EARTH MATTERS

Newsletter of UBC Earth, Ocean and Atmospheric Sciences

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From the Editor


Photo by Kirsten Hodge

It is my privilege to present to you the debut of Earth Matters, the newsletter of the Earth, Ocean and Atmospheric Sciences department at the University of British Columbia.

When I arrived in Vancouver this past September as a brand new MSc student, there was one thing that stood out to me more than anything about the city, UBC, and EOAS itself: the space. A car, bus pass, or bike is a *de facto* necessity for navigating the city. The University of British Columbia campus contains sufficient amenities and non-student housing to practically function as its own town, isolated by acres of Pacific Spirit Regional Park. Faculty, staff, and students of EOAS are housed among three separate buildings connected by the ubiquitous turquoise glass. Every building on campus is it's own trek from the nearest bus loop or parking garage (if you're willing to fork over some serious cash).

Space is also present within the relationships between EOAS. The oceanographers have their domain, as do the volcanologists, and the economic geologists, and every last Earth science subdiscipline imaginable, which upon greater scrutiny reveal further hierarchies rivaled only by the our subjects of study. "Who is that?" and "what do they do?" are not uncommon inquiries in EOAS due to our diversity, size, and our own artificial division. Despite everyone's clear enthusiasm for his or her own work demonstrated by the research productivity of our department, the distance between research groups in our department is like that between Alma Street and campus; short in actuality, but a chore to navigate in the absence of proper exchange (ah, the 99 bus in mid-term season).

Earth Matters is designed to be a part of an enhanced network. It is as much a vehicle to broadcast the world-class research conducted in EOAS to the public, industry and other researchers downtown and abroad as it is to members of our own department. My team members and I purposely interviewed faculty whose research topics had nothing to do with our own and it was a fantastic process of discovery. Our researchers were willing to share their scientific investigations in layman's terms to curious students.

Interesting science and a curious audience require networks and people in charge of building and maintaining them for meaningful exchange to occur. It is my personal wish that Earth Matters is but one step in the improvement of interdisciplinary communication within EOAS and to other Earth science departments worldwide. We present but a slice of the activities and research conducted here in EOAS in the hope that you will enjoy riding this bus as much as we have, reader.

Chuck Kosman
MSc Geological Sciences Candidate, UBC

From the Head

It is intimidating to become Head of EOAS after Greg Dipple. Indeed, it will be challenging to improve upon on the achievements of our staff, students, and faculty and under his energetic direction. During his five year tenure, Greg was an academic leader and a building contractor, managing EOAS as well as the construction and occupation of the Earth Sciences Building. He did all this while his research on carbonation of minerals and CO_2 sequestration not only grew, but flourished. I thank Greg for his tremendous service to the department and for maintaining his good-natured character through demanding times.

I have no record as Head, so I thought I would here share with you my aspirations. I have three principal objectives as the new Head of EOAS; to enhance our department's achievements and reputation as a world leader in earth, ocean and atmospheric sciences research and education, to engage the EOAS community in support of our leadership goals and to continue to build a sense of community from the diverse subdisciplines within the department.

While EOAS is recognized as a leader in research and education, to maintain our leadership requires that we continue to define the frontiers of knowledge. We need to innovate in traditional areas and to venture into new areas. We must identify important questions and then recruit and motivate enthusiastic people to work on them, providing a supportive research and educational environment.

The department can be justifiably proud of its achievements in education, particularly the innovations in pedagogy. Under the auspices of the Carl Wieman Science Education Initiative, EOAS is considered a leader in the Faculty of Science, at UBC and internationally in the implementation and research of innovative teaching methods. I want to maintain our leadership in not only teaching methods, but also in what we teach. As an educational research organization, part of our role is to define and refine programs to prepare people for future challenges and careers that are not yet known. Much of the understanding and methods that will be considered part of the earth sciences canon in twenty years have yet to be discovered.

At the root of our research and educational missions is to understand and explain Earth. To do this I believe it is crucial to maintain a balance between observations—data collected from the lab or field—and analysis using conceptual, statistical and mechanistic models. While we have been enormously successful in providing high-quality laboratory space for our faculty and students, our field schools need more support. Our second year Salt Spring Field School is at capacity, our Hydrogeology Field School is seeking a new home and we still have a significant way to go on our campaign to rebuild our Oliver Field Camp. As an Earth, ocean and atmospheric sciences department, it is vital that we continue to provide our students high-quality field experience.

I hope to engage the EOAS community of faculty, students, staff, alumni and industry partners and harness your collective energy, wisdom and resources to help support our leadership goals. To my mind, the most important components of engagement are communication, discussion and critical assessment.

What are our strengths? Where are the opportunities and new directions? Where should we diminish our efforts? How have we been doing? The last point is where I particularly want to hear from our alumni and industry partners. Research from the cognitive sciences, and a core principle of the Carl Wieman approach to education, is that timely and relevant feedback is crucial for learning. We need your feedback! From our alumni, I would like to know how well our programs prepared you for your life after UBC. What was particularly valuable in your program, and where do we need to improve? For those active in EOAS-related fields, where are the opportunities?

In parallel with the goal of engagement, I want to enhance the sense of community within EOAS. We are one of the most diverse departments in the Faculty of Science. Many of our faculty members are cross appointed to other departments; we maintain seven undergraduate degree programs. This diversity presents a challenge for integration, but an opportunity for enrichment. I see notable progress at the undergraduate level, facilitated in part by the large shared undergraduate learning space in the area that once was the Geology Department Library on the second floor of EOS-Main. This common space provides a central location for undergraduates to gather and meet each other. The EOAS Undergraduate Club Council, encompassing the clubs associated with our undergraduate programs, also plans many social and professional development events. The situation is more challenging for faculty, where there are fewer opportunities to gather together and informally discuss science and our avocations. The business literature is rife with the notion that personal interaction = innovation but there is another important benefit—I believe that we can more effectively make decisions if we know one another. Regrettably, most of us assign a relatively low priority to these types of activities, feeling that the pressures of academic life, real or perceived, do not tolerate such indulgences.

Although we face the challenge of diminishing budgets, I am optimistic about the future of EOAS, principally because we have such talented and well-meaning people. I must confess that when I finally realized that I was to become Head of EOAS, my first thought was Hippocratic: Do no harm (actually, my thought was a rather crude colloquial version of the antecedent). I know I will make mistakes, but I am confident that with the help of our staff, students, faculty and the wider community, EOAS will continue to flourish.

Roger

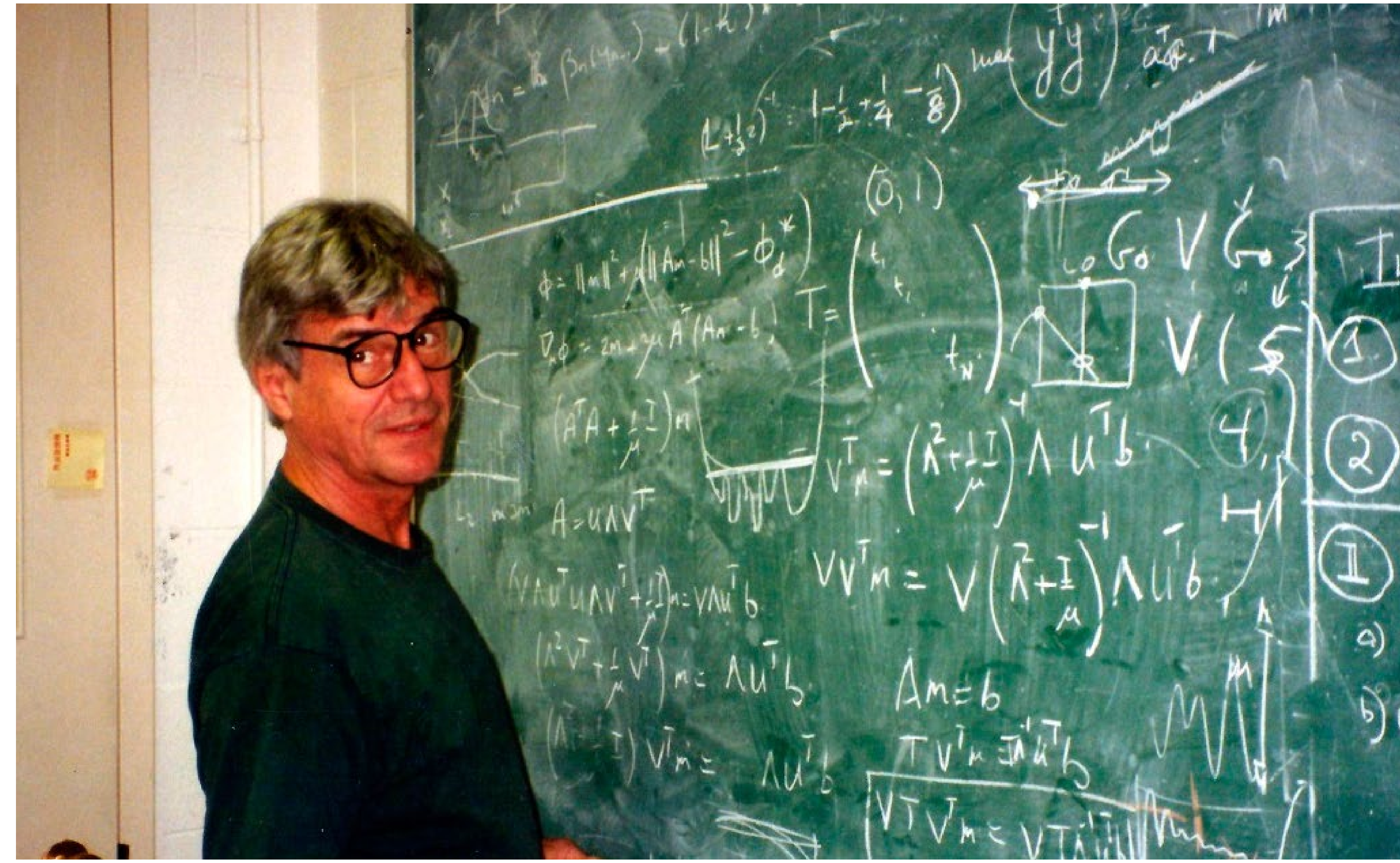
Professor Roger Beckie
Head of Earth, Oceran and Atmospheric Sciences

Words of Wisdom

The launching of a revamped EOAS newsletter comes in the waning days of my term as Head and the beginning of Roger Beckie's time at the helm. As the past five years have shown, the support of the larger EOAS community is critical to the success of the Department. New annual outreach events in Vancouver and Toronto have reinvigorated our connection with alumni and friends of the mineral exploration community. With this newsletter, which reflects the vision of Mark Jellinek's outreach committee and the efforts of Chuck Kosman's team, we are reaching out more broadly across the full spectrum of the Earth, ocean and atmospheric sciences to strengthen those relationships. Please take the time to learn more about recent happenings in the Department, send us your comments, and pass the newsletter along to friends and colleagues that we may have missed.

As I return to research and the classroom, I look back on a busy five years that were focused on the transformation of the facilities that house EOAS—both in the Earth Sciences Building and in renovations to the EOS-Main building that were completed only months ago. But there have been many other less visible changes as well. We have reorganized our administrative system on both the staff and faculty side. We have come through a major restructuring of the UBC budget system in a position of strength. Our undergraduate and graduate enrolments are at all time highs, and as the pages of this newsletter attest, we are once again rebuilding our faculty across the full breadth of the earth, ocean and atmospheric sciences. We continue to be ranked at the top nationally and recognized internationally for leadership in research and pedagogy. These incredible achievements represent the sustained effort of many EOAS staff, students and faculty, but I especially must thank Renee Haggart, Selene Chan, the Head's Advisory Committees, and the Associate Heads for their contributions. I am incredibly proud of the Department and what it has accomplished, and anticipate with relish what we will achieve in the coming years under Roger's leadership.

Professor Greg M Dipple
Former Head of Earth, Ocean and Atmospheric Sciences



In Memoriam: Tad Ulrych

August 9th 1935 – August 19th 2014

Beloved father, colleage, geophysicist, mentor, and professor Tad Ulrych passed away after four month battle with cancer. Tad never sight of the good fortune he had experienced, nor did his overwhelming gratitude for his family, colleagues and caretakers wane.

Tadeusz Jan Ulrych was born in Warsaw, Poland in 1935. He obtained a BSc degree in Electrical Engineering at London University. After a year working in ultrasonics he moved to Canada where he worked in Don Russell's laboratory at the University of Toronto. He then moved to Vancouver where he received both his MSc and PhD degrees at the University of British Columbia in the study of lead isotopes. His first academic position was as assistant professor at the University of Western Ontario. Following post-doctoral fellowships at Oxford University and the Bernard Price Institute of Geophysics, University of Witwatersrand, South Africa, Tad joined the University of British Columbia in 1965 as professor of geophysics. He taught at UBC for 35 years and became Emeritus Professor in 2001.

Technically, Tad was best known for his work on geophysical signal analysis and inverse theory. These topics were the highlights of his famous graduate course at UBC, "514". Tad was a passionate teacher and a fine mentor to many students over his years at UBC.

Tad's achievements were many. In 2004, Tas was awarded Honorary Membership to the *Society of Exploration Geophysicists*, one of it's highest awards. The SEG also named Tad SEG Distinguished Lecturer and sent him on a worldwide speakign tour. In 2013, the SEG honoured Tad by sponsoring a day-long symposium and presented him with a lifetime achievement award for his contributions to geophysics.

Those who have met Tad will have appreciated his remarkable charisma, energy, generosity, humility and humour. For his many and diverse contributions to geophysics research and education in Canada and around the world, we salute our friend Tad Ulrych.

A memorial for Tad will be held Saturday, September 20th at 3 pm in the atrium of the Earth Sciences Building, UBC.

News

EOAS Collaboration "AIMS" High

Douw Steyn

In mid May, 2013 seven members of UBC EOAS (Susan Allen, Mark Jellinek, Catherine Johnson, Doug Latournelle, Christian Schoof, Valentina Radic and Douw Steyn) presented a five day workshop, Mathematical Modelling of Geophysical Fluids, to 14 graduate-level students at the African Institute for Mathematical Sciences (AIMS) as part of the Mathematics of Planet Earth 2013 (MPE2013) programme. They were joined by Babatunde Abiodun from University of Cape Town and Mapundi Banda from Stellenbosch University.

The workshop covered mathematical modelling of the fluid dynamics of the atmosphere, the ocean, ice, lava and the deep mantle and core from a unified and coordinated perspective. A recurring theme throughout the workshop was the fundamental unity of these diverse geophysical flow phenomena through their all being subject to the governing equations of fluid motion.

Students attending the workshop were from a number of South African universities and institutes. The students were enthusiastic and fully engaged despite our subjecting them to five hours a day of gruelling work for five days. Instruction was interactive and consisted of lectures, class discussions, exercises and field work. This style of workshop was unusual for the attending students, but they eventually came to appreciate the benefits and by the end of the workshop were fully engaged in all the activities.

The workshop experience was enormously enjoyable and enlightening for UBC faculty. We enjoyed attending all classes, and hearing our colleagues' perspectives, and particularly liked the opportunities to discuss, in a classroom setting with students present, the differences and similarities in our understandings of diverse phenomena seen through the unifying perspective of the governing equations. Most important, we came away with a renewed interest in building this kind of collaborative, multi-instructor, interdisciplinary teaching back to EOAS. In a small way, the collegial interaction we experienced in the MPE 2013 workshop exemplifies the kind of collaboration we all aspire to build in EOAS.

Above:
MPE 2013 workshop attendees and instructors outside the AIMS main building.

A France-Canada Collaborative Effort to Tackle the Life and Death of a Volcanic Arc

Johan Gilchrist, BSc Geophysics and Thomas Aubry, PhD Candidate Geophysics

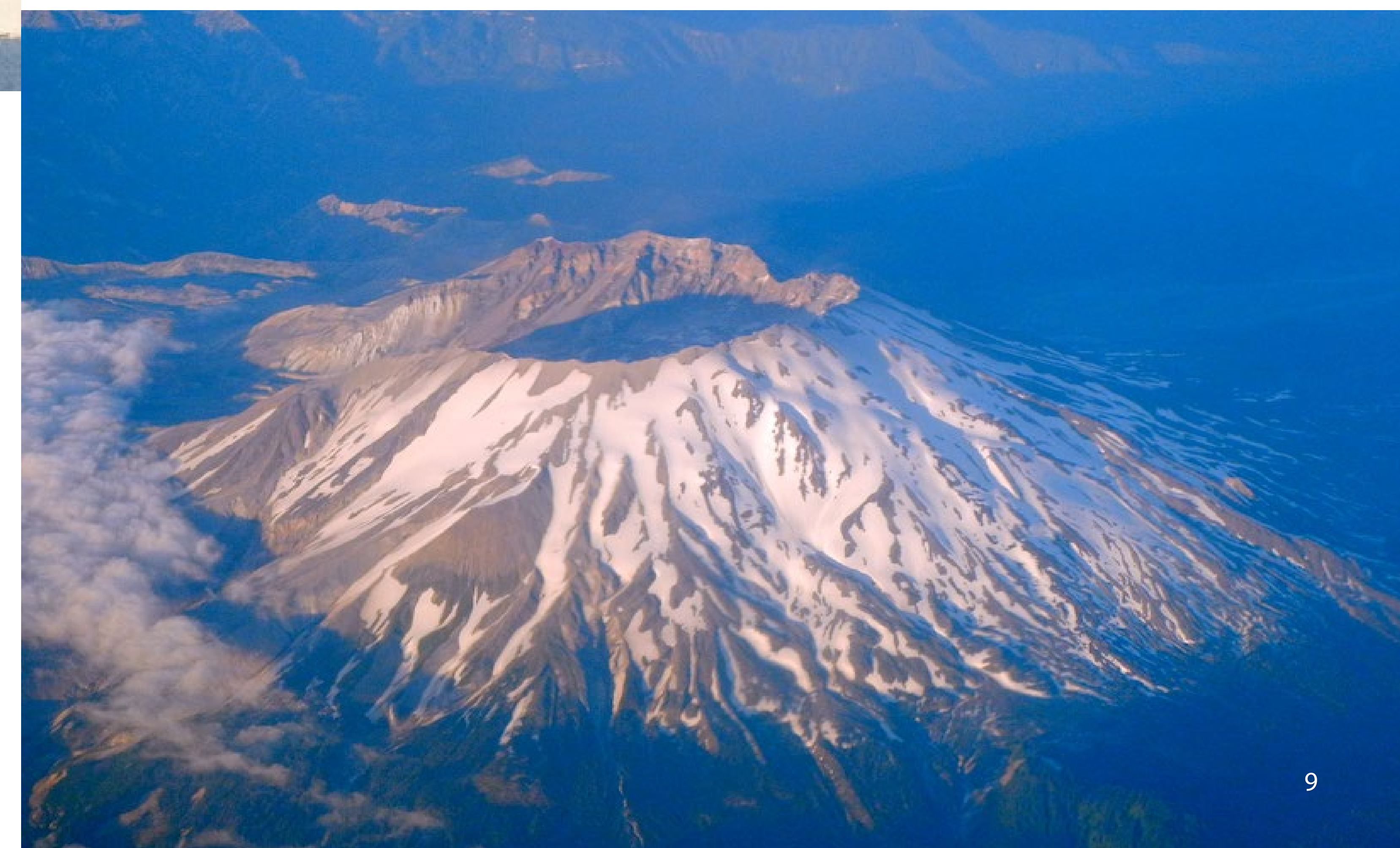
The Cascadia Subduction Zone, extending from Northern California to British Columbia, is an archetype of the classic model of continental arc volcanism. This model posits that water released by a subducting oceanic plate causes overlying mantle to melt and supply magma to volcanoes along the arc. Recent research has challenged the classic model by raising a number of questions concerning the compositional variability, spacing and eruption frequency among the arc volcanoes. In addition, the classic model predicts arc volcanism to cease at the transition from subduction to strike-slip regimes, yet continued volcanic activity north of the terminus of the subducting Juan de Fuca plate challenges this notion.

Seeking answers to these questions, three universities are joining forces in an ambitious effort to study the life and death of volcanic arcs and their associated hazards to society. A diverse team composed of researchers from the EOAS and Geography departments of UBC (PIs: Mark Jellinek and Marwan Hassan), Laboratoire Magmas et Volcans of Blaise Pascal University (LMV; PI: Severine Moune), and Simon Fraser University (SFU; PI: Glyn Williams-Jones) are combining their knowledge and skill to assess every part of the question. This is a massive endeavor and requires 30-40 volcanologists, geochemists, geologists, geological engineers, geophysicists and geomorphologists to collaborate over a long period in order to put the pieces of the puzzle together. Along with postdocs, MSc and PhD students will be based at LMV and UBC, respectively, who will also work at SFU to conduct fieldwork, analyze data and produce sophisticated models of the various phenomena associated with volcanic arcs.

A major aim of the collaboration is to exploit the joint facilities and diverse scientific staff of LMV, UBC and SFU to train young scientists to work at the highest level. During the initial 3-year pilot study in Auvergne, France will contribute $456,000 CAD to support two shared postdocs and enable extended visits for PIs traveling from LMV to UBC or from UBC to LMV. UBC will provide $215,000 CAD to support 3 PhD students for the 3-year period, in turn. If successful, this initial project may be extended for as long as ten years and ultimately train more than ten PhD students and postdocs and 20+ MSc students.

This project is the beginning of a profound relationship between UBC, SFU and LMV, the latter of which is the largest and most diverse Earth science laboratory in France. This project will bring together UBC EOAS and Geography researchers, marking a novel collaborative effort between the Science and Arts Faculties.

Below:
Mount Saint Helens in evening sunlight, view to the west, July 2011. Photo by Dominique Weis.



ENVR 400 Branches Out

Tara Ivanochko

When does a student become a scientist? In the UBC Environmental Science program it happens in 4th year in ENVR 400: Community Projects in Environmental Science, the new capstone course designed to connect students with community.

Over this last year—with financial support from the Faculty of Science and expertise from the Centre for Community Engaged Learning—we offered our students' services to the community. We found that MetroVancouver, the David Suzuki Foundation, the False Creek Residents Association, the Society Promoting Environmental Conservation (SPEC), Village Vancouver, the Burns Bog Conservation Society and UBC operations all had problems or questions that they couldn't answer by themselves.

Connecting academia with the community offers an opportunity for local organizations to access University resources and expertise. In collaboration with the students, these organizations can develop and execute projects that align with their priorities. As a partner in the research, they support students to gain a greater understanding of themselves and how they fit into the community, and to become more aware of complex community and social issues. From an educational perspective, this relationship allows students to; 1) connect classroom theory with real world environmental challenges by giving them the opportunity to apply skills and knowledge in environmental science to community issues; 2) connect with community organizations to do meaningful work that extends beyond the university and contributes to the organization and the community contexts in which they work; and 3) contribute to environmental organizations that deal with the impacts of human decision-making on our surrounding social, economical and ecological environments.

What are the impacts of dogs in Pacific Spirit Park? How can we host the 2014 Special Olympic at UBC as a bottled-water-free event? Are UBC's recent landscaping projects really sustainable in how they use water, impact soils and affect local vegetation? How can we incorporate urban agriculture in our communities' renewal plans? What would be the impacts of banning Styrofoam in Vancouver? How can we engage Canadians in monitoring their environment? How will climate change impact agriculture in the lower mainland?

When the community pitched these challenges in ENVR 400, the students' perception of themselves changed. They were being asked to help out. They were being seen as useful contributors with expertise that was needed in the community.

Over the last year, 10 teams of 4 students have been focused on these challenges. They have worked with their partner organization to scope the projects, articulate the research questions, devise appropriate methods—and they did the work. Throughout the process they developed teamwork, communication and time management skills. They all experienced the ups and downs of working on a long and complex project with others and an invested stakeholder. They all started to develop a personal concept of what the role of a scientist in society might be, and how they fit into that role.

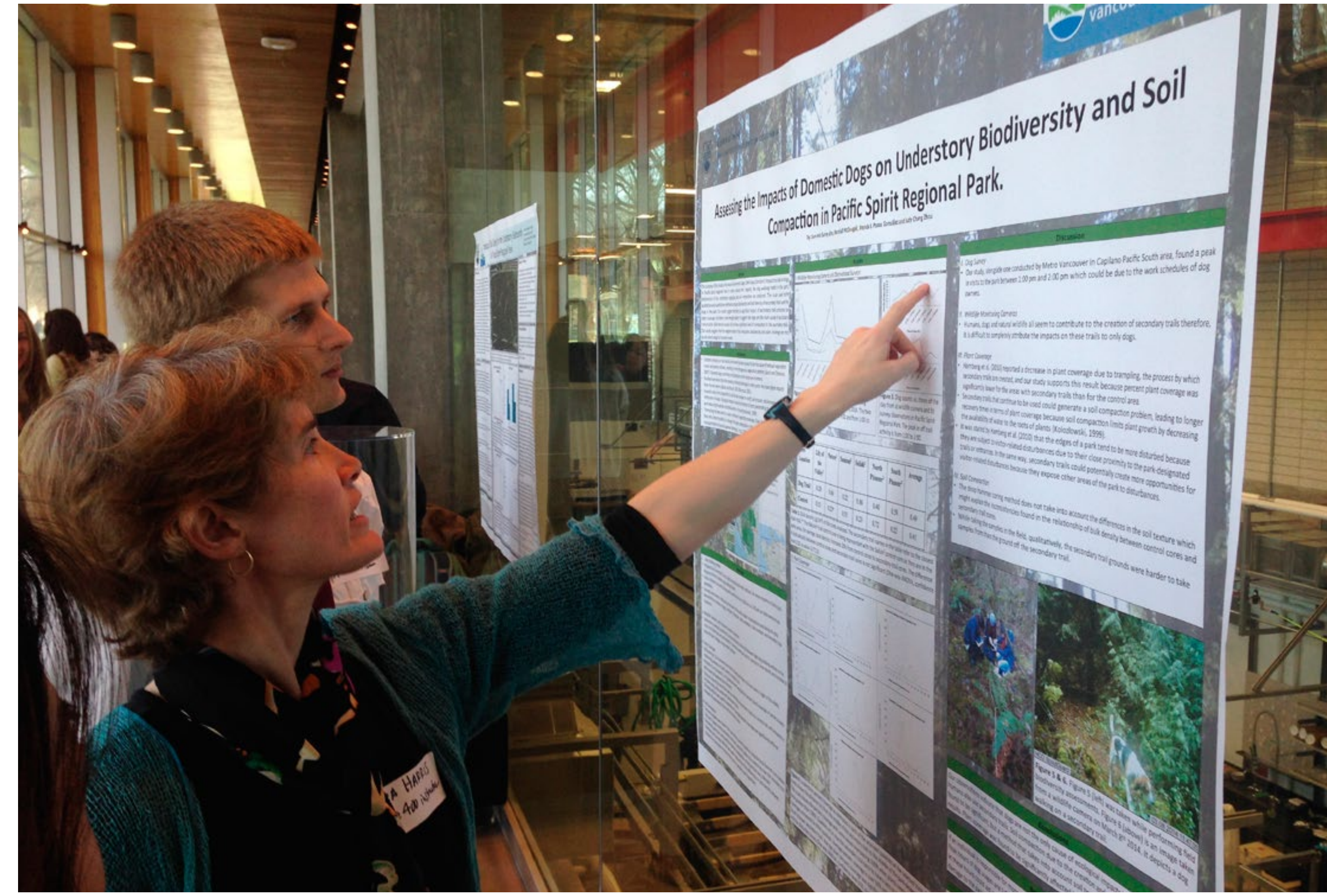
So has this experiment been successful? I think so. We now know that dogs aren't the only source of unsanctioned trails in Pacific Spirit Park. We now provided water recommendations for the 2014 Special Olympics at UBC. A new set of sustainability criteria, the Sustainable Sites Initiative (SITES), has been tested on a UBC landscaping plan. GIS analysis of the False Creek area has identified possible sites for new urban agriculture in this neighborhood. Styrofoam pollution in Vancouver has been quantified and the feasibility of transitioning to reusable containers has been investigated through public surveys. A comprehensive "Guide to Citizens Science" has been developed, focusing on how individuals can monitor local environmental impacts. First attempts have been made to understand regional impacts of climate change and population growth on food security goals in the lower mainland.

Conversations with the community partners suggest they are happy with the results. Conversations with the students reveal they have felt the thrill of a job well done, the satisfaction of completing a goal and the relief of meeting the partners' expectations.

Can we do this again? Yes. This is the first year that we have had formal partnerships with the community. Some of the projects are now finished, but many are the first step in an ongoing relationship. Next year we can take some projects further and follow-up on new challenges identified from this year's efforts. And word is spreading. Already new groups are contacting me. They want and need help to find solutions to environmental problems, achieve their mandates or venture into new territory. Developing and maintaining relationships with the community takes effort, but results are well worth it.

Community partnerships provide opportunities for students to bridge theory and practice, university and community, values and action, and education and experience. Through the process of completing the ENVR 400 community projects, I venture to say that the graduating environmental science students transitioned from students to scientists.

The final ENVR projects were shared with the UBC community on April 7th and with the larger community in May during Telus Science World's month-long celebration of Earth Day.



Above: Dr. Sara Harris examines a figure in student Marshall McDougall's poster during the April 7th ENVR 400 exhibition held in the UBC Earth Sciences Building atrium. Photo by Kari Grain.

Evolving Educational Culture in EOAS: Toward Transformative Learning

Sarah Harris, Francis Jones, and Brett Gilley

What does transformative education look like? What is the nature of effective learning opportunities, and what are the ideal roles of university scientists in teaching? How do we enable continued iteration toward better teaching and learning over time? In EOAS, we are now seven years into a department-wide effort to act on the answers to these questions, and we are looking toward better answers, and actions, in the future.

In 2007, EOAS became the first department to be funded by UBC's then-new Carl Wieman Science Education Initiative (CWSEI) when we launched the Earth & Ocean Sciences Science Education Initiative (EOS-SEI). The aims of CWSEI are ambitious—to fundamentally transform science education using evidence about how people learn. The cornerstones of this approach involve three questions: what *should* students learn? What instructional approaches *improve* student learning? And what *are* students learning? These are questions to revisit often, with answers that can evolve with emerging knowledge and changing settings. The answers are best informed by evidence-based research on learning, from which we borrow, and to which we contribute—a process entirely analogous to the way scientific research works. The larger goal is one of ongoing and thoughtful evolution of teaching and learning culture, with outcomes for students taking top priority.

The state of education in any department depends upon local cultural norms surrounding teaching and learning. What are our expectations of ourselves and our colleagues? What are faculty expectations of students, and student expectations of faculty? Traditional approaches to science education—typified by an expert delivering content to listeners—have been shown to be less useful for learning than instructional strategies that emphasize student action. More effective roles for faculty are as experts who design and facilitate opportunities for students to grapple with complex concepts, who can help as students build and refine their own mental models. It is these roles for faculty and students toward which EOAS is moving. Thirty-eight courses have been transformed so far, and use of research-based instructional strategies is now common. Students recognize the value for their learning, have come to expect active participation, and increasingly advocate for their own learning.

One key to the success of EOS-SEI has been hiring full time Science Teaching and Learning Fellows (STLFs). These individuals have relevant scientific expertise as well as a demonstrated commitment to applying and conducting discipline-specific education research. Faculty members and STLFs work together to choose, modify, implement and assess evidence-based strategies within each unique classroom. They have incorporated active learning in classes, addressed the practical challenges of new approaches to teaching, designed measures of student learning and student perceptions, gathered evidence of learning, and shared their successes and failures with the larger teaching community. Graduate student teaching assistants (TAs) also play key roles in delivery and development of teaching, and we now offer a graduate course about geoscience education. Helping TAs gain early-career experience as evidence-based educators is an important aspect of sustainable culture change. Other critical components of success have been highly supportive leadership, as well as enthusiastic, collegial attitudes among our own faculty and across campus. Authors of a March/April 2010 article in *Change* magazine refer to EOAS when they say, "[w]ithout exception, the more the department as a whole has been involved and seen this as a general departmental priority, the more successful and dramatic have been the improvements in teaching."

Where are we now, and what's next? We have documented successes with course transformations and faculty are spreading new approaches to other courses. We have published in peer-reviewed journals on teaching and learning, facilitated workshops locally, nationally, and internationally, and we have multiple sources of evidence for improved student learning. As UBC's Dean of Science, Simon Peacock, stated in an April 19th, 2013 *Science* article, "'We've hit it out of the park with Earth and Ocean Sciences, one of seven departments that are part of the university-funded initiative…I will declare them to be a success.'" Certainly our progress is encouraging. But, just as scientific research is never "finished", opportunities for further improvement and research abound, and we are now launching two new projects. The first is a two-year initiative to develop and study student-focused learning activities for use in courses conducted online, face to face, and those delivered over both platforms. We will leverage best practices from each teaching mode, and introduce new resources that work in all settings. The second is a three-year initiative to address the significant challenges that faculty and students face in shifting from traditional teaching methods toward strategies and habits informed by research about how people learn. This project will implement a co-teaching model so that faculty can develop and transfer new discipline-based educational expertise together with ongoing support from STLFs. The aim is to strengthen connections within the department in all aspects of undergraduate teaching.

Our cultural norm certainly has shifted over the past seven years; teaching and learning in the department has improved as a result. With continued effort, we can work toward more engaging, effective, and evidence-based approaches to science education that are more productive for students and more personally rewarding for faculty. It is an exciting time to be involved.

To see video demonstrations of transformative teaching and learning strategies in action in real classrooms visit: *http://blogs.ubc.ca/wpvc/*

One example of "transformative learning"—roughly 300 students in a two-stage midterm exam. During class, students actively engage with interesting and challenging concepts while instructors circulate and use strategies that give feedback to all students. Some "normal" lecturing does occur, but students are primed and ready to listen when the time comes. These practices, used in every lesson, are carried over into midterm and final tests in the form of two-stage exams.

The Pacific Museum of Earth: A New Window Into Our Geologic Past

Kirsten Hodge

The history of the Pacific Museum of Earth (PME) spans nearly 90 years. Founded in 1925 and originally named the Geological Museum and later the M.Y. Williams Geology Museum, the PME was UBC's first museum. Over the next several decades, the museum slowly expanded its collection through acquisition of valuable minerals, gems, and fossils. In 1995, budget constraints closed the museum until 2000, when UBC alumnus Ross Beaty recognized the museum's value and in an attempt to preserve and expand its existing collection and exhibits, Mr. Beaty with other supporters opened the Pacific Mineral Museum in downtown Vancouver. The Pacific Mineral Museum showcased an extensive assembly of spectacular mineral specimens donated or on loan from numerous collectors, including Mr. Beaty himself.

In 2003, the M.Y. Williams Geology Museum and the Pacific Mineral Museum merged. The new museum returned to its roots at UBC and became what is now the PME. This merger realized Mr. Beaty's original vision of an expanded Earth sciences museum on UBC's campus. Mr. Beaty contributed the cabinets and mineral collections of the Pacific Mineral Museum and UBC the physical space and historic collections of the M.Y. Williams Geology Museum.

Over the past two years, the PME has undergone a whirlwind of changes during which the museum remained closed to the public. From building renovations, to display reconstruction and updates including over 40 brand new displays, the addition of an OmniGlobe, the acquisition of the stunning and rare Dr. Ted Danner collection, a new website, logo, and curator, the museum's fresh new look and updated displays were worth the wait. Though these additions and changes to the PME transpired relatively quickly, the scientific stories told by its exhibits comprise hundreds of millions of years through Earth's history.

One of the newest permanent exhibits at the PME is the OmniGlobe. Located in the Globe and Gem Gallery, known to many as "The Vault", this interactive spherical display is the first and only of its kind in Canada. A touchscreen kiosk controls the content projected on the Globe allowing users to navigate through images and animations at the tap of a finger—from the topography of the moon, to real time weather, ocean currents, tsunami wave height data, ancient ice coverage, plate tectonics, and much more.

Exotic treasures including gold nuggets, diamonds, meteorites, and a particularly eccentric collection of nearly 130 rings are also housed in the Globe and Gem gallery. These dazzling specimens fill the displays that surround the OmniGlobe and are all part of the Dr. Ted Danner collection. Dr. Danner was a faculty member in the Earth, Ocean and Atmospheric Sciences for nearly six decades, known for his infectious enthusiasm for mineralogy and field geology. His rare collection will be permanently housed in the PME's displays and collection.

The Earth Sciences Building, home to Earth, Ocean and Atmospheric Sciences, Statistics, the Pacific Institute of Mathematical Sciences, the Faculty of Science Dean's office, and the expanded PME gallery space, is a prime example of architectural excellence on UBC's campus. The East Gallery, through whose glass walls the blue whale skeleton of the neighboring Beaty Biodiversity Museum is visible, takes visitors on a tour through Earth's rock cycle. Igneous, metamorphic, and sedimentary rocks line the gallery in modern cylindrical display cases. The Earth Sciences Building atrium holds the PME's newest permanent exhibit: the Evolution of Earth display. Suspended, rotating globes show snapshots of Earth as it evolved through time. Below the globes is a geologic timeline that illustrates the physical and chemical evolution of Earth. The data shown on the timeline tell a fascinating story about a changing planet and highlight the relationships between the episodic growth of Earth's continental crust, the formation and breakup of supercontinents, and the profound changes to the hydrosphere, biosphere, and atmosphere.

The PME is a small museum. With only one permanent staff member, the museum relies heavily on the support of volunteers. The volunteer group comprises graduate, undergraduate, and high school students, as well as retired members of community. From display research, design, and construction, to leading outreach programs for K-12 students, the volunteers are the heartbeat of the museum. We thank them for their continued hard work and dedication. (We would like to recognize and give special thanks to Kathi Unglert, Belle Cheng, Heather Wilson, Lydia Philpott, Brett Gilley, Michael Lipsen, Hanson Wong, Andrea Dixon, Evan Smith, Anaïs Fourny, Mehrnoush Javadi, Rose Gallo, Dana Caudle, Elliot Skierszkan, Mike McMillian, Chuck Kosman, Dave Newton, David Turner, David Nuttall, Anna Grau, Kaleb Boucher, Marie Turnbull, Kate Wodzicki, and Trevor Tamburri).

The museum's outreach team runs approximately 120 programs annually, catering to nearly 1600 schoolchildren and 1000 other visitors in addition to many patrons who browse the museum collections at their own pace. Since early 2013, we have begun a major restructuring and redesign of all existing outreach programs. Upon completion of this project, the outreach menu will include eight hands-on activity-based workshops such as *Rock Recognition* and *Mineral Mystery* as well as *Volcano Voyage* and *Fossil Finds*. The new workshops will not only inspire K-12 students to discover exciting science, but also provide educators with the topics and tools for novel curriculum design in their own classrooms. The PME outreach team is currently working with the Beaty Biodiversity Museum's education team to offer joint programs between the two museums. We hope that by combining these two already complementary outreach programs we can offer a more comprehensive science education experience to the public. With the museum's fresh new look, expanded exhibit space, and growing outreach program, the PME is definitely a site not to be missed during your next visit to UBC's campus.

For more information on the PME, including contact details to set up a tour for your own group, visit:
pme.ubc.ca

Opposite Top: The main gallery of the PME.

Opposite Bottom: Photo by Chuck Kosman

Bottom: A young PME patrons displays an image of the Moon using the OmniGlobe kiosk. Image by Derek Tan.

IN THE FIELD

Having a Field Day

EOAS undergrads took part in their programs' field courses this past year. Students enrolled in Field Techniques (EOSC 223), Field Geology (EOSC 328) and Field Techniques in Groundwater Hydrology (EOSC 428) partipated in outdoor technical exercises at Salt Spring Island, Oliver, and Richmond, respectively. Methods in Oceanography (EOSC 473) visited the Bamfield Marine Station on Vancouver Island during the February mid-term break.

African Adventure

Undergraduate and graduate students studying Economic Geology had opportunity to visit Namibia through an annual field trip organized by the University of British Columbia's Society of Economic Geology Student Chapter (SEG). The UBC SEG Student Chapter organizes the field trip to a different international location each year. Past trips have lead UBC students to locations hosting spectacular geology including Eastern Europe, the Philippines, and Western Australia. Namibia is no exception, with a myriad of mineral deposits including those of copper, gold, uranium, rare earth elements, diamonds, lead, and zinc.

Namibia was chosen among other potential destinations by the participating students themselves during the fall term. Participating students were also responsible for the organization and itinerary of the event down to the smallest details. A total of 23 individuals attnded the trip, half of whom are UBC graduate and undergraduate students and the other half industry participants. The latter provided their mining and exploration expertise and financial sponsorship.

The participants departed on the 28th of April and returned on the 15th of May. The trip commenced in Namibia's capital, Windhoek, where students spent a few days meeting fellow geologists from the University of Namibia. The travellers then headed to the south of the country to visit the Haib molybdenum-copper porphyry deposit owned by Teck Resources, the Skorpion zinc mine, and Fish River Canyon. Following the visit in the south, attendee's headed-north to visit the Otjikoto gold project, the Etendeka Province, the Husab uranium project, and Etosha National Park. Students also visited projects from other mining companies including the Rosh Pinah mine, Kombat Copper, and other local mining companies.

The trip was heavily subsidized by industry participants and sponsors, which included private consulting firms, KGHM International, the government of British Columbia, Minería Activa, and Namibia Rare Earths Inc. International field trips like this one provide a fantastic opportunity for Earth science students to see unique local and regional geology, observe international mines and exploration projects, and interact with industry members and aspiring student geologists worldwide.

Undergrads Say "Aloha" to the Big Island

Every year, the G.M. Dawson Club organizes a field trip for undergraduate students during Reading Week break in February. This year's destination was a real hotspot: Hawai'i. Participants visited the Hawai'i Volcano Observatory on the rim of Kīlauea Caldera. There they learned about monitoring ground deformation and gas emissions commonly associated with volcanism in addition to the spectacular geologic history of the Hawai'ian islands. The students also visited one of only two green sand beaches in the world, coloured so from grains of olivine eroded out of Hawai'ian lavas, and the black sand beach of Waipi'o Valley.

Undergraduates Joe Aslin, Omar Berbar, Grufford Roberts, J Iaopu Li, Anna Williams, and John Tejada in front of Kīlauea Iki lava lake during their trip to Hawai'i.

STUDENT TALKS

UBC Students Posters Shine at AMEBC Roundup

Every year the Association for Mineral Exploration British Columbia (AME BC) hosts the Mineral Exploration Roundup Conference here in Vancouver. Roundup is a networking and education opportunity for companies and individuals in the exploration industry. The conference draws nearly 8000 participants from around the globe and includes technical sessions, short courses, a trade show, and a poster session. The poster session highlights the results of geological mapping, geophysical surveys, research in economic geology and new technology. This session also provides university students an opportunity to showcase their research. This year 16 posters were presented by students from UBC's Mineral Deposit Research Unit. Mike Tucker was awarded first place in the Student Poster Competition for his poster *Geology, Alteration and Mineralization of the Carlin-type Conrad Zone, Yukon* and Lauren Greenlaw took second place for her poster *Regional Lithogeochemistry as a Tool for Porphyry Exploration: A Case Study on the Relincho Cu-Mo Porphyry Deposit, Chile.*

Three Minute Thesis

Can you condense the years of your research and its relevance into a three minute or less talk? This is the exciting challenge posed by the Three Minute Thesis (3MT) competition. Limited to a single slide, graduate students from universities worldwide get their audiences excited about their research.

3MT was first organized in 2008 at the University of Queensland and is now held in more than twelve countries around the world. UBC started participating in 2011 and EOAS organized its own departmental heat for the first time this year in February. Graduate students Emma Shelford (PhD Candidate, Oceanography), Evan Smith (PhD, Geological Sciences), Art Petrenko (MSc, Geophysics) and Thomas Aubry (PhD Candidate, Geophysics) were the four courageous candidates hoping to advance to the university wide competition. Their talks took the public from the deep diamond bearing Earth to the top of volcanic plumes. It was a great occasion for everyone to learn about the research conducted by our graduate students and a good opportunity for the candidates to think about the best way to convey their passion to the public.

Emma Shelford's talk "Viruses in the Ocean: An Invisible Universe of Interactions", was awarded first place and she went on to the UBC semi-finals. A special thanks goes out to Susan Hollingshead for organizing the EOAS heat and to the judges panel; CWSEI Teaching and Learning Fellow Brett Gilley, PhD Candidate Lauren Harrison, and UBC Dean of Science Simon Peacock. EOAS will hold its own heat again in March 2015.

3MT® THREE MINUTE THESIS
FOUNDED BY THE UNIVERSITY OF QUEENSLAND

EARTH *talks*

EarthTalks

This past November, EOAS Graduate Student Council (GSC) organized EarthTalks, a brand new forum for research communication. EarthTalks seeks to promote formation of inter-disciplinary relationships at the graduate student level. The five graduate student speakers delivered non-competitive presentations to an exclusively graduate student audience. This environment allowed for focus on outreach and relationship building rather assessment. The 10-minute, 4-slide talks included:

"Diamond is Nature's Tupperware". Evan Smith, PhD Candidate Geological Science, presented his research on fluids within octahedral diamonds and the curious nearly pure nitrogen bubbles contained within them.

"Ice Stream Margin Migration". Marianne Hasseloff, PhD Candidate Geophysics, showcased her work on the use of numerical models to describe the material behavior of Antarctic ice sheets.

"Geophysical Treasure Hunt". Dikun Yang, PhD Candidate Geophysics, brought to light the mathematical complexities involved in interpreting geophysical assay data obtained in mineral exploration programs.

"Salish Sea Ocean Circulation Model". Kate Le Souef, MSc Oceanography, presented her work on modeling the behavior of the Salish Sea and the many parameters involved in prediction of ocean circulation.

"The Ocean Goes Viral". Emma Shelford, PhD Candidate Oceanography, explored the active microscopic world of virus metabolism in Earth's oceans.

GSC will hold a second installment of EarthTalks in the upcoming fall semester.

New Faculty

Valentina Radic

Kate Le Souef, MSc Oceanography

Photo by Raja Yarra

Valentina Radic is a glaciologist who studies the impact of climate change on glaciers and the contribution of glaciers to sea level rise. Originally from Croatia, Valentina completed her PhD at the University of Alaska, Fairbanks in 2008 before moving to UBC to do a post-doctoral fellowship with Garry Clarke. She joined the faculty of Earth, Ocean and Atmospheric Sciences as Assistant Professor in October 2012.

Valentina studies the impact of melting glaciers on a range of scales, from the impact on regional hydrology to the impact on global sea level rise. Regional scale processes are important because melt cycles impact the availability of water for purposes such as irrigation and hydropower. Valentina's post-doctoral work focused on the impact of changing glacial changes on hydropower in British Columbia. On the global scale, Valentina provided one of the first regionally resolved predictions of how glacier mass will change with climate change.

She is also interested in how much water is contained in mountain glaciers. These glaciers are thinner than large ice sheets such as that of Greenland, so the errors from estimating their depth by satellite are large. The only way to estimate the depth of mountain glaciers is to use radar on the glacier surface and this process has only occurred on a few hundred of the world's 200,000 mountain glaciers. Valentina has worked on upscaling methods to more accurately estimate the volume of mountain glaciers where field measurements are not available.

Valentina has previously used models to determine the response of glaciers to climate change. However, since becoming EOAS faculty, she has begun a field monitoring program to collect meteorological data on two glaciers in British Columbia, one near the Rockies and one in the Coastal Mountains. Her instruments will provide in-situ measurements of meteorological parameters that are important to glacier melt, such as solar radiation and turbulent flux.

The field measurements that Valentina collect will be a valuable way to learn about physical processes at the glacier-atmosphere interface, rather than using empirical relationships as many glaciologists have done in the past. The measurements will be compared to meteorological predictions from global weather models such as the Weather Research and Forecasting (WRF) model. If there is good agreement between the measurements and the model, predictions from WRF could be more confidently applied to other glaciers to predict ice melt processes.

Collaborations with the Food Systems and Geography departments at UBC allow Valentina to access instruments and expertise to improve her field campaigns. Valentina also works with other EOAS faculty including atmospheric scientists Douw Steyn and Roland Stull, and she continues to collaborate with Garry Clarke.

Valentina currently supervises two graduate students and teaches undergraduate courses in Dynamic Meteorology and Research in Environmental Science.

Stephanie Waterman

Johan Gilchrist, BSc Geophysics

Many people are afraid of turbulence, whether in an airplane, on a boat or a turbulent period of their lives, but not Dr. Stephanie Waterman. She is one of the newest members of the EOAS faculty and turbulence is a part of her everyday life. Specializing in physical oceanography, her work focuses on the turbulent motions in ocean circulation and their connection to larger scales of motion.

Born and raised in Toronto, ON, Stephanie's hobby of sailing sparked her first interest in fluid dynamics. "I was a geeky kid in high school," she said, but she was not intimidated by the male dominated classes she took while attending Queens University for her undergraduate degree in Engineering Physics. During this time, she did an internship with Dr. Barry Ruddick at Dalhousie University and credits him with first exposing her to physical oceanography. After completing her BSc, she went on to pursue a MSc in Aeronautics at the California Institute of Technology, before realizing that "Dr. Ruddick" was right and studying fluid mechanics on the planetary scale was much more fun. After spending a year in Korea teaching English she applied to do a PhD in the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution (WHOI) joint program.

As with aeronautics, Stephanie had limited experience with oceanography. Fortunately for her, the first year of the WHOI graduate program involved taking classes and finding an advisor in the process. This gave her and other students a chance to learn the basics of oceanography and get a taste of the various projects available to them. Dr. Nelson Hogg and Dr. Stephen Jayne were working on a project studying the Kuroshio Extension, the western boundary current off the coast of Japan (the Pacific Ocean's version of the Gulf Stream current). They were taking measurements of water density and velocity at unprecedented spatial and temporal resolution to understand how the current evolved after leaving the coastal boundary and what role large-scale turbulence played. Intrigued by the Kuroshio project, Stephanie chose them as her advisors and when asked about the unusual situation of having two advisors she joked, "If you had a certain question, you could choose which 'parent' to ask."

After completing her PhD, Stephanie went on to work as a Research Associate at the Grantham Institute for Climate Change, Imperial College in London, UK, then as a Research Fellow at the National Oceanography Centre, in Southampton, UK. Here she become involved in a project responsible for making the first ever full-depth measurements of turbulence in the Southern Ocean designed to better understand how the oceans transform dense waters into light ones, a key control on the ocean's overturning circulation responsible for the deep ocean transport and storage of heat and carbon. She spent last year in Australia as a Research Fellow and Associate Investigator at The University of New South Wales, in Sydney, AU, working further on the topic of Southern Ocean mixing.

Fieldwork is big part of oceanography and Stephanie is no stranger to it. She has participated in research cruises in the Atlantic, Pacific and Southern Oceans, the latter having the highest average winds of any place in the world! These 50-60 day excursions were quite the opposite of the stereotypical "cruise"—she worked eight to twelve hour shifts seven days a week with a break here and there for hotly contested Wii Tennis games.

The Arctic Ocean is the next field site for Stephanie. She will work on the Canadian Arctic Geotraces program, which will send a research vessel equipped with an autonomous underwater vehicle to take measurements of turbulence in Arctic Ocean waters, with a team led by UBC's own Dr. Roger Francois. She will also teach several physical oceanography classes at the graduate and undergraduate level and co-teach field school in Banfield on Vancouver Island where students will learn the basics of oceanographic field methodology.

Photo by Raja Yarra

Photo by Chuck Kosman

Peter Winterburn

Kate Le Souef, MSc Oceanography

In late November 2013, Peter Winterburn was appointed to the newly created position of AcmeLabs Research Chair in Exploration Geochemistry in the Mineral Deposit Research Unit (MDRU), an industry aligned research group in EOAS.

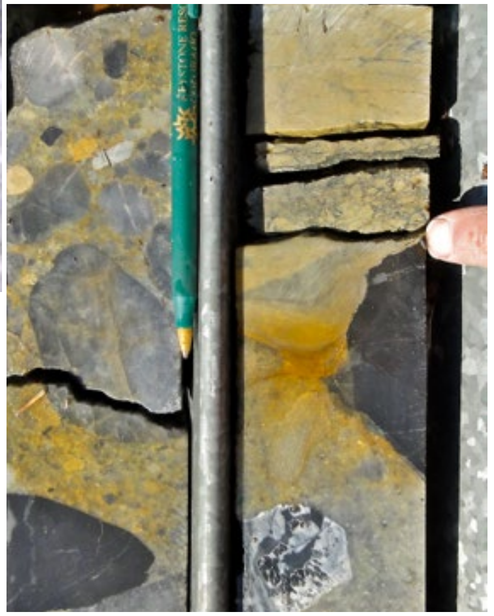
This Chair was created to address the need to develop geochemical exploration techniques and strategies that meet the present day requirements of industry. Mineral resource companies are constantly looking for efficient, cost-effective methods to help with the discovery of new mineral resources. This position will bridge the gap between industry and research, and re-invigorate the discipline of Exploration Geochemistry at UBC.

Peter comes to this position with over 25 years of experience in the minerals industry with a strong focus on mineral exploration. Peter has worked as a geochemist at Anglo American and Vale, where his work included the innovation of cost-effective and robust geochemical exploration methods for concealed deposits. He has worked on exploration techniques for various commodities including copper, gold, zinc, nickel and iron oxide hosted in diverse deposit types. Peter's work has taken him all over the world, having contributed to projects in Africa, Chile, Peru, Argentina, Morocco, Mongolia, Brazil, Indonesia and the Philippines.

Peter's appointment is the first step in the Exploration Geochemistry Initiative, which was developed by the MDRU in collaboration with industry. The objective of this initiative is to provide leadership and support to implement a 5-year program that significantly increases the amount and quality of research and training within exploration geochemistry. Over the next 5 years, the Initiative has three key objectives; 1) Provide leadership and innovation to establish a world-class research foundation in the field of exploration geochemistry; 2) establish a research program to understand element mobility and transport through the surficial environment and to develop foundations for new mineral exploration techniques; and 3) provide education, training and professional development opportunities for novice and veteran exploration geochemists alike.

Peter will now be leading this Initiative at MDRU. This position was made possible by industry contributions, including generous funding provided by Acme Analytical Laboratories Ltd.

Faculty Research



From the innermost iron core of the planet to the outer reaches of the solar system and (literally) everything in between, research in our Earth, Ocean and Atmoshperic Sciences comprises diverse topics, methods, places, and people. Biological oceanography, scientific computing, economic geology, glaciology, hydrology, isotope geochemistry, planetary science—the subdisciplines of study of our blue speck and its place in the cosmos are seemingly infinite. As the largest and most research productive Earth Sciences unit in Canada, the EOAS department certainly contributes toward its understanding. The following faculty vignettes showcase but a fraction of recent and exciting scientific investigations ongoing in EOAS.

Roger Beckie

Johan Gilchrist, BSc Geophysics, and
Thomas Aubry, PhD Candidate Geophysics

Photo by Raja Yarra

Tucked away in minuscule spaces between soil particles is a precious resource: water. Understanding the ways in which hazardous materials chemically and physically interact with groundwater aids in their proper management and remediation.

As a professor of groundwater hydrology and geochemistry in EOAS, Roger Beckie is responsible for plenty of global projects that help society and industry ranging from evaluating impacts of shale gas drilling in British Columbia to improving water supply in Bangladesh. Roger's research requires knowledge from a variety of disciplines. Groundwater hydrology uses principles from solid mechanics, fluid dynamics, geochemistry, geology, biology and environmental sciences.

One might assume he was trained in one of these fields initially, but this is not the case. Originally enrolled in electrical engineering at Waterloo, he switched gears, graduating from Geological Engineering—he wanted to live out west near the mountains—and later completed his PhD in Civil Engineering at Princeton University. Due to rapidly emerging environmental issues, particularly the pollution of groundwater resources, there was a spike in groundwater hydrology research at the time and he immediately received a position at UBC while still finishing his PhD.

With a foundation in engineering, Roger enjoys applying his trade to various issues affecting society. Why do we find high levels of heavy metals, such as iron and manganese, in the banks of the Fraser River delta? How and where can we sequester carbon dioxide to help mitigate climate change? Is there a "safe place" to bury nuclear waste for thousands of years? Which areas are ideal for geothermal energy plants? To answer these questions, he and the groundwater hydrology team at UBC must work efficiently with several industries. The companies provide the team with field sites, data and funding while receiving valuable information and field advice that helps them reduce their environmental footprint.

Since then, Roger has been combining data from field studies with sophisticated computer models to gain insight into underground water processes. He is looking at the way fluids such as water or methane gas propagate through very tight paths in the ground. To characterize the flow, groundwater hydrologists rely on hydraulic conductivity—a measure of how easy it is for a liquid to flow through porous media. Already, Roger is dipping into the toolkits of solid mechanics, fluid dynamics and geology—now he has to use tools from geochemistry and biology to understand the inorganic chemical reactions and biological processes that change the composition of the system. All this helps him and his team to determine the environmental impact of groundwater processes, which is valuable information for many industries concerned with oil, gas, mineral and groundwater extraction. While most fresh water resources are confined to the top two to three hundred metres of the subsurface, work on shale gas extraction can extend to three kilometres below the surface.

An example of collaboration between the hydrology lab and industry may be found in Peru at the Antamina Mine. One of the ten largest mines in the world, the operation extracts copper, zinc, lead and silver among other metals buried under many layers of unwanted waste rock. Where to put the waste rock is crucial, since as rainwater flows through waste rock piles, mineral reactions can lead to poor quality drainage. "This problem is multifaceted, in that it is a management project. [The mine operators] want to know how to manage their waste in a way that minimizes impacts," says Laura Laurenzi, one of five graduate students who are currently analyzing and modeling data from the mine. Laura deals with the fieldwork and laboratory analysis while other students, like Mehrnoush Javadi, are more focused on the computer modeling. This is a big project so their group meets with the mine's environmental groups once a month to discuss the data and results. This mutually beneficial relationship ensures that the students gain invaluable experience working with industry that leads to career paths in consulting, engineering and research.

Roger and his students also use their expertise to help resolve local environmental issues. While a big project like the Antamina mine requires a whole team of scientists, the influx of the heavy metals iron and manganese into the Fraser River can be tackled by one person. That person is Kun Jia and she does all the project's work herself from collecting samples from the banks of the Fraser River, to analyzing them in the lab and eventually creating computer model that captures the essence of this process.

An entirely separate issue concerning the Fraser River that Roger's group also works on originates from a hundred years ago when a large amount of creosote, the toxic and sticky wood preservative tar used on telephone poles and railroad ties, spilled and seeped into the ground near the Fraser River. The creosote is still there today due to its long time scale of natural degradation. Removal of the contaminant source is not feasible since it is too deep. One common management approach used now is "pump and treat" to capture the contaminant before it flows into the Fraser River. Roger noted that while the source will likely persist for hundreds of years more, a pump and treat procedure may not be required at all if naturally occurring bacteria in the subsurface can break down the contamination before it reaches the Fraser. The key issue then is to understand whether this natural attenuation can effectively protect the Fraser River.

Due to the many applications in industry and society, groundwater hydrologists perform their research worldwide .For centuries in Bangladesh and India, surface water fed by the monsoons has been the main source of water that was also highly susceptible to contamination from humans and livestock. Now, Roger and other groundwater hydrologists have helped Bangladesh take advantage of groundwater, providing pathogen-free water year-round. Switching from surface water to groundwater for drinking has reduced infant mortality by a factor of five and eliminated long walks for Bangladeshi women to obtain water from ponds. Irrigation with groundwater in the dry season has almost doubled Bangladesh's food production over the last twenty years. Regrettably, naturally occurring arsenic has been found in many of these aquifers, so he and others help determine which aquifers are safe to drink from.

Groundwater hydrology is a science applied all over the world for diverse purposes. Water is the one of the most important resources on the planet and will be in high demand as the global population increases. The knowledge and experience of Roger's group will be a major asset to those seeking advice on anything related to groundwater.

Roger will continue his research on groundwater hydrology in conjunction with his new duties as Head of EOAS.

Above:
Odiel River, Rio Tinto Area, Andalusia, Spain. Water resource pollution is a major concern for Roger and his group

Below:
Laura and Mehrnoush, two graduate students working with Roger, during a field trip at the Antamina Mine, Peru.

Eldad Haber

Chuck Kosman, MSc Candidate Geological Sciences,
and Nikolas Matysek, BSc Geology

Creating three-dimensional images of mineral and petroleum deposits from geophysical survery data is of utmost importance to resource exploration programs. The sheer size of these datasets and the need to image moving media require specialized attention.

At first glance, the subterranean flow of oil and the electrical conductivity of rocks appear worlds apart. To a computer whiz like Eldad Haber, Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Research chair in Computational Geoscience, their dissimilarity is only superficial. Though these are two very different real-world phenomena, a single mathematical equation describes both single-phase fluid flow and DC resistivity. "Math is a universal language," Eldad states confidently. "People in the field of scientific computing have a natural ability to move between different fields, different applications." The beauty of scientific computing to its practitioners is its versatility and freedom.

"People in the field of scientific computing have a natural ability to move between different fields, different applications."— **Eldad Haber**

The aim of scientific computing is different from that of observational disciplines like the geosciences or theoretical disciplines like mathematics. Scientific computing applies the best of both worlds in order to find solutions to problems with tangible and often economically rewarding implications. Furthermore, scientific computing aims to take in all the complexities of a system and provide solutions that pencil and paper are simply incapable of producing. Eldad explains in reference to the classic physicist joke; "It used to be that if you want to analyze the cow, for example, then you say 'let's assume the cow is spherical, and let's assume the world is flat, and the cow can roll on the flat Earth,'" he smiles. "But in reality, cows are not exactly spherical, the Earth is not exactly flat, and if you really want to go and start to study the behavior of a real cow on a real Earth, there is no way to do this analytically; you need to use computational models."

Fortunately for the geoscience community, Eldad does not computationally model cow behavior. Eldad's work focuses on the visualization of mineral and petroleum deposits and processes.

The application of scientific computing to provide faster and higher quality exploration targeting has certainly attracted the attention of industry. Over the last 15 years, Eldad has helped develop models for major mining companies including Teck Resources and Newmont. NSERC has matched the corporate grants and allowed for more collaborators to join his research.

One application of Eldad's scientific computing is to "big data"; datasets so large that any number of humans manually interpreting it would be impossible. The theory and techniques for analyzing large datasets have been around for 40 years, but it hasn't been until recently that large volumes of digital data have been generated, stored, and made easily accessible. For example, each Internet search a person makes is one data point with multiple variables—the search criteria itself, the time of the search, the location of the search, etc. Consider how many Internet searches are made in one day and all information that accompanies those searches, and you've got yourself a big dataset in no time.

Mineral exploration comapnies are no strangers to big data. The provincial government of British Columbia has recently made available huge troves of environmental data that span decades past. The data is categorized into layers that map different attributes, just like paper maps—one layer might be topography, another layer seismic attributes, another layer precipitation, etc. In total, there are more than 50 unique layers. The possibilities with such data have largely yet to be explored, but determining what patterns are significant across the layers is a challenge.

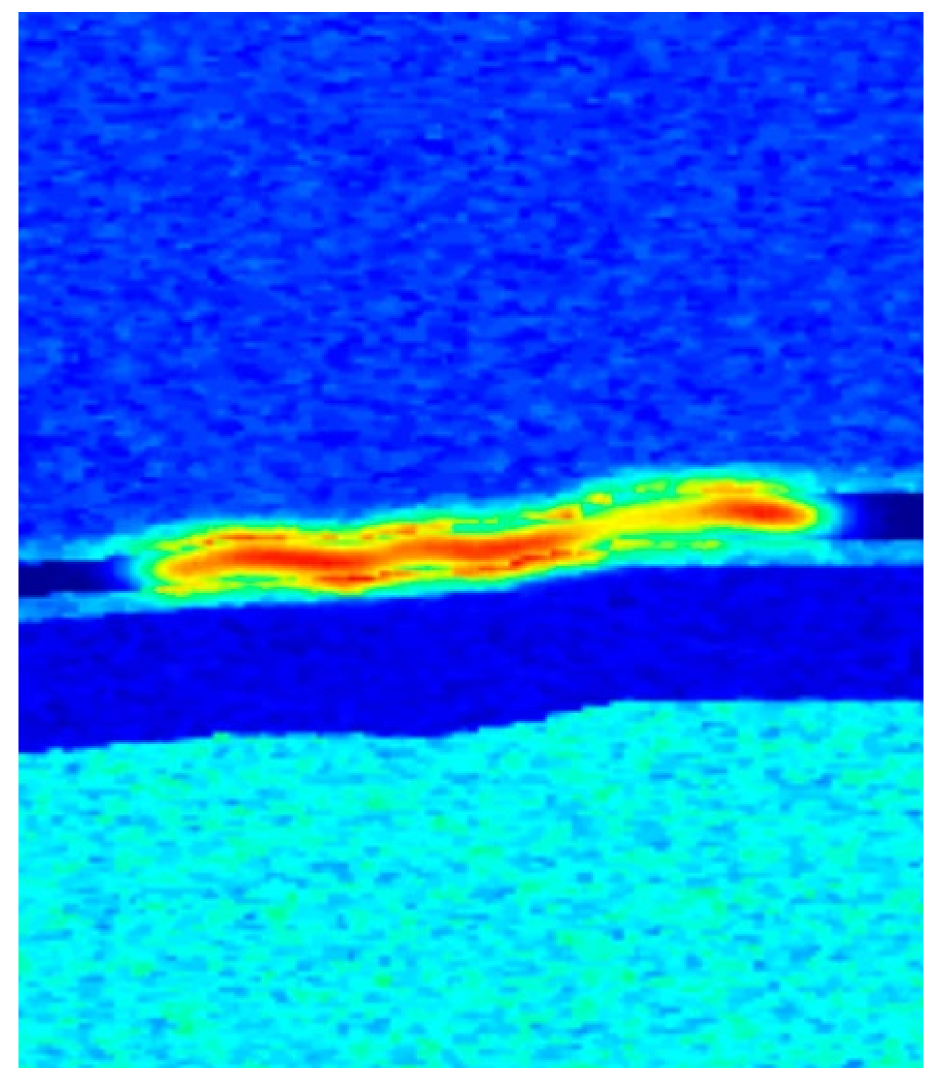
That is where a concept called machine learning comes in. Mineral explorers are interested in the geologic attributes that overlap in areas of known large deposits so that they can prioritize where to explore for the next economic deposit. The process of combining these layers to focus exploration would be easy if mineral deposits always had the same characteristics. But much like cows, mineral deposits are non-ideal. For instance, just because a gold deposit is associated with a high magnetic and a low gravitational anomaly does not mean that other deposits will be found in areas with similar characteristics, or that those signatures are unique to gold deposits. Rather than having a human sit down with 50 transparencies and examining overlapping attributes by eye (as was not so long ago a common practice), a computer can examine coincident attributes of many known deposits and learn the patterns associated with them, nothing short of artificial intelligence.

"Computers are good at learning these relationships," Eldad explains, "much better than humans are." Eldad writes programs that discover on their own what characterizes a deposit and searches for other locations that meet the same criteria. This delegation of judgment to artificial intelligence, used in conjunction with geologic context, will aid in satisfying humanity's increasing demand for resources.

Another facet of Eldad's scientific computing research focuses on imaging fluid flow. Whereas solid ore deposits are static (on human timescales), "there are a lot of problems that are not static." Eldad explains. "For example, saltwater intrusions are moving. Sometimes within mines you have water that is moving." Being able to image fluid flow at high resolution in real time is a powerful tool, especially for the petroleum industry. "In [the petroleum industry], they take CO_2 and inject it into the Earth. The CO_2 can displace the oil, and the oil is collected at the other side." Eldad explains. "The days where people drill a well and the oil comes out like you see in movies are gone," he smiles. Being able to image the motion of fluids like saltwater or petroleum provides immediate feedback on the technologies implemented to control and direct flow and ultimately improves them.

Very often, mineral and petroleum exploration problems deal with huge areas in three-dimensional space. Helicopter based geophysical assays are a common tool in the mineral exploration industry. These assays provide geophysical data over areas as large as 100 km by 50 km to varying depths resolved into 50 m^3 blocks. If for example a survey extends to 10 km depth, this results in 1 trillion cells. Each cell is in turn assigned a numerical value for each geophysical parameter measured by the helicopter survey, perhaps conductivity or magnetism. Performing even simple operations on that many cells requires enormous computing power, more than is available in most personal computers. Fortunately, many of the cells are generally similar, showing only slight oscillations around a mean value. In order to ease the computational burden, Eldad writes programs that combine very similar adjacent blocks while still preserving unique features. What makes this data compression challenging is determining how similar cells have to be before they can be aggregated; too much compression leads to a loss of interesting detail, while too little compression may not ease the computational burden by enough. Finding an optimal balance is critical to saving industry time and money.

Scientific computing is a powerful tool that can be applied to problems in everything from geophysics to biology. It is not, however, a substitute for the dedicated study required to improve our understanding of the world around us; models generated and patterns elicited by scientific computing are best interpreted in the context and theory of the discipline in which the problem lies. The amount of data amassed from diverse sources—geophysical assays, Internet searches, or otherwise—is in no sight of decline. So what is the next frontier? In short, collaboration and novel thinking. "It is us looking at all the quantities of data we're getting and then thinking 'what the hell can we do with this?'"



Left: A snapshot of computer simulated CO_2 flowing in an underground channel. CO_2 is used in the oil and gas industry as an extractive tool.

Maite Maldonado

Chuck Kosman, MSc Candidate Geological Sciences,
Thomas Aubry, PhD Candidate Geophysics

The microscopic organisms inhabiting the uppermost part of Earth's oceans play a vital role in the regulation of atmopsheric CO2. Characterizing the adaptations of these organisms in areas of low nutrients is vital in understanding and mitigating climate change.

What do director Alfred Hitchcock and the humble plankton that inhabit Earth's oceans have to do with one another? Maite Maldonado might be able to answer this riddle. However, Maite's university education began with neither film studies nor marine biology, but rather with agricultural engineering in her home country of Spain. After emigrating to North America to live in New York, she went north to Montreal to pursue her PhD at McGill University in her true love, biological oceanography. It was there that she began investigating the links between phytoplankton productivity and trace metals in Earth's oceans.

Phytoplankton aren't just a blue whale's lunch; though these oceanic photosynthesizing organisms may be just 5 microns in size (10x smaller than the width of a human hair), they represent Earth's largest sink for atmospheric CO_2 over the time scale of human lives. Furthermore, a remarkable sensitivity of their productivity to trace metals such as iron make phytoplankton a compelling target for scientists intent on mitigating the effects of anthropogenic greenhouse gas emissions on climate change.

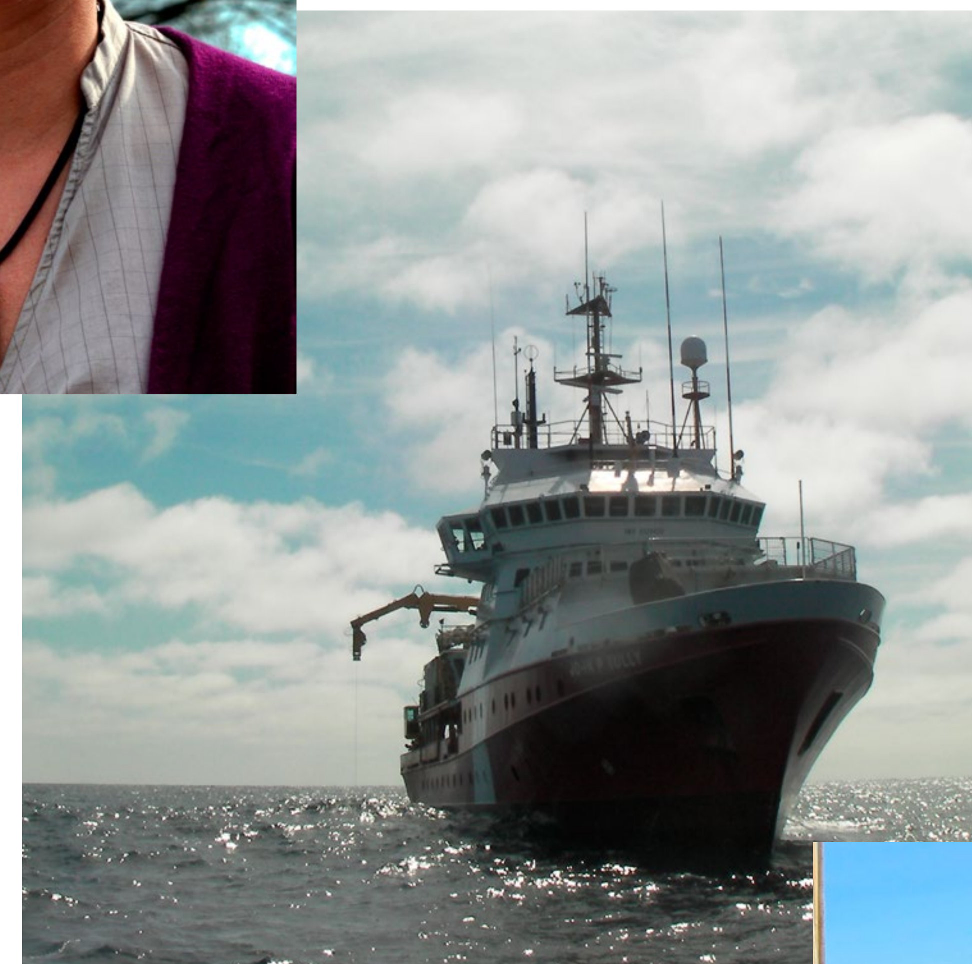
Iron is vital in biochemical reactions that provide energy for organisms—from plankton to humans and every creature in between—but its distribution is not uniform on Earth or in its oceans. "The most important source of iron to the open ocean is from atmospheric deposition," Maite explains. Patches of Earth's ocean far from dusty continents, the frigid Northern Pacific and Southern Oceans for example, contain almost no iron yet some phytoplankton. If there's no iron whatsoever, why should even one phytoplankton be found in these regions? How have these organisms adapted to low concentrations of essential nutrients? These questions were central to Maite's PhD thesis and continue to be in Maite's current research.

Some of these same regions depleted in iron are responsible for "deep water" formation, where cold and salty surface water is transferred to lower regions of the water column. CO_2 taken up by photosynthetic organisms in these regions therefore has the highest potential to be removed from the atmosphere permanently.

If you're thinking to yourself that fertilizing the ocean with iron to bioengineer CO_2 sequestration is the solution to humanity's climate crisis, you wouldn't be the first. Maite herself participated in the first iron-enrichment experiment in the Southern Ocean. The principle was simple; if one were to introduce iron at the ocean's surface, the subsequent growth of phytoplankton would result in a large CO_2 decrease in the upper ocean and in turn Earth's atmosphere. After enriching the ocean in iron over a 50 km^2 area, Maite and her colleagues observed an increase in phytoplankton concentration over an area of 1100 km^2 of up to a factor of ten, with local CO_2 decrease of 15%.

"It was a successful experiment. But, I wouldn't recommend it for climate engineering," Maite cautions. First, it isn't clear whether the carbon sequestered during an induced phytoplankton bloom is actually transferred deep enough into the ocean to be removed from the atmosphere over long enough timescales for average global temperatures to respond; only one of nearly ten past iron enrichment experiments have clearly shown that to be the case. More importantly, unanticipated consequences may occur when iron is artificially introduced to the oceans. Among other complications, a phytoplankton species that produces a deadly neurotoxin has bloomed in several past iron-enrichment experiments alongside other benign species of phytoplankton. This neurotoxin, called domoic acid, accumulates in the bodies of fish that eat these phytoplankton, in birds who eat these fish, and so forth across the complex oceanic ecosystem. In 1961, possibly due to a natural or anthropogenic iron-induced phytoplankton bloom, seabirds of the California Bay area flew into residents' rooftops and houses as a result of the effects of domoic acid; such display is said to have inspired the infamous avian horror, Alfred Hitchcock's *The Birds*. For these reasons, Maite has spoken out against iron enrichment experiments.

While iron has been established as key control on phytoplankton growth, Maite's current research focuses on the survival tricks that phytoplankton use in iron depleted oceanic regions. While iron is the ideal metal reagent in common biological energy producing reactions, it isn't the only option available. Maite has found phytoplankton in areas of low iron have been found to directly substitute other metals, namely copper, for iron. In addition to this direct substitution, Maite's work has shown that the phytoplankton who are efficient at uptaking iron in low iron regions rely on proteins that contains copper.

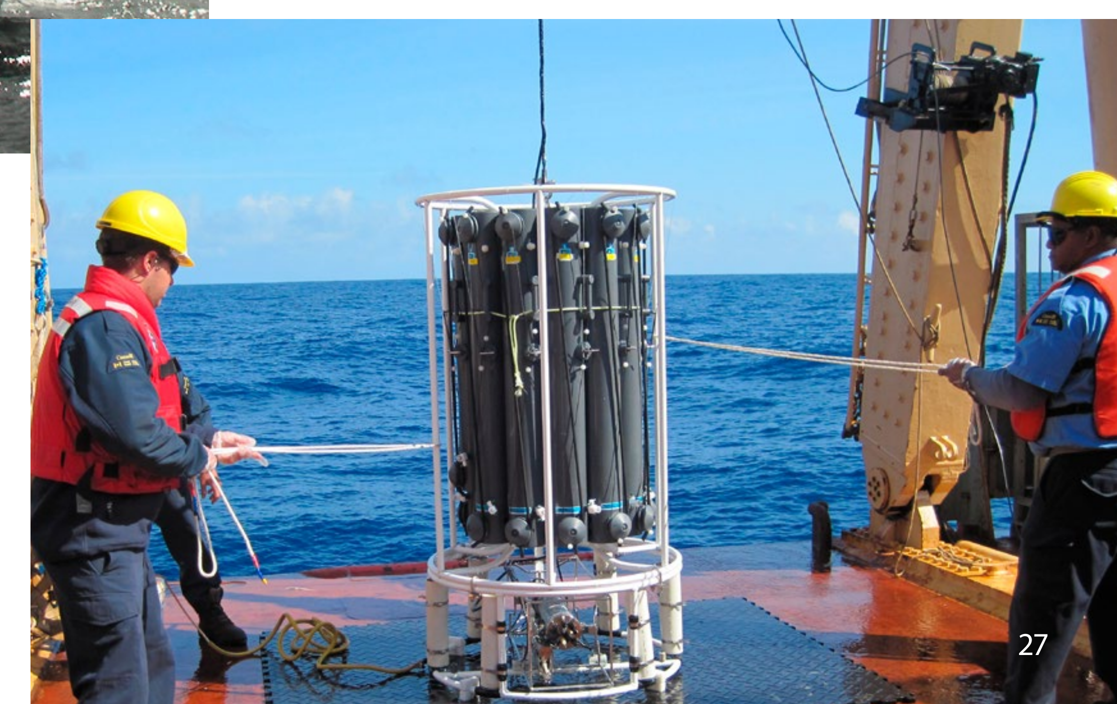


The dual utility of copper to phytoplankton comes as a bit of a surprise to the research community. "If you [were to] do a search on Google for copper and phytoplankton, 98% of the studies look at copper as a toxic trace element," Maite explains. "My lab, I think, for the last 10 years is sort of slowly changing the way people think about copper physiology and phytoplankton."

Working with organisms as tiny as phytoplankton requires technology with incredibly high resolution. In order to determine just how much of each trace element, including copper, is contained within a sample of seawater bearing phytoplankton, that water is filtered onto thin polycarbonate filters whose holes are just smaller than the cells. More impressively, the exact number of phytoplankton in a sample can be individually counted by using instruments that were originally developed to count red blood cells. The latest flow cytometers are laser-based instruments that allow phytoplankton to pass one by one through a tube while an incident laser light is shone on them. By examining the light scattering properties of the phytoplankton as well as the fluorescent frequencies emitted by the organisms, Maite can determine very accurately the size, number and phytoplankton species within a water sample.

The small size of the organisms isn't the only challenge in Maite's research. In order to quantify just how much copper phytoplankton uptake, Maite adds a radioactive isotope of copper to phytoplankton cultures as a tracer. The copper isotope is very short-lived, with a half-life of just 62 hours; virtually all of it decays within 10 days. The timing of research excursions to the open ocean must be carefully coordinated with the production and acquisition of the tracer, and many special precautions must be followed during research when working with this radioactive material. Furthermore, radioactive copper is not something produced and sold like other run-of-the-mill laboratory chemicals; it is produced especially for Maite by TRIUMF/Nordion, one of Canada's national laboratories for nuclear physics research located on the southern side of UBC's campus. "We're really lucky," she beams. "We are the only university in the world that has constant access to copper radioisotopes. I think we have an advantage to do a lot because it's very hard to study copper physiology without a tracer."

Examining the physiological adaptations of phytoplankton in regions where CO_2 has the best chance for sequestration in Earth's oceans is crucial in the context of climate change. Maite's ability to collaborate with TRIUMF/Nordion provides a unique opportunity to examine the role of trace elements on phytoplankton growth, and in turn their effect on atmospheric CO_2. Reversing climate change is clearly not as simple as loading iron into regions of deep-water formation, but phytoplankton's current contribution to mediating CO_2 is not to be overlooked. It seems phytoplankton aren't just for the birds after all.



Top:
Photo by Raja Yarra

Center:
The John P. Tully, an open ocean oceanographic science vessel in the Canadian Coast Guard, in the Gulf of Alaska September 2009. Photo by Christina Schallenberg.

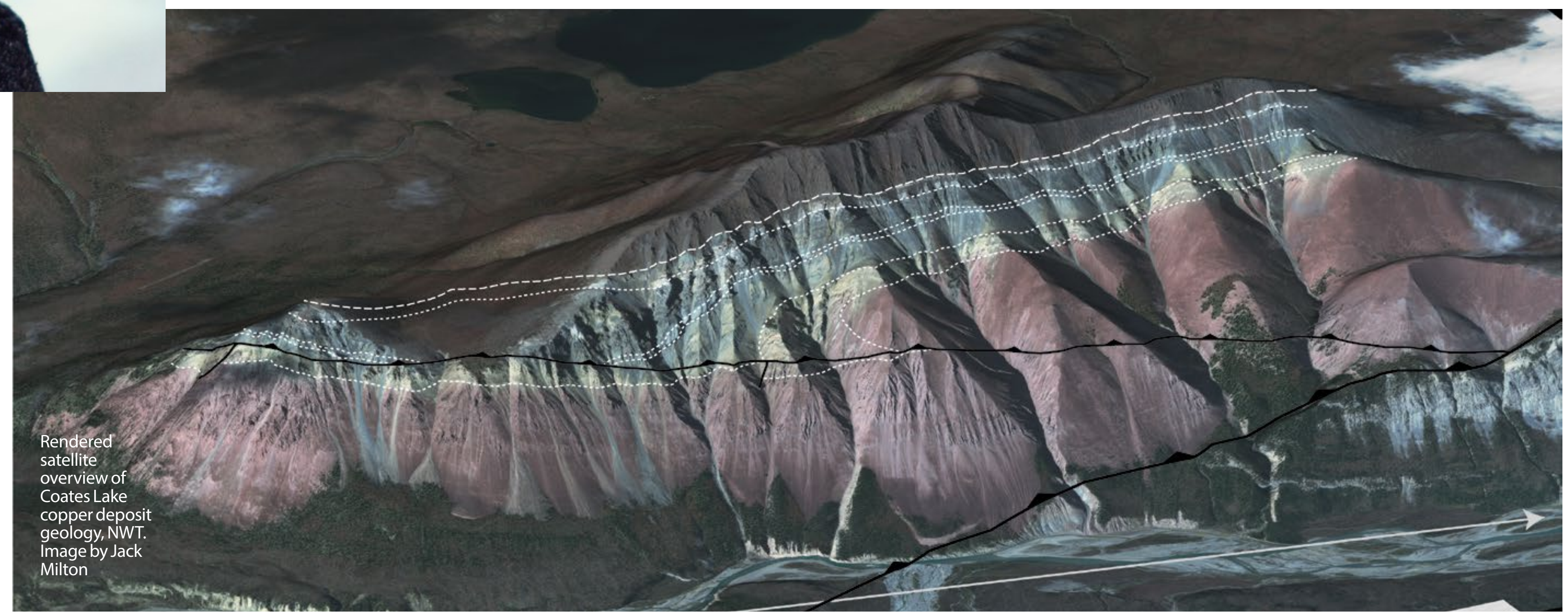
Bottom:
A seawater sampling rosette is retrieved by the sea by the crew of the John. P. Tully. This rosette holds twelve 12L bottles that can be triggered to sample water at specific depths. Special care is taken to prevent contamination of the rosette or bottles with rust from the ship. Photo by Nina Schuback.

Photo by Raja Yarra

Ken Hickey

Kate Le Souef, MSc Oceanography,
Anna Grau, PhD Candidate Geophysics

The key to discovering mineral deposits is understanding how they form. Ken Hickey and his team use innovative tools from a wide range of disciplines to piece together the geological history of gold and copper deposits throughout the world.



Rendered satellite overview of Coates Lake copper deposit geology, NWT. Image by Jack Milton

Minerals and metals have been a vital part of the history of mankind for thousands of years. Nowadays, the use of metals plays a major role in our society, with millions of tons of ore mined every year. As older deposits are depleted, more deposits have to be discovered to meet demand. This is the world of exploration geology, a world where geologists track what seem to be insignificant amounts of trace elements to lead them to deposits where the metal can even be invisible. This is the world of Kenneth Hickey.

Ken is a mineral deposit geologist who is particularly interested in the processes that form gold and copper deposits. He completed his BSc and MSc at Auckland University in New Zealand before moving to James Cook University in Australia for his PhD and a research fellowship. From 2000 to 2007, Ken worked as a Research Associate in the Mineral Deposit Research Unit at UBC and subsequently joined the faculty of EOAS.

The mineral deposits of most interest to Ken are hydrothermal deposits. These deposits are formed when hot, metal-laden water moves through fractured rocks. As this hydrothermal fluid flows through the rock, metals are precipitated from the fluid in "trap zones". Exploration geology consists of tracking down and finding these trap zones. The process of exploration requires tools and techniques from various fields within Earth sciences, as geologists collect any information possible to understand where fluids go and where they will deposit ore.

Ken's approach to exploration is particularly multidisciplinary, using field geology, structural geology, trace element geochemistry, isotopic analysis, thermochronology and geochronology.

"I am a geologist," says Ken, "and I use technologies that can help solve geological questions regarding the formation of mineral deposits."

Ken is interested in the controls, formation and origin of the fluids and deposit. His first approach to the study of a particular deposit includes developing geological maps of the deposit zone, determining structural controls of the deposit and field sampling. From the samples, the rock and mineral chemistry, isotopic ratios, and relative or absolute geological timing can be obtained.

Geological timing of a mineral deposit is an important part of understanding its formation. One technique used to time mineral deposits is thermochronology, which looks at the radioactive elements, like uranium, inside minerals that commonly host them, such as apatite. Uranium undergoes spontaneous fission and emits charged particles that tear through the mineral crystal, leaving linear tracks of damaged material. These "fission-tracks" can heal totally or partially with time and temperature, disappearing or shortening as the sample is heated. The low temperature (<100-150 °C) thermal history of a sample can be inferred from the number and length distribution of such fission-tracks. Under the right conditions, Ken has shown apatite fission-track thermochronology can be used to estimate not just the time at which a mineral deposit formed, but also how long it took to form.

One of Ken's current research interests is piecing together the paleogeographic and geological setting in which hydrothermal mineral deposits form. Trent Newkirk, one of Ken's PhD students, is currently undertaking such a study at Barrick Gold Corporation's recently discovered gold project at Cortez Hills, Nevada. Much of the gold at Cortez Hills is contained inside pyrite and is invisible to the naked eye, known as a "Carlin-type" deposit. Early prospectors overlooked these deposits because the gold is present in very low concentrations. However, their sheer volume means these deposits can actually contain huge volumes of gold. Some sources suggest these Nevada deposits contain up to 180 million ounces of gold, making them the second most well-endowed gold district in the world.

Ken explains that miners were so excited when they realized the potential of the Carlin-type gold in Nevada in the 1980s, they tore up the ground to get to it.

"The ground was literally made of gold," says Ken, "but in their haste to mine the gold, much of the geological information in the material above the deposit was lost."

The material that overlaid the deposit might have provided geological clues on how to identify other Carlin-type deposits hidden in the subsurface. Trent's PhD study of the Cortez Hills deposit included a unique opportunity to study the rocks covering the deposit prior to their removal for mining. Analysis of these rocks has contributed to a better understanding of the geological history of the deposit as it was brought closer to the Earth's surface by years of erosion. Trent's work will improve geological models used to explore for Carlin deposits in the subsurface.

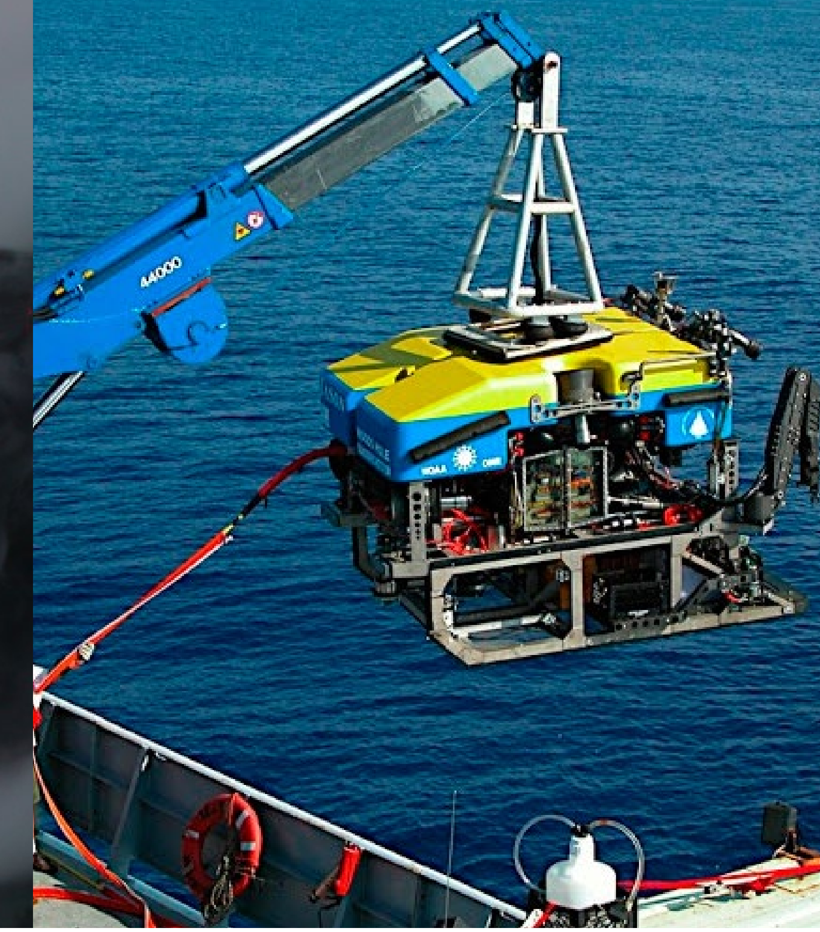
Subsurface exploration for mineral deposits requires a good understanding of their physical and chemical expressions far from the deposit so that exploration efforts can be focused into more prospective areas. Ken recently completed a large study looking at distal expression of Carlin gold deposits in Nevada. As part of that study Ken's research team showed that carbon and oxygen isotopes can be used to identify the distal most expression of the fluids that formed the deposits. During the project, Dr. Shaun Barker, a Postdoctoral Fellow in Ken's research team, developed a new desktop isotope analyzer that drastically reduced the operating costs of running isotopic analysis on field samples and allowed Ken's team to analyze 50-80 samples a day, where previously they could only analyze a few samples per week. Partly as a result of this work, isotopic analysis is now becoming more frequently used in exploration to better identify the location of new gold deposits in the subsurface.

Another of Ken's research interests is understanding the tectonic and hydrological setting of sedimentary copper deposits. Similar to his gold work, Ken uses a multidisciplinary approach to study the geological history of sedimentary copper deposits. These deposits form in sedimentary basins when brines containing copper within buried sediments rise and precipitate copper and other metals. Ken seeks to characterize the hydrothermal flow of known copper deposits to determine the basin wide setting of the deposit and therefore detect similar deposits at other locations. Another of Ken's PhD students, Jack Milton, is currently working on this question in the Redstone Sedimentary Copper Belt, in the remote eastern Mackenzie Mountains, Northwest Territories. This belt is one of the largest and least explored sediment-hosted copper deposits in the world. Jack's project includes fieldwork in remote mountain locations, surrounded by wolves and bears. Taking precautions against wild animals is just one element of the fieldwork required to study these giant copper deposits. Geological mapping of the region, geochronology and geochemical sampling are helping Ken and Jack gain an understanding of how and when the copper was deposited.

In the future, Ken hopes to incorporate any relevant emerging technology into his research. By combining tools from many different fields, he aims to gain a better grasp of how mineral deposits form in the hopes that this knowledge will lead to new mineral discoveries.

Dominique Weis

Above:
Dominique in front of the Nu 021 MC-ICP-MS device pipetting a sample for isotopic analyses.



Left:
Pu'u O'o lava (Kilauea volcano) entering the ocean, October 2002.

Right:
Retrieval of remotely operated vehicle Jason II onboard the Thomas Thompson - Mauna Loa, HUGO expedition in 2002.

Thomas Aubry, PhD Candidate Geophysics,
Johan Gilchrist, BSc Geophysics

Using isotopes to trace the origin and history of materials is a powerful tool in the Earth sciences and beyond. The precision afforded by cutting edge instrumentation at PCIGR combined with interdisciplinary opportunities delivers diverse world-class research.

What did Dr. Dominique Weis want? It took her a while to figure it out, but she is now director of the Pacific Centre for Isotopic and Geochemical Research (PCIGR), a unique analytical facility supported by a team of highly trained staff for the use of researchers, graduate and undergraduate students specializing in geochemistry. Using state-of-the-art instruments, they are working on projects ranging from the composition of the deep Earth to the source of high cadmium levels in BC oysters. Adding a mutually beneficial partnership with industry, a national student training program and over a hundred publications results in one of the top geochemical facilities in the world - and a lot of work for Dominique.

Initially, Dominique was not sure what she wanted. During her education in Belgium, she was constantly searching for a path, studying a variety of subjects such as law, mathematics, geography, geology and oceanography before settling with geochemistry. She first visited Vancouver in 1998 to attend the Conference on Multiple Platform Exploration discussing the future of scientific drilling in the oceans. She immediately fell in love with the city and secured a position at UBC in 2002. She has come a long way since then and was nominated for the American Geophysical Union fellowship in 2010, "for the elegance, precision and impact of her geochemical studies of the Earth from large igneous provinces to the environment."

Precision and accuracy are of utmost importance in geochemistry. Imagine you are given a handful of rice where the average weight difference among the grains is only one percent. Now you are tasked with the job of finding the heaviest grain. Substitute atoms for the rice grains and you have entered Dominique's world. The main goal of geochemistry is to exploit the differential mass, optical and thermal properties of atoms in order to distinguish and quantify their abundances in different materials. The ratio of heavy to light isotopes, that is atoms having equal number of protons but different number of neutrons, can be used to "fingerprint" different materials as well as determine their age. Isotopic analysis revealed the age of the Earth in 1956—about 4.5 billion years old.

Dominique and her team applied isotopic analysis to Hawaiian volcanic rocks and documented the existence of two distinct geochemical trends over 5 million years. Known as the Loa and Kea trends, these fingerprints suggest that the lava pouring out of Hawaiian volcanoes originates from two distinct sources in the Earth's deep mantle, a feature that seems to be also observed on other oceanic islands around the world.

Dominique is a detective and not only in the field of geochemistry. "I like applying geochemistry to other things" she proclaims. An example can be found in the field of environmental sciences where she investigated, with one of her students Dr. Alyssa Shiel and Kristin Orians, the source of excess cadmium in British Columbian oysters, an industry that is of critical importance for Aboriginal communities. The source turned out to be natural, associated with the upwelling deep ocean water off the coast of BC. Excess cadmium was also found in some of the best oysters from the French Garonne river system, a consequence of heavy industry in the past.

"I like the fun of science, decrypting interesting problems, and using amazing analytical instruments to decipher processes and pathways, almost like a detective."

While the rain in Vancouver helps to settle the dust, the fight against contamination never ends for the PCIGR staff. They are responsible for the sticky blue mats found at every entrance to EOS-Main, which catch dirt before it reaches the laboratories of the PCIGR. Some of the instruments of the PCIGR are housed in Class 1000 cleanrooms, which means the particle concentrations have to be less than 1000 particles per cubic metre—a thousand times cleaner than the outside air! This requires sample preparation rooms that fit the stereotype of a science lab with workers dressed from head to toe in white suits. Simply reaching or talking over a sample can ruin it.

It took Dominique five grant proposals over ten years to receive proper funding for the facility, but this is still not enough. User fees collected from industry, government agencies and the academic community are essential to support the PCIGR. An R&D partnership with Nu Instruments, the manufacturer of PCIGR's Nu Plasma 1700 mass spectrometer, only the fifth of its kind in the world, provides PCIGR with the latest analytical developments in mass spectrometry while PCIGR gives Nu Instruments feedback to improve performance, design and sensitivity of the instruments. Despite the connection with industry necessary in the Canadian system, Dominique reiterates that, "the PCIGR is a research driven facility," and she would like to collaborate with scientists from other fields such as medicine, forestry and anthropology.

Just as in research, Dominique strives for excellence in training and mentorship. Diane Hanano, the Program Coordinator for the Multidisciplinary Applied Geochemistry Network (MAGNET) and a former student of Dominique's shares this belief. "PCIGR places emphasis on training students: they are the next generation of researchers." Each year, the MAGNET program attracts trainees from all over the world to the Universities of British Columbia, Toronto, Ottawa, McGill and Quebec. Diane completed her master's degree under Dominique's guidance in 2008 and after working in industry for a few years Dominique offered her a job to help expand the PCIGR. She noted that Dominique also takes on many undergraduate research assistants, placing a high priority on ensuring students get to go through the whole process of geochemical analysis.

In addition to research and training, Dominique is passionate about societal issues, in particular gender equality in the sciences. She participated in a 2000 European Commission report entitled, "Science Policies in the European Union: Promoting Excellence through Mainstreaming Gender Equality," which concluded at the time, "women constitute half the undergraduate population. However, there is a continuous drop in the numbers of women at each level of the academic ladder and many highly trained women are lost to science." Despite some attempts to address this issue, the problem remains, so the fight is not over for her.

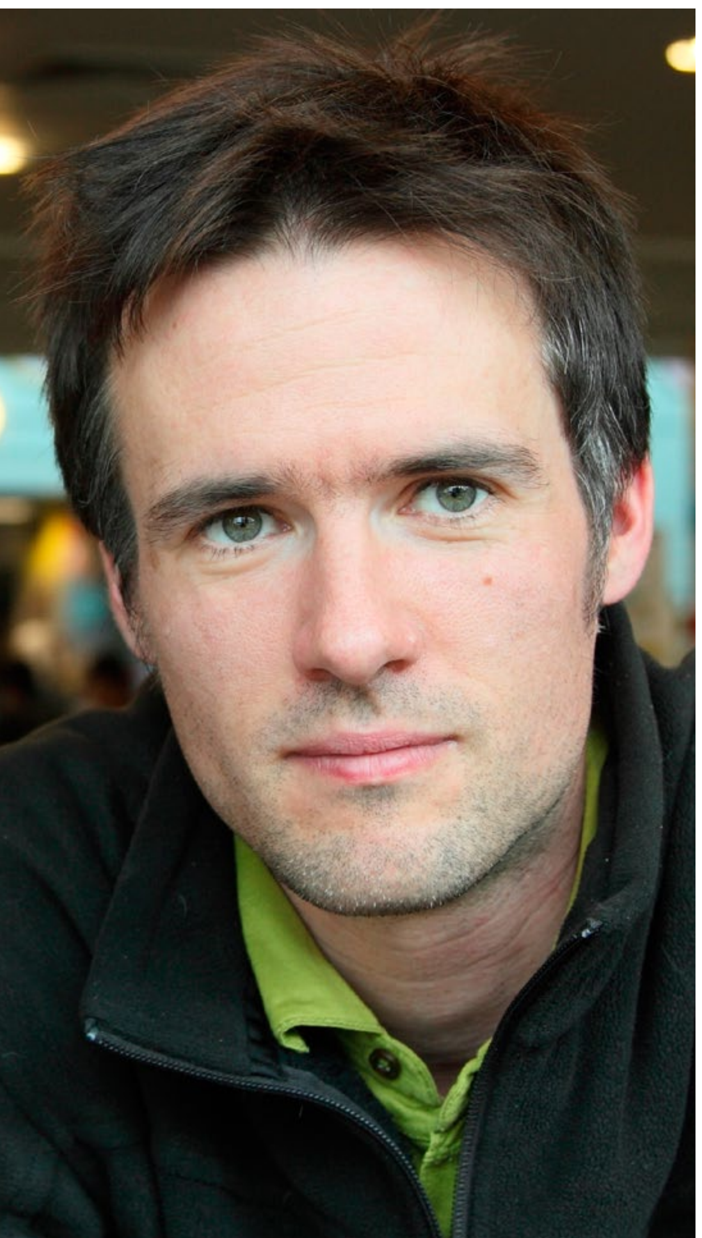
In a broader sense, Dominique feels that if scientists wish to see changes in societal issues like gender equality, climate change and environmental protection, they have a responsibility to speak out. To students and young scientists: "Don't rely on patterns or rules too much, do what you believe in, do what you enjoy doing, and be very good at it. If you are good, you'll achieve what you want and will have all the chances to realize your dreams."

Check out Dominique's research photos at:
http://www.eos.ubc.ca/personal/weis/photos-work.shtml
http://www.eos.ubc.ca/personal/weis/photos-public.shtml
https://picasaweb.google.com/111283684784795490034?noredirect=1

Christian Schoof

Anna Grau, PhD Candidate Geophysics,
Nikolas Matysek, BSc Geology

Extreme north and south latitudes of Earth are home to large volumes of ice. Due to positive feedback mechanisms, the rate at which an ice sheet disappears is strongly controlled by fast the sheet moves and thus the friction present at its base.



A figure in a blue jacket and helmet on a bike comes peddling through the morning mist. With no hurries, he appears to be interested by everything. Behind his ostensibly calm observation of his surroundings, Christian Schoof is mulling over nature far away—the fate of ice within Earth's polar regions.

Fluids flow downstream under the effect of gravity, and ice is no different. Depending on their size, ice masses can be classified as either mountain glaciers or ice sheets. The former are accumulations of ice and snow near topographic highs that flow like a viscous river. The latter are large accumulations of ice, covering areas of more than 50,000 km^2 to the depth of a few kilometers. Ice sheets accumulate snow at the high altitude zones within their centers. Similar to mountain glaciers, they too flow to the edges of the underlying continent where they eventually melt or fragment apart.

A large part of Christian's research is devoted to building understanding of how ice sheets flow. The speed of an ice flow is dependent on the friction between the ice mass and the underlying bedrock. Friction at the rock-ice boundary is greatly influenced by the presence or absence of water. Whereas the flow is sluggish for dry contacts characteristic of many areas of Antarctica, glacier motion is enhanced where a layer of water lowers friction at the base and lubricates the interface.

It is the wet contact scenario that interests Dr. Schoof, as it is the more effective mechanism of transporting ice away from ice sheet centers and causing their apparent retreat. Generally, the more water at the interface, the faster the flow of ice over the bedrock. He has proposed a new scenario where it is not the amount of water under the ice that matters, but the way in which that water flows. Squeezed under the weight of the ice, the water can drain out in two different ways (water is unlike many materials in that it turns to liquid under *higher* pressures—the same phenomenon that makes ice skating possible). In the first case, water drains out along channels and does not lubricate the contact. In the second case, water flows slowly in a system of shallow surface pools just beneath the ice. In this case, water flows much less efficiently and lubricates the base of the ice sheet, accelertating the flow rate of the ice mass. The type of drainage system developed depends on three things: the amount of water at the base, the water pressure, and the flow intensity. Adding meltwater to the base of a dry glacier will lubricate the ice up to a threshold. When the water flux exceeds this threshold, water will melt the ice to form channels leading to rapid drainage of the lubricating water and recovery of an effectively dry contact. Thus, whereas some water enhances glacial flow, too much can cause this flow to stall.

These contrasting flow regimes can explain the enigmatic behaviour of the Greenland Ice Sheet. The polar circle in the Arctic is humid and receives plentiful precipitation. Water then diffuses towards the bottom of the ice sheet and drains out either in form of channels or cavities. Depending on the season and the amount of meltwater, the ice flow rate may accelerate or decelerate.

The balance of precipitation and melting rates determines whether and ice sheet grows or shrinks in volume. Intuitively, an ice sheet will shrink if it melts at a faster rate than precipitation can keep up. In addition, reduced precipitation can lead to positive feedback in which continually less and less snow accumulates. For example, an increase in temperature raises the elevation where rain falls instead of snow, hence decreasing the total area where the ice sheet is replenished. The ice sheet continues to flow during this time, decreasing the size of the ice sheet. As the ice sheet shrinks, the area above the snowline decreases, in turn causing even faster retreat. Greenland is currently entering this feedback cycle, which according to Dr. Schoof will decrease the stability of the ice sheet over the next hundred years. This instability does not mean that the ice sheet will disappear in a hundred years. However, with the current rate of climate warming, Greenland will pass a point of no return such that its ice sheet may disappear irreversibly.

Antarctic ice sheets present a different situation to those of Greenland. There is significantly less precipitation over Antarctica and as a result the bedrock is much drier. Without effective lubrication, its ice sheet doesn't flow as quickly. For this reason, Antarctic ice sheet mass loss is confined relatively small areas in warmer, lower latitudes.

Additionally, the amount of ice flowing into the ocean is mitigated by the presence of ice shelves, or ice protruding into the ocean that is still connected to the continental ice sheets. These shelves serve as physical restraints to ice flowing completely off the continent and breaking off into the ocean. For this reason, one of the concerns in the context of climate change is the disappearance of entire ice shelves. Such a scenario could cause runaway feedback woes similar to those of Greenland.

Christian's ongoing fieldwork has focused on the nature of the ice-continent interface and its implications on ice flow speed. Currently, Christian is studying in detail a glacier on Mount St. Elias in the Yukon. The small, mountain glacier of about 500 km^2 cyclically changes flow speed over short timescales. Christian hypothesizes that the change in flow speed is caused by preferential formation of either cavities or channels. Initially, the glacier is not flowing fast enough to account for the snow input at the top of the mountain, so it increases its mass by thickening. It then suddenly switches to a flow where it flows much faster than its steady state flow. It starts to thin, until switching back again.

The measurements carried out by Christian's team consists of drilling holes to the base of the glacier to determine the amount of water and its pressure at the bottom of the ice. Precision GPS measurements allow assignment of the pressure reading to the exact position at which it was taken. They can then relate the amount of water under the ice to its pressure and how it influences the movement of the glaciers.

Global climate change has provided a new impetus for Christian's research. By understanding the nature of ice flow, we can better predict and mitigate the effects of a warmer climate. Areas with ice sheets at risk of lubricated surging should be of special importance as an unstable glacier can have a profound impact on those that depend on it.

A surface stream cascades over the edge of a large sink hole on a glacier and eventually reaches the glacier bed, where it can affect the sliding speed of the ice.

Photo by Gary Wagner

Catherine Johnson

Kate Le Souef, MSc Oceanography, Anna Grau, PhD Candidate Geophysics, Emily Botlon, BSc Geology

Earth is a rocky planet, thought to have formed from the accretion of asteroids early in its history. Scientific collaboration on the upcoming OSIRIS-REx mission to the Bennu asteroid will shed light on the origins of Earth and the other terrestial planets.

Catherine Johnson is a planetary geophysics professor in EOAS, but when she's not spreading the wonders of space to our undergraduate classrooms she keeps busy working on three NASA missions. Catherine is currently involved in the Mercury MESSENGER Mission, modelling and studying Mercury's internal magnetic field. She is also participating in the Mars InSight Mission set to launch in 2016, which aims to understand Mars' internal structure and the disappearance of its magnetic field. The InSight lander, capable of drilling into the planet's surface, will collect the first seismic information taken from another planet. Catherine has also recently begun work on the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) New Frontiers Mission. This mission is an exciting next step for Catherine who notes, "It's the first time I've been involved in a mission so far before launch."

OSIRIS-REx is a drastically different from planetary missions like MESSENGER and InSight. The main objective of this mission is to retrieve a sample of unconsolidated surface material from a near-Earth asteroid, 101955 Bennu, no more than 500 meters in diameter.

Asteroids are thought to be pieces of planetesimals which, rather than developing into full size planets, broke into fragments. As a result, the early state of our solar system may be frozen in these small bodies. Bennu is a dark, carbon-rich asteroid found in the asteroid belt between Mars and Jupiter. Bennu's proximity to Earth makes it accessible for direct sampling, though the same proximity provides the possiblility of collision with Earth. Studying the Bennu's orbit researchers will be able to better predict the trajectory of potential impactors.

By retrieving a sample from Bennu, the OSIRIS-REx team expects to learn more about the composition of asteroids and their formation, for instance whether they are a uniform, solid body of rock or more heterogeneous. The sample could also provide clues about the formation of the solar system and the origin of organic compounds that are the basis of life.

A unique challenge of working with asteroids is that gravity is incredibly weak, a mere fraction of that of the planetary bodies Catherine has worked on in the past. "Your intuition is so gravity central. Thinking about operations in an environment where gravity will only be important really, really close to the surface is just so different," Catherine explained. For example, if surface dirt is stirred up before the spacecraft successfully obtains its surface sample, the material won't settle and could interfere with subsequent attempts.

Though the OSIRIS-REx team involves a few geophysicists like Catherine, the science of the mission is focused on the mineralogical composition, morphology, and geochemistry of the asteroid. The role of geophysicists is to produce detailed maps of the asteroid's surface during mission operation to support sample collection. After 2 years of travel time, the spacecraft will arrive at Bennu and will orbit the asteroid for a 6 month reconnaissance period in order to map the global properties of the asteroid such as topography and composition. From topographic measurements collected during this period, Catherine and her teammates will create a 3D shape model of the asteroid. This model will be used to select a location on the asteroid's surface where a sample will be collected. Catherine contributed to shape modelling for the MESSENGER Mission but with OSIRIS she will be one of the lead investigators.

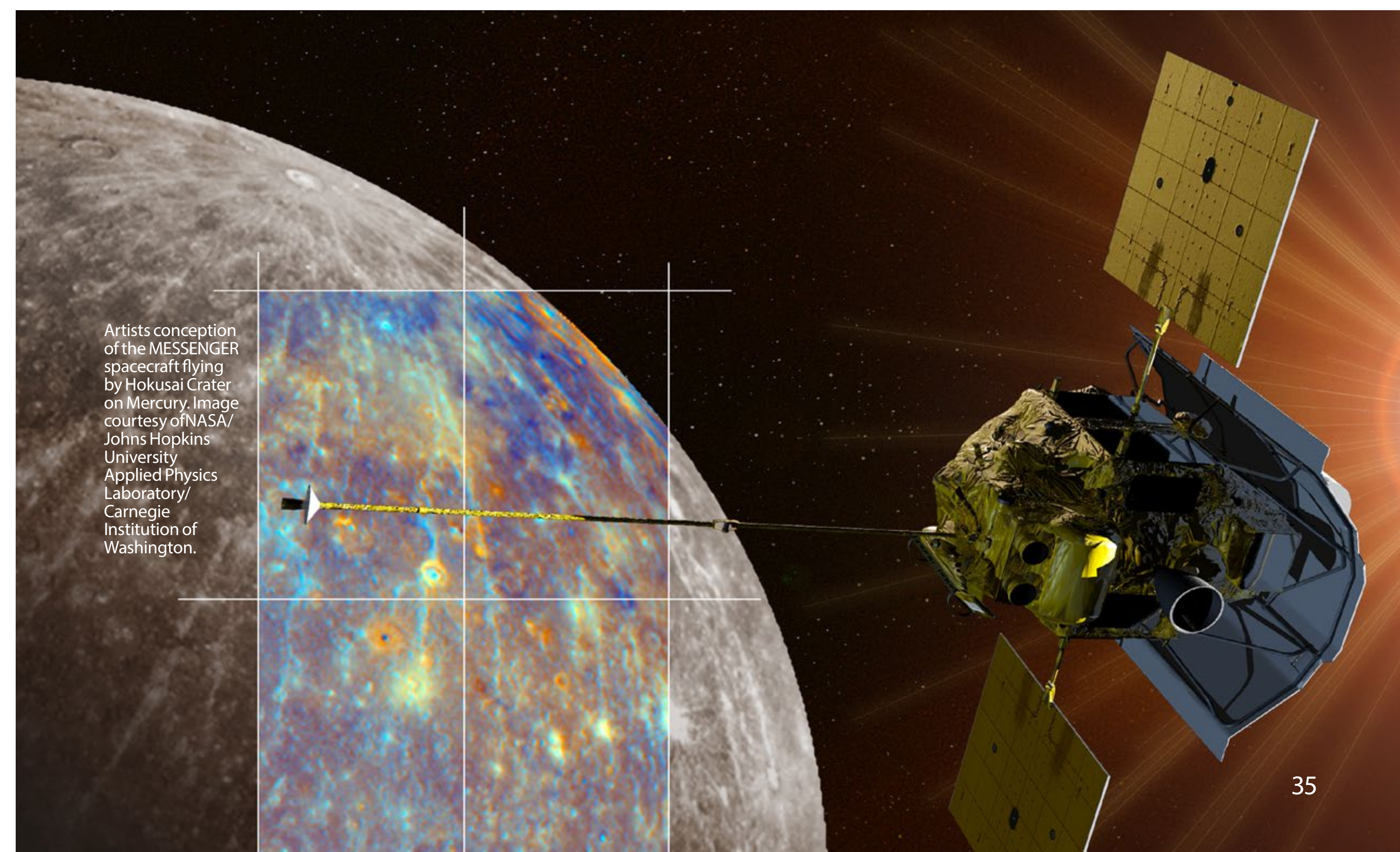
Once a sampling site has been selected, the spacecraft will be navigated slowly toward Bennu and will reach out a robotic arm to scoop up a sample of surface material, or regolith, without landing. The aim is to retrieve about 60 grams of this regolith material to bring back to Earth for the first detailed analysis of pristine carbonaceous asteroid material. Catherine's research will also involve working with the sample itself. She will investigate its magnetic properties to identify magnetic minerals and determine the composition of the material. As part of previous lunar research, Catherine performed similar analysis of samples from the moon.

One of the key tools for mapping the surface during the 6 month reconnaissance period is the OSIRIS-REx Laser Altimeter (OLA). This instrument is Canada's contribution to the mission and its development is being overseen by Dr. Michael Daly of York University. OLA's primary purpose is to provide Catherine and other scientists with the data needed to create a high resolution 3D model of the surface. Catherine and 4 or 5 other scientists are responsible for the processing and interpretation of this altimetry data. The laser altimeter provides elevation data by shooting laser pulses at the surface and measuring the time it takes for reflected rays to travel back to the altimeter. OLA provides elevation data as a series of point measurements in 3D space.

Catherine, Michael Daly and other scientists are currently working together to decide how best to process the raw data into a shape that accurately represents the surface of the asteroid and formatting of the final product. All the researchers come with their own code, software and format they use for shape modelling and the team must come to consensus on a method for analyzing the OLA data. The data processing must be seamless by the time the spacecraft is orbiting the asteroid and collecting data, because safe sampling depends on the accuracy of this model.

Shape modelling begins with a cloud of data points, the raw data provided by the altimeter. The first step in data processing for Catherine and the OSIRIS team will be to calibrate this raw data to account for reflectivity and other effects. Then, in order to turn the calibrated point data into a surface, the team must then decide how they will determine tilts and slopes that characterize a 3D shape.

With just over 2 years until the spacecraft launches, the OSIRIS-REx team will continue to refine and improve their data processing techniques for the mission. If all goes according to plan, OSIRIS-REx will successfully return a pristine sample of primitive asteroid thanks to maps produced by Catherine and the small team handling the altimetry data.



Artists conception of the MESSENGER spacecraft flying by Hokusai Crater on Mercury. Image courtesy ofNASA/ Johns Hopkins University Applied Physics Laboratory/ Carnegie Institution of Washington.

Sean Crowe

Anna Grau, PhD Candidate Geophysics,
Kate Le Souef, MSc Oceanography,
Emily Bolton, BSc Geology

Analysis of chromium isotopes in ancient soils indicate Earth's atmosphere was relatively oxygen rich 600 million years eariler than previosuly thought. This observation has far reaching implications in interpreting the origins and rise of photosynthetic organisms.

Today's oxygen-rich atmosphere depends on the activity of photosynthetic organisms that emerged over 3 billion years ago. Chemistry at the surface of the Earth changes as life evolves and in turn drives the evolution of life. The composition of the atmosphere is one of the largest-scale and most fundamental influences life has on Earth surface chemistry. This coevolution of life and Earth's surface chemistry is the focus of new hire Sean Crowe's research.

Sean came to UBC just over a year ago on a cross appointment between the Department of Microbiology and Immunology and EOAS. Upon arriving at UBC, he went to work studying the behaviour of chromium isotopes in ancient soils, called paleosols, from South Africa. The chemistry of chromium is sensitive to the amount of oxygen in its presence. Remarkably, Sean and his colleagues discovered the distinctive fingerprint of oxidative weathering in a 3 billion year old paleosol sample, which requires that the photosynthetic microorganisms responsible for producing oxygen appeared 600 million years earlier than previously thought. This re-timing of the rise of oxygen has major implications for our understanding of the early evolution of life and the evolution of the atmosphere.

The path to this discovery began in Indonesia where Sean and his colleagues were looking at chromium ions in order to address a very different problem. Chromium occurs naturally in the environment in two common states, chromium III and chromium VI. While chromium III is non-toxic and insoluble, chromium IV is a carcinogen and easily dissolved into water systems. Southeast Asia is one of a number of places around the globe with high levels of naturally occurring chromium.

Naturally sourced chromium comes from iron and magnesium rich rocks formed deep beneath the Earth's crust. These rocks contain chromium in its non-toxic form. However, when they are uplifted from depth and exposed at Earth's surface, harmless chromium III is oxidized into toxic chromium VI. Sean's research in Indonesia was focused on identifying ways to promote the natural attenuation of toxic chromium VI back into its non-toxic state, chromium III.

This research brought Sean to looking at chromium levels in a suite of 4 million year old lakes. Deep tropical lakes like these aren't stirred by seasonal changes in air temperature and consequently, do not mix like Canadian lakes where cooler air temperatures cause oxygen rich surface waters to become more dense and to sink to the bottom of the lake replenishing the oxygen supply. Because low latitudes don't experience drastic temperature changes, tropical lakes can be permanently stratified with low levels of oxygen at depth and high levels near the surface where it is continually replenished by the atmosphere.

The change in oxygen concentration with depth means the concentration of chromium as either chromium III or chromium VI also changes with depth. Sean's group found that the chromium VI, the oxidized state of chromium, was at higher concentration near the surface of the lake and had low concentration at depth.

This relationship between chromium concentration and atmospheric oxygen levels was the first hint that chromium analysis might be a way to track the progressive oxygenation of the atmosphere. At the same time Sean's group was working in Indonesia, their colleagues were looking at chromium isotopes in banded iron formations (BIFs). BIFs are ancient rocks that deposited when oceans were largely anoxic. Sean's colleagues found that the changes in chromium isotopes in BIFs over time were linked to the timing of atmospheric oxygenation. This evidence solidified chromium isotopes as a potential tool for studying the oxygenation of the atmosphere.

There was one last part of Sean's research in Indonesia that lead him to analyzing chromium isotopes in paleosols. When analyzing chromium levels in the ancient lakes, Sean's group also measured chromium isotopes in soils around the lake. From comparing chromium measurements from the soil with chromium measurements from the lake water, it was clear the lake was simply recording the signal that originally developed in the soils. This pointed to soils as the source of information about oxygen in the ancient atmosphere.

Sean was interested in the ancient atmosphere so he needed ancient soils. Fortunately for Sean, Nicolas Beukes of the University of Johannesburg had discovered a 2.2 billion year old paleosol around this time in South Africa which coincided well with other indications for the onset of large scale atmospheric oxygenation, the so-called Great Oxidation Event. When Sean and his Danish colleagues ran analyses on the 2.2 billion year old paleosol, they found the same chromium isotope signature he'd seen in modern oxidized soils in Indonesia. The similarity of this paleosol to modern soils confirmed the sample post-dated the Great Oxidation Event. In addition to the 2.2 billion year old paleosol, Nicolas had also discovered a 3 billion year paleosol sample, supposedly pre-dating the oxygenation of Earth's atmosphere. Sean got obtained these samples intending to use the 3 billion year old paleosol as a benchmark for what chromium isotopic signatures look like under anoxic conditions. It came as a bit of a surprise when this sample's chromium isotopic signature was consistent with fractionation in an oxygen-bearing atmosphere. Sean and his Danish colleagues ran the analysis again (and again), each time determining the same isotopic signature. In order to explain the fractionation of chromium isotopes in a 3 billion year old sample, there must have been appreciable oxygen hundreds of millions of years prior to our dating of Great Oxidation Event.

Seeing as the 3 billion year old paleosol sample was only the width of a drill hole (a few cm) and soils form locally, it could not be assumed to be regionally representative. To determine whether this oxygenation was a local or regional phenomenon, Sean's group turned to marine sediments, BIFs. If atmospheric oxygenation occurred on a regional scale, these oxygenated soils would have been weathered and carried downstream to the oceans and their oxygen-indicating chromium isotopic signature would also be conferred to the marine sediments. Sure enough, an isotopic analysis of marine sediments confirmed that oxygenated chromium was cycling through the environment at a regional scale 3 billion years ago. To gain additional confidence in this observation, they also studied other oxygen sensitive metals like uranium and these additional analyses confirmed the presence of oxygen.

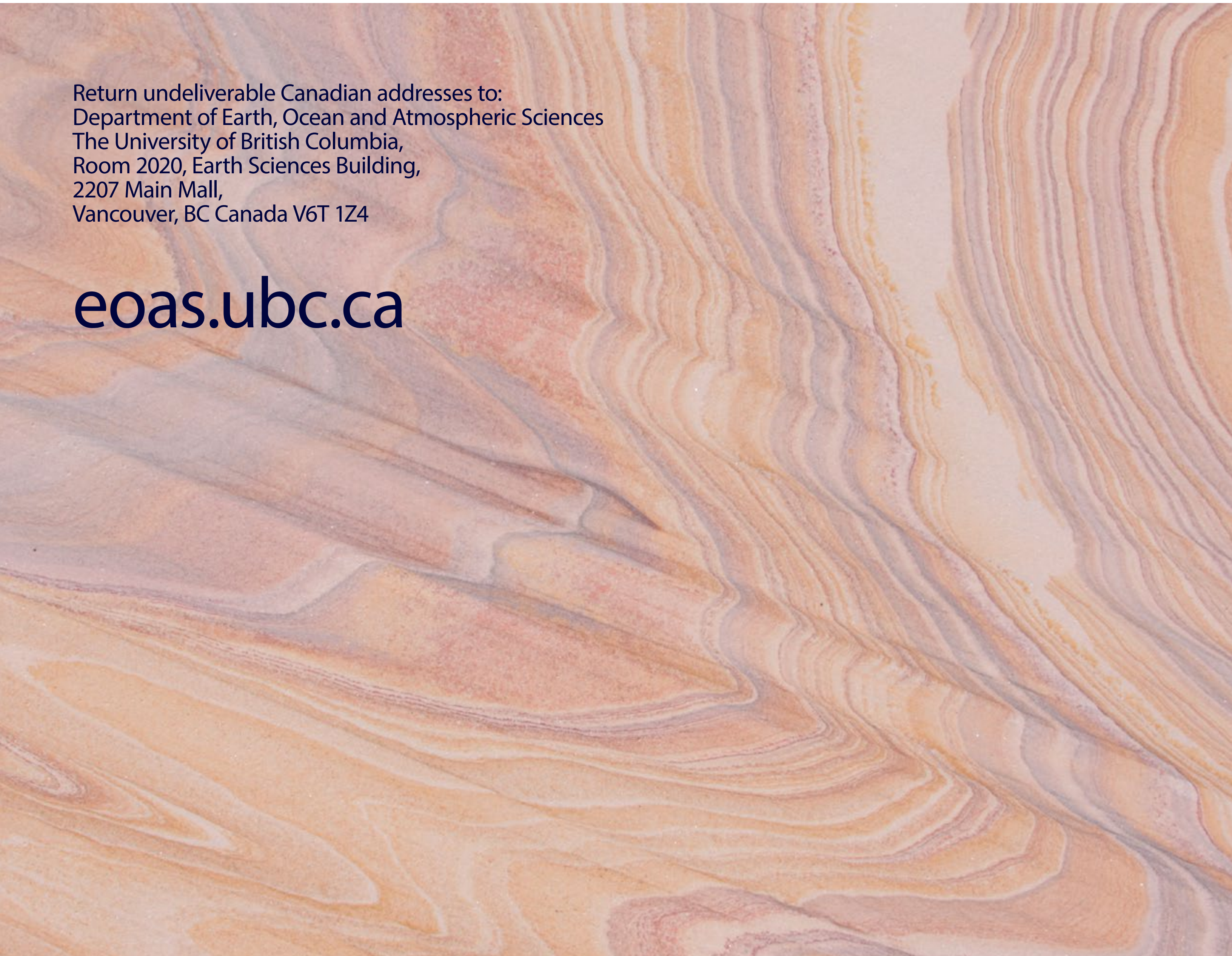
By this point they were confident about the presence of oxygen in the atmosphere. The next question was how much oxygen was present at this time? To get an answer Sean's group considered ferrous iron (iron II) which is released into the environment by the weathering of continental rocks. Like chromium, iron also exists in rocks as unoxidized, iron II, and oxidized, iron III, states. The unoxidized state, iron II, reacts with chromium IV to reform insoluble chromium III. So for chromium VI to appear in the ancient oceans for deposition in BIFs, the river runoff must have been free of iron II, otherwise the chromium VI would have deposited in terrestrial environments before entering the ocean. For iron II to be absent in the runoff, there must have been enough oxygen in the atmosphere to oxidize all the iron II produced by the weathering.

Based on rates of continental uplift, Sean's group could estimate continental weathering rates and thus get an approximation for how much iron II was being released into this ancient environment. Sean determined the minimum concentration of atmospheric oxygen needed to use up all the iron II being produced was about one ten thousandth of present oxygen levels.

Though small amounts of oxygen can be produced through non-biological reactions in the atmosphere, atmospheric models suggest the maximum concentration of oxygen these reactions could've produced is only *one billionth* of present levels. "This tells us that by 5 orders of magnitude, we can be certain that biological oxygen production was happening 3 billion years ago,"Sean states.

The presence of biological oxygen in the atmosphere 3 billion years ago significantly changes our understanding of early life as oxygen-producing cyanobacteria may have evolved 600 million years earlier than previously thought. Many aren't sure what to make of this result. Incorporating this evidence into our understanding of early life and atmospheric oxygenation will mean tackling many big questions such as why oxygen didn't reach higher concentrations until almost 600 million years after photosynthesis evolved? Though it is a challenge to find more rocks of this age that are well preserved, Sean and his colleagues are looking to confirm their results with greater temporal resolution.

Below:
The 2.9 billion year old Pongola banded iron formation (BIF), South Africa. Photo by Nicolas Buekes.



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