Scientia

THE EVOLVING EARTH

HIGHLIGHTS:

- Discovering how Mountains Grow
- What Seismic Imaging Tells Us About the Mysteries of the Tannwald Basin
- When Physics and Ecology Unite
- Cooperation Reveals Legacy of Ancient Land Use

Issue: #104

WELCOME...

It is my pleasure to introduce the first edition of Scientia entirely dedicated to the Earth Sciences. Earth scientists apply a variety of techniques to develop an understanding of the complex systems underlying the many phenomena present on our home planet. This can vary from studying the atmosphere, the interior, the oceans, and the landmasses right the way through to the electromagnetic field of the planet. For this issue, we have had the privilege of interviewing Vítor Correia, the president of the European Federation of Geologists (EFG), who gives us an overview of the activities of the EFG and its role in geological research and public outreach. Correia explains the challenge inherent in public dissemination of geological science, and its importance.

The ultimate goal of Scientia is to facilitate the communication of ground-breaking science in an accessible and visually appealing way. Effective dissemination of excellent science that is both engaging and illuminating, for the benefit of society as a whole, is at the core of our ethos. This is a sentiment shared by Professor Jonathan Sharp of the College of Earth, Ocean & Environment at the University of Delaware who has initiated a training workshop for scientists on how to communicate their science to a general audience. In this issue, we illustrate how the program trains scientists in how to produce short science videos, undertake oral presentations and write scientific papers and proposals.

From here, we delve into the world of geoscience, where we highlight four intriguing research projects, from uncovering how magnificent continental plateaus are formed, to developing new tools for seismic imaging of the Earth's interior. In the second half of the issue, we highlight the latest discoveries in the diverse world of ecology, from exploring how mathematical modelling can be used to investigate the resilience of ecosystems, to investigating how land usage of the ancient Maya people has affected the environment and our use of land today.

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Meet The Team...

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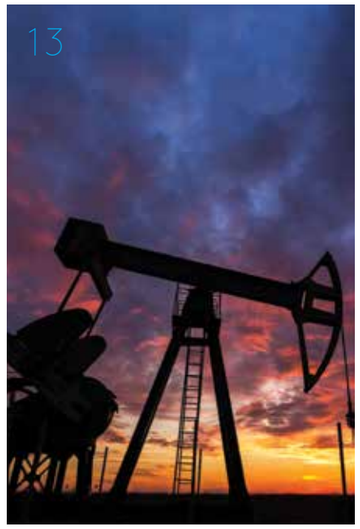

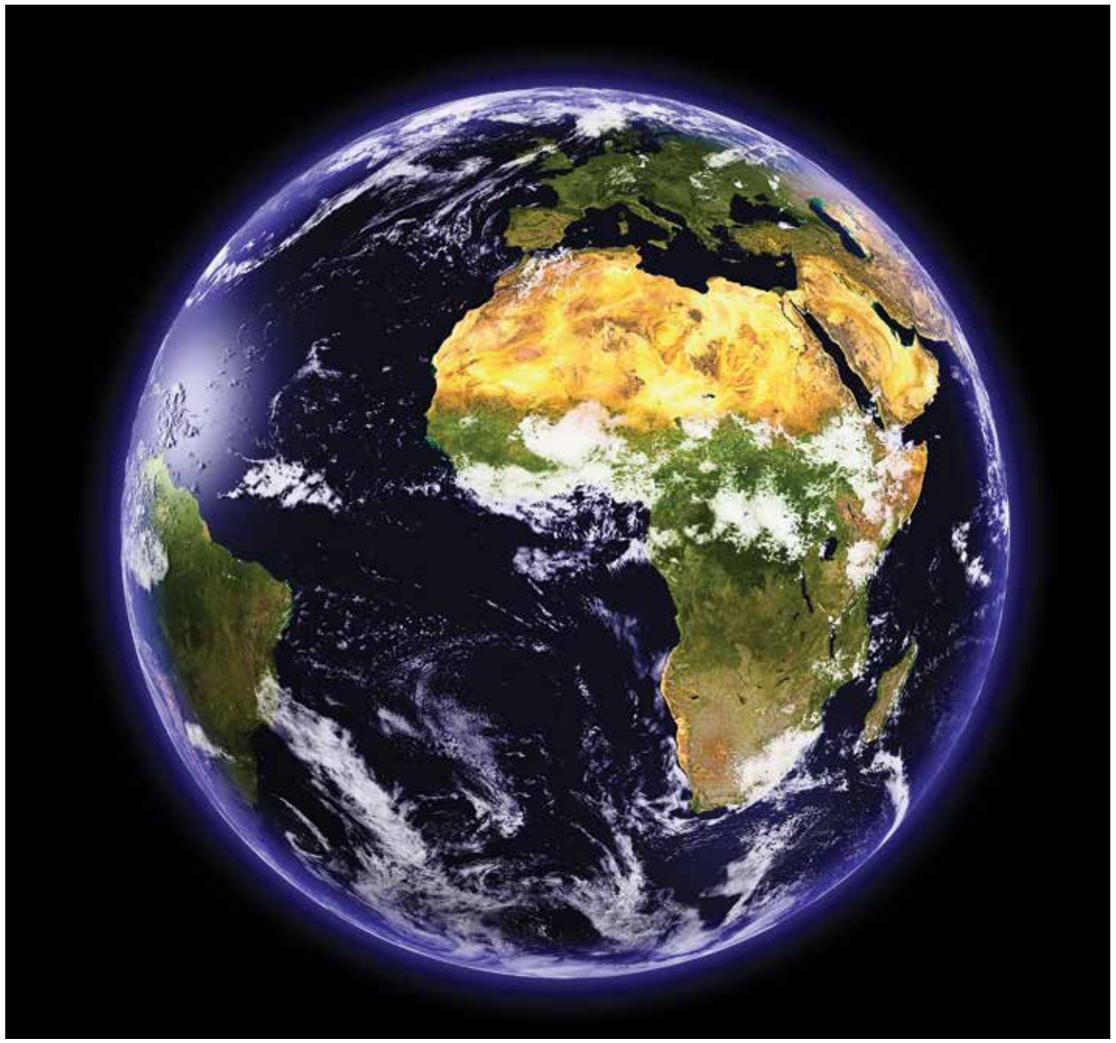

THE EUROPEAN FEDERATION OF GEOLOGISTS

Founded in 1981 in the European capital of Brussels, the European Federation of Geologists (EFG) is a non-governmental organization that represents over 50,000 geoscientists from 25 countries. EFG's primary aims are to work toward the safe and sustainable use of the natural environment, to protect and inform the public and to promote the responsible exploitation of natural resources. These aims are achieved through promoting excellence in the application of geology and by creating public awareness of the importance of geoscience for society. Here we speak to the president, **Vítor Correia,** who gives us an introduction to EFG, and speaks about its involvement in geology research, environmental protection, public outreach and European policy.

Today, EFG binds National Associations representing over 50,000 geoscientists from 25 European countries, and we work together to improve education and outreach, increase professional mobility and ensure ethical professional practice.

To start, please briefly introduce EFG, and tell us a bit about its objectives and vision.

EFG was established in 1981 as a not-for-profit professional organisation. It has evolved from an association focused mainly on professional issues, to an organisation committed to the EU development agenda, focused on promoting excellence in the application of geology and creating of public awareness on the importance of geosciences for the society.

We believe that public safety, sustainable development, responsible use of natural resources, wealth creation and effective prediction, prevention and mitigation of natural hazards are best served by educated and appropriately trained professional geologists working transparently with other professionals and communicating effectively with the public. To these ends, EFG encourages professional development by promoting training and professional development, and offering certification through its internationally recognised title 'European Geologist' (EurGeol).

Today, EFG binds National Associations representing over 50,000 geoscientists from 25 European countries, and we work together to improve education and outreach, increase professional mobility and ensure ethical professional practice.

Mention some of the ways that EFG contributes to environmental protection in Europe.

We believe effective environmental protection is fostered if we enforce professionalism in interdependent communities of researchers and practitioners, and work towards breaking down the barriers that normally exist between them. This way, geoscientists working in research can design research that is truly relevant to societal needs, while geoscientists working in industry have access to excellent underpinning research and high quality graduates, enabling them to deliver their expertise effectively. In practical terms, we emphasise the importance of sharing experience and continuing professional development among Eurogeologists, and we share best practice among the geoscientist community with the assistance of our 'Panel of Experts'. We use the communication network of all our Members (the National Associations) and give increasing importance to specialised thematic conferences as a tool to connect experts, professionals and policy makers.

Many of the environmental challenges we face today in Europe (e.g. decreasing soil fertility, fresh water demands, land use planning and the demand for energy and raw materials) call for concerted contributions from scientists, professionals and politicians. We try to bridge these groups, and convey to policy-makers the input received from geoscientists working all over Europe in many types of institutions, from governments to NGOs, to academia and industry.

How does EFG engage with European policy makers, and what are your greatest achievements in influencing environmental policy to date?

EFG provides high quality response to the European Commission and Parliament through its established nine Panels of Experts on natural hazards, soil protection, minerals, oil and gas, hydrogeology, geothermal energy, geological heritage, education and CO2 geological storage. EFG's Panels of Experts participate in congresses, working groups and consultation meetings of the European Commission and Parliament. They also emphasise the importance of geology to society and the benefits of incorporating geological advice, and promote the importance of the geo-scientific profession in all those activities. Alongside our engagement with EU policy makers, EFG's Panels of Experts also cooperate with international organisations, such as the United Nations and the International Union of Geological Sciences. This global activity facilitates the uptake of international best practices into EU policies.

Results of the engagement of EFG's Panels of Experts in policy making have been incorporated in Directives (e.g. the Water Framework Directive or the Directive for the Protection of Soils) and in Advisory Documents (e.g. advisory documents on risk reduction and protection against natural hazards). For a more detailed view of the past achievements and current activities of EFG's Panels of Experts I invite you to visit EFG's webpage (eurogeologists.eu).

Does EFG directly fund research? In what ways does EFG support earth and environmental science research in Europe?

The contribution of EFG to research is basically delivered throughout the participation in EU funded research projects. Currently EFG participates in seven H2020 funded projects, dealing with energy and raw materials supply, land use planning and groundwater. In all of these projects EFG is active in the dissemination of project outcomes, and in some cases we also provide data on user needs and geological data at country level, obtained with the active involvement of EFG Members. This approach is not new, and EFG has a good track record of participations in EU research projects, covering Education, Natural Hazards and Geothermal energy.

Notably, EFG participated as an associated partner in ERA-MIN, an ERA-NET program on the Industrial Handling of Raw Materials for European industries, supported by the European Commission under the 7th

Framework Programme. ERA-MIN produced an extensive roadmap for raw materials research and it has launched three joint calls for projects in 2013, 2014 and 2015. The calls, covering all aspects of the non-energy raw materials value chain, have been jointly generated by up to twelve countries. The funding for these projects came from national research agencies of the countries involved, topped by EU funds. ERA-MIN provided an extraordinary example of high quality value added by transnational research projects with a focus on common issues and needs. These results justify the preparation of new ERA-MIN, and EFG is available and interested in renew its participation in it.

Tell us about one or two interesting research projects that EFG is or has been involved with, and any major achievements made.

I would like to highlight two projects, named Geotrainet and INTRAW.

Geotrainet was funded by FP7, and it ran from 2008 to 2011. It was a project about low enthalpy geothermal energy, also known as shallow geothermal. Because the shallow geothermal market was (and still is) at the introduction stage, there is a lack of appropriately skilled personnel, and the quality of design and drilling is not always satisfactory. At this stage, the critical tasks are related to training and the setting of standards, because misinformation and a failure to meet standards can cause market failure. The basic aim of Geotrainet was to create training and certification programs recognised all over Europe for professionals involved in shallow geothermal installations, and to provide benchmark standards for further developments. The official activity of the funded project ended in February 2011, but the members of the consortium decided to capitalise on the results and knowledge harnessed by Geotrainet, which became an important step towards the certification of geothermal installations. In 2014, the GEOTRAINET Association was registered in Brussels as an international not-for-profit organisation, and eleven European countries have already confirmed their participation. The structure of the GEOTRAINET Association, jointly supported by EFG and EGEC (European Geothermal Energy Council), is based on a European Education Committee, ensuring the quality standards of the geothermal training programme on an international level and managing all documents. The GEOTRAINET Association is open to more participants, and it includes national coordinators, in charge of implementing the international quality standards on a national level with respect to specific national conditions, and certified training institutes, that will deliver the training courses in each country.

The second project, still being developed, also delivers an organisation that will remain active after the end of the funding period. The name of the project is INTRAW, and its main aim is the creation of the EU International Observatory for Raw Materials as a definitive raw materials knowledge management infrastructure. INTRAW is mapping best practices in education, research industry and trade in five reference countries (Australia, Canada, Japan, South Africa and the United States) and it seeks new cooperation opportunities related to raw materials between the EU and technologically advanced countries, in response to similar global challenges. INTRAW is coordinated by EFG, and it brings together an international consortium of 15 partners with extensive experience in research, innovation, education, industry, trade and international networking across the entire raw materials value chain. The project partners are actively supported by three Panels of Experts on 'Research & Innovation', 'Education & Outreach' and 'Industry & Trade'. Through EFG's members and international counterparts from the USA, Australia, South Africa and Canada, a broad network of more than 450,000 geoscientists will leverage the activity of the EU International Observatory for Raw Materials.

Please give our readers some information about the European Geologist (EurGeol) award. What does it take to be awarded this professional title?

The European Geologist professional title can be held by any professional geologist that has achieved suitable academic training and a level of professional experience, skill and competence to perform tasks within their professional practice. EurGeol title holders undertake continuing education and training and demonstrate a personal commitment to stay up to date and informed within the sphere of their professional work.

The title is awarded by EFG, and the process of vetting applications for the title is carried out for the Federation by its Licensed Bodies. National Licensed Bodies operating in Ireland, Spain, Switzerland and the United Kingdom receive applications from their own members. Applicants from other countries apply through a National Vetting Committee in their own country to the International Licensed Body, which is supported by the EFG Brussels office. The training and experience underlying the title is harmonised, and this means that the EurGeol title can be used as a passport to professional practice in Europe, thereby encouraging free movement of professionals.

All European Geologists are required to abide by EFG's Code of Ethics. The European Geologists who provide advice to others, whether it be to clients and employers in a professional capacity, through their membership in committees or to the general public either directly or via the media, are required, under the Code of Ethics, to restrict such advice to their own areas of expertise. This is a critical question because it sets the foundations for recognition agreements that support the use of the EurGeol professional title outside Europe.

On a practical level, European Geologists with sufficient experience and relevant expertise are recognised (via the applicable code or standard) by the regulators of stock exchanges in Australia, Canada, South Africa, London and elsewhere in Europe as professionals accredited to sign reports on mineral exploration results, resources and reserves within their area of expertise. They may also contribute to the valuation of mining companies quoted on the stock exchanges where these contributions fall within their expertise and experience.

Please tell us a bit about EFG's position on public outreach and knowledge dissemination.

Much of today's geological practice affects the health, safety and welfare of the public, the environment, and the economy and feasibility of engineered works. Geologists are the experts in discovering the raw materials that underpin and sustain modern life, such as oil and gas, base and precious metal ores and construction materials. Bedrock geologists educated in structural geology and tectonics work on locating sites for the disposal of radioactive waste, both regionally and locally. Engineering geologists evaluate the natural conditions necessary for the safe construction and operation of roads, railways, high-rise buildings, industrial complexes and dams. Hydrogeologists and environmental geologists are responsible for finding and advising on the protection of water supplies, for locating sites for the safe containment of hazardous wastes, and for mitigating the impact of floods that affect much of Europe every year. Geophysicists work at understanding and developing models to predict volcanic eruptions and earthquakes.

But, despite the unique contribution of geology for society (that is present since the Stone Age) the perception the public and policy makers have on geosciences is often biased by images from movies or memories of minerals and fossils collections. And because geological phenomena either take a long time to develop or are almost instantaneous, communication and outreach with the public and policy makers is not an easy task. Phenomena that take a long time to evolve, such as soil erosion, give the impression that there's no urgency in preventing their effects. Therefore, policies and actions to face these events are normally delayed or postponed. And phenomena that are almost instantaneous, like earthquakes, give the impression that there's nothing we can do, and mitigation or risk prevention measures are also postponed.

We understand that changing perceptions is difficult, and that's why we are giving great importance to communication with the public and policy makers. We also realise we need to communicate in an effective way, using a simplified language and providing clear, factual information. But the effectiveness of communication also depends on the level of knowledge of the audience, and that's why EFG is championing for early education on earth sciences at the basic school level in all EU countries.

In conclusion, enhanced public outreach and knowledge dissemination demands from geoscientists the use of simple, clear and effective messages, and is facilitated by investments in science and geoscience education. Combined, these aspects ensure more enlightened public participation in decision making and better informed political decisions.

Climate change and dwindling natural resources are two of the biggest challenges facing our generation, tell us about EFG's plans to address these challenges, in working towards a sustainable future.

There's no single solution or approach to the climate challenge problem. This is an issue that calls for collaborative work among different sciences and disciplines. The role of EFG, in this context, is to vouch those geoscientists working on this topic are working at a professional level, incorporating sound geoscience knowledge and application of theory, exceptional ethics, and good judgment, providing services and opinions only in the areas of geoscience in which they are competent.

Meeting the resource needs of our society and future generations is one of the greatest challenges facing global society – one in which geoscientists have a vital role to play. In the EU, the increasing emphasis on the need to secure the supply of raw materials for the EU industries has three main reasons: 1) the industrial supply chains created with globalisation began to spin with economic vulnerability and national volatility; 2) fast developing countries, like China or India, are competing with the western countries for raw materials to feed their economies; and 3) an increasing number of high-tech devices (electrical cars or smartphones) are a strong demand driver for specific elements (such as niobium, indium, tungsten or rare earths) that are obtained from mineral deposits only known in specific countries. In these circumstances the EU has defined the raw materials that have a significant economic importance for European industrial key sectors as 'critical', facing high supply risks and that can't be substituted. Within this framework, geoscientists have a crucial role in (re)evaluating the geological potential and availability of mineral deposits in European countries, and including in this evaluation secondary sources for raw materials such as old or abandoned mining sites and their remnants as well as urban mines and landfills. This evaluation is naturally framed by the requirement of creating sustainable exploitations, balancing social and environmental impacts and reinforcing public safety. But (re)evaluating Europe's geological potential and availability of mineral deposits requires best practice in exploring and in reporting, to ensure that the adequate mineral policies are based on consistent data. This subject and the related research rely fundamentally on geoscientists.

www.eurogeologists.eu

Communicating Science: Bridging the Great Divide

Making science engaging and fun is an art, and getting the public interested in science is a science in itself. An initiative led by Jonathan Sharp, Professor Emeritus of the University of Delaware, aims to train scientists in the finer art of science communication to help them better communicate their research.

Hollywood actor Brian Palermo instructs participants on communication skills at the Connection Workshop at the ASLO Aquatic Sciences Meeting held in Granada Spain in February 2015

There is increasing pressure on scientists to explain their research to a wider audience, including decision-makers, news journalists and the general public. Yet while scientists have experience in communicating their research to fellow scientists, most researchers lack the skills and training needed to present technical scientific information to a non-scientific audience in a manner that will capture and hold its attention.

For science to make a real impact on the world, it is essential that scientific findings are disseminated to the world at large rather than limited to an audience consisting of a handful of fellow scientists. For example, for the broader public to understand the importance of taking action to combat climate change, they need to understand the causes and impacts, how it will affect them, and what can be done to prevent or mitigate these impacts. This needs to be communicated in clear and simple terms in a manner that will engage this audience and stimulate debate, thought and action.

The public today is often overwhelmed by too much "data" and is unable to translate this into information. Scientists, as experts in their field, are routinely interviewed by the news media on topics that affect humankind such as health, climate change, and various aspects of technology and are called on to translate data into information. But for most scientists, communicating their knowledge to the layperson often poses a real challenge. How do they get the facts and key points across while at the same time still engaging the audience rather than coming across as dry and boring?

While there are a number of books that guide researchers on how to communicate science to a general audience, hands-on training is much needed. Recognizing the need for training opportunities in this regard, Jonathan Sharp, Professor Emeritus of Oceanography at University of Delaware's School of Marine Science and Policy, launched an initiative to train scientists in the art of communicating their research to a wider audience, in an effort to bridge this gap. This effort has been in collaboration with Dr. Adrienne Sponberg, Director of Communications and Science of the Association for the Sciences of Limnology and Oceanography (ASLO), and Randy Olson, an independent Hollywood filmmaker with a background in evolutionary biology and marine science.

According to Professor Sharp, there are several factors that contribute to poor performance in terms of communication and outreach by aquatic scientists. First, many scientists lack interest in taking part in outreach activities as they either do not have experience or do not recognize the importance of communicating their research. Second, not enough emphasis is placed on the importance of outreach activities by their superiors and peers in the research community. But the biggest hurdle most scientists face in effectively communicating their research is that they simply lack the skills to effectively communicate with the broader public.

This last issue, is arguably the most pressing, because if scientists were skilled in the art of communicating their science to the general public, the public would be more interested in what they have to say, which would in turn encourage scientists to actively engage with this new audience.

To address these shortcomings, Professor Sharp organized a series of training workshops and panel discussions at ASLO Aquatic Sciences Meetings and Ocean Sciences Meetings (jointly sponsored by ASLO, the Ocean Sciences Section of the American Geophysical Union, and The Oceanography Society) with input from science communication specialists, media professionals and non-scientists. The workshops provide scientists with training on a variety of communication skills, including how to produce short science videos and how to communicate with the general public. Launched in 2008, these training sessions were initially supported by ASLO. Due to the keen interest shown in the training workshops and discussions, and thanks to funding from the Ocean Sciences Division of the US National Science Foundation, these training workshops have continued annually, and extended into 2016.

PANEL DISCUSSIONS

Panel discussions were introduced at recent meetings to help scientists better understand public perceptions and attitudes towards science. The following panel discussions have been held to date:

Does Science Really Matter? (Ocean Sciences Meeting in Orlando, Florida; 2008) - This discussion focused on the importance of outreach to the public and the need to place more value on outreach activities.

The Cultural Gap Between Scientists and the Public (Ocean Sciences Meeting in Salt Lake City, Utah; 2012) - The aim of this discussion was to help scientists better understand public attitudes toward scientific 'evidence' and help them overcome challenges and barriers they face in effectively communicating their research to the public. This discussion was recorded and made available to a wider audience via an online podcast (http://udcapture.udel.edu/podcast/watch.php?c=531).

Why aren't they listening? (Ocean Sciences Meeting in Honolulu, Hawaii; 2014) - This discussion once again focused on the barrier between scientists and the public, and the general public apathy towards what scientists have to say.

What can you do, and should not do to inform the public about environmental problems? (Aquatic Sciences Meeting in Granada, Spain; 2015) - Panelists discussed outreach activities that they and fellow scientists had conducted to communicate science to the public, and addressed issues that were likely to result in a poor public reception by an already disinterested audience, notably 'doom and gloom' scenarios sometimes used by environmental scientists to get their message across.

VIDEO WORKSHOP

Several years ago, scientists started making their own videos to explain their research; however, most lacked the skills needed to make these videos interesting and appealing to a public audience. To address this, Randy Olson, a former scientist who traded an academic career in marine biology for a career as an independent filmmaker and communication consultant in Hollywood, presented a workshop on how to make short science videos at the 2008 Ocean Sciences Meeting. Following on from this initial workshop, video analysis workshops were held at subsequent Ocean Sciences and Aquatic Sciences Meetings, where the emphasis shifted to screening, critiquing and discussing videos submitted by scientists for analysis. Over the ensuing five years, the quality of videos submitted by workshop participants has improved considerably, which is partly attributed to the workshops.

SCINTILLATION WORKSHOP

To improve scientists communication skills in other areas, including oral presentations and writing scientific papers and proposals, two additional events were added to the 2013 Aquatic Science Meeting: 1) a Scintillation workshop, and 2) a Snap it Up Workshop. These workshops, together with the video workshop, were collectively advertised to the scientific community as 'Hollywood comes to ASLO'

The Scintillation workshop, titled Scintillation – a workshop to make your science communication scintillate through 'critical storytelling', was aimed at anyone from students to senior scientists who presented their stories at the workshop and then worked on improving them by developing a simple, yet compelling, storyline that was interesting and engaging.

SNAP-IT UP WORKSHOP

The third workshop in 2013, titled Snap it up — advice from Hollywood for short presentations, focused on scientific presentations given to fellow scientists at conferences. The Hollywood media team attended and evaluated a few talks. Then, at the workshop on the following day, they gave critiques (largely positive) and suggested small improvements that would make the talks more engaging to a broader audience. In this case, the target audience is a broad multi-disciplinary group of peers, as opposed to a small group of fellow specialists.

The Snap it up workshop was included in the 2014 Ocean Sciences Meeting and the 2015 Aquatic Sciences Meeting, but the Scintillation workshop was replaced with the Connection Workshop, outlined below.

CONNECTION WORKSHOP

Following the 2013 Scintillation Workshop, the presenters released a mobile app and a book titled: Connection: Hollywood Storytelling meets Critical Thinking. This theme was carried forward for the 2014 and 2015 Connection Workshops, where participants learned improvisation techniques to help boost self-confidence and help them come across less stiff and imposing to a public audience, as well as how to inject humour into their presentations to help them connect with an audience and make an audience more receptive.

FUTURE TRAINING

The Snap it Up and Connection workshops have both been scheduled for the 2016 Ocean Sciences Meeting, and Professor Sharp hopes to continue the workshops and expand their reach in the future.

"The Hollywood workshops have been well received and by participant evaluations and our own analysis are both successful and valuable to continue in the future," said Sharp. "It is rewarding to find growing enthusiasm and interest in these workshops and we are receiving feedback from participants on how the workshops have changed their presentations."

Future plans include finding other ways to reach the broader scientific community and finding other sources of financial support to expand this initiative.

"The workshops are fairly brief snapshots at the meetings and a relatively small number of attendees participate," notes Sharp. "We are exploring ways to get the workshop messages more extended and to reach larger audiences."

Researcher Profile

Jonathan H. Sharp
Professor Emeritus of Oceanography in the School of Marine Science and Policy
University of Delaware, College of Earth, Ocean & Environment

Professor Jonathan H. Sharp received a Ph. D in Oceanography from Dalhousie University (Halifax, Nova Scotia, Canada) in 1972. After completing a stint as a Post-graduate Research Biologist at Scripps Institution of Oceanography he joined the University of Delaware, where he served as a Professor until his retirement in 2014. Professor Sharp's primary research interests lie in estuarine, coastal, and open-ocean oceanography and in translating research for natural resource management. He has received several awards and honours recognizing his contribution to science and teaching. He was inducted into the Delaware Maritime Hall of Fame in 2008, and received a Lifetime Achievement Award from Delaware Estuary Program in 2011 (later named after him).

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KEY COLLABORATORS FOR COMMUNICATIONS ACTIVITIES

Dr. Adrienne Sponberg, Director of Communications and Science of the Association for the Sciences of Limnology and Oceanography (ASLO)

Dr. Randy Olson, marine biologist turned Hollywood filmmaker and communications consultant

Brian Palermo Hollywood actor and instructor in improvisational acting and communications consultant.

FUNDING
US National Science Foundation
Association for the Science of Limnology and Oceanography
University of Delaware, School of Marine Science and Policy

SEISMIC SHIFTS FOR GEOSCIENCE RESEARCH

Geoscience involves the study of the processes that shape and form the physical Earth. Geoscientists focus on the materials that make up our planet such as water and rock, and examine how they interact to produce the huge array of geological features that can be observed in the world around us. From lakes and rivers, to glaciers, volcanoes and earthquakes, geological features and phenomena can be awe inspiring in their scale and power.

Some geological processes take place over enormous periods of time. Studying these can uncover the history of our planet and the development and evolution of life on its surface and in its oceans. Conversely, phenomena such as earthquakes and volcanoes can take place very rapidly. Investigating such violent and disruptive events can help us to predict their occurrence more accurately, helping to save lives and reduce injury and damage. Indeed, modern geologists contribute significantly to our society by helping to mitigate the impact of natural disasters through sophisticated monitoring and early-warning systems. They are also key contributors in the search for natural resources found in the Earth's crust such as deposits of metal ores. Geologists are also involved in the study of climate change, both in the present world and in the ancient history of the Earth, by studying the ancient geological record and investigating features that are changing today such as glaciers and the ice caps.

One of the goals of this issue of Scientia is to pay homage to the work of geologists by showcasing some of the diverse and fascinating research they undertake, and demonstrating the value of such work to society at large. In this section, we introduce the work of four research groups who have made significant, albeit differing contributions in the field of geological sciences. In the first article, we present the work of Professor David Eaton of the University of Calgary whose research focuses on improving methods to detect microseismic events (small earth tremors) during hydraulic fracturing. His goal is to use this data to more accurately model the impact of hydraulic fracturing on the environment and predict the occurrence of larger tremor events as well as working out the potential consequences of such events on the surrounding area.

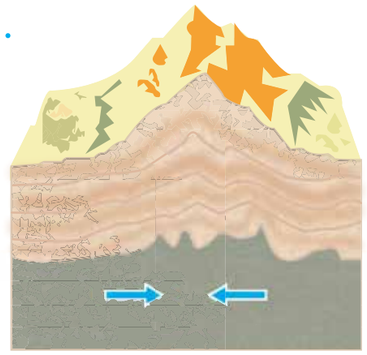
Our second featured article in this section also has a focus on seismology, but in this case, seismic imaging is used to study overdeepened valleys. Drs Gerald Gabriel and Thomas Burschil of the Leibniz Institute for Applied Geophysics use a new technique they have developed which incorporates different types of seismic waves to 'image' the subsurface structure of overdeepened valleys. Their research has focused on the Tannwald basin in Germany, as a model system for such valleys. Understanding the underlying valley structure could help with using the valleys as a source of groundwater and assist with understanding and identifying any potential hazards the valleys might pose, while enabling an analysis of how the valleys were originally formed by glaciation.

Next, we introduce the work of Professor Lindsay Schoenbohm at the University of Toronto. Professor Schoenbohm and her team specialise in tectonic geomorphology and study the development of continental plateaus in places as far flung as Turkey and Argentina. They use a combination of satellite image interpretation, field-based mapping and landscape analysis to determine how these geological features developed.

The final researcher in this section is Dr Hitomi Nakamura who studies the interaction between slab fluids and the tectonic plates at the plate boundaries underlying the islands of Japan. Slab fluids are water that is submerged along with subducted tectonic plates – that is, plates that become sunken beneath another plate. Dr Nakamura is interested in mapping the distribution of slab water and understanding the fluid dynamics beneath the Japanese islands to understand plate dynamics in the area. Dr Nakamura is also interested in how slab water forms natural springs in Japan.

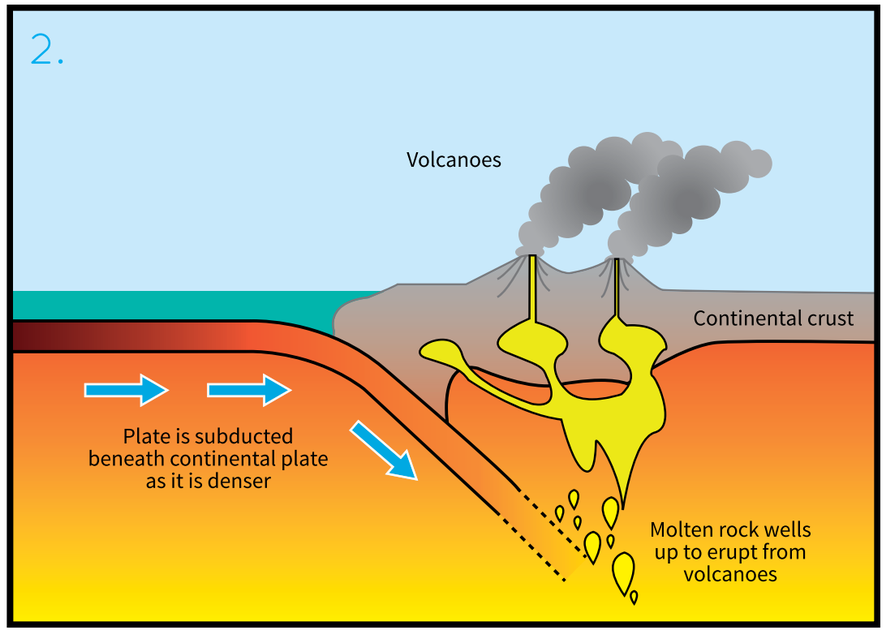
GEOLOGICAL PHENOMENA ARISING FROM PLATE TECTONICS

1.



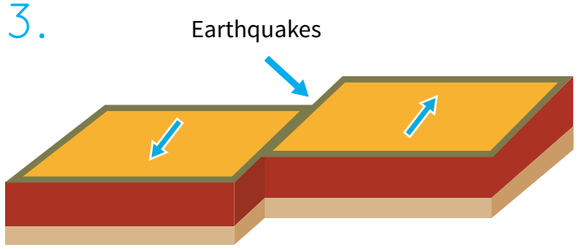
Plates collide → Mountain range forms

2.



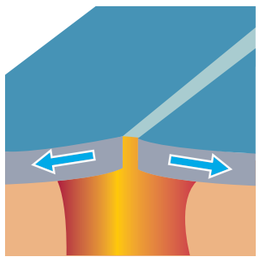
Plates collide and subduct → Volcanoes

3.

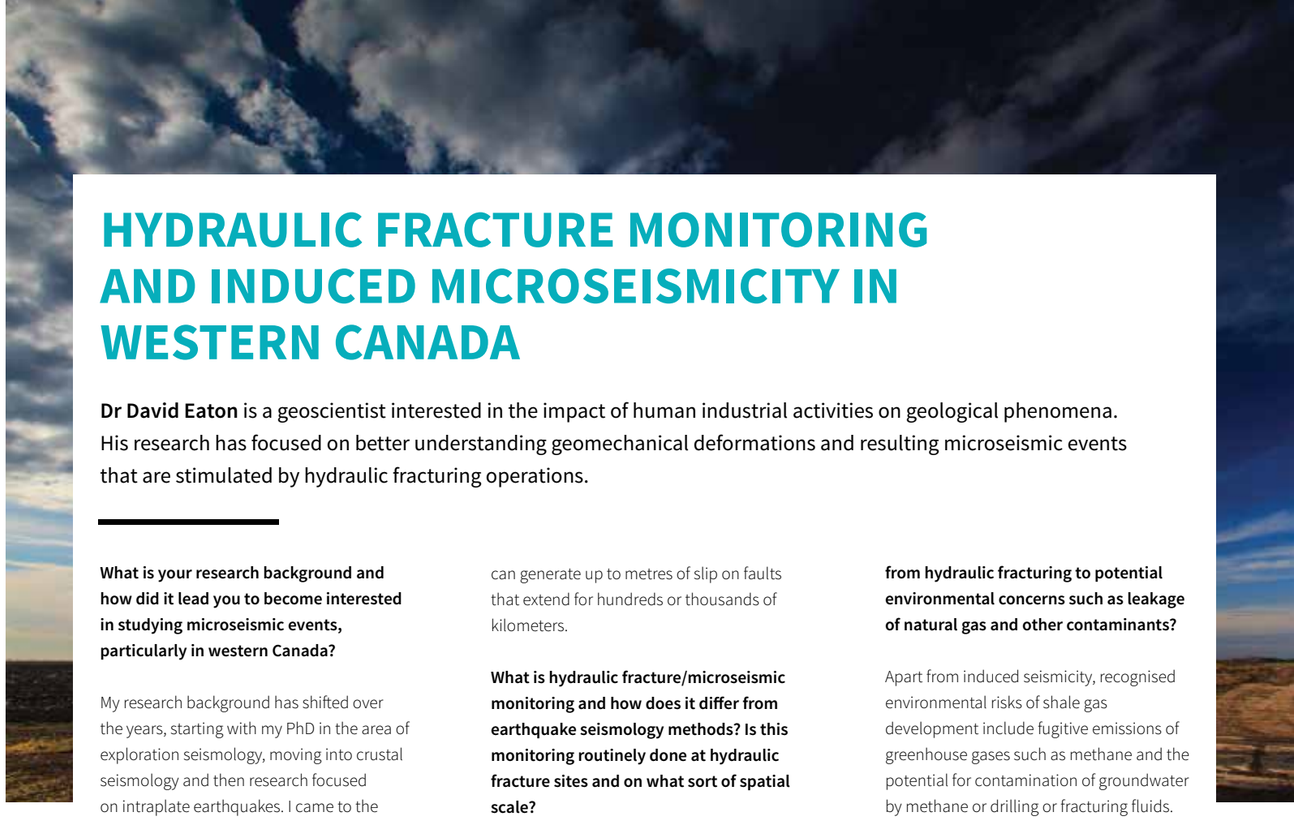


Plates slide past each other → Earthquakes

4.



Plates move apart → Magma pushes through and forms ocean ridge



HYDRAULIC FRACTURE MONITORING AND INDUCED MICROSEISMICITY IN WESTERN CANADA

Dr David Eaton is a geoscientist interested in the impact of human industrial activities on geological phenomena. His research has focused on better understanding geomechanical deformations and resulting microseismic events that are stimulated by hydraulic fracturing operations.

What is your research background and how did it lead you to become interested in studying microseismic events, particularly in western Canada?

My research background has shifted over the years, starting with my PhD in the area of exploration seismology, moving into crustal seismology and then research focused on intraplate earthquakes. I came to the University of Calgary in 2007 in the role of Head of the Department of Geoscience; at that time I started to contemplate areas of research that would be relevant to the oil and gas industry that would also leverage my past experience. Microseismic methods were emerging then as a very important monitoring technology for evaluating completion design as well as to assure minimal environmental impact of hydraulic fracturing.

Your research focuses on microseismic events. How do the scale, amplitude and duration of microseismic events differ from typical earthquake-scale seismic events?

As the name suggests, the scale, amplitude and duration of microseismic events are substantially less than earthquake-scale seismic events, although in many other respects they are equivalent physical phenomena. The vast majority of microseismic events observed during hydraulic fracturing occur in the magnitude range from -3 to 0, too tiny to be felt. This magnitude range implies sub-millimetre slip, on fracture surfaces that measure up to a few metres in spatial extent. In addition, the duration of microseismic events is typically a few tenths of a second. By comparison, ground shaking from earthquakes can last for more than a minute, and an earthquake can generate up to metres of slip on faults that extend for hundreds or thousands of kilometers.

What is hydraulic fracture/microseismic monitoring and how does it differ from earthquake seismology methods? Is this monitoring routinely done at hydraulic fracture sites and on what sort of spatial scale?

There are several approaches used for microseismic monitoring of hydraulic fracturing operations. In some cases, ground-motion sensors (geophones) are installed in a nearby wellbore in order to place them as close as possible to the treatment zone. In other cases, a large number of geophones are placed on the surface within an area that extends a few km away from the treatment well. Other types of sensors, such as seismometers developed for earthquake monitoring, are being increasingly used to improve the capability of monitoring systems.

How applicable is the information you stand to gain through monitoring in western Canada to other areas of N. America and the rest of the world?

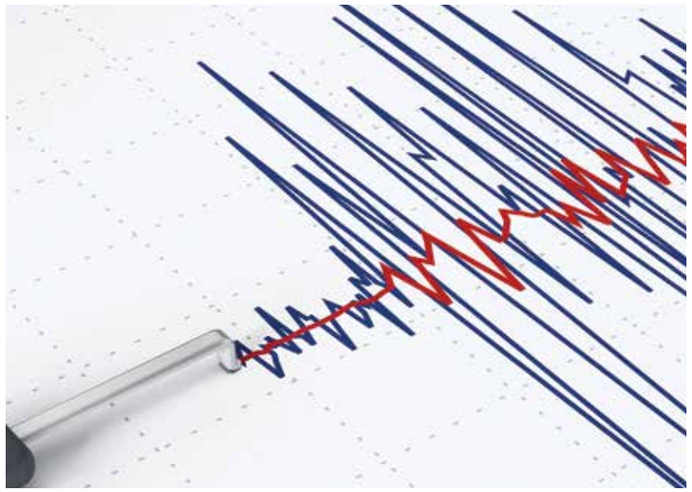
Microseismic techniques and underlying principles for hydraulic fracture monitoring that have been developed in western Canada are generally applicable throughout the world. However, there are a multitude of site-specific geotechnical factors, such as the magnitude and directionality of stresses in the subsurface as well as details of how different rock types respond to stress, that make every location unique.

What is the next step in correlating your research on induced microseismicity from hydraulic fracturing to potential environmental concerns such as leakage of natural gas and other contaminants?

Apart from induced seismicity, recognised environmental risks of shale gas development include fugitive emissions of greenhouse gases such as methane and the potential for contamination of groundwater by methane or drilling or fracturing fluids. While the focus of my research is on microseismic monitoring and induced seismicity, I am working closely with other researchers whose expertise enables them to contribute to a better understanding of these other potential environmental issues. These concerns may be linked – for example, damage to a wellbore from an induced earthquake could potentially result in higher levels of fugitive gas emissions due to diminished effectiveness of cement bonding of casings. More research is needed to understand these cross-linked issues.

Your research seems very multidisciplinary in nature. Are you working with other researchers/ industrial partners to meet the goals of your research? If so, what is their contribution?

A multi-disciplinary approach is needed to drive innovation in microseismic monitoring and induced seismicity research. Within the Hydraulic Fracturing Innovation Initiative at the University of Calgary, I am currently working closely with reservoir engineers, hydrogeologists, sedimentologists, structural geologists, geochemists, geomechanics experts, computer scientists, economists, political scientists and legal experts. All of these disciplines are required to contribute to a holistic understanding of the diverse issues involved.



MONITORING HYDRAULIC FRACTURING-STIMULATED MICROSEISMIC EVENTS

Microseismic activity (small tremors) may be stimulated by hydraulic fracturing. Dr David Eaton and his research team seek to improve monitoring and data interpretation from hydraulic fracture sites, in order to better understand the driving forces behind microseismic activity and improve predictions of larger induced events and their consequences.

Hydraulic fracturing and microseismic monitoring in Canada

While hydraulic fracturing has been used commercially for over 60 years to extract hydrocarbons from deep wells, it became increasingly common in the late 20th century when improvements in technology made unconventional hydrocarbon reservoirs more accessible. With the development of horizontal well drilling technologies, hydrocarbon-bearing shale formations, among other unconventional, low permeability reservoirs, became economic sources of natural gas. Since the early 21st century, the number of hydraulic fracturing operations has increased globally.

Oil and gas exports account for nearly 20% of Canada's annual export revenue. Of Canada's crude oil reserves, the majority are hosted in either oil sands formations or other unconventional reservoirs that require hydraulic fracturing stimulation for efficient extraction. While hydraulic fracturing has been used in Alberta since the late 1970s, the method has recently become widely used in the development of the Cardium, Duvernay, Montney and Viking Formations in Alberta, and the Montney and Horn River Formations in British Columbia, among others. Due to the relatively high development costs and the significant drop in crude oil prices over the past 2 years, improvements in cost-efficiency will have a profound effect on extraction of these resources. In addition to economic factors, hydraulic fracturing operations have been the subject of much scrutiny due to environmental concerns such as fugitive emissions of greenhouse gases like methane, the potential for contamination of groundwater with drilling and fracturing fluids, and the potential for induced earthquakes.

Microseismic monitoring may be pivotal in the future of hydraulic fracturing operations. Through monitoring, it may be possible to optimize the hydraulic fracturing processes to reduce cost and improve recovery, and predict and manage associated environmental risks. According to Dr Eaton: 'Microseismic data have been used to assess the effectiveness of well completions, including the volume of a reservoir formation that is stimulated during a hydraulic fracturing treatment and the extent of the fracture network that may contribute to hydrocarbon production.' However, the ability to perform realistic computer simulations of microseismicity and induced seismicity from specific planned hydraulic fracturing operations is diminished due to a lack of data on complex natural rock systems as well as a validated predictive framework. In the absence of quantitative models to predict induced seismicity, it is difficult to assess its significance or plan appropriate strategies to mitigate risk. A major focus of Dr Eaton's research is to use innovative ways to improve data collection from monitoring systems and to improve and validate predictive models, with the ultimate goals of improving recovery and determining potential economic and environmental risks of planned hydraulic fracturing operations.

Improving downhole microseismic event information

Downhole data acquisition is a commonly used configuration for obtaining microseismic data. However, as a consequence of the close proximity of sensors to treatment zones, downhole monitoring can suffer from limited observational aperture. In a recent article, 'Enhanced downhole microseismic processing using matched filtering analysis (MFA)' published in First Break (vol. 33, pp 49-55), Dr Eaton and his colleague, Dr Enrico Caffagni, introduce a new method to detect and locate microseismic events and analyse microseismicity from downhole data recording geometries, overcoming some of the limitations associated with the limited observational apertures and traditional data processing methods. By employing such a technique, the detection, location and analysis of microseismic events that may have been missed or diminished by traditional processing techniques is possible. As an example of the utility of the improved data processing technique, Eaton and Caffagni apply the procedure to the hydraulic fracturing treatment of a tight sand reservoir in western Canada and show a nearly four-fold increase in the number of located events compared to using traditional data processing. These results serve to significantly improve event data recovery from microseismic catalogues and thus are expected to improve predictive capabilities of stimulated microseismicity from hydraulic fracturing operations.

Interpretation of magnitude distributions

As instruments were being developed in the 1930s that could record earthquake magnitudes, modern earthquake seismology pioneers, Beno Gutenberg and Charles Richter, described a pattern in the seismic data that related the number of earthquakes in a given area over a fixed period of time to the magnitude of those earthquakes. This relationship is well known as the Gutenberg-Richter (G-R) relation and has been widely used to describe both earthquakes and microseismic events.

Using microseismic catalogues from two different hydrocarbon reservoirs in Western Canada (Horn River Basin in north-east British Columbia and Hoadley gas field of central Alberta) and one site in the United States, Dr Eaton and his colleagues address the breakdown of the G-R relationship for hydraulic-fracturing induced microseisms in Geophysical Prospecting (vol. 62, pp 806-818). In this article they suggest that stratabound fracture networks, in which brittle failure processes tend to be constrained to lie within discrete layers, are responsible for the observed magnitude distributions. In another recent article (First Break, vol. 33, pp. 79-86), Dr Eaton and his colleague Dr Samira Maghsoudi provide a critical assessment of factors that may influence magnitude distributions from hydraulic fracturing processes and the detection of magnitude distributions using downhole monitoring configurations, in part to determine whether the scaling behaviour of critically stressed natural fault systems such as earthquakes can be applied to brittle failure processes from hydraulic fracturing of hydrocarbon reservoirs. They suggest that because of the distance-dependent detection of small magnitude events with downhole monitoring of hydraulic fracturing operations, using the G-R relationship may require careful reanalysis. Furthermore, they show that other microseismic attributes may be more informative than the G-R parameters for predictive reservoir studies. By leading us to a better understanding of the geomechanical mechanisms at play during stimulated microseismic events, the predictive capabilities for future planned hydraulic fracturing operations are greatly improved.

The value of industry-academia collaborations

Dr Eaton's research focuses on improving detection methods and technologies and using microseismic catalogue data to formulate new models that challenge traditional approaches and ultimately lead to a deeper understanding of the geomechanical processes that occur during hydraulic fracture treatments. Through extensive collaborations across many disciplines, he aims to apply this improved understanding of induced microseismic activity to advance economic, geohazard and environmental hazard predictions from hydraulic fracture operations. His location at the University of Calgary and his established relationship with key partners from the public and private sectors places Dr Eaton at the frontier of microseismic monitoring research. While academic research in the field of microseismic monitoring can only be accomplished in close partnership with industry at hydraulic fracturing well sites, industrial partners are motivated to develop academic collaborations that enable fundamental scientific questions to be addressed. The University of Calgary is strategically located in Canada's energy centre providing a unique opportunity to become a leader in energy research.

Meet the researcher

Dr David Eaton
Professor
Department of Geoscience
University of Calgary

Dr David Eaton is a professor in the Department of Geoscience at the University of Calgary. After completing his MSc and PhD at the University of Calgary, Dr Eaton worked as a geophysical researcher in industry (Arco Research and Technical Services), government (Natural Resources Canada), and academia (University of Western Ontario). Subsequently, he returned to the University of Calgary as department head from 2007-2012. He is a key player in many collaborative initiatives including the Microseismic Industry Consortium and Canadian Induced Seismicity Collaboration. He has also recently been appointed as NSERC/Chevron Industrial Research Chair in Microseismic System Dynamics.

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REFERENCES

Eaton D., Davidsen J., Pedersen P. and Boroumand N., Breakdown of the Gutenberg-Richter relation for microearthquakes induced by hydraulic fracturing: influence of stratabound fractures, Geophys. Prosp., 2014, 62, 806–818.
Eaton D. and Caffagni E., Enhanced downhole microseismic processing using matched filtering analysis (MFA), First Break, 2015, 33, 49–55.
Eaton D. and Maghsoudi S., 2b... or not 2b? Interpreting magnitude distributions from microseismic catalogs, First Break, 2015, 33, 79–86.
van der Baan M., Eaton D. and Dusseault M., Microseismic Monitoring Developments in Hydraulic Fracture Stimulation, ISRM International Conference for Effective and Sustainable Hydraulic Fracturing, 20-22 May 2013, Brisbane, Australia.
Zhang H., Eaton D., Li G., Liu Y. and Harrington R., Discriminating induced seismicity from natural earthquakes using moment tensors and source spectra, J. Geophys. Res. Solid Earth, 2016, 121, DOI:10.1002/2015JB012603.

UNIVERSITY OF CALGARY

WHAT SEISMIC IMAGING TELLS US ABOUT THE MYSTERIES OF THE TANNWALD BASIN

A mutual interest in geological and geophysical processes within the Quaternary epoch motivated **Drs Gerald Gabriel and Thomas Burschil** at the Leibniz Institute for Applied Geophysics (LIAG) to study overdeepened valleys and basins, using seismic imaging to gain a better understanding of the evolution of these societally highly relevant structures in the entire Alpine region.

What is seismic imaging?

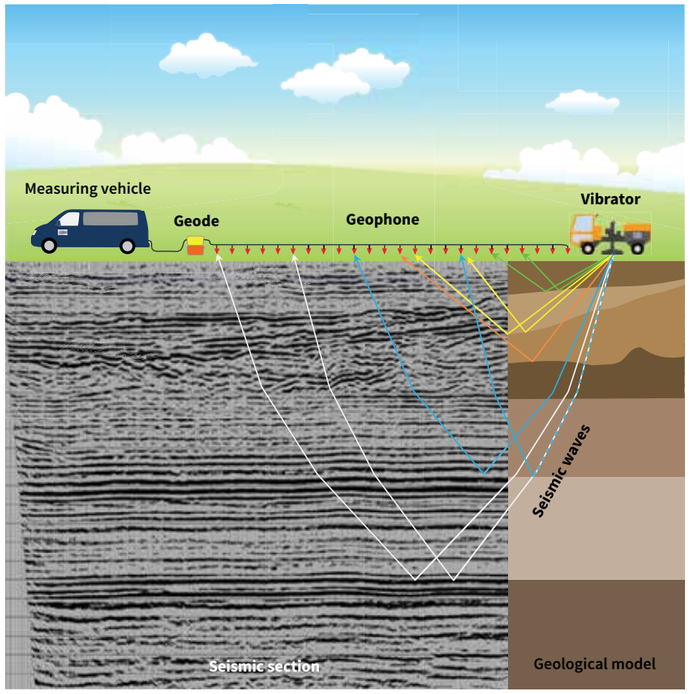
If you're not familiar with geological processes or their imaging techniques, then you may not have come across seismic surveying. For anyone who wants to understand the research concept, it is essential to understand the basics.

So what is seismic imaging? Seismic imaging can be carried out in 2-D and 3-D, and utilises different types of elastic waves – the Primary (P) wave or Secondary (S) wave. P-waves are compressional longitudinal waves which penetrate through subsurface layers, causing the Earth to compress and stretch along the axis of propagation of the wave in a similar fashion to sound waves. S-waves are shear waves which cause the ground to move perpendicular to the direction of propagation so that they can be separated into a vertical mode (SV) and a horizontal mode (SH). In general, S-waves are harder to receive for different reasons. They penetrate through the Earth much slower than P-waves do, and often image only the shallower part of the geological structure. Furthermore, they often interfere with surface waves (or ground roll) that cause a strong movement of the Earth's surface and, hence, cannot be detected easily. However, S-waves can provide geologists with a means of imaging shallow structures at a high resolution. Both types of waves produce different but complimentary data, and modern approaches in seismic imaging utilise both types of waves to build an image of structures beneath the Earth's surface.
This is a major focus of the research carried out at the Leibniz Institute for Applied

Geophysics (LIAG) in Hannover, Germany. Drs Gerald Gabriel and Thomas Burschil, along with their colleagues at LIAG, have developed a more sophisticated technique that employs horizontally polarized S-wave vibrations. This technique offers a greater ability to investigate structures at shallow depths and provide often a much higher resolution. The

‘Seismic imaging of Quaternary sediments and landscapes fascinates me, in particular buried valleys and glaciotectonic complexes formed by glacial advance from Scandinavia and overdeepened valleys carved out by glaciers from the Alps’

Dr Thomas Burschil



seismic waves are produced by a specially designed vibrator that excites elastic waves that propagate through the upper some hundred meters of the Earth’s crust and are then recorded by receivers, or so-called geophones. Afterwards, signals of reflections in the subsurface can be processed into a seismic image of the structures.

What is the Tannwald Basin? And why is it of geological interest?

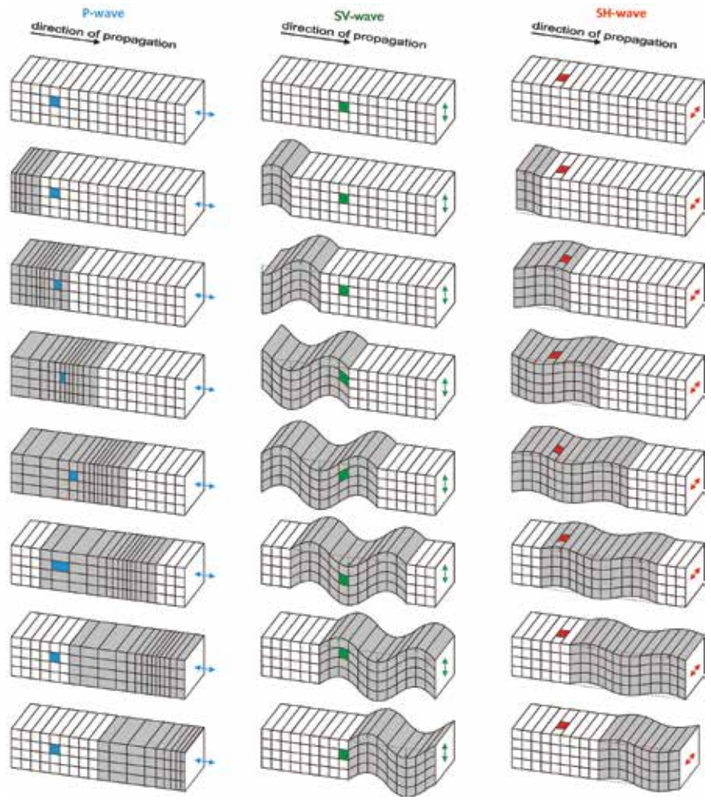
The Tannwald Basin is an example of an ‘overdeepened basin’, located in the state Baden-Württemberg in Germany, and hence in the foreland of the Alpine mountain range. The Tannwald Basin is a pilot region that is used to study overdeepened valleys and to transfer and link the results of the research to other more populous regions. Understanding the structures located here is of geological and environmental importance, and also of social relevance. In fact, this was one of Dr Gabriel’s motivations to study this particular region: ‘For me, the social relevance of these overdeepened valleys is attractive because I feel that we can serve society with our research’. The basin is part of a larger system of overdeepened valleys which are present across the entire Alpine region. The Tannwald Basin is one the many ‘branch’ basins that surround the core basin of the Rhine glacier, which formed, e.g. Lake Constance. With respect to the geological time scale, these basins were formed over a short period of time by glacial activities, and at least three occurrences of strong glacial activity are known to have happened in this region.

Overdeepened basins are located in regions that have been affected by glacial activity at some point in the Earth’s evolution. The term ‘overdeepened’ is a reference to the genesis of valleys and basins; they were presumably formed by pressurised, subglacial meltwater. As a result of glaciations, the overdeepened valleys elongated in the direction of the glacial flow. When the glaciers retreated, many of these valleys were quickly filled by various sediments and became buried. However, it is assumed that repeat glaciation events have caused major parts of the sediments, even all sediments, to be removed, leading to a complex infill pattern. Current information about structures within these basins has often been derived from drilling local boreholes and obtaining geophysical data. However, for the Tannwald basin, only a small amount of previous data is available, and this does not compare to the data that can be obtained using modern approaches. Furthermore, a borehole is only relevant to the local structures that surround it, and may not be an accurate representation of the entire basin. Research up to this point has not answered the vital questions required in order to use the valleys as groundwater sources and to understand the hazard potential associated with these valleys. By investigating the geophysical and geological data of the entire Alpine region, the climatic history can be deciphered and future scenarios can be developed.

One way of answering these questions could be to embark upon a comprehensive drilling project. However, drilling multiple boreholes is a large undertaking, so by providing a complex and accurate seismic survey of the area allows precautions to be taken and to determine where the drilling of the borehole should take place.

Applying seismic imaging to the Tannwald Basin

Although there are many techniques that can be applied to analyse basins, seismic imaging is most commonly employed because it gives the most detailed images of sedimentary layers. Other methods used in the past could only reveal the outlines of large geological structures, or could not penetrate the structures clearly to show the finer structures that can be seen using P- and S-wave reflection seismic techniques. However, conventional reflection seismic imaging techniques generally investigate a deeper domain than the depth of the basin. Dr Burschil tells Scientia about the technique they employ in order to image overdeepened basins: ‘We apply multi-component reflection seismic techniques, using 3-component receivers and two different orientations of S-wave sources to investigate Quaternary sediments’. Implementing this new way of imaging by applying a multi-component method, marks a milestone within this field of research, allowing for more detailed images of many subsurface structures to be produced.



During the seismic surveys, Drs Gabriel and Burschil use different types of seismic waves to build a clearer picture of the structures of the valley. So far, five P-wave, two SH-wave and one multi-component reflection seismic profiles have been acquired to investigate the sediment succession in detail. Cross-lines have also been recorded to study the 3-D effects and to test to see if a 3-D multi-component analysis is a feasible approach.

Both the observed P-wave and SH-wave profiles are of very high quality and exhibit the similar structures. The P-waves have strong reflections at the base (top Molasse) of the basin, consistent with the data collected from a borehole in the 1990s. The depth of the Tannwald Basin ranges between 80 and 240 m, depending on the location. P-waves also show partial incoherent reflections below the top Molasse, and the sedimentary infill displays segments of faint reflection signals which are partially connected to each other. However, the SH-waves provide more structural detail with higher resolution than the P-waves, but image fewer geological structures in comparison.

The area of the examined basin can be classified into two main regions – the western part and the eastern part. Below the base of the basin, the reflections were found to be brighter in the P-wave profiles than the SH-wave profiles, whereas shear waves lack penetration power. Parts of the basin infill are better resolved by S-waves, while for others, P-waves are the most suitable option. The combination of the two gives the best results. Further analysis of the multi-component data will give new information about anisotropy of the deposits due to the glacial overprint and tectonics.

The analysis of the seismic data is major step forward for a new proposal under the umbrella of the International Continental Scientific Drilling Program (ICDP) called DOVE (Drilling Overdeepened Alpine Valleys). The new data obtained from the geophysical survey combined with the previous borehole studies have allowed a new borehole drill site to be chosen for the Tannwald Basin; further complementary borehole sites are suggested for other regions in the Alps. As part of this ICDP proposal, existing data will be reinterpreted against the background of geophysical characteristics, by combining the seismic data with the results of the drilling activities. The new findings from the Tannwald Basin may also suggest additional target-orientated pre-site surveys elsewhere. The advances in the methodology and hypotheses derived from this project will then be applied to other overdeepened structures in the Alps. Combining the multiple data sets from all investigation sites will allow for a clearer picture to be built of the Quaternary sedimentation and deposition changes over the entire Alpine region.

‘The seismic data itself will certainly provide important information about the structure and also the evolution of the Tannwald Basin’
Dr Gerald Gabriel

What to expect in the future

Analysis and interpretation of the seismic data acquired at the Tannwald basin is to be explored further. In addition to the analysis of this site, there are plans to use seismic imaging at a secondary location (Lienz Basin, Austria) as well as potentially introducing 3-D, multi-component analysis into the seismic surveying.

A key test will be to start drilling cored boreholes within the basin to enhance and broaden the scientific approach and to confirm the seismic interpretation. One of Drs Gabriel and Burschil’s aims is to gather a team of interdisciplinary scientists to analyse the core material using various methods, in order to date the sediments as well as analyse their physical properties. These future investigations will provide information about the glaciational and depositional environments in southwest Germany. In addition, the anisotropic physical properties of the rocks can be determined.

Meet the researchers

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Dr Gerald Gabriel is a senior scientist at the Leibniz Institute for Applied Geophysics in Hannover, Germany. He obtained his PhD at the University of Clausthal, Germany, with a project investigating the geodynamic evolution of the Harz Mountains. Following this, he began postdoctoral work at the Leibniz Institute for Applied Geosciences, where he currently holds a senior research position working in the areas of section seismics, gravimetry, and magnetics. He is also an Associate Editor for Near Surface Geophysics.

Dr Thomas Burschil is a research scientist, also working at the Leibniz Institute for Applied Geophysics. After obtaining his degree in Physics, he started his career by working as a project scientist on the EU Interreg project CLIWAT. Following this, he went on to achieve a PhD in Geophysics at the Technical University of Berlin, with a thesis titled 'Geophysical characterization of the Föhr island groundwater system'. At the Leibniz Institute for Applied Geophysics, he currently works on multi-component seismics in overdeepened Alpine valleys and basins.

The Leibniz Institute for Applied Geophysics (LIAG) in Hannover, Germany conducts research in the field of physical geosciences to meet the future needs of society. Researchers at the institute investigate the uppermost part of the Earth's crust which is accessible for economic use and of primary importance for the supply of essential resources. The institute consists of 90 employees from various backgrounds and covering many disciplines, and has strong research focus on the fields of groundwater systems, geothermal energy and terrestrial sediment systems. The institute is member of the Leibniz Association.

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REFERENCES

Buness H., Gabriel G., and Ellwanger D., Quaternary Science Journal (Eiszeitalter und Gegenwart), 2008, 57, 338–366.

Burschil T., Scheer W., Kirsch R., and Wiederhold H., Hydrology and Earth System Sciences, 2012, 16, 3485–3498.

Gabriel G., Ellwanger D., Hoselmann C., Weidenfeller M., and Wielandt-Schuster U., Quaternary International, 2013, 292, 43–58.

Gabriel G., Kirsch R., Siemon B., and Wiederhold H., Journal of Applied Geophysics, 2003, 53, 159–180.

Krawczyk C.M., Polom U., and Beilecke T., The Leading Edge, 2013, 32, 256–263.

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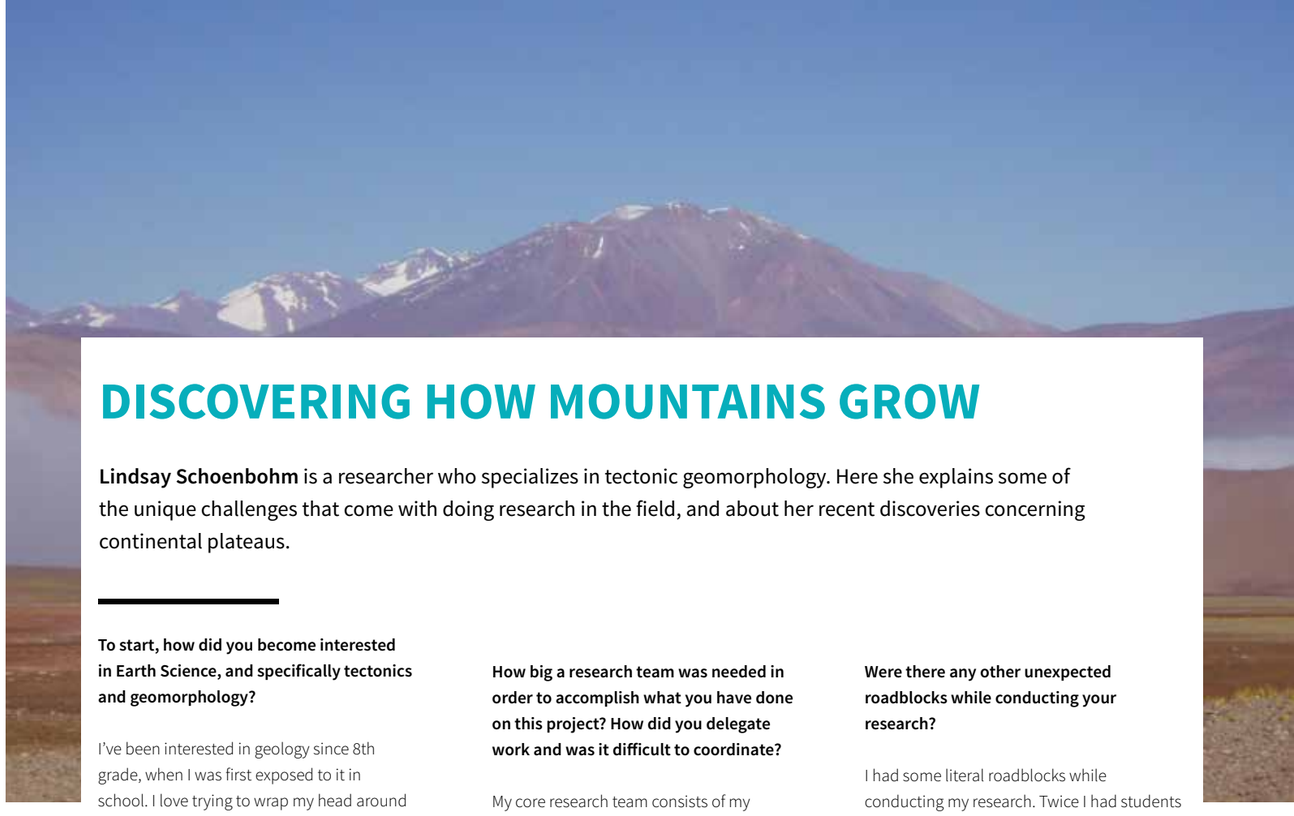

DISCOVERING HOW MOUNTAINS GROW

Lindsay Schoenbohm is a researcher who specializes in tectonic geomorphology. Here she explains some of the unique challenges that come with doing research in the field, and about her recent discoveries concerning continental plateaus.

To start, how did you become interested in Earth Science, and specifically tectonics and geomorphology?

I've been interested in geology since 8th grade, when I was first exposed to it in school. I love trying to wrap my head around the immensity of geologic time. I also like the forensic aspects of geology. You never have complete information and experiments often aren't an option, so you end up piecing together bits of evidence to make the best story you can. It's a fun challenge. And last, I love being outside and enjoy the many opportunities for travel and adventure offered through doing research in my field.

Your research team needed a combination of landscape analysis, structural geology, geomorphology, and sedimentology in order to understand continental plateaus more fully. Did you consult outside specialists for data analysis, or were they all directly part of your team?

Almost all of the research we do is collaborative – single author manuscripts in my field are rare. My students and I are competent in landscape analysis, structural geology and geomorphology. We work with other scientists who are experts in thermochronology, cosmogenic dating, sedimentology, geochemistry, and many other fields. We do field work with colleagues whenever possible, in large part because the field is such an excellent place for exchange of ideas. We do geology together every day, then sit around together over dinner talking about what we've seen and how it all works, and mapping out future papers and proposals.

How big a research team was needed in order to accomplish what you have done on this project? How did you delegate work and was it difficult to coordinate?

My core research team consists of my students and myself. I generally have 3-4 graduate students and 2-3 undergraduate students working with me at any given time. My students are partners rather than employees. I have an idea when they start about what they should work on, and I guide them along the way of course, but I expect them to have their own ideas and I support them in pursuing their own interests.

Did you have any difficulty securing funding for the project?

Securing enough funding for my projects requires ongoing effort. The majority of my funding comes from the Discovery Grant program at NSERC (Natural Sciences and Engineering Research Council), Canada's major funding agency for the Natural Sciences. These grants support my core research and provide funding for several graduate students. However, international field work can be wildly expensive; even though we camp much of the time, airfare and 4WD truck rental really add up. I've received funding from the US National Science Foundation in the past to help support my program. I've also moved over the years into more remote sensing work, done on computers in the lab, which is less expensive and can be very efficient.

Were there any other unexpected roadblocks while conducting your research?

I had some literal roadblocks while conducting my research. Twice I had students get stuck in the field while doing work off-road. In each case it took more than a week before we were able to pull their trucks out and get the research back on track. One student had to hike 80 km over a 5000 m mountain range to get help. The Argentine Gendarmeria were sent out to retrieve the other lost students. Another time we tipped our canoe going through some major rapids on the Red River in China. We've had people charge into our hotel rooms at night to shake us down for money. But for the most part I've been lucky and my research has proceeded smoothly.

You mention that your research team will constrain hazards associated with active faults in central Turkey. Is this a future project or did your previous work inform geologists working in this area?

We're just getting started on our hazards work in central Turkey. Two of my recent graduate students mapped fault strands, but in the next stage of the project we'll do trenching to really get at the frequency and timing of earthquakes along key faults in central Turkey. This information, coupled with estimates of the size of each past earthquake based on the amount of offset, can be used to predict the damage potential of future earthquakes. This isn't work I've done in detail before, but I'm eager to get started.

HIGH AND DRY: WHAT IT TAKES TO FORM A PLATEAU

Professor Lindsay Schoenbohm of the University of Toronto and her team have made some ground-breaking discoveries in the field of tectonics and geomorphology. A combination of field-based mapping, satellite image interpretation, landscape analysis, geochronology and other techniques were needed to understand the formation of continental plateaus.

Tectonics: A Relatively Recent Geological Puzzle

Even though students of geology are taught that the theory of tectonics is fundamental to the science, it actually has a very recent history of controversy. The theory was not formally introduced to the scientific community until the early twentieth century (at the time it was called the "theory of continental drift"), and was not widely accepted by geologists until the 1960s.

Researchers in the field of tectonics study the plates that form the crust of the Earth. These plates (an outer "shell" covering the Earth) move slowly over time, and while they move just a few centimetres a year on average, that movement can build dramatic terrain like mountains over the span of millions of years.

There are still controversies today regarding the specifics of how certain tectonic features form, but a consensus is slowly building, thanks in part to the work of Professor Lindsay Schoenbohm.

Schoenbohm is interested in features called continental plateaus – striking landforms whose origin has always eluded explanation, the most famous example being the Tibetan Plateau. They are typically associated with collisional tectonic settings in which two discrete plates collide. However, plateaus are not present in all collisional settings, and some plateaus form far from these areas. Furthermore, although all plateaus have the same shape – flat on top with steep sides – they display different styles and varying amounts of deformation. In other words, there are no common features with which to identify the exact processes that create, sustain and destroy plateaus.

Reading the Surface to Understand the Depths

Scientists have several ideas about how plateaus can form. One group argues for the importance of thickening the crust – by stacking one tectonic plate on top of another, by crumpling one plate, or by injecting magma. Once the crust is thickened, it "floats" higher and starts to spread outward, forming a plateau. Other scientists think that thickening the crust is not enough – as the crust is thickened, the denser lower part of the tectonic plate, known as the "mantle lithosphere," is thickened as well and acts like an anchor on the plate, pulling it down. Therefore, a second group of scientists reasons that the mantle lithosphere must "detach" before a plateau can form. A third group emphasizes the role of climate, arguing that a plateau cannot form unless it is protected from erosion (by rivers and glaciers) in an arid environment.

Because of the way these possible formation mechanisms may feed into each other, and because the evidence for each can be cryptic, it is not easy to identify exactly which processes are driving the plateau growth. It is also not so easy to explain the forces that support the plateau's continued existence, since there needs to be an ongoing source of uplift for the plateau to remain a prominent feature of the landscape.

Schoenbohm's recent research focused on two plateaus. One, called the Puna Plateau, is located in north-western Argentina, and the other, known as the Central Anatolian Plateau, is found in central Turkey.

In Argentina, Schoenbohm focuses on the growth of the Puna Plateau. It is likely that the Puna Plateau's uplift is controlled by detachment of the lower part of the tectonic plate, but how, when, and why this happened remains a question. The Puna may have resulted from delamination, in which lower parts of the plate peel off and sink down into the "asthenosphere" beneath the plate.

It could also be the result of "dripping", a process in which dense, colder parts of the plate sink into the relatively warm and fluid mantle below in the style of a lava lamp. There may have been one huge drip (the width of the plateau) or many smaller "driplets", each 40–100 km across. In any scenario, the combination of the loss of the mantle lithosphere anchor and the injection of hot rocks to fill the space would have caused uplift at the surface. This uplift would have been big enough to affect the regional and global climate.

There are additional questions about the Puna Plateau that Schoenbohm hopes to answer. The steep mountain ranges along the sides of plateaus have long been thought to protect the flatness of the plateau interior. This works because as moist air tries to flow over the plateau, it cools and forms rain which falls heavily on the steep sides of the plateau, leaving the interior of the plateau arid and protected from aggressive erosion. Schoenbohm's research has led her to believe that this phenomenon not only protects the plateau, but may actually help it to grow wider. As new mountains deform the area around the plateau, they create obstacles that the rain-laden clouds must pass over, forming a "bathtub" basin between the mountains and the plateau edge. If conditions are right, this basin can fill with small pieces of rock and dirt eroded from the mountains all the way up to the top, expanding the flat area of the plateau.

When it comes to the Central Anatolian Plateau, Schoenbohm is interested in explaining its internal deformation in a different way. Although similar in some aspects, the Central Anatolian Plateau differs from the Puna Plateau in that it is cut by major "strike-slip faults". These are formed when tectonic plates break into two pieces that slide past each other in order to accommodate the growing pressure of the collision, causing major, periodic earthquakes. While there are many prominent strike-slip faults near the Eastern Anatolian Plateau, there is still a debate in the community as to which of these faults are important, and how they help or hinder growth of the plateau. These faults also change as mountains continue to rise from the collision, making their significance difficult to nail down.

Real Results

The research team, led by Schoenbohm, has already made some key findings. Their work in Argentina has revealed that lithospheric dripping in the Puna Plateau occurs in small "driplets" rather than larger-scale drips, and they have identified two that have occurred in the last 20 million years. The team was also able to demonstrate that mountain uplift and local climate change, rather than global climate change, control sediment deposition in the "bathtubs" around the edge of the modern Puna Plateau. That revelation was the answer to a long-standing question in the field of tectonics, and suggests the importance of this mechanism in growing the plateau. In Turkey, Schoenbohm has demonstrated that the Central Anatolian Fault Zone, thought to be a major strike-slip fault, is actually a collection of less-significant, loosely linked faults, although they still pose a significant earthquake risk.

Schoenbohm's continuing work will give scientists much insight into tectonic processes. While the team's work is still far from done, they have made some huge contributions to the field of tectonics and geomorphology and have even more ambitious plans for the future. They will demonstrate in finer detail how activity deep within the tectonic plate and mantle can affect the landscape above, and elucidate the relationship between tectonic activity and climate. This task is famously difficult, but Schoenbohm's interdisciplinary approach has already made important breakthroughs.

Meet the researcher

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Professor Lindsay Schoenbohm received her bachelor's degree in Geology from Carleton College in Minnesota and went on to earn her Ph.D. in Geology from the Massachusetts Institute of Technology. She worked as a postdoctoral research associate at the University of Postdam in Germany and taught at Ohio State University before accepting her current position at the University of Toronto. She has won many grants for her research, and also serves as an Associate Editor for Tectonics. She currently teaches at the University of Toronto Mississauga where she continues her work in geomorphology and tectonics, specifically continental plateau formation.

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UNDERSTANDING THE PROCESSES OF THE MULTIPLE SUBDUCTION PLATE BOUNDARY AROUND JAPAN

Dr Hitomi Nakamura uses knowledge from studying slab fluids in magma formation and applies it to study spring waters formed from a similar process. In this interview, she discusses what is special about the Japanese plate system and why such fluids are important.

Let's start at the beginning so that everyone can understand about more about what you do. What's your research background? And how did you get into your chosen field?

I am a volcanologist/petrologist/geochemist. My PhD thesis concerns Quaternary magmatism in Central Japan where the multiple plates meet and interact, which led me to realize the importance of fluid, particularly salty aqueous fluid derived from the subducting plates, to magma genesis. My research activity includes field works, rock/water sampling, laboratory works (e.g., chemical and isotope analyses utilizing 'clean room' and mass spectrometer), and data analyses using computers. Now I am involved in a project on magmatism in Kamchatka, where again fluids play an important role, collaborating with Dr Tatiana Churikova in IVS FEB RAS. Based on these studies and my background, I have also started to study a new target 'spring water'. Many spring waters are upwelling in Japan, some of which seem to have the same origin with the deep-seated fluid triggering magma generation.

Many people are familiar with tectonic plates, but what is special about the subducting plates found on the islands of Japan?

Two features are highlighted here. First, since the Pacific Plate that subducts beneath Japan is the largest on Earth, the subduction power is the greatest, exposing the islands to the most tectonically active environment in the world. In particular, after the '2011 off the Pacific coast of Tohoku Earthquake', the Japanese islands seemed to enter a tectonically active period: in addition to a series of aftershocks, a number of volcanoes have been and are going to erupt, such as Ontake Volcano and Sakurajima Volcano. One of the important factors for these eruptions is water. When magmas ascend and the pressure is released, water is degassed from magmas and quickly expands, causing explosion and eruption. The water source is a fluid liberated from the subducting plates. Beneath the Japanese islands, the two oceanic plates (Pacific Plate and Philippine Sea Plate) subduct beneath the two continental plates, with complex plate geometry. Therefore, the average amount of water supplied from the plates is greater than in other subduction zones, with complex spatial variations in both amount and composition, through many faults that have been created by tectonic stress applied from the four colliding plates along the Japanese islands.

A lot of your focus is centred around 'slab fluids'. What are slab fluids, and what important role do they play at plate boundaries?

The reason why we have plate boundaries and subduction is probably due to liquid water on this planet, which weakens the rock strength. Therefore, how water interacts with rocks in subduction zones is related to the uniqueness of this planet. Another unique feature of Earth is the presence of the continents, which is thought to be produced also via water-rock interactions. Slab fluid is such water, derived from subducting slabs. Slab fluids are not pure water, but a brine containing abundant metals, as a result of water-slab material interactions at high pressure and temperature. In many arcs, slab fluids are upwelling beneath volcanic region and produce magmas and possibly ore deposits, in which they can be trapped as 'fluid inclusions'. Recent studies suggest that slab fluids are also upwelling in non-volcanic regions, especially through faults in the fore-arc region.

So what is next for your research?

Since I have just started to study spring waters, there are many things to do at the moment. In particular, I will continue to search for deep-seated brines that correspond to slab fluids along the entire Japanese islands, first mapping their distributions. The detailed compositions of the brines will tell us both their origin (from which we may infer the physical-chemical condition of the subducted plates) and ascent processes (from which tectonic settings and aquifer interactions may be discussed). Including these brines, I have a plan to map and geochemically classify all the spring waters in Japan, in order to envisage 'fluid circulation' beneath the Japanese islands, which is important in understanding the geological phenomena and plate dynamics in subduction zones, as well as the Earth's unique features.

CAPTURING THE SLAB-DERIVED FLUIDS IN SPRING WATER

Slab fluids are impure water solutions found at subduction zones at plate boundaries. They have generally been derived to produce magma formation. Dr Nakamura and her colleagues have used their knowledge and applied it to similar principles that occur for the heating of spring water in Japan.

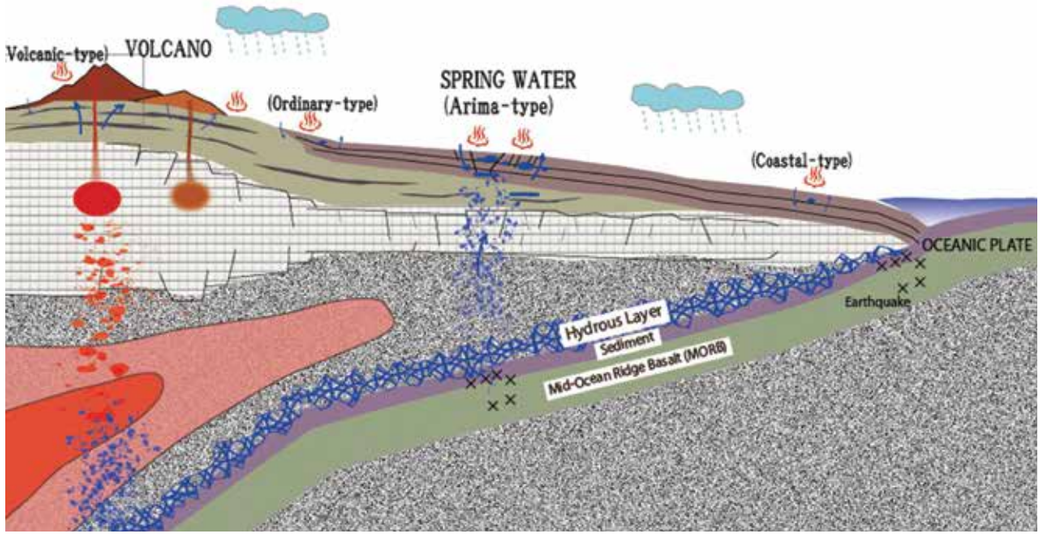
Tectonic Tales

As many people are aware, unlike other planetary bodies in our solar system, the Earth is made up of multitude of massive rock slabs which move over each other known as Tectonic plates. Tectonic plates interact with each other at plate boundaries and most commonly occur in two ways: The first, where the plate is constructive and the plates move away from each other. And second, where the plates move towards each other where one plate becomes submerged under the other. This article is concerned with the latter upon which they occur between an oceanic plate and a continental plate (at boundaries between land and sea). The oceanic plate is much heavier than the continental plate due to heavier elements making up the composition in the rocks (and they generally a more mafic composition), so the oceanic plate submerges (subducts) beneath the continental plate under gravity. If you have two plates which are of the same composition (oceanic-oceanic and continental-continental) then you get a 'collision' plate boundary where it concerned with making geological structure such as mountain building (like Himalaya). Around the Japanese islands, the tectonic activity is concerned with subduction plate boundaries.

What makes the Japanese subduction zone so special is the fact that the oceanic plate is the largest on Earth, giving the greatest subduction power in the world

Japan's Special Environment

But did you know that this can occur for more than one plate simultaneously? This is the case in Japan where the Pacific Plate submerges at the Japan Trench under multiple continental volcanic arc-magma with multiple continental shelfs containing less dense rock. This phenomenon is not exclusive to Japan as it also occurs at various points over the Pacific Islands and is known as 'the Ring of Fire' because of the amount of induced volcanoes and earthquakes caused by the multiple plate system. However, beneath the Japanese islands, the two oceanic plates (Pacific Plate and Philippine Sea Plate) subduct partly overlapping beneath the two continental plates, which leads to complex plate geometry and



unstable torque balance. Especially near the junctions where these plates meet, northward progress of the subducted Philippine Sea Plate was stuck by the geometrical constraints (no space for progress, being sandwiched by the upper and lower plates), which resulted in a significant change in motion of the Philippine Sea Plate in the past (~3 million years ago). What makes the Japanese subduction zone so special is this complex geometry and interaction among the plates, in addition to the fact that the Pacific Plate is the largest and the most powerful on Earth, and therefore exposing Japan to immense levels of tectonic activity. Because of this activity, the Japanese Islands are susceptible to both earthquakes and volcanic activity.

Slab fluids? Hot Springs? What's occurring under the surface?

As we are concerning ourselves with not only the geological environment but also the slab fluids that these environments produce, you may be wondering what slab fluids are and why they are relevant. To put it simply, a slab fluid is water that is derived form a subducting plate. Slab fluids are the water that get submerged with the plate during the submersion process (there is always so water lubrication present). However, it is unlike the water that we are accustomed to in everyday living, but an impure water form with a high salinity and are earth elements (REEs) concentration- essentially if you mixed 'hard water' with salt water, it would loosely represent the composition of slab fluids. The reason for the impure fluid is due to the intense heat and pressure it is subjected to during the submersion. Slab fluids then travel upwards, generally through aquifer rocks and can produce magmas or ores.

When slab fluids ascend from the plate beneath the non-volcanic region, upwelling velocity and total time to reach the surface seem to be fast and short where they have no interaction with magmas on the way. This can be observed as is observed by a special type of earthquake, called 'non-volcanic tremor'. Such deep-seated brines could have ascended to a rather shallow depth without being significantly modified until it meets the aquifer water/meteoric water. This can be shallower than several hundred meters in depth. This means that two very different fluids: a high-temperature brine with abundant metals formed under an oxygen-poor conditions and a low-temperature meteoric water formed under an oxidized condition, meet to react and precipitate the metals from the former that is significantly oxidized and cooled by the meteoric water. On the other hand, the meteoric water in the aquifer receives gas components (e.g., CO_2 and helium) degassed from the cooled brine. This combination of liquids is what forms the spring waters in regions and faults between the rocks cause the springs to physically form by upwelling from the aquifers. There is a higher spring water abundance around Japan because there are two oceanic plates being submerged, causing the amount of slab fluid at the boundary to be doubled, resulting in a larger quantity of spring water produced. The Arima Springs is one such area of spring water accumulation where this is physically shown.

How to determine the composition of slab fluids to give an accurate representation?

Because Slab fluids have a high amount of rare earth elements (REEs) it means that the ions in solution behave uniquely and coherently and are sensitive to changes in temperature, pH, fO_2 (oxygen environment) and fCO_2 (CO_2 environment). This sensitivity can provide key information on the process at shallow levels where these variables may significantly change. In spite of such usefulness of REEs, the analysis of spring waters is not trivial. Partly due to the variations and due to mixing with meteoric waters, the concentrations of REEs in the spring waters are variable, being very low (a ppb level) on average, which requires an analytical method with a very high sensitivity and a wide dynamic range, such as Inductively Coupled Plasma - Mass Spectrometry (ICP-MS). High salinity and other dissolved metals and elements interfere the REE analysis (even more so with a high-sensitivity method like ICP-MS), but procedures have been developed by the group to cope with the difficulties so that cataloguing of compositions is possible.

Meet the researcher

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Dr Hitomi Nakamura is a scientist in igneous petrology and geochemistry at Japan Agency for Marine-Earth Science and Technology (JAMSTEC). She is also a researcher in Department of Earth and Planetary Sciences at Tokyo Institute of Technology (TITECH). Nakamura works within the group of Dr Hikaru Iwamori and her research focuses around the multiple subducting plates around Japan and related slab fluids and magmatism, as well as global mantle heterogeneity. More recently she extended these fluid studies to include spring waters formed from slab fluids. She has published 14 international and 4 domestic peer-reviewed publications to date.

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REFERENCES

H. Nakamura, K. Chiba, Q. Chang, S. Nakai, K. Kazahaya and H. Iwamori, Rare earth elements of the Arima spring waters, southwest Japan: Implications for fluid-crust interaction during ascent of deep brine, Journal of Geology & Geosciences, 2015, 4, 4:217, doi:10.4172/jgg.1000217.
H. Iwamori and H. Nakamura, Isotopic heterogeneity of oceanic, arc and continental basalts and its implications for mantle dynamics, Gondwana Research, 2015, 27, 1131–1152.
H. Nakamura and H. Iwamori, Generation of adakites in a cold subduction zone due to double subducting plates, Contribution to Mineralogy and Petrology, 2013, 165, 1107–1134.
H. Nakamura and H. Iwamori, Contribution of slab-fluid in arc magmas beneath the Japan arcs, Gondwana Research, 2009, 16, 431–445.
H. Nakamura, H. Iwamori and J.I. Kimura, Geochemical evidence for enhanced fluid flux due to overlapping subducting plates, Nature Geoscience, 2008, 1, 380–384.

ECOLOGICAL SCIENCES – DIVERSITY IS THE SPICE OF LIFE

Ecology is the study of how organisms interact with their environment and each other in competitive or collaborative ways. Ecologists observe and study the natural world as ecosystems, which constitute a system of both non-living elements and a community of living organisms. Ecological research is very often concerned with measuring and tracking the abundance of species in our environment. The variety of organisms in the environment is termed biodiversity. We are living in an age where a massive decline in biodiversity is taking place, in large part caused by human activities and their effect on the climate and destruction of species-rich or unique habitats such as the rainforest and polar regions. Therefore, measuring and assessing the biodiversity on our planet is of utmost importance, to allow us to accurately determine the effects that our activities have on other species and successfully implement preventative measures to decrease negative human impacts. In addition to looking at wild species, ecology can also encompass domesticated species that are farmed, which is termed agroecology. Using ecological principles in farm management and considering the farm as an agroecosystem can result in a paradigm shift in farm management techniques for more productive and ecologically sensitive farming. In this section of the issue we celebrate the diversity of the ecological sciences through the research of four very different research groups. In the first of four articles in this section we look at the work of Dr Netta Dorchin at Tel Aviv University. Dr Dorchin studies the ecology, physiology and speciation of gall midges, which are small insects that feed and live in plant tissues, primarily in their larval stage, and cause plant tissue swellings known as galls. In particular, Dr Dorchin studies the process of cascading speciation in gall midges, whereby a shift in niche for gall midges, for example to a new type of plant, provides

an opportunity for their natural predators to adapt, thereby facilitating the evolution of new lineages, which results in different species.

Next, we focus on the work of Professor Ehud Meron of the Ben-Gurion University of the Negev. Professor Meron approaches ecological questions as a physicist and uses mathematical modelling to investigate the resilience of ecosystems to changes in the environment, the mechanisms by which species co-exist and the potential for repairing ecosystems which are not functioning correctly. In recent work the team have provided insights into the self-organisation of the Namibian fairy circle ecosystem (fairy circles are circular patches of sandy ground which appear on the Namibian grasslands).

Our third article on the topic of ecology details the work of Dr Nicholas Brokaw of the University of Peurto Rico and Dr Sheila Ward, a consultant based in San Juan, Puerto Rico. The team's fascinating work concerns the land use of the ancient Maya people and how this has affected land use and the environment in present day Belize. This research involves a synergistic combination of archaeology and ecology. The team have shown that the Maya altered the topography and soil through their use of the land, which has had a significant impact on the distribution and abundance of tree species in the affected areas. Our final article in this section is also concerned with the use of the land by humans. We explore the research of Dr Nicolas Friggens of the INRA-AgroparisTech MOSAR research unit. This work focuses on developing precision farming technologies, which can provide highly detailed data about livestock. The researcher can then apply mathematical modelling to interpret and analyse the data. The idea is to help farmers to maximise their outputs and most efficiently use their land, while protecting animal welfare. The technology permits for predictions about the results of changes in farm management or changes in genetic selection for selective breeding programs.

Tiny ecosystem engineers: diversity and evolution of gall midges

Dr. Netta Dorchin is the chief curator of entomology of the Steinhardt Museum of Natural History at Tel Aviv University. As biosystematist, her research has been focused on the diversity and evolution of gall-inducing insects.

Could you describe your academic background and tell the readers what initially sparked your interest in studying gall-inducing insects?

I completed my BSc in biology, MSc in ecology and environmental studies, and PhD in zoology, all in Tel Aviv University. I have always been drawn to organismal biology and it was clear to me that I want to study animals and plants rather than work in the fields of cellular or molecular biology. The opportunity to conduct fieldwork rather than being restricted to the laboratory has always appealed to me, and as an undergraduate I took every course I could which included field excursions. Because my father is a beetle collector and taxonomist, I became familiar with insects already as a child. The facts that most creatures on earth are insects and that so many of them are still unknown and misunderstood has made them even more interesting to me. Wanting to combine my interests in entomology and botany, I chose to work on gall-inducing insects, which exhibit the most intimate and complicated of insect-plant interactions.

Why are these organisms good models for addressing questions in evolutionary biology?

Phytophagous insects are extremely numerous and diverse, and it has been shown that the rate of speciation among such insects is higher than in sister lineages which are not phytophagous. One level of this diversity is manifested by the different degrees of specialization found among plant-feeding insects, and this diversity can serve to investigate the role of host-specialization in the formation of new species. Gall-inducing insects are usually very host specific because they live inside the plant tissues and must develop adaptations that enable them to use the plant resources and overcome its defence mechanisms. Evolutionary shifts in host preferences among such insects require the development of adaptations to the new hosts and may thus lead to the formation of new species.

Cascading speciation is a relatively new subject, and studies addressing this process are scarce. Could you tell us the importance of understanding how prevalent this phenomenon is in a variety of organisms?

To assess whether cascading speciation is an important promoter of biodiversity, it is crucial to know how prevalent it is in different taxa and ecological systems, and why it occurs in some cases but not in others. If, for example, it will be found that external parasitoids are more prone to cascading speciation than internal parasitoids, or that predators are less prone to experience this process than parasitoids, we could start to make generalizations about what life-history attributes make speciation more likely.

What main ecological features do you expect to promote gall-midge diversification?

The ability to adapt to a new host-plant or to a different plant part on the same plant species must be a major driving force toward speciation in gall midges, and in phytophagous species in general. Shifts in activity times can also lead to diversification because they create temporal barriers between populations. To allow for diversification, a gall midge species should have adapted to exploit the tissues of a specific host plant, and its phenology should be synchronized with that of the plant. But at the same time it cannot be so specific that it cannot make the shift to new plants or new activity times. In other words, it should be specific, but not too specific.

We are living in a period of great biodiversity loss. Could you tell the readers about the importance of your research in this context?

To understand ecosystems and the role of their components, we must first know what these components are. If we don't know what species exist in a certain area and what they do there, we cannot make educated decisions about conservation programs and prioritize conservation efforts. For example, if we are familiar with the diversity and life history of natural enemies that attack certain agricultural pests, we can use chemical pesticides in a way that would minimize the negative impact on these natural enemies. If we need to decide which out of several areas should be declared as a natural reserve, we need to know what organisms are found in those areas, how common or rare they are, and what function they have in the ecological system. This is the type of information that taxonomists can offer to conservation biologists, ecologists and agriculturists.

Patterns and processes of diversification in gall-inducing insects

Gall midges are specialized herbivores that comprise a diverse and ecologically important group of insects. Diversification in these organisms may occur through shifts to new host plants. Here Dr. Dorchin discusses how her research has improved the understanding of this phenomenon.

ECOLOGY AND EVOLUTION OF GALL MIDGES

Evolution is change in heritable characteristics of natural populations over time. Several evolutionary mechanisms like natural selection and random genetic change are responsible for the vast biological diversification we see in nature. An intriguing topic in evolutionary biology is how and why species diverge in time and space resulting in the formation of new species. Dr. Netta Dorchin has been dedicating her career to this topic, seeking to describe the patterns of diversification in gall midges generated by thousands and millions of years of evolution and to understand what factors have led to such diversity. But why gall midges?

Flies comprise one of the most diverse and studied groups of insects. A particular group of phytophagous flies, the cecidomyiids or gall midges, induce galls in their host-plant tissues as part of their life cycle. Plant galls are abnormal outgrowths in vegetal tissues that may serve as both habitat and food source to the insect. Despite their great diversity of over 6000 species, knowledge on the diversity and biology of cecidomyiids is still lacking, especially in the Afrotropical and the Neotropical regions. To explain the reasons for this knowledge gap, Dr. Dorchin argues: "While many fly species are pests or disease vectors and therefore receive a lot of attention, the overwhelming majority of species are tiny, inconspicuous creatures with neither positive nor negative impact on man. Gall midges are tiny, fragile flies that are also short lived, and as such, do not appeal to many taxonomists". Their ecological importance is unquestionable though. By inducing gall formation, gall midges create new micro-environmental conditions that represent potential niches which can be exploited by other organisms. For this reason, gall-inducers may be considered ecosystem engineers or niche constructors.

DESCRIBING AND NAMING BIODIVERSITY

Biodiversity is being lost at unprecedented rates and many species will become extinct before they are described. For most groups of living organisms, researchers are still far from understanding how many species compose the ecosystems on both global and regional scales. This limitation makes taxonomy a priority field of study. In taxonomic studies, species are named and components of biodiversity are described in detail. Without a robust taxonomic knowledge, researchers cannot start addressing questions about ecological and evolutionary features of particular groups of organisms.

There is much more knowledge and progress is faster in groups which have some appeal or economic importance to humans. To improve this situation, aspiring taxonomists especially in those parts of the world for which knowledge is scarce, should be trained by specialists such that the taxonomic work produced is robust and of high quality.

Several of Dr. Dorchin's research projects have provided basic understanding about the components of biodiversity in gall midges, including description of new species, systematic revisions and faunal surveys. Such studies provided fundamental basis for further projects dealing with the ecological forces behind the diversification of gall midges.

ECOLOGICAL SPECIATION THROUGH HOST-PLANT SHIFTS

High species diversity in organisms with tight host specialization has been an intriguing question to evolutionary biologists and ecologists. In phytophagous insects, one of the main ecological events that can lead to the formation of new species is shifts to new host plants. When individuals or populations of phytophages shift to a new plant, they become subjected to different conditions. Over several generations, such new conditions may lead these organisms to change and adapt.

On one hand, shifts to new hosts can be disadvantageous to the insect due to possible physiological maladaptations to the new host. On the other hand, because natural enemies are also expected to be highly specialized, escape from these enemies may be a factor that offsets possible physiological constraints. Although evidence in favour of speciation through host shifts has increased in recent years, most studies are restricted to a single type of evidence, for example, genetic variation. "If multiple, independent types of evidence all point to the same conclusions, this makes the conclusions more robust and more likely to be correct. Combining multiple types of data in a phylogenetic reconstruction of a group can also provide insight into the evolution of certain characters in that group, such as adaptive morphological characters and host associations", explains Dr. Dorchin.

Dr. Netta Dorchin and collaborators employed a powerful approach based on multiple types of evidence to understand what factors may be involved in the diversification of *Dasineura folliculi*, a midge that induces galls in goldenrods (plants from the family Asteraceae). They tested if populations of the midge reared from two distinct species of host plants, *Solidago rugosa* and *Solidago gigantea,* were differentiated in terms of morphology, behaviour and genetics. Morphological analyses revealed that adult gall midges reared from *S. rugosa* were larger than those reared from *S. gigantea.* In terms of behaviour, the researchers showed that individuals chose to mate preferentially with individuals from the same host plant. Finally, populations of midges from *S. rugosa* were also different from populations of *S. gigantea* with respect to genetic variation. These results provide strong evidence that *D. folliculi* has differentiated into two distinct host races on its two hosts, suggesting that shifts between host plants may be important factors promoting biological diversification in gall midges.

CASCADING SPECIATION IS A PROMISING RESEARCH FIELD

Another theory that has recently been brought to the context of biological diversification in specialized herbivores is the concept of cascading speciation. It postulates that diversification of herbivorous insects through shifts in their host plants may lead to diversification in their natural enemies in response. The idea behind this theory is that these natural enemies are often as specialized as the gall-inducing species, which made the researchers believe that, when shifting their host plants, gall inducers may create new niches and thus enable diversification of their natural enemies. Gall midges represent an excellent model for studies of cascading speciation since they have intimate relations with different guilds of natural enemies: endo and ectoparasitoid wasps, herbivorous caterpillars that invade the galls and larvae of predatory organisms.

Despite its importance in the context of biological diversification, researchers are far from understanding the role of cascading speciation in promoting biological diversity. Dr. Dorchin's research has been expanding to elucidate not only the potential drivers of diversification in gall midges but also the coevolutionary processes between them and their natural enemies. What types of natural enemies of gall midges evolve in response to host shifts? How prevalent is this phenomenon in different groups of natural enemies that attack the same herbivorous species? "If this escalation of the speciation process up the trophic chain is common, it may be a major source of biodiversity, but because this concept is relatively new, the abundance of this process in nature is unknown and requires more study. Within the context of cascading speciation, I hope to improve the understanding of what life-history attributes dispose an insect to this process and why", says Dr. Dorchin. These novel contributions will be of great significance not only to specialists in gall midges, but also to the scientific community interested in cascading speciation in general.

Researcher Profile

Dr. Netta Dorchin
Chief curator of entomology in the Steinhardt Museum of Natural History
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With years' of experience in studying phytophagous insects, Dr. Netta Dorchin is one of a handful of experts in gall-midge taxonomy and ecology. Her research is focused on the systematics, ecology, physiology, and speciation of these organisms. To address questions in these areas she uses a variety of approaches such as classical taxonomy, molecular systematics, and experimental biology.

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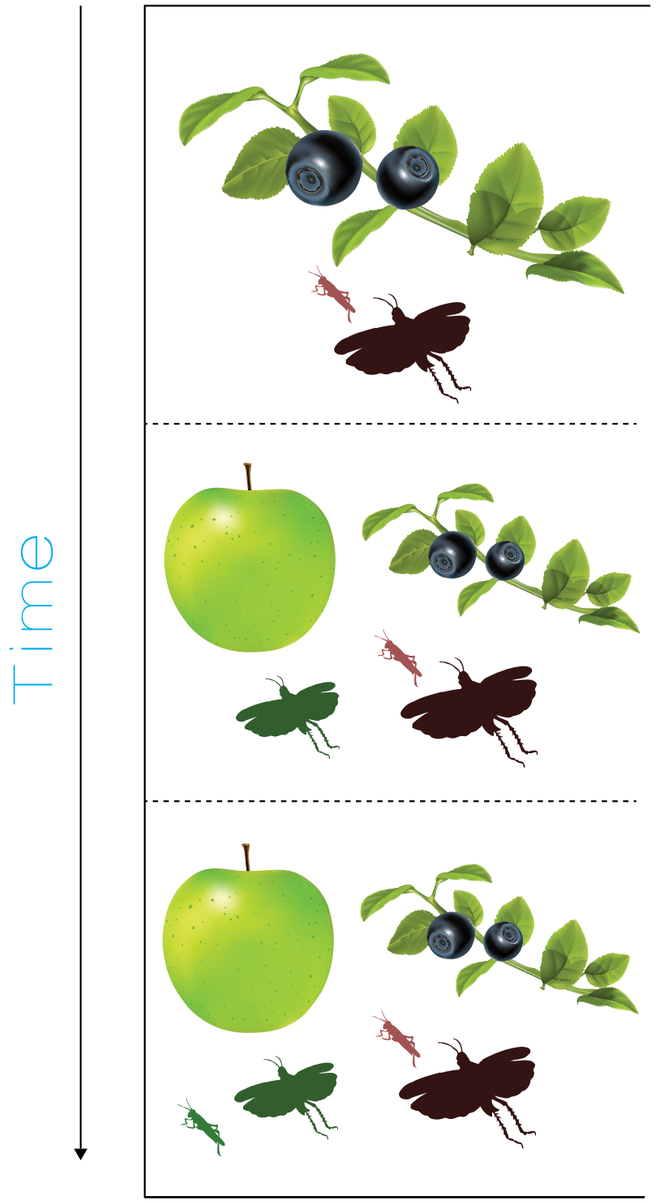
CASCADING SPECIATION: A METHOD FOR THE FORMATION OF NEW SPECIES



An insect and its predator are both highly adapted to live on a particular plant.

The insect makes the shift to start living on a new plant, thereby becoming a new species and avoiding the predator.

The predator also makes the shift to start living on the new plant. Two new species are formed.

When physics and ecology unite

Professor Ehud Meron is a researcher at Ben-Gurion University of the Negev. Here, he discusses how his background in nonlinear physics has helped answer ecological questions.

Could you tell us a little about your academic background and how you came to study physics?

I did my undergraduate studies in chemistry at the Technion. This was a four-year physics-enhanced program, during which I also published my first two articles. During my PhD at the Weizmann Institute I moved to nonlinear physics.

I was fascinated by the beautiful patterns of chemical spiral waves that I first encountered in one of Ilya Prigogine's books. From there, I decided to study nonlinear partial differential equations (PDEs) that describe pattern-forming systems, such as convective fluids and chemical reactions. I pursued these research directions during my postdoctoral training at the University of Chicago (Physics Department) and at the Columbia University Astronomy Department. I continued on this path until my employment at the University of Arizona Mathematics Department, where I focused on the mathematical aspects of similar nonlinear PDEs. Although my academic background includes chemistry and applied mathematics, I approach scientific questions as a physicist and regard myself as such.

How did your background in physics led to your interest in ecology? How are these areas connected in your research?

My interest in ecology started after I joined Ben-Gurion University in 1994. My affiliation with the Blaustein Institutes for Desert Research (jointly with the Physics Department) exposed me to interesting problems in the ecology of drylands. However, it was a few papers on vegetation patterns in semi-arid regions, which appeared sometime during 1997 and 1999 that got me actively involved. I realised the close relationship between these phenomena and the principles of nonlinear physics.

At first, my research group focused on applying these principles to vegetation pattern formation, identifying positive feedbacks that can destabilise spatially uniform vegetation to form periodic patterns, building mathematical models that capture these feedbacks, and investigating the variety of patterns that can appear along the rainfall gradient, among others. More recently, our interests have shifted to the roles that pattern formation plays in the ecosystem function. Specifically, we aim to address questions that tackle the resilience of ecosystems to environmental changes, mechanisms of species coexistence, the restoration of malfunctioning ecosystems and the like. As we continue with these research directions, asking questions that ecologists would ask, we occasionally encounter new pattern formation problems that have not been studied before. In turn, this helps further expand our area of research.

Your research is characterised by interdisciplinarity. Why is this important?

Most phenomena in living systems intermingle biological, chemical and physical processes and the study of these processes further calls for integrating experimental sciences with mathematical and computational sciences. The shortcomings of disciplinary sciences to explain these phenomena have led to the emergence of interdisciplinary sciences such as biochemistry, biophysics and biomathematics, which have become themselves new scientific disciplines.

The emergence of these new disciplines that bridge over established disciplines is a continual process that goes along with the overall increase in scientific activity. At any period, truly interdisciplinary research occupies a very small percentage of overall scientific activity. However, this is only the case because of the subsequent consolidation of such research into new disciplines. In this sense, science is becoming more and more interdisciplinary, as it should be. My current research lies on the interface between two disparate scientific fields, spatial ecology and pattern formation. Whether research at this interface will result in a new discipline is an interesting question—we can do another interview in 10 years and find out.

We are living in a period of great biodiversity loss. How can your research be inserted in this context?

This question touches upon a wider concern - the impact of human intervention on ecosystem dynamics. Pattern formation theory provides tools for identifying the inherent modes of undisturbed or disturbed ecosystem dynamics. Once such modes are identified, intervention along these modes can better maintain ecosystem function.

One such example is our current study on vegetation restoration by periodic landscape modulations. Our study deals with the likes of parallel embankments that intercept runoff and along which vegetation is planted. From there, we see that the inherent modes are a stripe mode dictated by the embankments, and two additional modes representing slanted stripes. Restoration that includes all three modes—which can be obtained by fragmented plantation along the embankments to form spot-like rhombic patterns—results in a better functioning ecosystem. This is reflected by high resilience to droughts and high biological productivity.

A similar approach may be applied to the question of biodiversity loss as a result of human intervention. The big and hard question in this context is this: What are the inherent spatial modes of self-organizing communities?

Have you experienced funding challenges in your career?

It is indeed harder to get funding for interdisciplinary studies. What has become easier throughout our research is finding which funding resources are more problematic, or which disciplinary section should be chosen when submitting a proposal to a given foundation.

I was lucky to receive a James S. McDonnell grant in the Studying Complex Systems Program in 2003, which helped me significantly upgrade the computational power available to my group. The Israel Science Foundation has also become a major funding resource for the interdisciplinary studies in my group. I was funded several times in the past by the US-Israel Binational Science Foundation on disciplinary topics. Also, I receive funding from an interdisciplinary H2020 EU project.

Understanding vegetation pattern formation and its roles in ecosystem function: What can mathematical models tell us?

To understand the dynamics of an ecosystem, it is necessary to consider the spatial relationships between biological, chemical and physical processes and, at the same time, identify possible positive feedbacks between these processes. In this sense, the spatial dynamics of ecosystems can be seen as a problem of pattern formation, which is a nonlinear physics subject. The research of Professor Meron is focused on understanding these dynamics and their implications for ecosystem function using mathematical modelling and model studies.

ECOLOGY AS AN INTERDISCIPLINARY FIELD

The composition and structure of the ecosystems we observe in nature are dictated by biological, chemical, and physical processes. Examples of such processes are biogeochemical cycling, species dynamics, and the physical forces that create wind and water regimes. In this light, Ecology must be seen as a cross-disciplinary field that bears different aspects of science. Because such natural processes do not distinguish between the traditional disciplines that humans have delineated, addressing a particular ecological issue by integrating multiple approaches can be highly advantageous.

We are living in a period of great biodiversity loss and mass extinctions—two aspects that have been mostly regarded as a consequence of human intervention on ecosystem integrity.

Ecosystem integrity is a relatively new concept that may be defined as the degree to which an ecosystem is self-organised. In other words, it measures the potential of an ecosystem to follow its inherent modes of development. Habitat degradation, whether by anthropic actions such as rural development and urbanisation or the conversion of natural ecosystems into agroecosystems, often results in the loss of ecological integrity. Professor Meron's research inserts into this context by approaching questions of spatial ecology using physics theories and mathematical modelling.

THE THEORY OF PATTERN FORMATION AND THE ECOLOGICAL CONTEXT

The main approach to studying the inherent modes of undisturbed or disturbed ecosystem dynamics lies in the theory of pattern formation. The theory addresses the spontaneous appearance of spatial patterns in nature. For example, such patterns may be animal-coats, spiral waves in the heart, vegetation bands or columnar lava patterns.

In the context of dryland ecosystems, the theory provides predictions about the mechanisms by which small, patch-scale processes lead to large, landscape-scale vegetation patterns. It also looks into the spatial modes that grow in these pattern-formation dynamics and the particular patterns that can form in different environments.

Such predictions are often hard to test with direct empirical experiments because of the long spatial and temporal scales that characterise such ecological processes. Through mathematical modelling, however, this difficulty can be circumvented. Rather than testing a particular pattern-formation mechanism directly, the theory can be used to test whether the behaviour implied by this mechanism agrees with available field observations.

Vegetation pattern formation is a key process not only in questions of landscape ecology, but since it involves the redistribution of critical resources like water and nutrients, it also affects interspecific interactions and species assemblage properties, such as biodiversity-productivity relations. "In studying vegetation patterns, we do not look for new ecological problems to address; rather, we ask the same questions ecologists ask, but make use of vegetation patterning in the process. We show that vegetation patterning is an inherent ecological process that must be taken into account in many fields of ecology, including landscape ecology, community ecology, ecosystem ecology, and restoration ecology," said Professor Ehud Meron.

THE CURIOUS CASE OF THE NAMIBIAN FAIRY CIRCLES

Mathematical models can be a powerful tool to address questions of spatial self-organization of ecosystems. Using these techniques, Professor Meron and collaborators have recently provided exciting novelties about the peculiar Namibian fairy circle ecosystem. The ecosystem is relatively poor in animal and plant diversity, and consists of a uniform grassland punctuated by circular gaps of sandy bare soil, dubbed as the fairy circles. Local myths believe these fairy circles are footprints of gods or burn marks of dragons living beneath the ground. How exactly this spatial organization would have emerged is a question that has intrigued the scientists for decades.

Several explanations for the emergence of these circles have been suggested and some of the earlier ones have already been refuted. More recent explanations attribute fairy circles to microseepage of hydrocarbon gases that displace oxygen in the root zone. Other explanations have referred to grass or seed harvesting by social insects such as termites. These explanations all share one essential drawback – they do not account for the emergence of large-scale order. Could the fairy circles in the Namibian ecosystem be explained as a pattern formation phenomenon, in which small-scale processes induce large-scale order?

Combining mathematical modelling and empirical studies, Professor Meron and collaborators have provided two types of supporting evidence for the pattern-formation hypothesis. The first is based on comparative model and empirical studies of statistical properties, such as the nearly hexagonal order of fairy circle patterns (any fairy circle is surrounded by six nearest-neighbour circles). The second evidence is dynamical by its nature and related to fairy circle birth and death events. According to the pattern formation theory, uniform vegetation and hexagonal gap (fairy circle) patterns can coexist as alternative stable ecosystem states. The theory further predicts that a multitude of additional stable hybrid states can exist, consisting of spatial mixtures of patterned and uniform domains.

Integrating satellite image and rainfall data analyses over a period of 10 years, from 2004 to 2013, with model simulations, and using initial conditions derived from satellite images taken in 2004, Professor Meron and collaborators have shown that, in essence, fairy circle birth and death events are transitions between hybrid states induced by droughts and spates respectively. This is a nice example of the indirect evidence that model studies can provide; the association of fairy circle birth and death events with hybrid-state transitions supports the view of fairy circles as a self-organisation pattern-formation phenomenon that is responsible for the appearance of hybrid states in the first place.

Besides providing a new kind of evidence for the pattern-formation hypothesis of fairy circles, the observation of hybrid states and hybrid-state transitions modifies the way we understand regime shifts.

Professor Meron explains: "Unlike the common view of regime shifts as sudden 'catastrophic' transitions between alternative stable states, our results indicate that regime shifts in pattern-forming systems can proceed gradually through cascades of hybrid-state transitions. Being fairly uniform and undisturbed, the Namibian fairy circle ecosystem provides an excellent field model for studying gradual regime shifts in general.

THE FUTURE PERSPECTIVES

Two broadly explored topics in ecological studies are how ecosystems respond to environmental variability and the impact of this response on ecosystem function. Addressing these issues can be very challenging, essentially because of the multiple spatial scales and organisation levels that characterise ecosystem complexity. While empirical studies usually focus on particular scales and organisation levels, mathematical modeling allows more complex route.

"The model platform that our group has developed allows for integrative studies across spatial scales and organization levels. It does so by scaling up organism-level traits and small-scale spatial processes to higher levels of organization and larger spatial scales," says Professor Meron. On future studies, he plans to use this platform to combine the theory of pattern formation and biodiversity and understand this coupling in the context of ecosystem function. His team will also study how to achieve and maintain high ecological integrity in human-intervention contexts, such as restoration ecology and agro-ecology.

Researcher Profile

Professor Ehud Meron
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Professor Ehud Meron is a researcher at Ben-Gurion University of the Negev. He received his PhD in nonlinear physics from the Weizmann Institute of Science. Later on, he followed this up with his postdoctoral research in the Physics Department of the University of Chicago and in the Astronomy Department of Columbia University. After a three-year term as a faculty member in the Mathematics Department of the University of Arizona, he joined the Blaustein Institutes for Desert Research and the Physics Department at BGU. Among his areas of expertise are nonlinear dynamics and pattern formation, complex systems and spatial ecology. Professor Meron has made significant contributions to the understanding of pulse and front dynamics in reaction-diffusion systems. He has also pioneered research in the response of pattern-forming systems to periodic temporal and spatial forces. During the past 15 years, he has been devoting his knowledge and expertise in pattern formation theory, to the mathematical modelling of dryland ecosystems and the understanding of the roles that pattern formation plays in their response to varying environments. Professor Meron has also authored the Nonlinear Physics of Ecosystems (CRC Press 2015), a monograph which aims to help in closing the gap between the two disparate research fields of spatial ecology and pattern-formation.

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Cooperation Reveals Legacy of Ancient Land Use

Dr. Nicholas Brokaw and Dr. Sheila Ward of the University of Puerto Rico recently conducted a multidisciplinary study with collaborators from around the United States to decipher how and to what extent ancient Maya land use affects land management and the environment today.

Nicholas Brokaw by S. Eshleman

This project is multidisciplinary and many people were involved. How did the project come together?

Fortunately for us, archaeologist Stan Walling invited us to his study area in the Rio Bravo Conservation and Management Area (RBCMA), Belize, to look at the present abundance of some tree species used by the ancient Maya. He thought the present distribution and abundance of those species might reflect ancient rituals. Stan also introduced us to archaeologist Marisol Cortez-Rincon, and geo-archaeologists Tim Beach and Sheryl Luzzadder-Beach, who study the impacts of the ancient Maya on topography, soil, and hydrology. We realized that we had the inter-disciplinary team to look at how the Maya used the land (archaeology), how that land use changed topography and soil for the long term (geo-archaeology), and how those long-term topography and soil changes still affect the present forest (ecology).

The team needed access to landscapes that had been used and shaped by the ancient Maya to conduct your research, and you worked on the Rio Bravo Conservation and Management Area. What was it like working with them and was it at all difficult to get permission for land access?

That was the easy part. The RBCMA is owned and managed by Programme for Belize (PfB), a Belizean NGO whose mission is to manage and conserve their 100,000 ha reserve through research and sustainable uses. Our work is part of the research agendas of the Programme for Belize Archaeology Project, In the RBCMA, and the Maya Research Program (MRP), nearby. PfB and MRP make our work logistically possible.

The RBCMA is a great place to look at the effect of the ancient Maya on the present forest. It has: 1) a large area, to take in variation of landscape and topography, 2) a great variety and number of ancient Maya features – temples, house mounds, causeways, reservoirs, terraces – the variation that we want to relate to variation in the present forest, and 3) mostly old-growth forest undisturbed (except for some light logging for mahogany and Spanish cedar) since the departure of the Maya in about 900 AD. So there is little subsequent disturbance to obscure the direct effects of Maya land use. It's also great fun to work in this big, wild area. Working in the field Last summer we saw a puma and a jaguar.

Did you have difficulty getting funding for the project, or experience any major obstacles to securing funding?

Our work is supported by the US National Science Foundation (NSF) and through university field courses. Our timing has been good. NSF has been funding more interdisciplinary work and work on nature/human interactions, and NSF likes collaborations among diverse institutions. That is what we proposed and NSF funded. Also, everyone is fascinated by the ancient Maya and by the tropical forest. We put all that together.

Did any other complications arise during your research?

A complication is the nature of the Maya forest "experiment". Widespread ancient Maya land use and subsequent forest regrowth amount to a large-scale, long-term experiment on biodiversity. Like a normal experiment we have experimental results, in this case the present forest. But unlike a normal experiment we do not know what the experimental treatments were, in this case the ancient Maya land uses a thousand years ago. So the archaeological and geo-archaeological work is to reveal the treatments, and the ecological research is to describe the details of the results, that is, the tree species composition of the present forest. Also, there are no places we can be assured were never cleared by the ancient Maya, to serve as experimental controls. Thus our method is to compare present forests in areas of different ancient land uses.

Another "complication" is that the field work can be pretty grueling. There are heat, rain, sharp spines, mosquitos, botflies. But the forest is so beautiful and interesting, and the camaraderie is so good. Those keep you going.

Communicating with the Past through the Forest

A multidisciplinary group of archaeologists, geo-archaeologists, and ecologists are working together to study the impact of the ancient Maya on the modern environment. To succeed, they need to account for culture, land use, and the environment.

Sheila Ward by N. Brokaw

WORKING TOGETHER

Archaeology and ecology study the same things, sometimes, because their search for evidence often lead them to far-off, remote places where the environment has been relatively untouched by human hands, at least recently. In this case, Dr. Nicholas Brokaw and Dr. Sheila Ward travel to the 100,000 hectare Rio Bravo Conservation and Management Area (RBCMA) in Belize to study how the ancient Maya affect the environment there to this day. The Maya civilization has long impressed and puzzled scientists. How did they grow enough food to feed their high populations and support an elite class who oversaw the building of temples, the development of astronomy, and other achievements? Why did the Maya decline so quickly and what were the long-term environmental consequences of their land use? By visiting the RBCMA, the researchers are able to "speak" to these ancient people about their lives using the evidence they left behind. Though it provides some interesting challenges, working as a team, rather than apart, ultimately allows the archaeologists, geo-archaeologists, and ecologists to better understand the Maya and the tropical forest of the RBCMA.

MAYA ENVIRONMENTAL HISTORY

The RBCMA is now covered largely with old-growth tropical forest, having been selectively logged for mahogany and Spanish cedar but little disturbed otherwise. But at one time it was home to many types of Maya structures: cities, villages, reservoirs, terraces, canals and more. The forest is underlain by porous limestone and surface water is rare in the uplands of the RBCMA. Despite this, annual rainy seasons have created a tropical forest of many broadleaf tree species, palm trees, thick vines, and large herbs.

In the Maya area humans entered the picture around 7,000 BC, and by 1,000 BC, the Maya civilization began, peaking at a high population in about 900 AD. Scientists note that fossil pollen, carbon-13 isotopes, and lake-bottom sediments all suggest that agriculture became prominent and the forest began declining at around 3,000-1,000 BC. When the Maya declined, following about 900 AD, the forest returned.

To support their impressive cities and high population the Maya must have been masters of agriculture. Their probable farming methods

could have included swidden (shifting or slash-and-burn) agriculture and probably larger-scale, intensive farming of annual crops. Of special interest was agriculture that may have included trees and from which the modern forest may have developed. Possible household gardens near dwellings would have contained a variety of useful trees and other plants. Patches of land further away may have been used to grow specific types of fruit trees, while other forest patches may have been allowed to grow more naturally but with selective cultivation and harvest of certain tree species and other products. Forests in remote areas or areas bordering Maya city-states were perhaps left partly untouched.

Only a multi-disciplinary team can evaluate the long-term impacts of this ancient land use. The archaeologists study the ancient structures that remain today to suggest ancient land uses. The geo-archaeologists study how that land use changed topography and soils, while the ecologists view the same sites with different eyes, seeing the effects of the past on the present and future forest. Together, they are working to answer the question: Did Maya land use decrease tree species diversity and productivity of the regrown forests? Or rather, did the Maya use of the land enrich diversity and productivity? Since the RBCMA's forest, once home to a thriving Maya civilization, dates from the time of the Maya collapse, it is a perfect laboratory for this study.

TREE DISTRIBUTIONS TODAY: CURRENT ENVIRONMENT? ANCIENT CULTIVATION?

Brokaw, Ward and their collaborators believe that the ancient Maya did have a major impact on the modern forest. First, the archaeologists have shown that the Maya erected many different types of structures, which created long-lasting, novel substrates for the regrown forest. Second, a record of erosion and deposition due to land use, uncovered by the geo-archaeologists, showed that the Maya inadvertently moved tons of soil permanently downslope. That probably exaggerated the substrate difference between uplands, with drier, thinner soil, versus lowlands, with wetter, thicker soil. Early results from Brokaw and Ward's study show that many tree species at the RBCMA have preferences for distinctive soil characteristics. Therefore, this soil movement from uplands to lowlands could have had a large impact on the present, post-Maya distribution and abundance of tree species.

The distribution of the ramón tree *(Brosimum alicastrum),* for example, shows that it prefers the calcium-rich soil in natural uplands and on Maya temples constructed with calcium-rich limestone blocks.

While the evidence suggests that ancient land management had lasting effects on the future forest, the researchers are not yet able to determine whether Maya tree cultivation affected the distribution of tree species in the modern forest of the RBCMA. The hypothesis is that the Maya would have preferred certain tree species to others, and they would have planted and protected those species. Would the effect be large enough to still influence the spatial distribution and abundance of the descendants of those species today, 1000 years after the Maya decline and forest regrowth? There are many species useful to humans in the forest of the RBCMA. Many researchers see that as evidence that the Maya cultivated those tree species so effectively that they enriched the species composition of the current forest. Unlike researchers at some other sites, The University of Puerto Rico team has not yet found evidence in the RBCMA to support that conclusion. Of course, future research could provide new insights.

FUTURE OF THE FOREST

Ward and Brokaw hope that by using information available about the past, it is possible to make the present and future a better place. However, it is not certain what aspects of Maya agriculture and deforestation are a useful analogue for modern civilization. The research team points out that, although some archaeologists believe Maya agriculture was ultimately unsustainable, its variety did support a populous civilization for hundreds of years, and thus adaptations of their methods might enhance sustainability today. Also, although the Maya likely deforested a large area of Mesoamerica, there probably were many interspersed patches of regrowth and uncut forest, in which most forest species survived, unlike in the larger cleared areas lacking patches of regrowth today. The Maya might teach us how to supply humanity with the resources it needs and teach us why we should not clear the forest far and wide. They could light the way forward in a time of great global change and environmental risk. Brokaw and Ward will soon have more conclusions and yet more questions from analysing the data already in hand, "then it's back to the forest".

Researcher Profile

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Dr. Nicholas Brokaw was educated at Princeton University and the University of Chicago. He now teaches environmental science at the University of Puerto Rico. His research focuses on tracking and understanding long-term changes in tropical forests, and his work has been published in *Trends in Ecology and Evolution and Encyclopedia of the Ancient Maya.*

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FUTURISTIC FARMING

Dr Nicolas C. Friggens, head of research at MoSAR discusses his technological approach for the 21st century farmer

Could you describe your academic background and tell us what got you interested in precision farming technologies?

I did a BSc in Animal Physiology and Nutrition and followed that up with a PhD looking at the way lactating females used their body reserves to support lactation. In that PhD I was extremely lucky to be in a department of the Scottish Agricultural College that included researchers, farm advisors and lecturers. If you had an idea that spoke to all three of these then it was a good one! Since body reserves are a key factor underpinning good health and reproduction, studying these reserves naturally led to health and reproduction research, which I did during 12 years at the Danish National Institute for Agricultural Research. In this domain, a key factor is early-warning, i.e. identifying animals that are at risk before problems get serious, and precision livestock technologies have really opened the door for monitoring of individual animals. Throughout the above, I have approached the issues from a modelling perspective. I am now head of a research unit at INRA called "Systemic Modelling Applied to Ruminants" (MoSAR in French).

Is this project the first of its kind, or does it expand on previous work that has been undertaken in this area?

The recent projects we have been involved in build on a significant number of precision farm technology projects. A good example of a prior project is Herd Navigator (www.herdnavigator.com) which uses biosensor technology in milk to measure key indicators of reproductive status (progesterone) and health (LDH for mastitis, BHB for ketosis). In that project, we provided the biological and statistical modelling expertise to turn the data into meaningful information for end-users.

In today's world, farmers have a tough time balancing sustainable farming with efficient farming methods that maximize profits. How does this technology benefit farmers?

This type of technology provides reliable information on animal status to the farmer. In a situation where one solution to today's economic pressures is to scale-up farm sizes, the monitoring provided by these technologies is an important factor for keeping track - to not lose sight of the individual in ever larger herds. This not only frees up valuable time, but also provides the farmer with real-time diagnostics, allowing earlier and thus more effective intervention.

Using genetics and models to manage cows sounds quite futuristic; what are the applications in terms of herd management — how can farmers apply the technology on their farms?

Mathematical modelling serves two functions: 1) It is a way to structure existing knowledge and data about complex systems, which often yields simplifying insights of value to animal science; 2) It is a way to develop predictions — what will happen next, what will happen if I make a change? Both of these elements are needed if we are to make good use of precision farming technologies. Technologies such as accelerometers produce multiple measurements per second, i.e. huge piles of data that are quite useless unless models are applied to distil this into the biologically relevant information and present it to the farmer in a user-friendly way. With multiple technologies, the models become even more crucial since there is not only distillation, but also combining of information, and we all know how crucial the blending process is to produce a quality product! Combining information is especially important for complex characteristics such as resilience and efficiency, which are by their nature combinations of underlying physiological mechanisms.

How does the project contribute to animal science in general, and do you foresee any future multi-disciplinary research being undertaken in this field?

In addition to providing better tools for farmers to monitor their animals, i.e. better models to distil the data from farm technology, my research unit is increasingly involved in using modelling to move from a monitoring perspective towards a predictive phenotyping perspective. We have the models needed to predict genotype x environment interactions both at animal-and herd-level, and are working to bring them together with information from precision technologies for phenotyping efficiency and resilience. This is important as it allows these general 'animal biology' models to be calibrated for specific production environments. This then allows prediction of the long-term consequences of, for example, a change in farm management or a change in genetic selection. The work of building such predictive frameworks requires close collaboration between modellers, nutritional physiologists, geneticists, and scientists studying farm systems.

PRECISION FARMING TECHNOLOGY

Animal scientist Dr Nicolas C. Friggens is using modelling to develop precision livestock technology that will give farmers the tools to allow them to move with the times and adapt to the challenges of the future.

With the global human population expected to reach 10 Billion by 2060, there is growing competition for space between livestock and crop production to provide food to feed the ballooning human populace. As a result, livestock are likely to be pushed into less favourable environments in the future to make arable land available for crop production, posing a unique challenge to livestock farmers.

Automated technology can play a key role in helping farmers manage their livestock in these difficult conditions, ensuring that farms continue to operate efficiently and productively, and that the welfare of the animals is maintained. Using precision phenotyping, this technology allows us to readily identify specific traits, such as adaptive capacity and robustness, that will be advantageous in the future, and apply them in our management strategies to selectively breed animals with the desired characteristics.

However, it is essential that we fully understand the complexities of these traits; for example, how they change over time as the animal ages, or how they trade-off with production. We also need to understand and be able to predict how these attributes can contribute to the overall resilience of the farm system, and how they will evolve in the future. Biological modelling offers a powerful tool that not only gives farmers a much more precise view of how their herd and farm are performing, but also addresses these more complex questions to ensure that livestock farming is sustainable in the future.

Addressing Climate Change & Food Security

Climate change and food security are two key areas of concern today. Precision farm technologies are developing to measure some key factors relating to the environmental footprint of livestock farming; things which were until recently impossible to measure outside of research stations, such as methane production by ruminants, or components of animal efficiency. As these developments mature to become commercially available, they will allow farmers to adjust their management to local environmental conditions.

The push for global food security will reduce the use by farm animals of cereals and other foods that can be directly used by humans. Farm animals will increasingly exploit marginal land and by-products of human food and biofuel production. These resources will be more variable in nature and quality; the same applies to the marginal environments that will be exposed to the increasing climate variability that climate change is bringing. In this situation we need animals that are resilient, i.e. that have an in-built adaptability. We also need farm management systems that can respond rapidly and appropriately to fluctuating conditions. Technology to monitor how animals are coping, how the available feed and water supply is holding up, etc. will be of considerable value.

The models can help us understand which combinations of mechanisms confer the right balance of resilience and efficiency for different environments. This is highly important information for breeding animals that are better adapted to future conditions. Data from precision technologies, when treated with the appropriate models, will provide much more precise phenotypic information on these complex traits for the geneticists who today have genomic information.

Contribution to Animal Welfare

The public is generally becoming more aware of animal welfare issues and many people are concerned about the welfare of farm animals, particularly those farmed intensively, and consumers often take these factors into account in their purchasing decisions. But will precision livestock technology mean a better life for farm animals?

The answer is yes, if used properly, it will definitely improve the well-being of farm animals. If you can identify an animal that is going to get sick at a very early stage, then you have a much better chance of taking preventive action to avoid it becoming really sick. The time gained in early identification can be used to better target treatment. For example, different strains of mastitis require different antibiotics, and a significant proportion of mastitis should not be treated with antibiotics. Traditionally, typically, when the signs of mastitis are detected things are sufficiently serious that immediate treatment is needed with no time to culture the bacteria to find out which type they are. But with precision technology, cases can be detected several days earlier, allowing time to type the bacteria and thus target treatment. This results in better cure rates, and reduced use of antibiotics. The other key area where these technologies will really come into their own is when animals are kept in extensive conditions, e.g. grazing on difficult to access rangelands. Precision technologies in these conditions will be a huge help for early detection of animals that need attention, but which are often difficult for the farmer to keep an eye on.

Applications

Precision farming technology is not limited to managing cattle, it is already in use in a range of farmed livestock, with applications in pigs and poultry already well advanced. There are also initiatives to use it in aquaculture. The main issue is not the technology, but rather its cost relative to the value of the individual animal. In some situations, e.g. dairy cows, it is frequently worth monitoring at the level of the individual animal, in others, e.g. broiler chickens, monitoring is often at the level of groups of animals, either through measures of group behaviour etc., or using a few 'sentinel' animals.

As the technology becomes more and more sophisticated and the associated costs continue to fall, we can increasingly access measures considered virtually impossible a decade or two ago. Today there are commercial on-farm systems measuring real-time progesterone levels in milk — this reproductive hormone is present in nanogram concentrations. Twenty-five years ago it required a lengthy lab-based method using radio-immuno assay, with turn-around times of days or weeks.

Implementation of the Technology

While there is already a significant amount of precision farming technology being made available to farmers, including accelerometers to measure activity and thereby assess if a cow is in heat, or is getting lame, or is going off-feed, the key issue is that the information is reliable and that it is condensed and presented in a useful user-friendly format that a farmer can readily interpret. Maximising the farmer utility of such technology requires not only statistical modelling to filter data and biological modelling to achieve context-sensitive interpretation, but also an on-going interaction with the farmers themselves in order to build software that responds to their needs and fits with their user practises. We have clearly seen that when we have engaged with the farmer from the start, i.e. from the design stage, we have produced tools that have a significantly higher uptake potential. There is also a need for some of these technologies to provide the advisors with the information to propose more strategic changes to farm management. The above mastitis example is a case in point; if vets have herd level information about pathogen types and seasonal variation in mastitis, they can propose broader preventive strategies rather than just treating individuals as they become sick.

The second issue for implementation by farmers is how to reconcile information from different systems. Although some companies — in the dairy sector, typically the milking machine providers — offer bundles of technologies, e.g. accelerometers with in-line milk measures and in-line weighing of cows, the farmer is often confronted with different brands and software. This can considerably increase the time needed to monitor one's animals, and it represents a missed opportunity. Typically, the individual technologies are sold for monitoring the one or two types of event that the technology is best at detecting. However, these technologies could provide useful elements of other more complex quantities. Two highly relevant quantities are animal resilience and efficiency; there is no direct real-time measure of either of these and yet they are increasingly important to future sustainable breeding and management of farmed animals.

It would be highly useful if a farmer could make his breeding decisions (which animals to re-breed and which to cull) according to some ranking of his animals on their worth for resilience (ability to cope) and their efficiency. Today, in cattle breeding, sexed semen has become available, which means that the dairy farmer can use sexed semen on his highest worth cows to get milk breed daughters, freeing up the rest to produce cross-bred animals that will give extra value as meat-producing offspring. Such ranking tools will require the combination of genetic information with multiple farm technology measures to assess the phenotype at point of breeding. Modelling is the key to developing such tools.

Meet the researcher

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Dr Nicolas C. Friggens received a PhD in Animal Physiology and Nutrition from the University of Edinburgh, with a research focus on how lactating females use body reserves to support lactation. This was followed by a 12-year stint with the Danish National Institute for Agricultural Research, researching health and reproduction of livestock from a modelling perspective, before joining INRA, where he is currently head of the INRA-AgroParisTech research unit, MoSAR.

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REFERENCES

Sadoul, B., Martin, O., Prunet, P. and Friggens, N. C., On the use of a simple physical system analogy to study robustness features in animal sciences, PLOS ONE, 2015, 10, e0137333, 14pp.
Savietto, D., Friggens, N. C. and Pascual, J.J., Reproductive robustness differs between generalist and specialist maternal rabbit lines: the role of acquisition and allocation of resources, Genet. Sel. Evol., 2015, 47, 11pp.
Douhard, F., Friggens, N. C., Amer, P. R. and Tichit, M., Synergy between selection for production and longevity and the use of extended lactation: insights from a resource allocation model in a dairy goat herd, J. Anim. Sci., 2014, 92, 5251–5266.
Friggens, N. C., Brun-Lafleur, L., Faverdin, P., Sauvant, D. and Martin, O., Advances in predicting nutrient partitioning in the dairy cow: recognizing the central role of genotype and its expression through time, Animal, 2013, 7 89–101.
Friggens N. C., Ingvartsen K. L., Korsgaard I. R., Larsen T., Ridder C. and Nielsen N. I., System and a method for observing and predicting a physiological state of an animal., 2010, US patent: 7676346; EU patent: 7302349.
Højsgaard, S. and Friggens, N. C., Quantifying degree of mastitis from common trends in a panel of indicators for mastitis in dairy cows, J. Dairy Sci., 2010, 93, 582–592.

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