure 20. (a) Resistivity and (b) conductivity models produced from ERT over an excavated tunnel entrance of the Ponary extermination site in Lithuania. The tunnel entrance coincides with a low-resistivity (or high-conductivity) circular anomaly approximately 80 cm below the ground surface. The layer of high-resistivity material (the pink blobs) above the tunnel entrance anomaly is interpreted as sand and potential stone debris from the pit walls, with shallow fill (McClymont, 2022).

Key geoscience skills

- **Technical:** field geophysical data acquisition, seismic data processing, seismic modelling
- **Conceptual:** field-based learning, 3D and 4D thinking, interdisciplinary problem solving
- **Social:** multidisciplinary teamwork, application of technology to real-world problems, understanding of societal relevance

Upscaling and accelerating actions

- The story of the Holocaust and associated atrocities is incomplete because of the scarcity of data.
- Geophysical surveys can be used to unearth mass graves associated with war crimes and other atrocities and for forensic investigations associated with individual clandestine graves.
- Geophysical techniques can also be used to guide the excavation of other types of archaeological, palaeontological and anthropological sites.
- Geoheritage sites stimulate local community enterprise, support workforce training and development, provide public education, and promote peace.

Where to find out more

McClymont, A. F., Bauman, P. D., Freund, R. A., Seligman, J., Jol, H. M., Reeder, P., Bensimon, K. and Vengalis, R. 2022. Preserving Holocaust history: geophysical investigations at the Ponary (Paneriai) extermination site. *Geophysics*, Vol. 87, No. 1, pp. WA15–WA25. https://doi.org/10.1190/geo2021-0065.1

4.5 The Heat Map

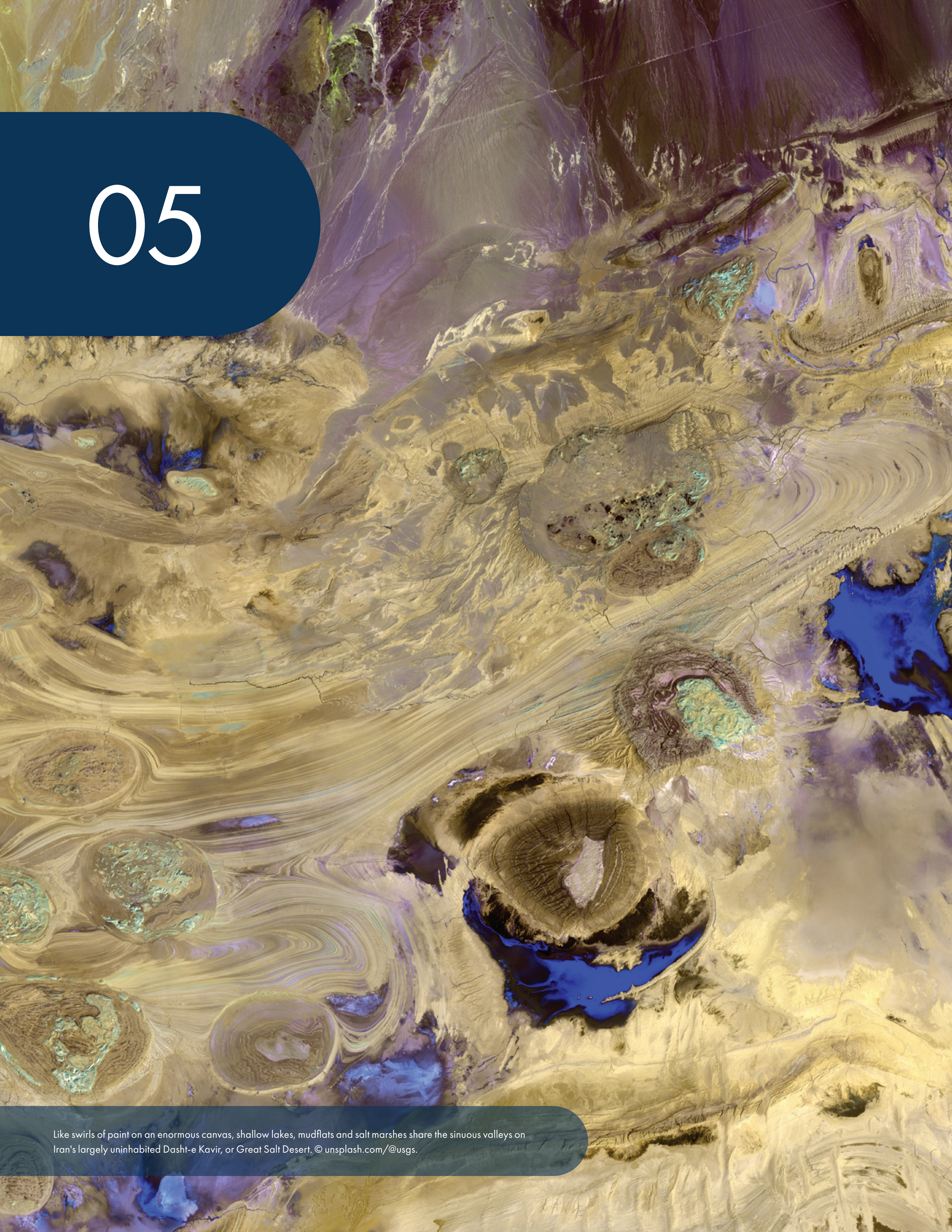
By understanding how various types of geoscience activity align with the SDGs, geoscientists may discover relationships between initiatives that can lead to new collaborations and efficiencies. To illustrate this, we created a heat map (Table 5) showing which examples presented in this report advance which SDGs. Each example was assigned a primary SDG – the goal to which the example contributes most. Other SDGs to which each example also contributes are named in a separate row.

The examples do not cover a full range of geoscience sustainable development activity but are offered as a collection that includes six describing positive impacts on individuals, six illustrating positive impacts on physical systems, and another six that show positive impacts on socioeconomic systems. The examples together map to all 17 SDGs when one considers that SDG 16 (peace, justice and strong institutions) and SDG 17 (partnerships for the goals) are a feature of every initiative described.

Table 5. The *Geoscience in Action* Heat Map, showing how geoscience examples align with the SDGs and the people, planet and prosperity dimensions.

		SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
People dimension: positive impact on individuals																		
People 1	Geoscientific data for policy decisions	●	○	○			○				○	○						○
People 2	Supporting agriculture and health policies		●	○									○					○
People 3	Geologic mapping to identify health risks			●	○													○
People 4	Creating awareness of geoscience in society			○	●					○	○	○						○
People 5	Towards gender equity in geoscience				○	●		○	○								○	○
People 6	Access to Water		○	○			●			○		○						○
Planet dimension: positive impact on physical systems																		
Planet 1	Monitoring water quality and infrastructure development			○			●			○		○						○
Planet 2	Affordable and clean energy							●		○			○	○				○
Planet 5	Protecting geodiversity and biodiversity with responsible production and consumption		○		○							○	●			○		○
Planet 3	Accelerating decarbonisation				○			○		○		○	○	●				○
Planet 4	Understanding resource and health of water environments	○	○		○				○				○		●			○
Planet 6	Assessing forest ecosystem health		○						○		○	○				●		○
Prosperity dimension: positive impact on socioeconomic systems																		
Prosperity 1	Setting standards for resource extraction and reporting			○				●	○				○				○	○
Prosperity 2	Geoethics and accountability				○				●		○		○				○	○
Prosperity 3	Building resilience to geoenvironmental hazards			○						●	○	○						○
Prosperity 4	Addressing discrimination in all forms				○	○					●							○
Prosperity 5	Forecasting volcanic activity and risks			○						○	○	●						○
Prosperity 6	Heritage site preservation				○				○		○	○					●	○

05



Like swirls of paint on an enormous canvas, shallow lakes, mudflats and salt marshes share the sinuous valleys on Iran's largely uninhabited Dasht-e Kavir, or Great Salt Desert. © unsplash.com/@usgs.

GEOSCIENCE SUSTAINABILITY: DEFINING THE STAKEHOLDERS AND IMPACT

The success of geoscience in advancing sustainability is heavily dependent on an understanding of how the different disciplines of geoscience contribute to the SDGs. This understanding empowers and motivates geoscientists to do more towards advancing the sustainability agenda. In this report, we use the term *stakeholder* informally to define significant groups involved with sustainability and their relationship to geoscience. It is a starting point for discussion of partnerships to help advance geoscience and the SDGs.

Geoscientists are the fundamental stakeholders in geoscience but are not the only significant group. A deep understanding of the stakeholders' composition is key for identifying partnerships and influencers for sustainability transformations that require geoscience.

To realize the intrinsic value of geoscience, it is imperative to identify the stakeholders relevant to the profession. The stakeholders determine, to different extents, the future of geoscience as an appealing and successful profession with a beneficial value proposition for people, planet and prosperity. Furthermore, defining and mapping stakeholders in geoscience help us frame the opportunities to develop strategies for outreach with customized communication of geoscience's value proposition.

Defining our stakeholders is constructive not only for geoscientists but also for the other individuals, social groups and organizations that may not yet have the knowledge, perspective or understanding of potential solutions that geoscience may bring to their activities in pursuit of common sustainability goals. From motivating primary- and secondary-school students to be the geoscientists of the future to collaborating with legislators on sustainable development, the identification of stakeholders and partnerships is vital for the very sustainability of the profession.

Categorizing the stakeholders of geoscience from the current complex and intricate systems according to their conceptual or potential role is not trivial.

We have clustered the main stakeholders of geoscience into four groups, without any implied ranking:

- essential
- immediate
- adjacent
- peripheral

Essential stakeholders include:

- geoscientists
- universities
- state and national geoscience surveys
- geoscience industries
- sustainable development non-governmental organizations (NGOs)
- geoscience NGOs

Immediate stakeholders include:

- community groups and community leaders
- media, journalists, and science social media influencers
- museums and science centres
- disaster-planning and civil defence organizations

Adjacent stakeholders include:

- schools: teachers and students
- Indigenous and First Nations peoples
- local and municipal authorities
- investors and financial institutions
- national governments

Peripheral stakeholders include:

- international organizations (e.g. UNESCO, United Nations Office for Disaster Risk Reduction, United Nations Economic Commission for Europe, UNDP)
- civil society groups
- the general public

After identifying significant groups, we engaged in an exercise to propose a ranked approach to the stakeholders listed above by means of two considerations:

- *Y* axis: stakeholder influence, impact and interest in geoscience and its application to global sustainable development
- *X* axis: interpreted impact of geoscience on stakeholders to achieve SDGs

This approach produces an infographic divided into four quadrants that exemplifies how the stakeholders are related to geoscience (Figure 21). We do not claim to have completed a rigorous ranking process or traditional stakeholder analysis. We used the shared perception among geoscience practitioners of the relationships and interactions that occur among the sectors involved. A rigorous geoscience stakeholder-engagement analysis is needed to complete this approach.

The ranked quadrant approach consisted of plotting the stakeholders as follows:

- Essential stakeholders: These stakeholders have high influence, impact and interest in geoscience and its application to global sustainable development. Geoscience has a high impact on these stakeholders in SDG achievement pursuits. It is key to strengthen relationships, assess and monitor impacts, focus efforts, and strengthen collaborative work with these stakeholders.
- Immediate stakeholders: These stakeholders have low influence, impact and interest in geoscience and its application to global sustainable development. Geoscience has a high impact on these stakeholders in SDG achievement pursuits. It is important to establish relationships, assess actual impacts, and monitor potential impacts with these stakeholders.
- Adjacent stakeholders: These stakeholders have high influence, impact and interest in geoscience and its application to global sustainable development. Geoscience has a low impact on these stakeholders in SDG achievement pursuits. These stakeholders need to be informed, and their interests and expectations need to be monitored.
- Peripheral stakeholders: These stakeholders have low influence, impact and interest in geoscience. Geoscience has a low impact on these stakeholders. These stakeholders need to be informed.

Notably, we have deliberately placed the role of media and journalists in the immediate cluster, as they are central to all the quadrants to emphasize the importance of informed communication. Geoscience, as an Earth science, offers employment and rewarding careers with extractive industries. The media has a responsibility and should have a sense of urgency to communicate the value of geoscience knowledge for sustainable development of resources to meet the needs of a global population now and in the future.

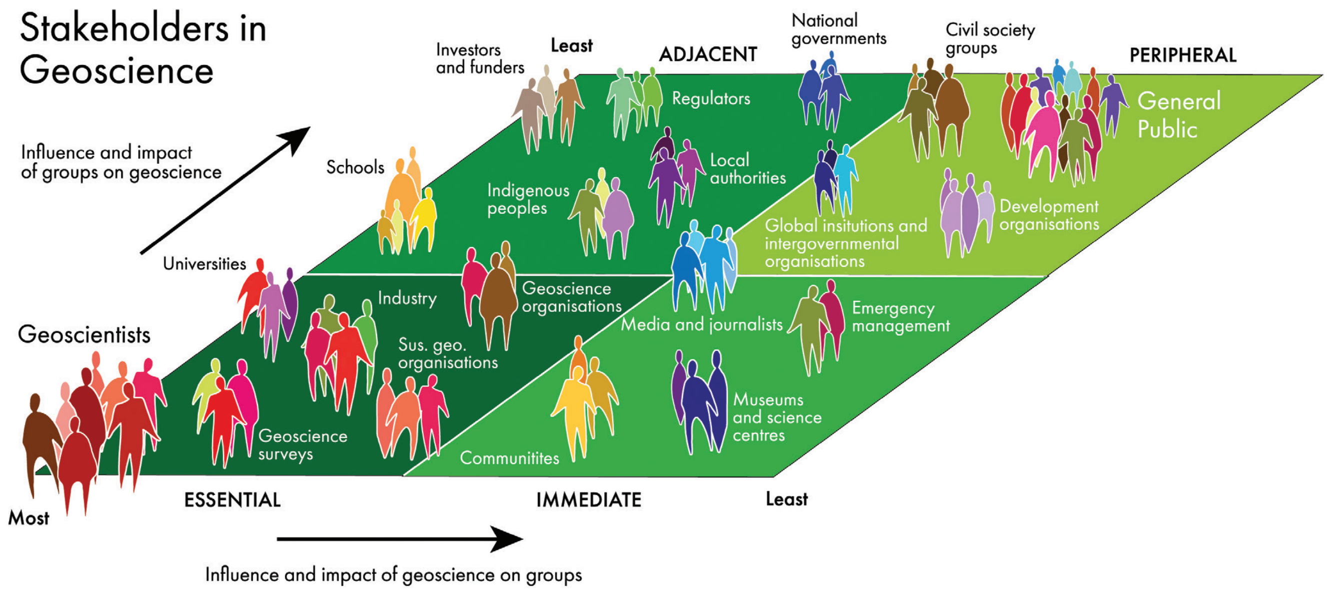


Figure 21. Significant sectors and groups, informally defined as stakeholders, are influential to geoscience and advancing the SDGs. Although the quadrant labelled "Essential" captures typical close relationships geoscientists hold with peers and connected organisations, they must reach out to those groups in the quadrants labelled "Adjacent," "Immediate" and, especially, "Peripheral," where the general public stands. To engage with groups across these quadrants, we require more powerful and efficient communication with enhanced narratives about geoscience. Successfully reaching out to these stakeholders with a new narrative about geoscience can help ground better decision-making and policy development and is pivotal to influence public opinion and individual actions to advance the SDGs, enlarging geoscientists' scope of action, influence and self-empowerment related to sustainability.

We have also included legislators and disaster-planning and civil defence organizations in the immediate cluster because we think that decisions for geohazards and resources planning require geoscience knowledge and perspective.

By definition, geoscientists are naturally clustered in the essential quadrant. We postulate that a focus on specific projects has been segregated from global-scope and humanitarian, legislative or quality-of-life objectives. The broader perspectives that are inherent to stakeholders in other quadrants are needed to highlight the value of geoscience in achieving the SDGs. For the value proposition of geoscience to be recognized, it is important that geoscientists and the professional organizations that support them start to fill the existing gaps between their current operations and what is needed to sustain best practices and standards in pursuit of the SDGs.

SDG 17, which reads, 'Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development', seeks to encourage and promote effective public, public–private, and civil society partnerships. It recognizes multistakeholder partnerships as pivotal in mobilizing and sharing knowledge, expertise, technologies and financial resources to support the achievement of the SDGs in all countries.

Geoscientists need to understand the importance of going out of their comfort zone to reach out to individuals and organizations in other quadrants. They need to acquire communication skills to simplify the message from high-end scientific terms to layperson language for more effective communication and collaboration. The geoscientist with a commitment that comes from within, who has an understanding that only as a global community can we confidently pursue and attain our most challenging sustainable development goals and who can communicate effectively, will be the geoscientist most in tune with other sectors in our emerging world and best able to provide leadership.

Our hope is that *Geoscience in Action* will help give focus to the discipline's strengths and challenges and will elevate the appeal of geoscience professions for emerging and future generations. We see it as being similar to a multifaceted mirror in which each geoscientist – whether focused on leadership, research or applied practice – may see themself or the applicability of their activities in a modern global and strategic framework.

06

Located on the Italian island of Sicily, Mt. Etna is one of the world's most active volcanoes. In this image of the volcano in 2001, a plume of steam and smoke rising from the crater drifts over some of the many dark lava flows that cover its slopes. © unsplash.com/@usgs.

QUESTIONS TO PROMPT FURTHER ENGAGEMENT

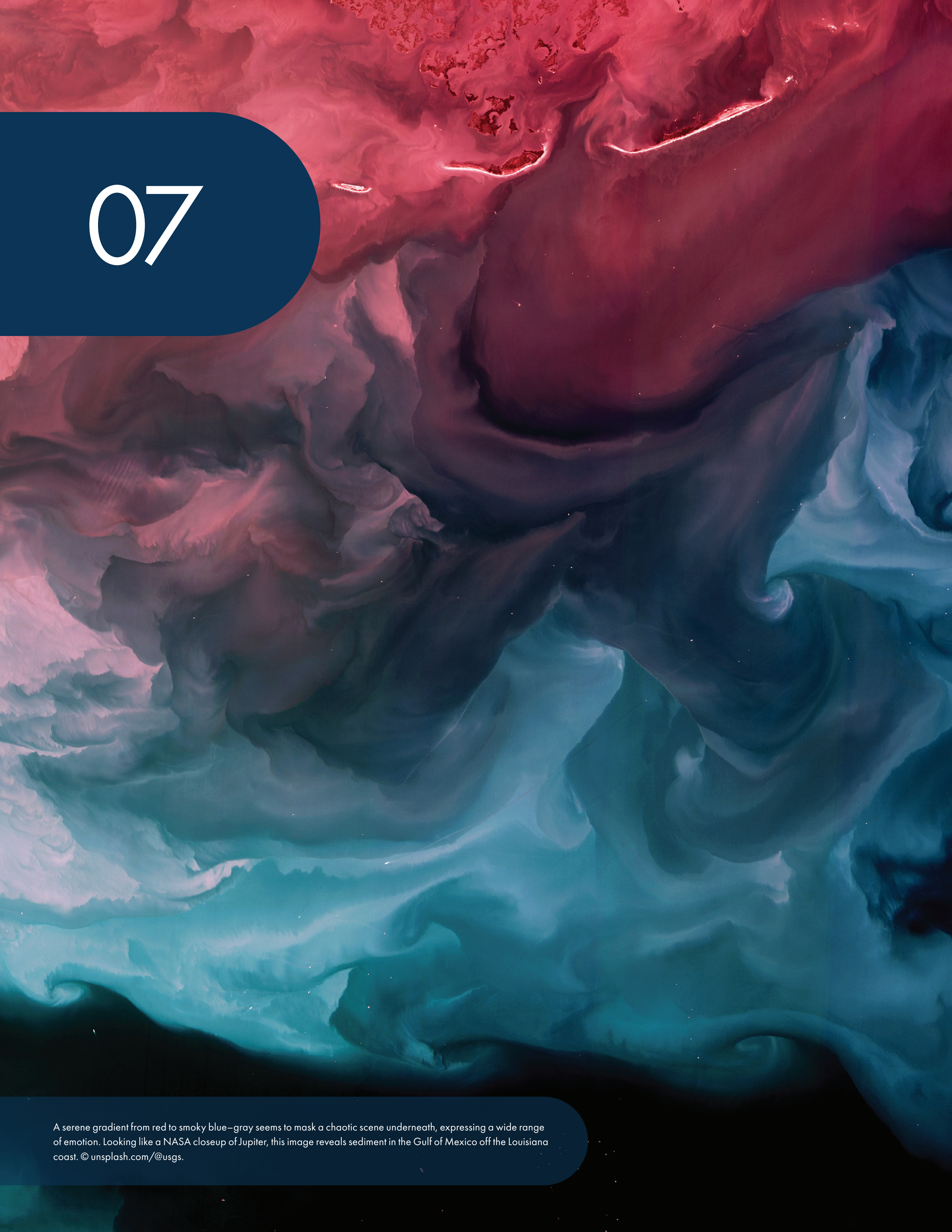
The biggest questions that geoscientists need to ask are the following: Are we ready to identify our responsibility towards achieving the SDGs by 2030? Are we ready to realign our research to help policy-makers and society at large? Are we ready to change the way we work or shift our priorities so that no one is left behind?

If the answer to each of these questions is yes but there are doubts regarding how to start, then we may begin by asking a series of more granular questions that can help to clarify our position and map our paths forward. The following set of such questions is not exhaustive but is meant to foster reflection and action:

- Are we ready to diagnose, define and develop strategies to reach the SDGs with geoscience in our lives and in our organizations?
- Do we have a way to plan, measure and manage the progress of geoscience in advancing the SDGs?
- How are geologic surveys useful for decarbonization initiatives in your city?
- What role do geoscientists have in supporting policy-making for sustainable development?
- Are geoscientists aware of how to leverage partnerships, such as public–private partnerships, to contribute to achievement of the SDGs?
- Do you know how recent Earth observation technologies are helping to address societal issues?
- Are geoscientists and other people in your city, area, community, country or region aware of how geoscience contributes to societal issues (energy; water and food security; mitigation of natural hazards such as earthquakes, floods and landslides; sustainable mineral resources)?
- How can we help the public understand the role of geological surveys?
- Who are the key players in facilitating change in geoscience education?
- Do communities and geoscientists have access to educational materials about their own geologic settings?
- What mechanisms would benefit geoscientists' dialogue, interactions and knowledge sharing with other professions?

- How are geoscientists engaging with schoolteachers to include the latest local geoscience developments in their learning and teaching?
- Are the geoscientists, communities, and educators and teachers in your area aware of the United Nations' SDGs, and do they understand them? What can you do to foster more understanding?
- Do the geoscientists in your locale know how to engage and mobilize the public for citizen science, including community-driven data collection?
- Do you know the importance of data to inform enabling policies and interventions?
- Is the community of a given area prepared for the eminent geohazards that may affect them?
- Do the people in a given area, city, neighbourhood or community know how they can have access to potable water, and are they able to assess the water quality?
- Are communities aware of the biodiversity implications of their agricultural activities and how they relate to the availability of fresh and underground water, quality of soils, monitoring of erosion, and potential landslides or tsunamis?
- Are there seismicity standards and legislation pertinent to infrastructure-building parameters for human, industrial and animal settlement in your country, region and organizations?
- Are electromagnetic surveys required to preserve your city, area, community, country or regional underground aquifers and water courses on the ground (seasonal rivers, streams, and seasonal flooding plains)? Is there legislation that supports the sustainability of these resources?
- How do communities relate to the energy companies operating on their lands?
- Are geoscientists aware of how to make geoscience more inclusive and, if so, are they acting on this awareness?
- Do you know how to practice geoscience while respecting the cultural and traditional values of the local communities in your research area?
- How can geoscientists localize their interventions to advance the SDGs?
- Are you aware of further examples of geoscience advancing sustainability that would be helpful to share?

07



A serene gradient from red to smoky blue–gray seems to mask a chaotic scene underneath, expressing a wide range of emotion. Looking like a NASA closeup of Jupiter, this image reveals sediment in the Gulf of Mexico off the Louisiana coast. © unsplash.com/@usgs.

PATHS FORWARD FOR GEOSCIENCE

We present *Geoscience in Action* to inspire geoscientists and their collaborators to apply more of their focus to advancing sustainability.

We encourage other researchers to further our work, to identify additional actions geoscientists can take to advance the SDGs, and to envision ways that gaps found in our mapping can be addressed.

- This report outlines an approach to consider what the SDGs mean to the world of geoscience.
- The design of the report includes all sectors of geoscience, with the aim of triggering a sense of pride and belonging across the profession, plus awareness about the many noble goals being pursued with geoscience activity in the global SDG context.
- The many ways with which geoscience can advance the SDGs are summarized with the geoscience sustainability clock and the people, planet and prosperity clocks, which we hope will help inspire in geoscientists the need to make timely contributions towards sustainability.
- This report should be supported by an awareness campaign to maximize its value within and beyond the profession in all sectors of current practice, including oil and gas, renewable energy, near-surface applications, sea bottom activity, infrastructure integrity, groundwater management, geoheritage preservation, academia, mining and others.
- There is a clear need to improve the skills, knowledge and willingness of geoscientists and geoscience organizations to engage in assessments of economic, social and environmental impacts of their activities to optimize and inform their participation in initiatives advancing the SDGs.
- Sharing findings, methodologies of analysis of SDGs, and understandings of the social and environmental impact of activities from different sectors was revealing and rewarding work, made stronger by the diverse expertise of our team. We ask that readers take action on insights they may have gained from this work.
- We are impressed with the United Nations' work in establishing and supporting the expansion of the SDGs, and it is with honour that we have lit a path for geoscientists to become further involved with people worldwide in pursuing SDG achievement.

08

Namib-Naukluft National Park is an ecological preserve in Namibia's vast Namib Desert. Coastal winds create the tallest sand dunes in the world here, with some dunes reaching 980 feet (300 meters) in height. © unsplash.com/@usgs.

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Note: References and additional resources associated with the examples in Chapter 4 are provided with each example.

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Additional Resources

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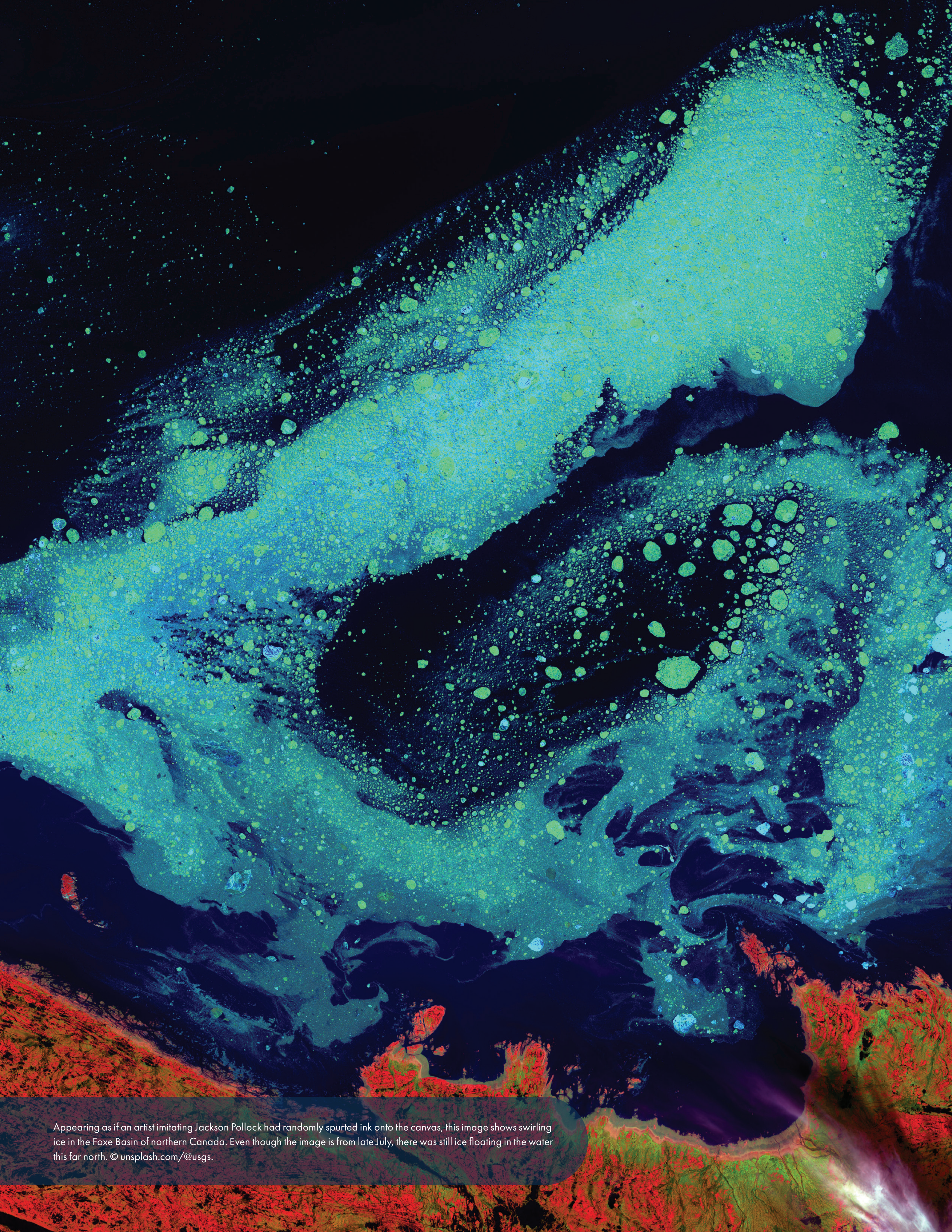

Appearing as if an artist imitating Jackson Pollock had randomly spurted ink onto the canvas, this image shows swirling ice in the Foxe Basin of northern Canada. Even though the image is from late July, there was still ice floating in the water this far north. © unsplash.com/@usgs.

ABOUT THE AUTHORS

Geoscience in Action: Advancing Sustainable Development is an initiative carried out by 12 geoscientists who volunteered their enthusiasm, expertise and time in the creation of this report. The team was composed of professionals of different disciplines, perspectives and levels of experience not only in the branches and applications of their specific field in the geosciences, but also in different regions of the world.

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Maria Angela is the leader of *Geoscience in Action: Advancing Sustainable Development.* She is the Managing Director of Red Tree Consulting LLC and a relentless advocate for sustainability. Her passion lies in promoting the juxtaposition of the geosciences and the future of the energy sector through training, mentoring and corporate strategies. She has been recognized with the Star of Italy knighthood, Society of Petroleum Engineers Honorary Membership, and Society of Exploration Geophysicists Lifetime Membership.

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Estella is Dean, College of Letters and Science and Distinguished Professor of Earth and Planetary Sciences at the University of California, Davis. She studies microbial-modulated geophysical property changes and continental rift initiation. She is a champion for developing a diverse talent pool in STEM and capacity building in developing countries.

Heather K. Handley

Enschede, Netherlands and Melbourne, Australia

Heather is an Associate Professor of Volcanic Hazards and Geoscience Communication at the University of Twente and Adjunct Associate Professor at Monash University. Her research seeks to improve understanding of how volcanoes work to reduce volcanic risk. She is co-founder and Director of the Earth Futures Festival, showcasing the role of geoscience in sustainable development, and co-founder of Women in Earth and Environmental Sciences in Australasia (WOMEESA).

Ted Bakamjian

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Ted is a geoscience editor and publisher who led the Society of Exploration Geophysicists' publishing program for 24 years, attaining the title of Associate Executive Director. He currently consults in publications and association management and governance. His interests include developing publications that support early-career and sustainability-focused professionals in geoscience.

Ludivine Wouters

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Ludivine, as Managing Partner of Latitude Five, assists natural resources investors in emerging markets with governance and regulatory and governmental affairs. She also works on technical assistance programmes for states, focusing on minerals policy, governance and taxation, and she assists donor agencies in the definition, assessment and implementation of critical minerals and responsible sourcing priorities, policies and initiatives.

Miriam S. Winsten

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Miriam is President of Mangrum Hill Associates, a boutique firm offering consulting on all aspects of energy sustainability. She has more than 40 years of experience working in the energy industry. At Schlumberger, she held various management positions, including Global Social Responsibility & ESG Reporting Director. She is actively involved in various industry associations.

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Vimal is a Professor in the Department of Geology at the University of Delhi. He is a geomorphologist. His research interests primarily involve studying Earth surface processes. He currently is involved in the development of a Critical Zone Observatory in the northwest Himalayas.

Kombada Mhopjeni

Windhoek, Namibia

Kombada is the Deputy Director of Geo-Information at the Geological Survey of Namibia and National Programme Officer for Natural Sciences at the UNESCO Windhoek office. She has more than 17 years of scientific experience in the government and leads the delivery of UNESCO's science programs in Namibia.

Though there are more than 400,000 geoscientists worldwide, the profession is going through an identity crisis. University enrollment in geology courses is declining in many countries. Young people are being put off by the close association between geoscience and extractive or fossil fuel industries.

Geoscience in Action: Advancing Sustainable Development is a practical guide that shows how the profession can find a new purpose that is more in tune with evolving societal needs and the expectations of budding scientists.

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Written by leading geoscientists from around the globe, *Geoscience in Action* seeks to inspire geoscientists everywhere to give more focus to advancing sustainability. It not only explains why we need more geoscientists to be part of the decisions shaping our future—it also shows us how.

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