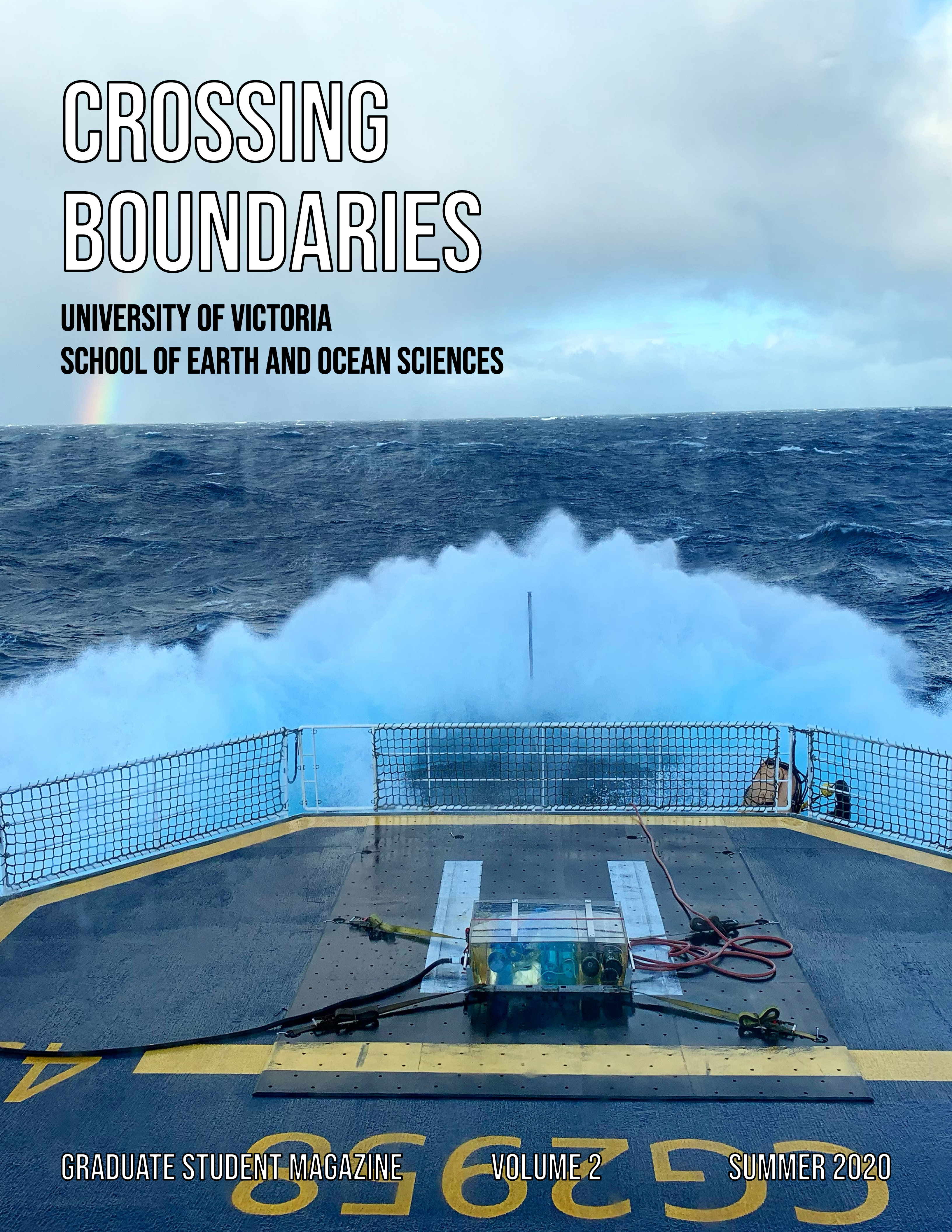
CROSSING BOUNDARIES

UNIVERSITY OF VICTORIA
SCHOOL OF EARTH AND OCEAN SCIENCES



GRADUATE STUDENT MAGAZINE VOLUME 2 SUMMER 2020

VOLUME CONTENTS

On the Cover

Photo by Sile Kafrissen (MSc)

This volume's cover photo captures a rainbow on the horizon as a wave crashes against the hull of the CCGS John P. Tully during one of three annual research cruises along the Line P transect in the Northeast Pacific.

Graduate Research Features

Honours Undergraduate Research Spotlight

Columns

Photo Gallery

LETTER FROM THE DIRECTOR

It is a pleasure to write a few words of introduction to this second issue of *Crossing Boundaries*, the annual Graduate Student Magazine of the School of Earth and Ocean Sciences (SEOS) at the University of Victoria. Like last summer's inaugural volume, this issue combines a selection of highly-readable scientific articles on graduate student research (written and edited by students) with Photo Galleries featuring field work (Fresh Air), laboratory research (The Lab Bench), and SEOS Events (in this case, good times at the SEOS curling bonspiel). New this year are an Honours Undergraduate Research Spotlight, and Catching Up on activities of SEOS graduate-student alumni.

Certainly a challenge for this year's magazine authors and editors, and for all in SEOS, has been the COVID-19 pandemic, which has affected virtually all aspects of the graduate-student experience over the past six months. While 2020 will be remembered as the "pandemic year" (I hope it's just one year!), I trust there will also be fonder memories associated with this period by SEOS students. We have done our best to allow field studies and laboratory work to go ahead for graduate students this summer, and will soon be reopening graduate-student office space, with some constraints, so that students can once again work on campus and interact in person (at a 2 metre physical separation, of course). I appreciate the flexibility, ingenuity, and patience students (and faculty/staff) have shown in learning to work in new ways during these challenging times.

Congratulations to the Editorial Staff, Sheryl Murdock (Editor-in-Chief), Rebecca Morris, Ahron Cervania, Alex Green, Erinn Raftery, and Mallory van Wyngaarden, for their outstanding job putting together a professional and attractive volume that captures something of the multi-disciplinary, Earth Systems vision of the School. And thanks to the student authors for contributing clear and concise expositions of their work to the broad scientific audience in the School. I trust that a new group of grad students and staff will be take up the baton next year to continue the fine new tradition of this magazine into the future.

All the Best,

Stan Dosso
Director of SEOS

Editor-in-Chief: Sheryl Murdock

Editors: Ahron Cervania, Alex Geen, Rebecca Morris, Erinn Raftery, Mallory Van Wyngaarden

Layout and Print Design: Ahron Cervania

Nitrous Oxide is No "Laughing" Matter

Investigating Microbial N_2O Production on Canada's Western Continental Slope

Brett Jameson

Nitrous oxide (N_2O), colloquially referred to as 'laughing gas', is known primarily for its uses in medical and dental fields as a general anesthetic. Many are not aware that N_2O is also produced biologically by a wide variety of microbial organisms, and contributes both to ozone layer destruction and climate change. As a potent greenhouse gas, N_2O has a radiative warming potential that is nearly 300 times more powerful than carbon dioxide. At present, it is the third most important greenhouse gas behind carbon dioxide and methane, and studies indicate that atmospheric concentrations are increasing in response to human activities.

The majority of previous research into the drivers causing elevated rates of N_2O production is focused on land-based systems, with emphasis placed on the role of agricultural soils. In recent years, attempts have been made to quantify the contributions of aquatic systems to the global N_2O budget, as observational studies continue to highlight their importance. Current estimates suggest that the global oceans account for approximately 10-50% of annual emissions, and scientists are now starting to discern between natural and human-related contributions [1]. However, these estimates are associated with a large degree of uncertainty due to sparse data coverage and an incomplete theoretical understanding of how microbial community dynamics contribute to net N_2O production in the environment.

How is Nitrous Oxide Produced?

Biological N_2O production is a consequence of the microbial nitrogen cycle, and results from the combined processes of nitrification and denitrification (Fig. 1). Both of these processes involve metabolic transformations of nitrogen-containing nutrients such as ammonium (NH_4^+) and nitrate (NO_3^-) by specialized groups of bacteria and archaea. N_2O is produced as a byproduct of the first step of nitrification, when ammonium is not completely reacted to the end product, nitrite (NO_2^-). In the case of denitrification, N_2O serves as an intermediate product in a sequence of transformations, and can escape into the environment if it is not subsequently reduced to N_2 gas during the final step. Elevated N_2O yields are observed for both pathways in areas of low oxygen, but for different reasons. Since nitrification requires oxygen, low concentrations stifle the complete oxidation of ammonium. In contrast, similar oxygen concentrations are capable of inhibiting the enzymes that convert N_2O to N_2 gas during complete denitrification. When oxygen is absent, complete denitrification drives N_2O concentrations to undetectable levels.

The Role of Marine Oxygen Minimum Zones

Oxygen minimum zones (OMZs) are natural features of marine water columns that occur when the biological

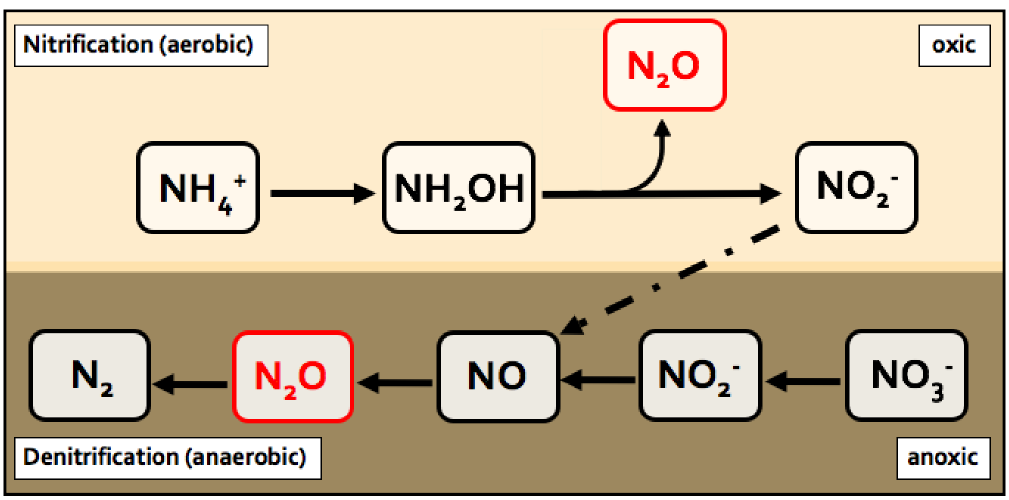


Figure 1: Microbial metabolic pathways of the nitrogen cycle that lead to N_2O production in marine environments. Nitrification is an aerobic process that requires oxygen, while denitrification is an anaerobic process that occurs in oxygen deficient regions. Elevated rates of N_2O production via both of these pathways are observed in areas where oxygen is reduced, but still present.

decomposition of organic matter consumes more oxygen than is resupplied to the system via processes like vertical mixing. In the open ocean, this results in a band of low-oxygen water at intermediate depths, and an accumulation of N_2O in the water column. In many cases, N_2O originating within OMZs can be emitted when these water masses are upwelled to shallower depths and brought in contact with the atmosphere. Numerous studies have investigated the source of water column N_2O production in relationship to environmental characteristics such as dissolved oxygen and nutrient concentrations [2]. However, there has been no research into N_2O production in continental margin sediments, where high metabolic rates drive oxygen concentrations to near-zero values within millimeters of the sediment-water interface. Evidence suggests that global OMZs are experiencing an increase in size and severity as a result of human-related nutrient inputs, and water column stratification due to warming [3]. This is likely to have considerable consequences for the global nitrogen cycle, and net N_2O production in marine environments. Understanding the trajectory of oceanic N_2O emissions in the context of a changing climate requires an understanding of how sediment environments contribute to N_2O concentrations in the water column.

Assessing the Role of Sediments Underlying an OMZ

In the Northeast Subarctic Pacific Ocean (NESAP), an intermediate OMZ impinges on the sedimented continental slope between approximately 400 and 1200 m depth. In the fall of 2019, I was onboard the Canadian Coast Guard Vessel John P. Tully to collect sediment cores in an effort to close this data gap. Replicated sediment cores were obtained using a multicorer (Fig. 2) from three separate locations along a continental slope transect that spanned the entire bottom water oxygen gradient (200–850 m depth). I then maintained these sediment cores in a shipboard cold room under *in-situ* oxygen concentrations to estimate rates of N_2O production (Fig. 3). As an additional experiment, I incubated sediment cores from the well-oxygenated area under both high and low oxygen conditions to simulate the effects of an upwelling event.

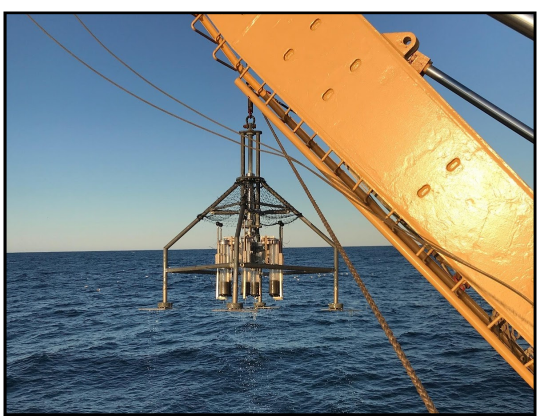


Figure 2: The multicorer returns to deck containing sediment samples collected at approximately 500 m depth.

Figure 3: Sediment cores incubating in the ship-board cold room. Seawater was circulated between the reservoirs and the sediment cores to maintain constant oxygen concentrations.

Following the incubation period, I obtained pore water concentration versus depth profiles of oxygen and N_2O in the sediments using microelectrode sensors (Fig. 4). These small, glass sensors allowed us to measure concentrations at sub-millimeter scales, providing high-resolution data of sediment N_2O distribution (Fig. 5). Using these concentration values and some additional information on sediment characteristics, such as grain size and water content, I will utilize a series of numerical models to estimate depth-dependent rates of N_2O production, consumption and sediment-seawater flux. The results we obtain will provide the first known estimates of net N_2O production in continental margin sediments of the NESAP, and their relative contributions to N_2O concentrations in the overlying seawater. Furthermore, these data will provide insights into the impact of OMZ expansion on N_2O cycling in marine sediments.

Linking N_2O Production to Microbial Community Dynamics

The enzymes involved in the pathways that regulate the metabolic production and consumption of N_2O are encoded by a relatively small set of genes that are distributed across a wide range of microbial lineages. The advent of modern molecular techniques has allowed microbial ecologists to probe deeper into the diversity of these lineages, and the variability that exists within specific types of genes that are involved in N_2O production. Although microbes capable of nitrification and denitrification are ubiquitous throughout different marine environments, there are considerable differences in the microbial communities in terms of the groups that perform these fundamental processes. The next step of my research is to investigate the relationships between microbial community structure and the net production of N_2O in samples taken from the Northeast Pacific continental slope.

I will be designing molecular 'probes' using DNA

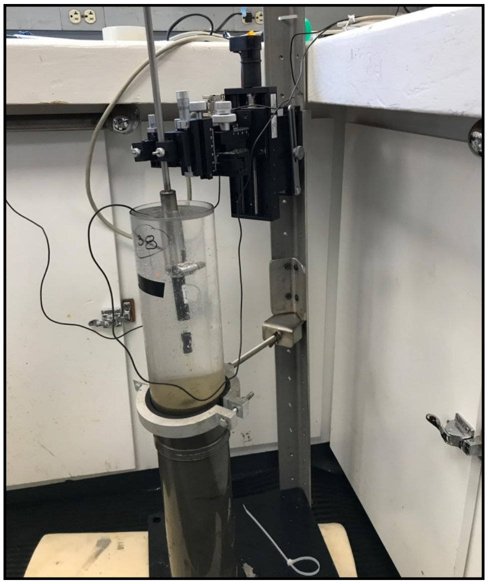


Figure 4: Image showing a sediment N_2O profile in action. Sensors are inserted step-wise into the sediment at predefined intervals to measure how N_2O concentrations change with depth.

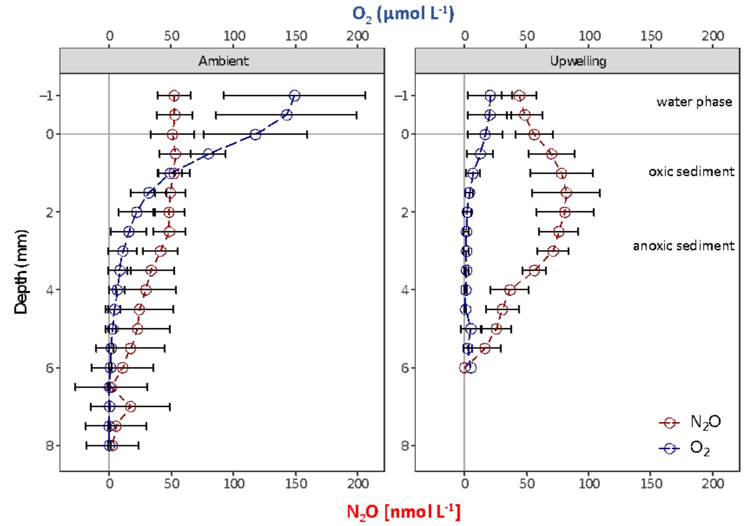


Figure 5: Microprofile results from the upwelling experiment conducted for cores taken at 200 m depth, and showing elevated N_2O concentrations in cores incubated under low-oxygen upwelling conditions (right panel).

sequence databases to target specific N_2O production genes, and using these probes to investigate the presence and activity of relevant genes in microbial community samples that I obtained from each sediment core. I took separate subsamples for both microbial DNA (genes), and RNA (gene transcripts), which will allow me to quantify the approximate number of genes present, as well as the relative activity of each gene. I will also use similar molecular probes to sequence the DNA and RNA of these genes to investigate how much diversity is present in the N_2O-cycling microbial community, and determine what constituents are actually active.

Significance and Research Impacts

Climate models of marine N_2O emissions view microbial community dynamics as inconsequential, and focus instead on environmental variables that correlate to differential rates of N_2O production. The large degree of uncertainty associated with these models has been attributed, in part, to limited information on spatial and temporal variability. In addition, the relative importance of the respective N_2O production pathways is still being debated, and the influence of microbial community dynamics is largely unknown. There is evidence to suggest that disparities in microbial community composition may drive differences in overall metabolic rates, and thus net N_2O production between different environments [4,5]. The research described above will help close the marine sediment data gap with respect to N_2O production, while also providing insights into the role of microbial communities in mediating these processes.

References

1) Bange, H. W. et al. A Harmonized Nitrous Oxide (N_2O) Ocean Observation Network for the 21st Century. Front. Mar. Sci. 6, (2019).
2) Freing, A., Wallace, D. W. R. & Bange, H. W. Global oceanic production of nitrous oxide. Philos Trans R Soc Lond B Biol Sci 367, 1245–1255 (2012).
3) Keeling, R. F., Körtzinger, A. & Gruber, N. Ocean Deoxygenation in a Warming World. Annual Review of Marine Science 2, 199–229 (2010).
4) Zhao, S. et al. NirS-type N_2O-producers and nosZ II-type N2O-reducers determine the N_2O emission potential in farmland rhizosphere soils. J Soils Sediments (2019) doi:10.1007/s11368-019-02395-3.
5) Yoon, S., Nissen, S., Park, D., Sanford, R. A. & Löffler, F. E. Nitrous Oxide Reduction Kinetics Distinguish Bacteria Harboring Clade I NosZ from Those Harboring Clade II NosZ. Appl. Environ. Microbiol. 82, 3793–3800 (2016).

About the Author

Brett Jameson
Advisor: Kim Juniper

Despite being raised in the land-locked prairies of Saskatchewan, Brett became intrigued by the ocean at a young age. This keen interest eventually led him to Halifax, Nova Scotia, where he obtained his BSc degree in Marine Biology from Dalhousie University. Following a brief work term at the Bermuda Institute of Ocean Sciences and some time scuba diving abroad, he moved to Victoria B.C. to explore the waters of the Pacific Northwest and to continue his studies. Brett is now a PhD candidate at the University of Victoria's School of Earth and Ocean Sciences, where he is studying microbial ecophysiology in low-oxygen marine environments.

FRESH AIR

Graduate student adventures and field research

Megan Caston (PhD) looks out from the top of Mount Wells during a future crustal deformation analysis study in 2019.

Sile Kafrissen (MSc) poses with Cape Scott in the background while cruising on the CCGS John P. Tully in August 2019.

Fengzhou Tan (PhD) preparing to dig a hole for a seismometer in Fort St. John, BC.

Sean Gazdewich (MSc) next to an outcrop in Strathcona Provincial Park while TA'ing for the EOS 300 field school in May 2019.

The Missing Carbon Sink

Reinterpreting the Global Carbon Cycle Using Stable Isotopes

Sean Gazdewich

Throughout Earth's history, the surface of our planet has undergone a succession of environmental changes to become what it is today. The goal of geologists is to explore and characterize the evolution of the Earth system over geologic time. To accomplish this goal, scientists use a variety of methods to gather information about paleoenvironments from the rock record. A key aspect to deciphering previous environmental conditions involves evaluating how biogeochemical cycles have evolved through time. In other words, how have the pathways of elements essential to living matter (e.g. oxygen, sulfur, nitrogen, phosphorous and carbon) changed as a result of various perturbations? Arguably, no element is presently of more interest to the public than carbon. This is due to the significant role carbon plays in regulating the Earth's surface temperature, but also as a source for atmospheric oxygen via photosynthesis. Studying Earth's long-term carbon cycle aids not only in our understanding of the co-evolution of life and the climate, but also the oxygenation of our atmosphere. Despite the importance of the carbon cycle, our understanding of its behavior, particularly in response to significant perturbation events, remains incomplete. Put another way, there is a deviation between how we expect the carbon cycle to respond and what recorded paleoclimate data is telling us. My goal is to help explain these discrepancies which ultimately will help the scientific community understand how the Earth system responded to past climate change events.

Long-term Carbon Cycle and Stable Isotopes

To understand the importance of carbon, we must begin with a simplified understanding of how it is transferred across the Earth system. Carbon, ultimately sourced from the Earth's mantle, is released into the environment primarily through volcanic outgassing and weathering. Within the lithosphere, most inorganic carbon is held in the crystal lattice of carbonate minerals, while organic carbon is preserved as buried organic matter originating from the biosphere. This carbon may be returned to the mantle if sedimentary rocks are subducted, and can be further outgassed from the mantle as CO_2 at active volcanoes.

Carbon makes its way into the oceans through surface erosion and weathering processes, where it is released from carbonate rocks and transported via river drainage systems or from chemical weathering of igneous rocks. This carbon, which takes the form of various chemical species (HCO_3^-, CO_3^{2-}, $CO_{2(aq)}$), is collectively referred to as dissolved inorganic carbon (DIC). DIC is converted into calcium carbonate ($CaCO_3$) by calcifying organisms, and later deposited as a carbonate sediment, or used by photosynthesizing organisms to produce organic matter (i.e. organic carbon). A portion of this organic carbon is buried over time and returned to the lithosphere (Fig. 1). The carbon that is contained within: 1) buried organic matter or; 2) buried $CaCO_3$ represents Earth's two main known carbon sinks.

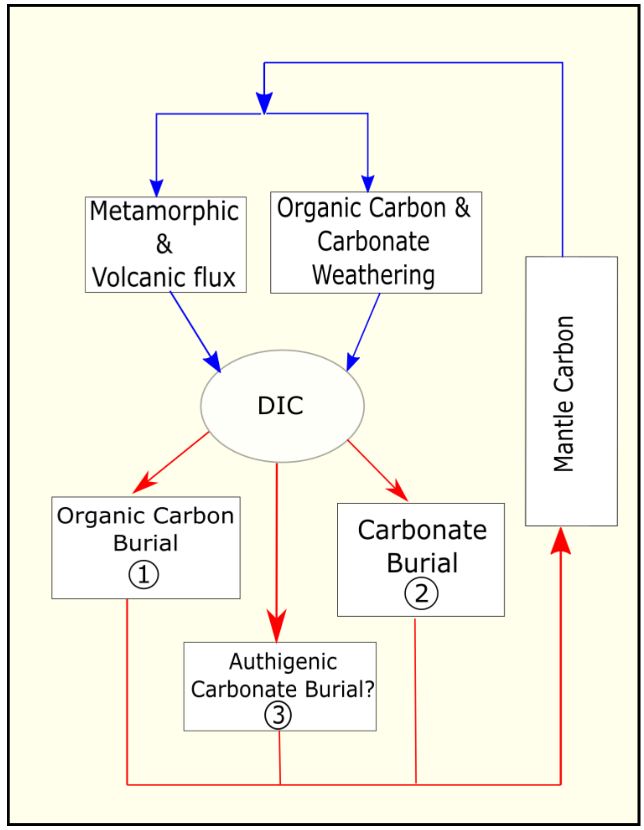


Figure 1: Schematic illustrating the main fluxes of the long-term carbon cycle. Blue arrows indicate source pathways, red arrows indicate sink pathways. Sink reservoirs: (1) organic carbon burial, (2), carbonate burial and possibly (3) authigenic carbonate burial.

There is a limited understanding of carbon sinks, their quantities, and how carbon is cycled in and out of these sinks over time. Stable isotopes can be used as a tool to track this movement (or flux) of mass in and out of Earth's carbon sinks. Carbon has two stable isotopes: ^{13}C and ^{12}C. The measurement of the relative abundance of these isotopes within sediment (relative to a standard) is what's referred to as the isotopic composition, and is represented in delta notation (δ). The ratio of ^{13}C to ^{12}C of Earth materials is determined by isotope fractionation processes. Primary production, through the process of photosynthesis, will preferentially remove ^{12}C from the

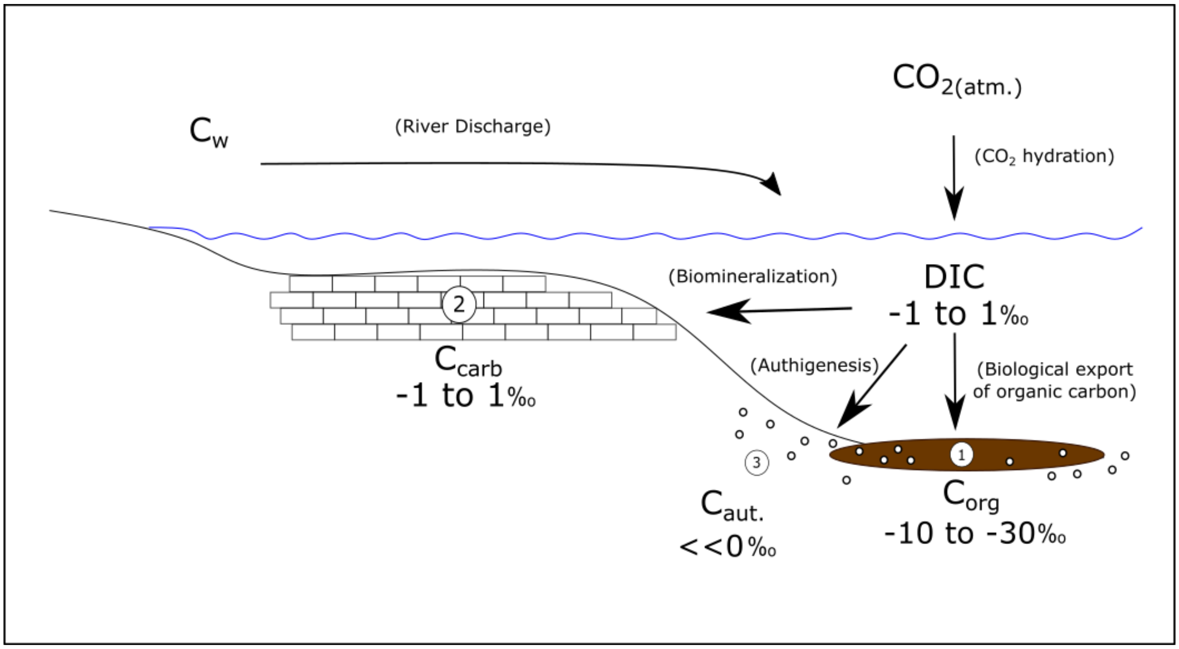


Figure 2: A schematic representation of the marine offshore depositional system. Depicted are the main fluxes of carbon: ($C_{w)}$ continental weathering, with $CO_{2\,(atm.)}$ mainly originating from volcanic outgassing, (C_{org}) organic burial (2) and (C_{carb}) carbonate burial (1). Authigenic carbonate (3) takes the form of disseminated carbonate minerals within seafloor sediments (both organic and non-organic). Also included are the main pathway processes between the different reservoirs and the estimated isotopic composition of the burial reservoirs and DIC (all values in δ).

DIC pool. As a result, the isotopic composition of organic matter is depleted [e.g. $^{13}C/^{12}C$ (organic) < $^{13}C/^{12}C$ (standard)] while that of DIC becomes enriched [e.g. $^{13}C/^{12}C$ (DIC) > $^{13}C/^{12}C$ (standard)]. For marine carbonates, most precipitate in or near equilibrium concentration with the seawater and carry little isotopic offset from DIC. This implies that the isotopic composition of carbonate sediments ($\delta^{13}C_{carb}$) will reflect that of DIC. The typical range for modern marine values $\delta^{13}C_{carb}$ is -1‰ to 1‰ (Fig. 2). If the carbon cycle is in equilibrium, the isotope composition of carbonate sediments should not exceed those ranges. However, geologic evidence suggests that over time isotope values for marine carbonates have changed significantly. Such events are referred to as carbon isotope excursions, and are considered to be instances of imbalance between carbon inputs from weathering and volcanism, and carbon outputs from burial [2].

The isotopic composition of DIC (and therefore marine carbonate) is linked to the export of carbon as organic matter (Fig. 2). In this way, the increased burial of organic matter will lead to a positive isotope excursion. Conversely, if significant amounts of organic matter were oxidized this would drive the isotopic composition of the DIC reservoir to negative values. This is the framework that has been used to interpret carbon isotope excursions, allowing geologists to qualitatively estimate the strength of biological export. However, in certain instances over geologic time, this relationship breaks down, such as the Precambrian where some of the largest positive excursions have been reported [3]. Presuming a larger fraction of organic matter burial, this would imply high rates of primary production and an increase in atmospheric O_2 (a byproduct of photosynthesis). However, this is inconsistent with evidence suggesting lower O_2 levels during this time [4]. We are therefore forced to assume there is another process causing large isotopic variations without changing the Earth's O_2 budget. Here we investigate the possibility of a third sink for carbon.

Recent work within the Earth Science community has proposed that authigenic carbonate (defined below) may have played a prominent role in the carbon cycle during times where anoxic conditions were prevalent, such as the Precambrian and the transient global anoxic events of the Phanerozoic [5]. The term "authigenic carbonate" refers to any carbonate mineral that was formed within sediment after deposition, through metabolic reactions involving anaerobic bacteria. The isotopic composition of authigenic carbonate is thought to be depleted in C^{13} because it is often associated with the degradation of organic matter. If appreciable amounts of authigenic carbonate were buried, this would increase the isotopic composition of the DIC reservoir to more positive values. Thus, the burial of authigenic carbonate provides a mechanism for a positive isotope excursion without calling upon large changes in atmospheric O_2. It is this hypothesis which forms the basis of my research.

The Late Devonian and the Western Canadian Sedimentary Basin

As mentioned, an active authigenic sink requires pervasive anoxic conditions. Thus, one is obligated to seek out well preserved rocks from instances of global ocean anoxia in Earth's history such as that which occurred in the Late Devonian (~383 to 359 Ma). During this time, western

Canada was located at equatorial latitudes and was covered by a vast tropical sea conducive to the widespread deposition of limestones and shale in what is now known as the Western Canadian Sedimentary Basin (WCSB). Various lines of evidence, such as the presence of $\delta^{13}C$ excursions in globally dispersed rocks of equivalent age and the widespread deposition of organic-rich black shales suggest a significant perturbation of the carbon cycle [1]. Such environmental conditions could have promoted the re-emergence of the authigenic carbonate sink and thus, an ideal target for field-based research.

To properly assess the impact of authigenic carbonate, my goal is to measure the isotope composition of shale and carbonate formations over a regional extent to elucidate how the DIC reservoir has evolved during this period. According to hypothesis, depleted $\delta^{13}C$ should be observed in shales (which represent the basinal environment where authigenic carbonate should have accumulated) and enriched $\delta^{13}C$ in marine carbonates (which represent the DIC signal). This will be done using UVic's very own isotope ratio mass spectrometer! Furthermore, I aim to quantify the actual amount of authigenic carbonate found within shale formations. Collectively, this research will determine not only whether the authigenic sink was active during this period of Earth history, but whether it could be an important driver for isotope excursions. This research is significant not only because it represents one of the first field-based studies of the authigenic sink hypothesis, but if isotopically depleted authigenic carbonate is found to be a prominent sink in deep time, then our understanding of the $\delta^{13}C$ record and the carbon cycle needs to be redressed at a fundamental level. Work is ongoing with results to be published later this year.

References

1) Kaiser, S.I., Aretz, M. and Becker, R.T. 2015. The global Hangenberg Crisis (Devonian–Carboniferous transition): review of a first-order mass extinction. Geological Society, London, Special Publications, **423**: 387-437.

2) Kump, L.R. and Arthur, M.A. 1999. Interpreting carbon-isotope excursions: carbonates and organic matter. Chemical Geology, **161**: 181-198.

3) Knoll, A.H., Hayes, J.M., Kaufman, A.J., Swett, K. and Lambert, I.B. 1986. Secular variation in carbon isotope ratios from Upper Proterozoic successions of Svalbard and East Greenland. Nature, **321**: 832-838.

4) Catling, D.C. and Claire, M.W. 2005. How Earth's atmosphere evolved to an oxic state: a status report. Earth and Planetary Science Letters, **237**: 1-20.

5) Schrag, D.P., Higgins, J.A., Macdonald, F.A and Johnston, D.T. Authigenic carbonate and the history of the global carbon cycle. Science, **339**: 540-543.

About the Author

Sean Gazdewich
Advisor: Jon Husson

I am a native of Montreal, Québec and currently an MSc student at the University of Victoria. I am equal parts a field geologist and geochemist with extensive experience exploring Canada's vast and diverse geology. My research interests involve using the principles of sedimentology and stratigraphy to unravel the cause and effect of anomalous events in Earth history.

SEOS Trivia!

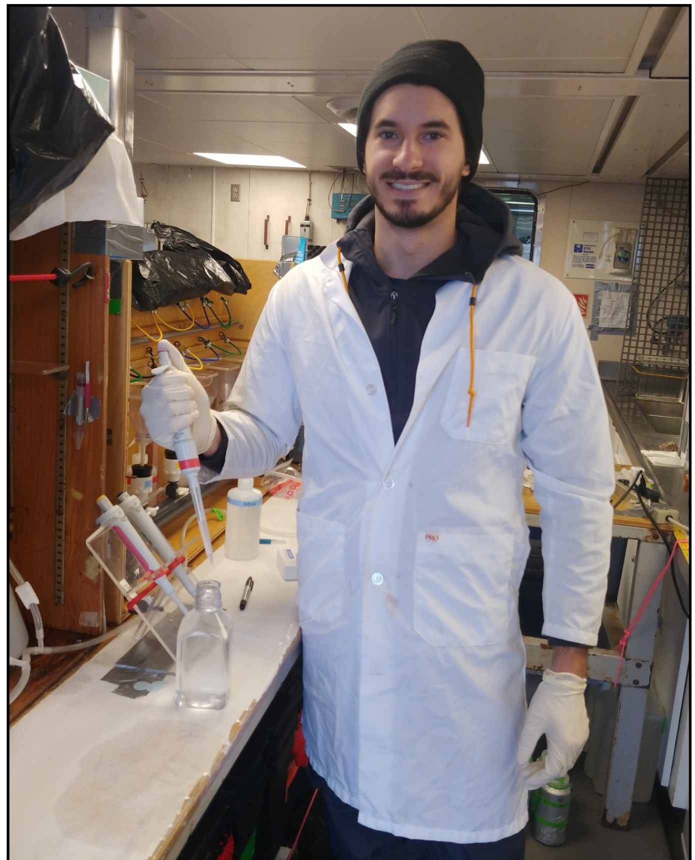
1. How many SEOS faculty members hold a Canada Research Chair?
2. Which SEOS faculty member made it to the short list of candidates to become an astronaut?

1. Three faculty members! Verena Tunnicliffe and Roberta Hamme in Oceanography, and Edwin Nissen in Geophysics.
2. Jay Cullen made it to the top 2% out of all the applicants in 2017!

THE LAB BENCH

Graduate student views inside the lab

Matt Miller (PhD) incubated this live pteropod specimen on a research cruise and brought it back to the lab at UVic. It is imaged in water using a dissecting microscope with polarized light to reduce glare off the shell.



Michael Livingston (MSc) spiking seawater samples with natural silica for an incubation experiment aboard the CCGS John P. Tully in June 2019.

Rebecca Morris (PhD) captured these thin section images of gabbro (left, center) and basalt (right) displaying different textures and grain sizes of minerals. These samples are collected near the contact of a 197 million year old iron-rich magma with >205 million year-old limestone. Field of view is ~5 mm (left, right) and ~2 mm (center) across. Images are in cross -polarized light

Hydrothermal Vents

A Major Source of New Discoveries

Thomas Giguère

Hydrothermal circulation is the process in which water seeps into the Earth's crust and becomes altered by an underlying source of magma. As the temperature rises, minerals and compounds in the crust dissolve into the water, creating hydrothermal fluid. A hydrothermal vent is an area where this fluid escapes back into the ocean. Vents are highly unique habitats, but despite their initial discovery over 40 years ago, there is still much to learn about them and their role in seafloor ecology. As deep sea exploration technology becomes increasingly more sophisticated, further expeditions have continuously revealed new vent sites in every ocean. However, basic biological details of the world's vents still remain largely undefined in many areas; these include the identities of the species living in these habitats, their geographic ranges and the mechanisms shaping their distribution patterns. Researchers discover new species quite often, especially when they explore vent sites for the first time. Describing the new species takes an enormous amount of work and time, and requires major contributions from leading taxonomic experts.

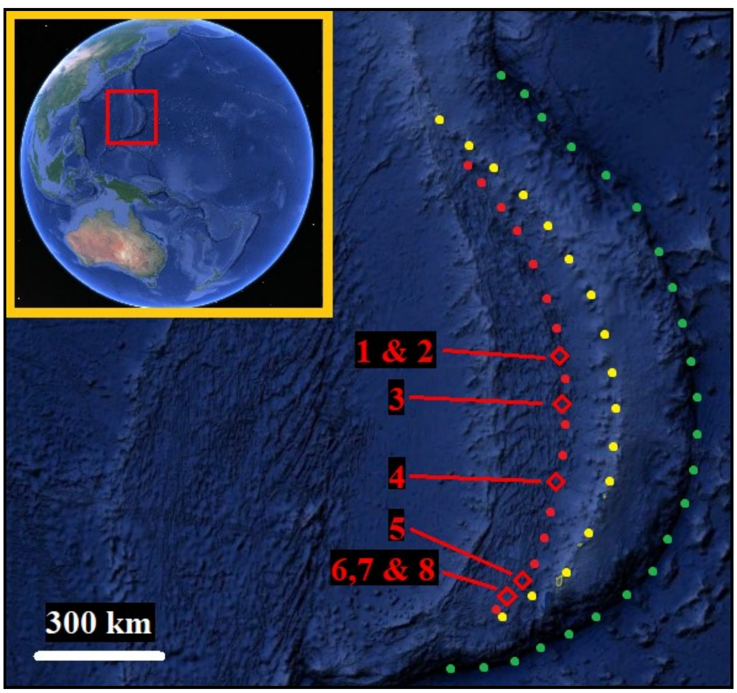


Figure 1: The top-left inset map illustrates the Western Pacific, with Australia and Papua New Guinea to the south, and Japan to the North. The red rectangle indicates the location of the larger image, showing the bathymetry of the Mariana region. The locations of the Mariana Trench, volcanic arc, and backarc spreading center are respectively indicated by the green, yellow, and red dotted lines. Red diamonds indicate the locations of known vent sites in the Mariana back-arc. These vent sites are numbered from north to south: 1 = Illium-Alice Springs, 2 = Burke, 3 = Hafa Adai, 4 = Perseverance, 5 = Forecast, 6 = Snail, 7 = Archaean, and 8 = Urashima-Pika.

Hydrothermal vents are present in every ocean around the world, but my research focuses on those in the Mariana region. This area is located in the Northwestern Pacific, and is defined by its geologic setting—the Mariana microplate. The well-known Mariana Trench defines the eastern boundary, and the backarc—where seafloor spreading occurs—defines the western boundary; the volcanic arc lies in the center of the microplate and supports a chain of seamounts and islands, including Guam (Fig. 1) [1]. Both the arc and backarc support hydrothermal vents, but my research specifically focuses on the animals living in the back-arc vent sites. The first two vent site discoveries in the Mariana back-arc occurred in 1987 [2], and the first expedition to these sites collected 30 taxa, 22 of which represented new species discoveries at the time. By 2015, further explorations had revealed four more vent sites in the region. The most recent study on the animals present in these vent fields estimated a total of 51 taxa [2]. However, they only identified 26 of these taxa to the species-level. Furthermore, they base their estimates on both their own samples and the data presented in the literature; this means that they may have reported the same species multiple times, which is often a challenge faced in vent diversity research.

In the winter of 2016, an expedition explored and collected biological samples from the two vent sites originally discovered in 1987 and two newly discovered vent fields named Hafa Adai (Fig. 2) and Perseverance. My research focuses on identifying the animals in the collections from this expedition. Using these samples and the data in the literature, I determined the species present in each of the eight back-arc vent sites (Fig. 1). Using this data, I then described the diversity distribution patterns throughout the region.

Setting the Stage on the Seafloor

Vents are most commonly located along tectonic boundaries and they are present at depths ranging from 2 m to ~5 km. Hydrothermal fluids drastically alter the environmental conditions of the vent habitats. Their temperatures can exceed 400 ˚C at the crust-ocean interface, so steep temperature gradients are a common characteristic of vents. Hydrothermal fluids are highly anoxic and contain many reduced chemicals. Once they

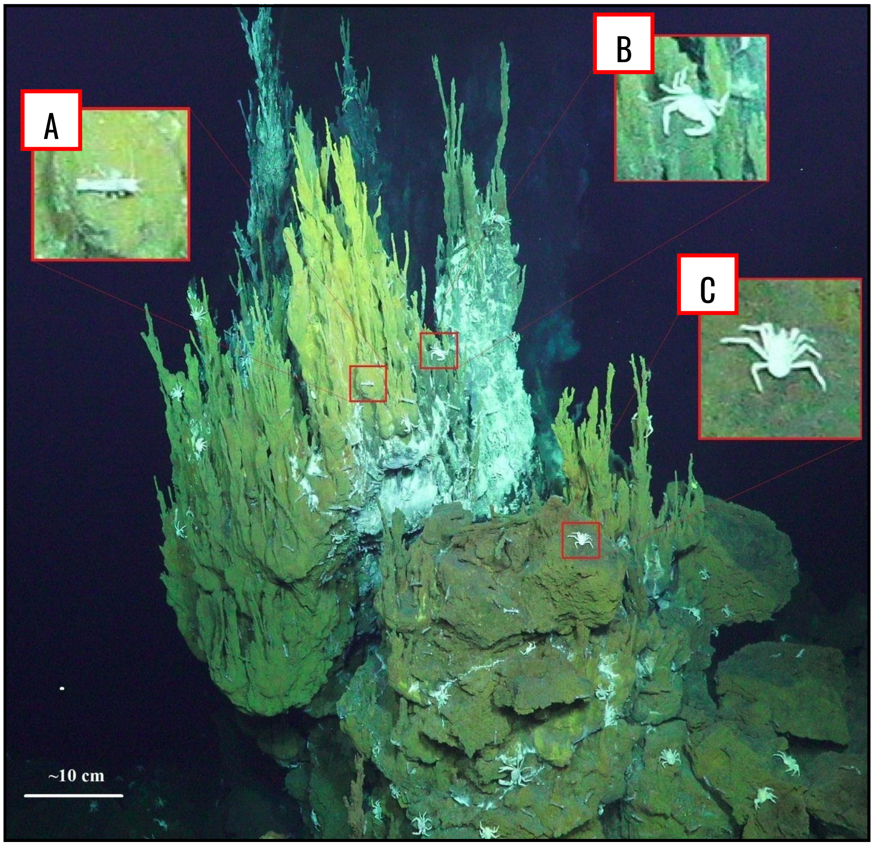


Figure 2: A black smoker chimney in the newly discovered vent field, Hafa Adai, located in the central Mariana back-arc. White bacterial mats are present in areas of hydrothermal outflow. Three white crustaceans are present on this structure: *Rimicaris* shrimp (A), *Austinograea* crabs (B), and *Munidopsis* squat lobsters (C).

escape from the crust, these chemicals quickly oxidize in the oxygenated water, causing vents to act as oxygen sinks. Depending on their temperatures, the rapid decrease in temperature can also cause the dissolved minerals in the fluid to quickly precipitate and form both black, smoke-like effluent and large chimney structures (Fig. 2).

The high temperatures and toxic chemicals characteristic of hydrothermal vent fluids are highly lethal to most animals, but vent species have evolved to tolerate these conditions. Vents contain groups of thermophilic (heat-loving) microbes that undergo chemosynthesis and provide food for the animals [3]. The microbes oxidize reduced chemicals (e.g. hydrogen sulfide, methane, hydrogen) and harness energy from the reactions to generate organic compounds. The presence of these microbes make vents one of the most productive habitats in the deep sea and capable of supporting a high abundance of animals. Many of these species are arthropods, annelids, and molluscs, but other phyla are present in much lower numbers. Many species simply feed on the microbes by grazing on rock surfaces or filtering the water; others will quickly scavenge dead or dying animals. Some species engage in endosymbiotic relationships with the chemosynthetic microbes, hosting the microbes within their bodies; as a supplement or alternative to feeding, these animals will capture the reduced chemicals used in chemosynthesis and transport them to the microbes to directly benefit from the primary production. The harsh conditions of vents also impose a physiological barrier that prevents most animal species from accessing these valuable resources. Therefore, the specialized vent animals also use the hydrothermal fluids as refuges from non-specialized predators.

As a result of their specialized adaptations, most of these species are vent-endemic [4], meaning that vents are the only type of habitat where they can survive and reproduce, so the animal assemblages at vents are very unique. However, vents can be relatively short-lived habitats, and although they are present in every ocean, they are very small (average of ~10 m^2), patchy and sometimes separated by hundreds of kilometers. These features provide a major evolutionary pressure for strong dispersal capabilities in vent-endemic animals. These vent-endemic animals mostly disperse as free-swimming larvae and ocean currents primarily drive their dispersal, although larval behaviours increase their likelihood of settling in appropriate habitats.

Discovery Summary

A total of 43 taxa are present in the biological samples collected from the Mariana back-arc in 2016. I identified many of these animals using their morphological traits, but some required the use of gene sequencing tools to

Figure 3: A new species of *Vulcanolepas* barnacle collected from the newly discovered Hafa Adai vent site during the 2016 research expedition to the Mariana backarc.

determine their identities. Previous studies have already found many of the species present in this collection, but the samples also contained some new discoveries. With the help of taxonomic experts, four new species have been—or are in the process of being—described from these specimens: a shrimp [5], a limpet, a polychaete worm, and a barnacle (Fig. 3). Some other taxa in the collection that I have not identified to the species-level seem to also be undescribed species, including an anemone and many copepods, but confirmation from taxonomic experts is required. Based on the previous literature and these new discoveries, I have confirmed that at least 55 vent-endemic species are likely present in this region.

Shrimp, crabs, barnacles, limpets and hairy snails dominate all the vent sites in the Mariana back-arc, but these eight sites do not contain all the same species; the four sites in the south have lower species diversity on average than those in the central backarc. Ecologists broadly use the term "β-diversity" to refer to the biological similarities or differences between species assemblages. In my work, the β-diversity values indicate that these eight vent sites share ~48% of species on average, but some pairs of vent sites share as little as 30%, and others as much as 96% of their species.

Now that I have identified the vent-endemic species in the Mariana back-arc and determined the vent sites where they are present, my next step is to determine which environmental variables are shaping their diversity and distribution patterns. Although I do not have a conclusive estimate yet, I suspect that a few environmental variables are the main driving forces. Firstly, habitat heterogeneity should have a strong influence on the diversity patterns because a greater diversity of habitats usually supports a greater diversity of species. Secondly, I suspect that if vent conditions are the same across all the sites, distance between the sites should shape the β-diversity patterns; neighbouring sites should share more species than distant sites because it is more likely for vent larvae to reach a closer, neighbouring site than one that is more distant. Lastly, the fluid chemistry has a strong influence on vent habitats, so I suspect that vents with similar fluid characteristics will share more species than those with different fluid characteristics.

References

1) Anderson, M. O., Chadwick Jr, W. W., Hannington, M. D., Merle, S. G., Resing, J. A., Baker, E. T., Augustin, N. (2017). Geological interpretation of volcanism and segmentation of the Mariana back□arc spreading center between 12.7° N and 18.3° N. Geochemistry, Geophysics, Geosystems, 18(6), 2240-2274.

2) Kojima, S., & Watanabe, H. (2015). Vent fauna in the Mariana Trough. In Subseafloor biosphere Linked to hydrothermal systems (pp. 313 -323): Springer.

3) Dick, G. J. (2019). The microbiomes of deep-sea hydrothermal vents: distributed globally, shaped locally. Nature Reviews Microbiology, 1.

4) Tunnicliffe, V., McArthur, A. G., & McHugh, D. (1998). A biogeographical perspective of the deep-sea hydrothermal vent fauna. In Advances in marine biology (Vol. 34, pp. 353-442): Elsevier.

5) Komai, T., & Giguère, T. (2019). A new species of alvinocaridid shrimp Rimicaris Williams & Rona, 1986 (Decapoda: Caridea) from hydrothermal vents on the Mariana Back Arc Spreading Center, northwestern Pacific. Journal of Crustacean Biology.

About the Author

Thomas Giguère
Advisor: Verena Tunnicliffe

I am originally from southern Ontario but moved to Victoria to pursue a Master's degree. My main focus during my undergraduate degree was freshwater biology, but I have always been interested in marine biology and I developed an interest in hydrothermal vent habitats early in my degree. I was lucky enough to get an opportunity to study vents here on the west coast. Now that I've completed my Master's degree, my main research interests lie broadly in benthic ecology, whether it is marine or freshwater. If possible, I would like to stick with vent ecology because it's the most exciting.

SEOS EVENTS

Good friends, good times

In early March 2020, the SEOS graduate representatives arranged a curling bonspiel. After some quick lessons in proper safety and technique, the students, faculty, staff, and guests in attendance got to challenge each other in a tournament and enjoy some good company in the lounge between matches.

Sean Gazdewich (MSc) and Duncan Johannessen (staff) pose on the ice with their brushes. Sean would later be awarded the prize for Most Valuable Player!

Ahron Cervania (MSc) throwing a stone.

Team Fun–composed of Amanda Willms, Melissa Mills (MSc), Sandy McLachlan (PhD), and Brandon Smith (MSc)–posing with their awards for winning 3rd place in the tournament.

Team Curliolis Force–composed of Johanna Länger (MSc), Geordie Wilson, Elizabeth Ramsey (MSc), and Raj Deepak (PhD)–posing with a trophy in the lounge.

The Ocean's Deep Breath

Dynamics of Dissolved Oxygen in the Labrador Sea based on Robotic Profiling Floats

Wylee Fitz-Gerald

Have you ever thought of the ocean breathing before? How oxygen is exchanged across the ocean-atmosphere boundary and transported deep into the belly of the ocean like one big breath? Imagine a parcel of water holding its breath as it's transported along a massive oceanic conveyor belt that circulates the world's oceans. The water slowly becoming depleted in oxygen, as the oxygen is consumed by organisms or is physically mixed out of the surface. At the end of its transit, the oxygen-depleted water is replenished by a new convection event, breathing in, and starting the cycle again.

Research and Importance

My work is focused in the Labrador Sea, one of the few places where mixing within the ocean water column, known as convection, brings oxygenated surface waters to the deep (Fig. 1). A cold, dense current, known as the Deep Western Boundary Current, exports polar waters towards the equator, redistributing newly re-oxygenated deep water from the Labrador Sea globally [1]. How close the surface water and atmosphere are to equilibrium governs how much oxygen is transported to the deep ocean and therefore available to support marine life [1]. This convection of oxygen is essential for deep sea ecosystems to survive. A reduction in convective events in the Labrador Sea would disrupt the fragile balance between deep sea oxygen supply and demand, having detrimental effects on downstream marine environments that depend on this oxygen availability [1]. My study focuses on investigating the deep convection in the Labrador Sea, and its effect on the oxygen content in the water column. This study was completed to investigate if more recent data follows previously determined patterns using similar analytical methods [2].

Convection in the Labrador Sea

One characteristic that water masses are defined by is their density, which is a product of temperature and salinity. Differences in density keep water masses separate, causing distinct vertical layering of water bodies known as stratification. For example, colder water is denser than warmer water, and therefore has a tendency to sink below the warmer water. In the Labrador Sea, the stratification of the water column fluctuates between pre-convection, convection and post-convection states (Fig. 2). Prior to convection, the surface layer is thin (i.e. typically <100 m) and has an oxygen content near equilibrium with the atmosphere, as the water mass has had time for gas exchange to occur [2]. The pre-convection deep layer is oxygen depleted due to biological respiration and sits below the surface layer. Stratification must be broken down in the water column in order for deep convection to occur [1]. Destratification in the Labrador Sea is caused by atmospheric forcing, where cold dry winds remove heat from the top of the water column. This heat loss makes the surface water colder, subsequently increasing the density of the top of the water column to match the density of the layer below. This induces mixing of the layers [1,4]. Once atmospheric forcing has broken down the stratification and initiated convection, the mixed layer deepens and combines a larger volume of low oxygen deep water with a comparatively small volume of high oxygen surface water. This results in a post-convection water column that consists of a surface mixed layer that is now deep (i.e. typically ~2000 m in the Labrador Sea) with an overall lower oxygen content relative to equilibrium with the atmosphere. This means that while surface waters are now less saturated with oxygen than pre-convection conditions, the oxygen content at depth is significantly higher than it was prior to the convective event, increasing the supply for deep sea ecosystems. Following convection, the surface waters become quickly restratified due to the waters surrounding the convective region flooding in over the top of the deep mixed layer [2].

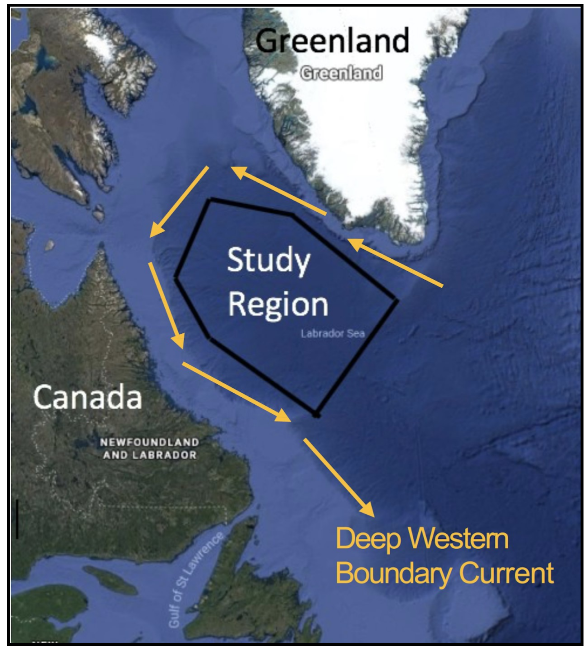


Figure 1: Map outlining the study region (black) in the Labrador Sea between Canada and Greenland. Yellow arrows indicate the path of the Deep Western Boundary Current. Modified from Google Earth Labrador Sea Map, 2019 [3].

Argo: Robotic Profiling Floats

To understand these deep convection events, collecting oxygen samples for the 2000 m water column is crucial. However, collecting these samples comes with limitations. In the Labrador Sea, these deep convection events occur during the wintertime, where rough seas limit access by ship. In addition to difficult access, the lifespan of these convection events are short-lived, where the water column can become stratified quickly (i.e. < 10 days), and therefore difficult to sample. The use of robotic profiling floats, such as Argo, can address both of these problems. Argo is an international program that uses robotic profiling floats to measure the upper 2000 m of the world's oceans for biological, chemical, and physical properties [5]. Floats can adjust their density using a bladder located at the bottom, which allows them to change their position in the water column. Combined with oceanographic instruments to measure salinity, temperature, pressure, and oxygen, these floats obtain profiles of the water column and transmit the data via satellite to shore. Argo floats take profiles every 10 days in a region over a 5-7 year period. This frequent sampling increases the likelihood of observing a deep convection event, making them a useful tool to observe deep convection in the Labrador Sea [2]. In addition, these floats operate year round including when access for ships is not ideal. More information on Argo floats, their design, and sampling technique can be found online at the Argo Global Data Assembly Centre (Argo GDAC) [5].

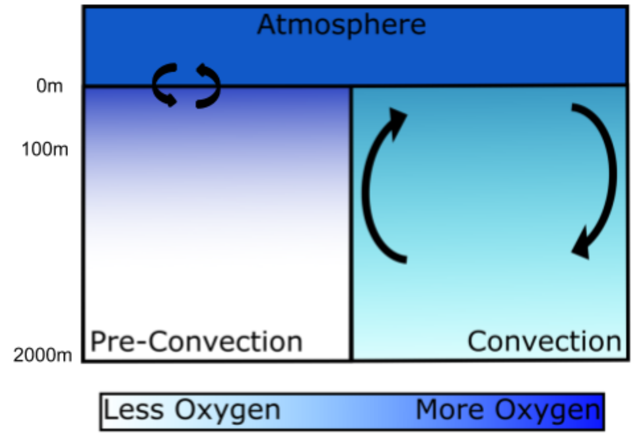


Figure 2: Conceptual model of convection in the Labrador Sea illustrating the pre-convection and convection states. Pre-convection, the surface layer (<100 m) oxygen content is close to or at equilibrium with the atmosphere as air-sea gas exchange (small black arrows) has had time to occur. Conversely, the deep layer (>100 m) during pre-convection is low in oxygen content due to biological respiration. During convection, the stratification of the water column is broken down and convection (large black arrows) mixes the surface and part of the deep layer resulting in a homogenous, lower oxygen content, deeper mixed layer (~2000 m).

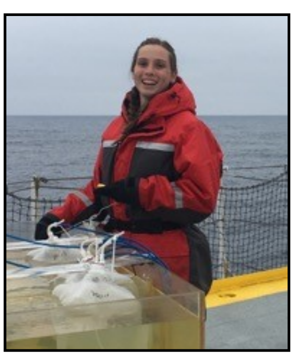
Observing and Quantifying Deep Convection

Despite taking multiple profiles of the water column at a high frequency, the rapid and sporadic nature of deep convection often means that only one of these profiles captures the deep convection event. For our study, the profile with the deepest mixed layer (annually), shown by a deep vertical profile of uniform oxygen concentrations, was chosen as the convection event. The date associated with this profile was considered to be the convection end date, allowing for a further understanding of the timing of these events. The maximum depth convection reached was visually determined as the inflection point between the constant vertical oxygen value in the mixed layer and the sloped decreasing oxygen values in the deep ocean layer.

This study found deeper convection after 2016 resulting in values of the deep mixed layer closer to equilibrium with the atmosphere. This suggests an opposite trend than previously documented in literature by Wolf et al. (2018) where deeper convection led to oxygen values further from equilibrium [2]. These findings are helpful for looking at the timing of deep convection events in the Labrador Sea and how convection can change interannually. This study helps to quantify how much oxygen is transported to the deep sea, and therefore the rest of the global ocean environment via the thermohaline circulation.

References

1) Yashayaev, I., 2007, Hydrographic changes in the Labrador Sea, 1960-2005: Progress in Oceanography, v. 73, no. 3-4, p. 242-276.
2) Wolf, M. K., Hamme, R. C., Gilbert, D., Yashayaev, I., and Thierry, V., 2018, Oxygen Saturation Surrounding Deep Water Formation Events in the Labrador Sea from Argo-O-2 Data: Global Biogeochemical Cycles, v. 32, no. 4, p. 635-653.
3) Google Earth Labrador Sea Map, 2019, Google Earth, https://www.google.com/earth/ (accessed December 2019).
4) Marshall, J., and Fiadeiro, M., 2002, The Labrador Sea Deep Convection Experiment: Journal of Physical Oceanography, v. 32, no. 2, p. 381.
5) Argo (2019). Argo - part of the integrated global observation strategy. http://www.argo.ucsd.edu



About the Author

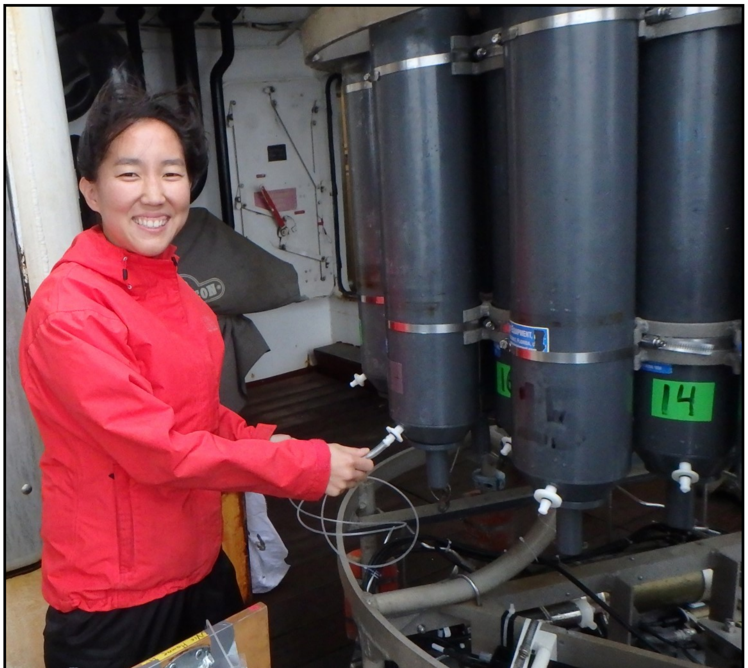
Wylee Fitz-Gerald

Advisor: Roberta Hamme

Wylee's introduction to oceanography began when she set sail to Greenland in 2014. This is when she first fell in love with studying the ocean. She pursued this passion in her undergraduate degree by completing an honours project investigating oxygen dynamics in the Labrador Sea. Shifting oceans from the Atlantic to the Pacific, Wylee is now a graduate student in the School of Earth and Oceans Sciences at UBC where she will undertake large scientific expeditions to elucidate the role of aerosols on primary productivity in the NE Pacific.

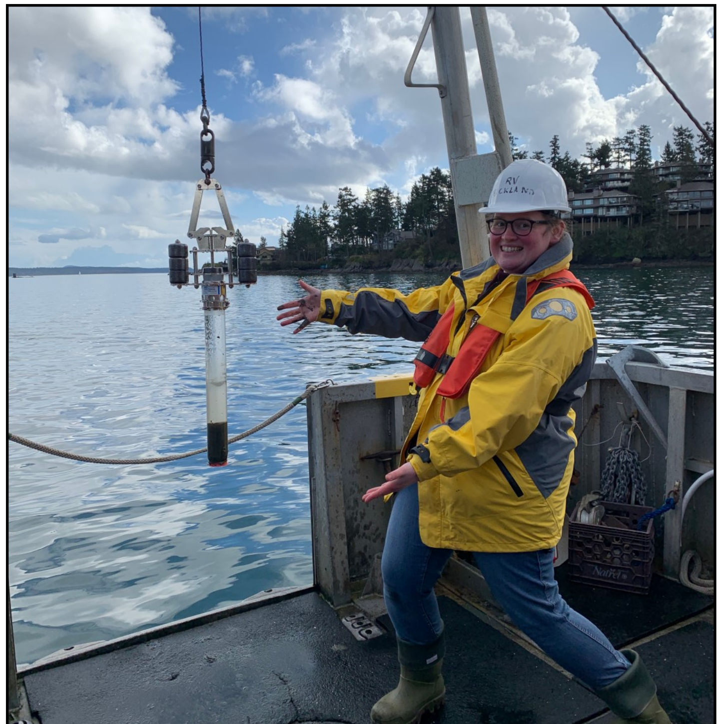
CATCHING UP

The current activities of SEOS alumni



Amanda Timmerman, last year's editor-in-chief and the motivation behind the creation of Crossing Boundaries, finished her PhD in Chemical Oceanography in 2019 and is now working at Scripps Institution of Oceanography in San Diego, California. She is part of a large monitoring program called the California Cooperative Oceanic Fisheries Investigations (CalCOFI) that has been running for over seven decades.

Ken Hughes finished a PhD in Physical Oceanography in 2018 and is currently in a postdoctoral position at Oregon State University. His research uses turbulence observations to understand mixing in the tropical ocean. Ken was also selected as an Outstanding Reviewer for the Journal of Geophysical Research: Oceans in 2019.



Karina Giesbrecht completed her PhD in Biological Oceanography in 2018, shortly after becoming a new mom. She is now the Senior Laboratory Instructor for Oceanography and Geochemistry here in SEOS.

Emma Pascoe completed her MSc in Biological Oceanography in 2018 and is now in Ottawa working at the Canadian Wildlife Service, a branch of Environment and Climate Change Canada. She is a biologist on the Species at Risk Recovery Planning team.

LETTER FROM THE EDITOR

To our readers,

As an antidote to overwhelming and sometimes depressing news, we proudly present to you the second volume of Crossing Boundaries, the magazine that showcases graduate student research in the School of Earth and Ocean Sciences (SEOS). Although our second volume ended up being more ocean-focused, we strive to highlight the breadth of research in our highly multi-disciplinary department. From oceans to climate, geophysics to sedimentology, SEOS endeavours to understand Earth's processes as one system with many interacting components. This year's student contributions truly highlight the quality of research undertaken by our graduate students and undergraduate honours students.

Although the initial impetus for the magazine was to showcase the diverse research of our students, it has also become a valuable opportunity to challenge students to communicate their research to a broad audience. If the unusual events of 2020 have taught us anything, it is the value and necessity of good science communication. I am fortunate to have worked with an incredible team of fellow student editors who soldiered on, despite a global pandemic, to finalize this volume. Many thanks for your dedication. Thanks to our contributing authors who endured many rounds of edits with patience and unwavering commitment. Thank you to the students who contributed photos and to the recent graduates for sharing their current whereabouts. Special thanks to Ahron Cervania for the layout and final design.

We hope you enjoy this second installment of Crossing Boundaries.

Sheryl Murdock
Editor-in-Chief

Meet the Editors

Sheryl Murdock (PhD)
Advisor: Kim Juniper
Fun Fact: Has been in the submersible Alvin

Rebecca Morris (PhD)
Advisor: Dante Canil
Fun Fact: Favorite outcrop in Victoria is Holland Point

Ahron Cervania (MSc)
Advisor: Roberta Hamme
Fun Fact: Learning to fire spin

Alex Geen (MSc)
Advisor: Dante Canil
Fun Fact: Grew up on a cherry farm

Erinn Raftery (Staff)
Supervisor: Roberta Hamme
Fun Fact: Has been on the MSV John Strickland 30+ times

Mallory Van Wyngaarden (Staff)
Supervisor: John Nelson
Fun Fact: Has a parasitic wasp named after her

If you are interested in contributing to future volumes of Crossing Boundaries by writing a piece, editing, or submitting photos, please reach out to us at uvic.crossingboundaries@gmail.com