Will the Next Global Crisis Be Produced by Volcanic Eruptions? Constraining the Source Volcanoes for 6th Century Eruptions

Background: The fifteen year period from 536 to 545 CE was hard on both trees and on people. There were numerous famines during this time. Trees grew very slowly, putting on light rings in 536 CE and for four consecutive years from 539 to 542 CE. (Light rings are rare- they typically form a few times per century.) An extremely large eruption occurred in early 541 CE. It was larger than the 1815 eruption of Tambora that produced the "year without a summer in 1816" and subsequent starvation in much of the northern hemisphere. An eruption in early 536 CE produced the lowest tree growth in the last 2500 years but is ranked 18th in sulfate loading. Previous work found two significant eruptions: one in 536 and one in 540/541 CE. Because tree growth recovered after 536 CE, the light rings in 539 and 540 are difficult to explain with only two eruptions. The big climatic effects of the 536 CE eruption are also hard to explain. Using our data from the GISP ice core , we found volcanic glass from 6 significant eruptions, three in early 535, 536 and 537 CE and three in late 537, early 541 and late 541 CE. The latter three eruptions may explain the four years of light rings from 539 to 542 CE. We believe the climatic effects of three of these eruptions (all submarine and low latitude) were magnified by their ejection of tropical to subtropical marine microfossils, marine clay and carbonate dust. Each of the three submarine eruptions has a distinct marine microfossil assemblage that will constrain their unknown source volcanoes.

Analysis Required: The student will make cross sections of all Holocene seamounts/ volcanoes between 35°N and 35°S using the Geomapapp software package developed at LDEO. Our goal is to map caldera widths, depths and apparent age to constrain which volcanoes are most likely to have experienced a large explosive eruption during the late Holocene. Many submerged volcanoes have little to no published data on the composition and age of their ejecta. The student will search the literature for data on ejecta composition to add to our large database. If no data on glass compositions are available in the literature, the student will sieve samples from nearby deep sea sediments to identify silicic volcanic glass and will pick marine microfossils for ^{14}C dating of the ash layers. The student and the Pi will also work with available databases of the microfossil assemblages in marine sediment to constrain which submarine volcanoes are the most likely sources of the three submarine eruptions between 535 and 542 CE.

Prerequisites: A strong interest in earth science and adequate computer and microscope skills. Competence in plotting and manipulating data with excel is required. Competence with MatLab would be useful but is not essential. Student should be able to use a microscope several hours a day. This project could be done remotely for all or part of the summer if it is necessary or desirable. (We would loan you a microscope.)

Mentors: Dr. Dallas Abbott dallashabbott@gmail.com
Dr. Karin Block kblock@ccny.cuny.edu

What are the Dates and Climatic Effects of the Proposed Impact Crater in the Ross Sea?

Background: Many cores from the Ross Sea contain silicate spherules with several proposed origins; biological precipitates and impact spherules are among them. In 2020, we showed that these spherules have shapes that are not consistent with a biological origin; they are not spherically symmetric and some have long tails. More recently, gravity gradients have revealed a partial circle 200 km in diameter in the Ross Sea. In other regions, such circles are interpreted as impact craters. We have also performed some dating on the spherule-bearing layer. It has about the same age as the Younger Dryas, a time when the climate abruptly shifted from warming to glacial cold. Other scientists have proposed that the younger Dryas was produced by an impact but no viable source crater has been found.

Analysis Required: Although Antarctic marine sediments are usually difficult to date, a few cores are well-dated. The student and PI will sieve and examine sieved samples from already dated cores to see if there is a layer of silicate spherules around the time of the Younger Dryas. To see if they have formed at high temperatures, some spherules will be sent out for determination of their oxygen isotopes on an ion probe. We will also separate out the fine fraction from cores already known to contain spherule bearing horizons to see if an Ir anomaly (diagnostic for impacts) is present. We will examine spherule bearing cores close to the proposed rim and will search for impact glass within the spherule bearing layer and volcanic glass above and below the layer. There are many active volcanoes near the Ross Sea so we can use previous ice core studies on local volcanic eruptions to further constrain the age of the impact event.

Prerequisites: A strong interest in earth science and adequate computer and microscope skills. Competence in plotting and manipulating data with excel is required. Competence with MatLab would be useful but is not essential. Student should be able to use a microscope several hours a day. This project could be done remotely for all or part of the summer if it is necessary or desirable. (We would loan you a microscope.)

Mentors: Dr. Dallas Abbott dallashabbott@gmail.com
Dr. Steven Jaret sjjaret@yahoo.com

How Did the Location and Intensity of the Westerly Winds Change Over the Last 150,000 Years? How Will They Change with Increased Global Warming?

Background: The westerlies are the prevailing west-to-east winds in the middle latitudes of Earth's northern and southern hemispheres. These westerly winds play an important role in both regional and global climate, impacting aerosol distribution, precipitation patterns, and ocean circulation. Recently, observations have shown that the location and intensity of the westerlies have been changing, likely influenced by anthropogenically-induced global warming. However, it is widely debated if these changes detected over the last several decades will continue into the future, and to what degree. To better understand how the westerlies respond to changes in climate, we can look to past warm intervals in Earth's history, and apply previously developed methods during these periods that allow for the reconstruction of fluctuations in wind systems. One time period of interest is the last interglacial period ~125 thousand years ago, when temperatures and sea level were slightly higher than today. Using dust brought to the ocean, as well as ocean productivity affected by wind-driven currents, changes in the strength and position of the westerlies can be ascertained. The timing of any shifts detected in the winds can be compared to climate variables, such as temperature and ice volume, and from this we can better understand the mechanisms responsible for changes in the westerlies. We plan to test the hypothesis that the westerlies were located poleward and were weaker during the last interglacial interval compared to today, and progressively shifted equatorward and strengthened through the last glacial cycle (~120 to 20 thousand years ago).

Analysis Required: This project will analyze the concentrations and fluxes of dust and productivity from sediment cores collected from the North Pacific Ocean to reconstruct variability in the Northern Hemisphere westerly winds over the last ~150 thousand years. Laboratory work includes weighing, chemical digestion, column chemistry, and analysis of sediment samples. Analyses will include the measurement of 1) helium isotopes on an MAP215-50 mass spectrometer, 2) uranium and thorium isotopes along with trace and rare-earth elements on an inductively coupled plasma mass spectrometer (ICP-MS), 3) and major elements on an inductively coupled plasma optical emissions spectrometer (ICP-OES). Lab work will average ~25-30 hours per week, with the rest of the time dedicated to literature review, data analysis and discussion of the results, and preparation of results for presentation in both oral and written formats. In the event that the REU would need to be virtual, suggested lab work will be fully replaced by a modeling study in collaboration with Stefan Rahimi, a postdoctoral student at the University of California, Los Angeles, looking into the effects of warmer climate on the westerlies and dust over Eastern Asia and the North Pacific Ocean. As such, the principles and main objectives of the project will be the same, but approached from a different angle.

Prerequisites: General chemistry and lab courses are required; Interests in past climate and modern climate change would be a plus.

Mentors: Jordan Abell, jabell@ldeo.columbia.edu, 443-974-2149
Gisela Winckler, winckler@ldeo.columbia.edu, 845-365-8756."

What Controls Bacterially Regenerated N:P Ratios?

Background: Bacterial regeneration mechanisms have important global implications as bacteria process 50% of marine primary production daily. In the upper ~100 meters of the ocean, Nitrogen (N) and Phosphorus (P) are recycled and exported to the deep ocean in different forms. The Redfield ratio links oceanic N and P cycles through a canonical N:P ratio of 16:1 for organic matter production and decomposition. However, many upper oceanic regions have dissolved N:P ratios lower than 16:1, implying that P is preferentially remineralized into dissolved forms and retained in the upper ocean while N is exported in sinking particles. However, the N:P of bacterial remineralization varies across studies. Explanations for N:P regeneration ratios in different studies lead to three hypotheses for preferential remineralization of P in low N:P waters. My objective is to understand what controls the bacterially regenerated N:P ratio. We will conduct experiments and create ecosystem models to investigate three explanations for low N:P bacterial remineralization in N-limited regions:

1. Remineralization corresponds to organic matter N:P. In N-limited waters, N-limited bacteria excrete P.
2. Remineralization corresponds to the biochemical composition of organic matter. If P-rich compounds (nucleic acids, phospholipids) are inherently more labile than N-rich compounds (proteins), then P is released during decomposition, regardless of the bulk N:P ratio.
3. Remineralization stoichiometry for organic matter is set, independent of N:P or biochemical composition.

Analysis Required: The work will begin with controlled lab experiments providing *Halomonas halodurans*, a temperate heterotrophic marine bacterium, with dissolved organic matter in seawater media. We will provide the bacteria with organic matter of consistent biochemical composition, but different N:P, or organic matter of consistent N:P, but different biochemical composition. Explanation 1 suggests regenerated N:P will reflect the N:P of the organic matter. Explanation 2 suggests regenerated N:P will reflect the biochemical composition of the organic matter. Explanation 3 suggests regenerated N:P will be similar under both conditions. By varying the P content of the nucleotide, the protein: nucleotide ratio can be maintained across a range of N:P. Similarly, different biochemical compositions can be produced with the same N:P. After experiments on a cultured isolate, we will conduct similar trials using natural communities from the N-limited Long Island Sound. We will prepare 8 treatments (filtered control, killed control, high and low N:P, high and low protein: nucleotide, nucleotide only, and protein only), and measure remineralization changes in N and P over 6 days.

To connect the experimental results to P retention in the upper ocean, we will create a simplified statistical ecosystem model to assess vertical N and P fluxes. Model parameters will be informed by our experiments and literature values. We will investigate the relative importance of P retention and bacterial remineralization in the upper ocean by parameterizing N:P ratios according to the 3 different hypotheses tested above. Comprehending the mechanistic basis for bacterial remineralization of N and P will improve modeling and prediction of N:P in the upper ocean. Because the N:P ratio is a fundamental aspect of ocean biogeochemistry, this research is locally and globally applicable."

Prerequisites: None except for an intense interest in marine microbiology..

Mentors: Kailani Acosta, kga2108@columbia.edu, 631-681-552

How Well Are Microfossils Preserved Under the Seafloor After Being Buried for Millions of Years?

"**Background:** Tiny, sand grain-sized microfossils (foraminifera) buried under the seafloor of the deep ocean illustrate seawater chemistry and climate conditions far back in time. While foraminifera live and grow, they record the chemistry of surrounding seawater as they build their shells. After they die and their empty shells sink to the seafloor, this chemical information remains within their fossil shell structure as an archive of ocean and climate history. By selecting suitable microfossils from ocean sediment samples and analyzing the chemistry of these hard skeletons, we can therefore estimate seawater properties from millions of years ago, such as temperature, acidity, and carbon content. However, for many of these estimates to be accurate, these microfossil specimens must be well-preserved, meaning that their shells retain the structure and chemical composition acquired in the surface of the ocean where these organisms grew while they were alive. Some studies have evaluated this preservation qualitatively, but there has not been a more thorough, quantitative assessment of how the sedimentary preservation of different species of microfossils may have changed over millions of years. A recently-developed, unique combination of detailed microscope imaging and precise weighing of individual shells now enables quantification of possible changes in this microfossil preservation millions of years in the past.

Project Analysis: This project will assess changes in the sedimentary preservation of two or three different species of microfossils over time, using samples from two sites in the tropical Atlantic (ODP Site 925) and tropical Pacific (ODP Site 872). These ocean sediment cores span 15 million years of Earth history from the mid-Miocene to modern times. They contain abundant fossil shells of foraminifera species that are widely used in paleoclimate reconstructions, but whose preservation over time is not well documented. Lab work includes identifying and selecting shells of microfossil species from ocean sediment samples using a binocular microscope, qualitatively characterizing individual fossil shell preservation using scanning electron microscopy (SEM), and quantitatively evaluating microfossil preservation using area density analysis of microfossil shells. The area density method pairs highly detailed surface area and weight measurements of individual shells using a microscope-mounted camera, imaging software, and a precise microbalance. Lab work will average 30 hours per week, with the remaining time dedicated to data analysis and exploring scientific literature surrounding the project. Most lab work will occur at the Lamont-Doherty Earth Observatory (LDEO), and several days will be devoted to SEM imaging at the American Museum of Natural History (AMNH). Both Anderson (LDEO) and Umling (AMNH) will guide training and investigation in different laboratory techniques.

Prerequisites: General chemistry and lab courses are ideal. Most important is an interest and curiosity in earth and environmental science, earth history, and/or climate change.

Mentors: Lloyd Anderson, lloyd@ldeo.columbia.edu, 330-907-0203
Natalie Umling, numling@amnh.org, 704-301-4872
Baerbel Hoenisch, hoenisch@ldeo.columbia.edu, 845-365-8828

What Do Lake Sediments Deposited at Different Latitudes Tell Us About Climate Under High CO_2 Conditions on Earth, in Ancient Environments or on Mars?

Background: This project focuses on fossil lake sediments from the eastern and western US and northeastern and northwestern China, comprising some of the most famous fossil deposits in the world, including those that produce feathered dinosaurs, as well as mammals, fish, insects, and plants. The lakes formed during the Mesozoic, a time period that spans from 66 million to 250 million years ago, during which the areas were in different latitudes than now because of continental drift. The US deposits were tropical, while those of China were temperate to arctic. Atmospheric CO_2 was much higher than present, more like what we will see in the future by 2100 to 2400.

Project description: The student will quantitatively characterize and visually describe lake sediments and fossils. They will disaggregate the samples to examine sediment grains and look for fossils, use high-resolution microscopes to image grains and fossils (charcoal and plants, fish scales, invertebrate fossils, teeth, etc.), and perform automated grain size analysis to measure the distributions of sediment size that reflect physical processes that deposited the sediments. Depending of the specifics of the project, the student may use techniques such as X-Ray Fluorescence and X-Ray Diffraction to characterize the chemical composition of samples, Micro-CT scanning to characterize sediment grain and fossil morphology, nanoSIMS, and clumped isotopes of fossil mollusks as appropriate.

If possible, we may take a one-day field trip in NY to observe a modern lake and to collect sediments and microbes for lab analysis. Another one-day field trip could visit local outcrops in NJ and look at fossil lake deposits in person. By the end of the summer, the student will have gained skills in lake sediment lab work, fieldwork, and data analysis.

Prerequisites: No prerequisites. All are welcome; we will teach you what you need to know and can adjust the project based on your interests.
"

Mentors: Clara Chang, chang@ldeo.columbia.edu 914-843-5398
Paul Olsen, polsen@ldeo.columbia.edu
Sean Kinney, kinney@ldeo.columbia.edu
Chris Lepre, clepre@eps.rutgers.edu

Can We Store Carbon Dioxide in the Oceanic Crust?

Background: Cutting carbon dioxide (CO_2) emissions and lowering its concentrations in the atmosphere is one of the greatest challenges of this century. Geologic storage of CO_2 by injecting it into porous rock formations where it will be trapped as nontoxic carbonate minerals may be an important key to reducing atmospheric concentration of CO_2 and mitigating the negative impacts of climate change. We are investigating offshore carbon storage in sub-seafloor basalt offshore off British Columbia in the Cascadia Basin, where the seafloor has been sampled extensively at Scientific Ocean Drilling sites and using the NEPTUNE real-time seafloor cabled network. The ocean crust may have enormous capacity for fluid injection and may become a critical reservoir for safe and secure disposal of CO2 from a variety of man-made sources.

Analysis Required: This project will continue ongoing research efforts to compile geophysical data that has been collected previously in and near the Cascadia Basin on ODP Legs 150, 168, 174 and IODP Legs 301, 313 and 327, assessing its quality for improving analysis of the ocean crust, and interpreting the results in the context of CO_2 storage potential. These data will include geophysical well logs and core data from the IODP data repositories and marine survey data (bathymetric maps and seismic profiles) from Ocean Networks Canada, US BOEM, USGS, and other geophysical data repositories. Tables, plots, and maps will be produced from this information and then analyzed, with the student gaining experience in image and numerical data handling. On-line database software and spreadsheets will be utilized.

Prerequisites: Intense interest in geophysics and earth science. Experience with using spreadsheets. Experience with geographic information system (GIS) software or other data visualization tools would be helpful.

Co-mentors: David Goldberg goldberg@ldeo.columbia.edu
Angela Slagle aslagle@ldeo.columbia.edu 845-365-8444

What Is the Ice-Calving History of Antarctica Based on Iceberg-Rafted Debris From IODP Expedition 382 Sediment Cores?

Background: As large ice sheets grow and flow across a rocky landscape, they grind up and incorporate the basal continental rock into their mass. When icebergs calve off of the land and float out to sea, they bring those grains with them. As the icebergs melt, the sediment falls into deep ocean sediments. This material is called iceberg-rafted debris, or IRD. IRD grains are distinctly different from silty clays typically found in deep ocean sediments and we can use them as a proxy for glacial ice discharge. From March to May of 2019 the International Ocean Discovery Program (IODP) drilled sediment cores in the Southern Ocean, just off the coast of Antarctica on IODP Expedition 382. We will be using samples from these sediment cores to study the ice-calving history of Antarctica.

Project description The student will be counting and quantifying Antarctic IRD fluctuations using sediment samples from IODP Expedition 382. The samples will first be wet sieved to divide the silts and clays from the larger size class containing IRD and microfossils. There will then be a density separation step using a safe and non-toxic heavy liquid. This step will separate the IRD from the microfossils. Once we have the IRD isolated, we will count the IRD grains to quantify fluxes throughout time. There is already an age model for these sediment cores so once we have IRD amounts we can put those amounts on a timescale to interpret the pacing of IRD fluctuations. This is vital research in understanding the volatility of the Antarctic ice sheet in the past.

Skills required/Prerequisites: We are looking for someone who is eager to learn and work with deep-sea sediment cores and feels comfortable using a microscope. We expect that the student is well organized and has great attention to detail. Besides those expectations, there are no specific prerequisites. All are welcome; we will teach you what you need to know. Please note: the majority of this work will be laboratory work.

Mentors: Claire Jasper (primary), email: cjasper@ ldeo.columbia.edu
Maureen Raymo, email raymo@ ldeo.columbia.edu, website: https://moraymo.us/

Tracking the Last Moments Before Explosive Volcanic Eruptions: What Can Water in Quartz Tell Us?

Background: Even with advances in monitoring techniques, some volcanoes still erupt without warning, as seen in the recent, fatal eruption of White Island in New Zealand. This suggests that the processes responsible for providing the final trigger for the eruption could occur just moments before the explosion, but exactly how much time remains an open question.

A new way to track the timescales of eruptions comes from measuring profiles of water in crystals ejected by volcanoes. These crystals, often including quartz, form in magma chambers below volcanoes, then might sit for tens, thousands or even hundreds of thousands of years before eruption. During this time, the intense heat and pressure force small amounts of water, in the form of hydrogen, into the quartz. During, or just before the eruption, when the pressure is finally released, this hydrogen tries to escape the crystals, leaving lower water concentrations at the crystal edges than in their cores. Because we now know how fast hydrogen moves in crystals, we can start to work out, based on the concentration difference between the rim and core of the quartz, how long the eruption process took.

This is a new and emerging field. The speed of hydrogen movement in quartz has only just been fully measured during 2019. This project therefore provides a unique opportunity to be one of the first people to ever determine volcanic eruption rates from water profiles in quartz, which has the potential to be an important tool in the future.

Analyses required: This project will involve preparation and analysis of quartz (and possibly feldspar) samples from the Bishop Tuff, a >2000 km^2 volcanic deposit in the western USA formed some 767,000 years ago. These crystals will then be analyzed by Fourier Transform Infrared (FTIR) spectroscopy to measure their water contents. Lab work will be ~20 hours per week, with the rest of the time spent on literature review, data processing and analysis.

Prerequisites: None required, although some knowledge of chemistry / mineralogy / physics / programming would be useful.

Mentors: Mike Jollands, jollands@ldeo.columbia.edu, 845-365-8649
Terry Plank, plank@ldeo.columbia.edu, 845-365-8733

How Much do Glaciers and Ice Sheets Affect Volcanic Activity? Research Using Ocean Drilling Program Cores and Online Data

Background: An important question is whether glaciers and ice sheets, and Ice Ages in general, affect volcanic activity. Around 2.6 million years ago, at what is termed the Plio-Pleistocene transition , a fundamental shift occurred in Earth's climate. After this time, Ice Age cycles in the Northern Hemisphere intensified and large ice sheets prominently came and went over North America, northern Europe, and likely elsewhere. Next, between 1.25 and 0.7 million years ago, at what is termed the Mid-Pleistocene transition - another important shift occurred in Earth's climate. At that point, ice sheets over North America and glaciers elsewhere, and Ice Age climate cycles in general started fluctuating steadily on a 100,000-year rhythm, which was paced ultimately by Milankovitch orbital cycles. A question is, can we see changes in volcanic activity associated with major climate shifts and glaciers expanding and retreating during Earth's history? Tephras and associated volcanic products are transported or carried out to the ocean by the wind, and rivers in some places, where they are deposited in deep sea sediments. So, if there are major changes in volcanic activity, where glaciers expand and retreat during Ice Age cycles, then we might expect nearby deep sea sediments to record such a change. The project will focus on marine or deep sea sediment records near or adjacent to central and northern South America, to determine if the pattern of volcanism in the Andes has changed over time. The focus is on (at least) the Andes of South America because volcanoes have been erupting over the entire time interval of interest. In addition, glaciers have repeatedly expanded and retreated on the highest mountains and volcanoes. Glaciers coming and going may affect volcanic activity given the change in overburden pressure. Whether Ice Age climate cycles affect volcanism in the Andes is still poorly understood. The project will try to answer questions such as, in areas where glaciers came and went, did volcanism or volcanic products deposited in nearby deep sea sediments increase or decrease after 2.6 million and after 0.7 million years ago? Are changes in volcanic products on land, carried out to the sea, observed on a 100,000-year rhythm, or at a particular time during these glacier cycles?

Skills Required: The main effort will involve the study of Ocean Drilling Program data and shipboard cruise reports already online, to analyze and evaluate patterns of volcanic materials transported to the ocean (tephras, for example). The study will focus on Ocean Drilling Program cores already taken near or adjacent to subtropical and tropical South America, as well as perhaps other regions, where volcanic materials are transported to the ocean by winds and rivers. There is no lab work required. If possible, the student may look at tephras under the microscope for some hands-on experience, as conditions permit in the summer of 2021. This project is ideal if a virtual internship is required due to COVID 19.

Prerequisites: None required, but comfort with Excel, or other data-oriented programs are a plus.

Mentors: Mike Kaplan, mkaplan@ldeo.columbia.edu;
Carolina Muñoz Saez, cmsaez@ldeo.columbia.edu
Steve Goldstein, steveg@ldeo.columbia.edu
Sidney Hemming, sidney@ldeo.columbia.edu

Why Did the 2020 Hurricane Season Produce a Record Breaking Number of Storms but Lower Hurricane Bulk Energy Than in Some Previous Active Years?

Background: The 2020 hurricane season was arguably the most active season in recent history. There were a record-breaking number of storms (30) in the North Atlantic and also a record-breaking number (12) made landfall in the US. From other measures of hurricane activity, such as numbers of the most extreme cases (the Saffir-Simpson Category 5) and the accumulated cyclone energy (ACE), 2020 was not the 'most' active season when compared to seasons like 2005. ACE is a metric representing the total energy of hurricanes across the season, not just the number of storms. Back in May, the NOAA Climate Prediction Center issued a seasonal outlook that predicted an above normal and perhaps hyperactive hurricane season. NOAA's forecast was partially because of the combination of a *La Nina* year and abnormally warm sea surface temperatures in the tropical Atlantic. Both provide favorable atmospheric and oceanic conditions for storms to form and to intensify. In other words, it was not surprising that we had an active year; it was surprising that 2020 was so extreme in terms of number but not so in other measures.

Analysis Required: To answer the questions posed above, we propose 4 tasks. First (1), we will calculate hurricane-metrics for 2020 and other known active hurricane seasons in the past. The hurricane-metrics are the number of hurricanes, ACE, number of hurricane days, etc. Second (2) we will calculate individual atmospheric and oceanic conditions, such as vertical wind shear and sea surface temperature, and a few proxies and climate index that comprehensively represent the favorability of the ambient environmental conditions in the tropical Atlantic during 2020 and in other active hurricane seasons in the past. Then, (3) we will compare and contrast our analysis of these metrics and environmental conditions between 2020 and other previous active hurricane seasons to understand how 2020 differed from other active seasons. Lastly (4), we will again perform analysis of these metrics and environmental conditions but between the early and later part of 2020 season to examine what changed from the early to the late season. The mentee will write a scientific report on the findings of these tasks by the end of the internship.

Prerequisites: All the tasks will be conducted using Python. Experience in programing in the Python language is required. Knowledge of statistics and atmospheric science would be great but are not necessary. We especially welcome students who are interested in learning about hurricanes.

Mentors: Chia-Ying Lee, cl3225@columbia.edu
Suzana Camargo, suzana.camargo@columbia.edu

What Was the Jurassic World Like During the Rise of Theropod Dinosaurs in Eastern North America?

Background: At nearly 200 million years ago, the beginning of the Jurassic Period witnessed a whole host of environmental changes that may have influenced the evolution of dinosaurs. Several geologic formations within the New York, New Jersey, and Connecticut areas preserve important clues to these events, as well as the footprints of the theropod dinosaurs *Coelophysis* and *Eubrontes*. From the studies of the ancient soils encasing the fossils, we know that atmospheric carbon dioxide, a notable greenhouse gas, more than doubled in concentration as a result of a series of volcanic eruptions associated with the plate tectonic breakup of the Pangaean Supercontinent. These eruptions, collectively part of the Central Atlantic Magmatic Province or CAMP, mark a cataclysmic beginning to the Jurassic world. A sizeable increase in the number of theropods at the expense of other land-dwelling tetrapods (e.g., reptiles), numerous floral changes, and marine biotic events are all attributed to the impact of CAMP on Jurassic ecosystems. However, several outstanding questions still exist, such as: how did CAMP directly affect the environment? And, what was the climate like during the rise of the theropods? The paleoclimate and paleo-vegetation history of the Early Jurassic in eastern North America has already been demonstrated through the analysis of Newark Basin cores taken from sites in New Jersey. A second core taken from the Hartford Basin of Connecticut was examined late last year and the samples are yet to be analyzed. The sampled interval for the Hartford Basin core spanned at least four Milankovitch climate cycles that represent insolation forcing of the intensity of monsoonal rainfall over Pangaea. The purpose of this project is thus to (1) analyze the Hartford Basin samples, (2) sample and analyze the comparable interval from the Newark Basin core, and (3) compare the results of the two datasets.

Analysis Required: The intern will help to sample, prepare, and process ancient soils for the measurement of hematite and other iron oxide minerals in the Hartford Basin and Newark Basin core. Principally, this will involve using diffuse reflectance spectroscopy (DRS). The student will also learn rock and mineral magnetism through a series of magnetic susceptibility, isothermal remanent magnetization, and anhysteretic remanent magnetization experiments. The research also will characterize the stratigraphic context of the Newark Basin samples, describing in detail the sampled positions relative to marker horizons, changes in lithology, texture, primary sedimentary structure or color, and sedimentary facies.

Prerequisites: a strong curiosity about the environment and willingness to learn how to operate technical instruments.

Principle mentor: Christopher J Lepre, PhD (lepre@ldeo.columbia.edu)
Co-mentor: Paul E Olsen (polsen@ldeo.columbia.edu)

Did Icebergs Cause the Most Dramatic Climate Changes of the Last Ice Age?

Background: The last ice age was punctuated by repeated abrupt climate changes that involved dramatic cooling of the northern hemisphere at times when much of southern hemisphere was warming. These climate shifts occurred at times of episodes of catastrophic iceberg discharge from the vast Laurentide ice sheet that covered much of North America, and the melting icebergs may have reduced northward heat transport by weakening the large-scale Atlantic meridional overturning circulation (AMOC). Although computer simulations consistently suggest it is possible, and this mechanism is widely favored as a potential explanation for these otherwise puzzling climate oscillations, some studies have argued that the bipolar temperature changes actually happened first, thus causing iceberg outbursts into the glacial ocean. A seagoing expedition to the Labrador Sea in the northwest Atlantic as part of the ICY-LAB project in the summer of 2016 recovered several sediment cores from this key area where the icebergs emanated. The cores hold the promise of an answer to whether the icebergs initiated the climate changes, or were instead released subsequently as glaciers grew in response to the northern cooling. What is needed is a sequence of evidence in the same sediments, from locations proximal to the ice sheet, that can unequivocally clarify the roles of icebergs, ocean circulation and sea-surface temperature (SST) change. Simultaneous investigation of proxies for all three processes in these new cores can provide such insight.

Analysis Required: This project will require a student to process samples taken from the ICY-LAB cores, identify and quantify ice-rafted debris, determine the relative abundance of polar foraminifera species, select and prepare specimens for isotopic analysis. They will then apply visual and simple time-series analyses to assess the sequence of climate events. Training / guidance will be provided for all procedures. Lab work will require 20 hrs./wk.

Prerequisites: None, although knowledge of basic oceanography and climate are helpful.

Mentor: Jerry McManus: jmcmanus@ldeo.columbia.edu, 845-365-8722

"

How Hot Are the Rocks Beneath North America?

Background: The North American continent was assembled during the course of many plate tectonic events, spanning a period of over three billion years, as is evidenced by the geologic ages of surface rocks in its many terranes and the geological structures within them. Continents, however, are more than rocks exposed on the earth's surface; they are part of a tectonic plate that extends to several hundred kilometers depth. The base of this plate is the region where geodynamic processes are in play and where heat from the deeper convective motions is applied. Recent research has pointed to the variability of these processes, with some regions being heated to much higher temperatures than others. The deep continent can be studied using seismic imaging techniques, similar to medical imaging, which use seismic (earthquake) waves to probe structure. Furthermore, recent observations at thousands of sites by the United States Earthscope project created a large and very high quality dataset of seismic recordings. These new data will be used to address three important questions related to continental evolution: 1) how variable temperature is at a given depth; 2) whether the hottest regions are above their melting point and contain magma; and 3) whether in places the North American plate actively is being eroded away.

Analysis Required: The intern will be responsible for analyzing and interpreting a seismic wave data set. Properties that will be studied include wave speed and attenuation of wave energy, with the object of using their variability to map out earth properties.

Prerequisites: The intern needs to be willing to learn a little seismology and to spend a long time staring at wiggly lines. Some prior exposure to the physics of vibrations and waves and to data analysis would be helpful.

Mentors: William Menke, menke@ldeo.columbia.edu 845-304-5381

What Drives Oxygen Uptake in the Eastern Subpolar North Atlantic Ocean?

Background: Greenhouse gas emissions have raised the atmospheric concentration of carbon dioxide (CO_2) from a pre-industrial level of 280 parts per million (ppm) to more than 410 ppm, the highest level in over 100,000 years. The impact of anthropogenic forcing on the global climate system is significantly moderated by the ocean, which absorbs excess heat and CO_2 emissions. As the ocean continues to warm, and there is increasing demand for oxygen by marine animals, it is critical to understand how oxygen enters the ocean and circulates within it. One of the most important regions for oxygen uptake is the subpolar North Atlantic Ocean, where strong winds during the winter cause particularly deep mixing which injects oxygen-rich surface waters to depth. Recent findings from the 2014-2016 OSNAP moored arrays reveal most of the North Atlantic overturning—in which newly formed water masses sink to depth and travel southward—occurs in the Irminger, Greenland, and Norwegian Seas. Thus, the oxygen-rich waters produced by deep convection in these three seas are extremely important for global ocean ventilation.

Project description: This project will focus on improving our understanding of the oxygenation of the eastern subpolar North Atlantic. Specifically, how does the oxygen content of this region change over time? What is the primary driver of oxygenation? And how does oxygen uptake respond to climate variability? To investigate these questions, the student will construct an oxygen budget to establish a process-based understanding of oxygen uptake in the region. The budget will be constructed using output from a biogeochemically-coupled version of a regional physical model of the North Atlantic Ocean for 2002-2017. This model estimates oxygen concentration over space and time, and allows us to decompose total oxygen into its components: advection, diffusion, biology, and air-sea gas exchange. Previous work in our lab using this methodology shows that air-sea gas exchange is the dominant driver of Labrador Sea oxygen uptake. By conducting this study, the student will verify whether this is also true in the eastern subpolar North Atlantic. The entirety of this project can be completed remotely.

Skills required: Some knowledge/experience with Python and Unix would be extremely helpful. The student will be using Python to analyze model output, mostly by running and modifying existing Python scripts.

Mentors: Primary: Lauren Moseley: laurenm@ldeo.columbia.edu
Secondary: Galen McKinley: mckinley@ldeo.columbia.edu

What New Scientific Insights Can We Gain From X-Ray Fluorescence Scans of ~200-Million-Year Old Cores? What Is the Astronomical Pacing of Climate at Different Time Scales?

Background: Ever since the seminal ,"Pace Maker of the Ice Ages" paper by Hays, Imbrie and Shackleton in 1976, it has been known that the gravitational interactions of the masses in the Solar System produce changes in the geometry of the Earth's spin axis and orbit that produce cycles in climate on Earth (and other planets)- so called Milankovitch cycles. It has also been theorized that changes in solar luminosity caused by sun spots cycles and other mechanisms also influence climate at decadal to millennial time scales, often referred to as sub- Milankovitch cycles. Geological records of these celestial processes have the potential to help us understand Solar System and solar dynamics and how they have changed over hundreds of millions of years. Cores of lake sediments from the Late Triassic and Early Jurassic of Eastern North America (New Jersey and Connecticut) exhibit sedimentary cycles caused by the rise and fall of lakes on Milankovitch timescales of tens of thousands to millions of years as well as much smaller times scales reflecting the yearly seasonal cycle (varves) to clear and very intriguing larger cycles at decadal to millennial sub-Milankovitch-cycle-scale. These cycles at multiple scales, spanning orders of magnitude different frequencies, can be seen not-only visually, but also in geochemical data and have the potential to reveal 200-million-year old Solar System and solar dynamics, unobtainable by other means. However, it is extremely challenging and expensive to use conventional geochemistry to quickly and efficiently obtain enough data to examine these cyclical patterns. X-Ray Fluorescence (XRF) spectroscopy can be used to get very fast, high density, and high quality data that can be input into mathematical timeseries and processed to reveal the frequencies at which ancient tropical climate responded to astronomical effects, from yearly to the million year scales.

Analysis Required: The intern will obtain XRF scan data from a variety of core and outcrop samples, as suits the intern's interests, and then explore the patterns of climate-relevant chemical data as revealed by timeseries and signal process analysis via user-friendly computer programs, such as Acycle that runs on PCs or Macs. These cyclical and periodic patterns revealed by mathematical analyses will be interpreted by the intern in light of celestial mechanical and solar physics.

Prerequisites: A background in introductory geology is useful and some experience with basic math and basic running of computer programs is needed, However, use of the timeseries program(s) will be taught. Some knowledge of Astronomy is a plus. Experience with MS Word, Excel, and PowerPoint is important although they can also be learned though the project.

Mentors: Paul Olsen, polsen@ldeo.columbia.edu
Clara Chang, cchang@ldeo.columbia.edu
Sean Kinney, kinney@ldeo.columbia.edu

What Can Detrital Zircons Tell Us About the Sources of Gigantic, Climate-Changing Volcanic Eruptions (the CAMP) and Their Transit Through the Earth's Crust?

Background: Causing massive and abrupt changes in climate though the release of gasses, gigantic volcanic eruptions of basaltic lava in flood basalts are implicated as the cause or a major factor in almost all of the major mass extinctions and several major biotic disruptions of the past 500 million years of Earth history. One of these, the Central Atlantic Magmatic (CAMP) had a significant impact on the global environment and is causally linked to the End Triassic Extinction (ETE) at about 202 million years ago. Recent geochronological studies on the CAMP established very precise temporal constraints on the emplacement of the oldest basalt flows and their correlation to the extinction level using zircons and the U-Pb CA-ID-TIMS method, that crystalized out of segregation veins in lava flows and related intrusions feeding the flows. However, there are other, older zircons, populations herein referred to as detrital zircons, that are found within all units of the CAMP that represent a thus far untapped source of information about where CAMP magmas were prior to their arrival in the upper crust and eruption onto the surface.

Analysis Required: In this project an intern will attempt to address the question: What do these detrital zircons tell us about the source of CAMP magmas and the route those magmas took from their source or sources to the surface. For example, many workers agree that CAMP magmas have a major component of recycled Iapetus ocean crust that was subducted during the early Paleozoic. One might expect to see zircons from gabbros in that subducted crust if it was sourced from a relatively shallow subducted slab. On the other hand, if the subducted slab made it all the way down to the core-mantle boundary and came back up in a plume, once might expect complete remelting and no inherited zircons of that age. The zircons present should also reflect assimilated crust with zircons of varying age depending where the magmas intruded. The intern will analyze the age spectra, Hf isotopes, and trace element chemistry of zircons (run at LaserChron at U of AZ remotely) from at least two flows or intrusions and compare them with possible sources of the zircons yielding fresh insights into the dynamics of these gigantic eruptions and their effects on the history of life.

Prerequisites: A background in introductory geology and general chemistry is useful. Experience with MS Word, Excel, and Powerpoint is important although they can be learned though the project.

Mentors: Paul Olsen, polsen@ldeo.columbia.edu; Sean Kinney, kinney@ldeo.columbia.edu; Clara Chang, cchang@ldeo.columbia.edu .
"

Did ENSO and the Eastern Equatorial Pacific Thermocline Depth Vary During the Last Ice Age?

Background: Today, cold and CO_2 rich waters from the deep ocean are upwelled into the surface ocean in the Eastern Equatorial Pacific (EEP). Here, the ocean and atmosphere exchange heat and CO_2, influencing local and global climate. The thermocline, the zone of the water column where temperature decreases rapidly with depth, is relatively near the surface. The depth of the thermocline varies during El Niño and La Niña events, which occur every 2-7 years. During an El Niño event, less cold, deep water upwells from depth and the thermocline is deeper in the water column, while the opposite occurs during La Nina. These ocean-atmosphere oscillations may have varied differently in the past, with potentially large climate implications.

Project Goal: To assess how changes in global climate and in the distribution of solar radiation on Earth's surface have affected the structure of the water column in the Eastern Equatorial Pacific over Earth's recent history. If the mean position of the thermocline was different in the past, the amount of CO_2 exchange between the ocean and the atmosphere and the strength and frequency of El Niño and La Niña events could have changed.

Analysis Required: Deep sea marine sediment cores are archives of past ocean conditions and contain proxies for variables such as temperature. The oxygen isotope ratio of the fossil shells of calcareous organisms called foraminifera, which live at different depths in the water column, are a widely used proxy for past ocean temperatures. Comparisons of multiple species of foraminifera that live at different depths in the water column will allow us to reconstruct the position of the thermocline, and the temperature structure in the Eastern Equatorial Pacific in the past.

The intern will sieve marine sediment samples from ODP Sites 1240, 1242 and 849 and will search for species of foraminifera, such as N. dutertrei, that typically live in the thermocline. The student will select a time period of interest, such as the Holocene and the Last Glacial Maximum (0-21,000 years before present). The intern will gain laboratory skills such as sediment sampling and washing and will learn how to pick foraminifera under a microscope and how to load foraminifera for oxygen isotope analyses. The intern will also learn about how marine sediment cores are collected, dated, and stored. The oxygen isotope records of foraminifera that the intern constructs will be used to constrain the position of the thermocline in the past and will be compared to previously published records. If remote work is required, samples and necessary supplies can be shipped to the student.

Skills Required: A basic understanding of Earth's climate and oceans, or an interest in learning about these systems is required. No prior laboratory experience is required, and all sampling and microscope techniques will be taught. Experience with Microsoft excel, Python, or other data analysis/plotting software is preferred. Attention to detail, organizational skills, and a creative outlook are appreciated.

Mentors: Celeste Pallone (cpallone@ldeo.columbia.edu)
Jerry McManus (jmcmanus@ldeo.columbia.edu)

How Frequent Are Catastrophic, Climate-Affecting Volcanic Eruptions During the Pleistocene?

Background: The logarithmic volcanic explosivity index (VEI) of explosive volcanic eruptions is measured on a scale 0 to 8. While still deadly, comparatively smaller volcanic eruptions like the Mt. St. Helens (Cascades, USA) eruption in 1980 (VEI ~4-5), rarely affect the global climate. However, catastrophic eruptions with VEIs> 6 are known to affect climate. For example, the 1815 eruption (VEI = 7) of Mt Tambora (Indonesia) is famous for having caused global cooling for several years, which led to famine and disease in the Northern Hemisphere and "the year without a summer'. Because on land volcanic records older than a few 10,000 years are destroyed by erosion or inaccessibly buried under younger geological material, they cannot be used to reliably determine the frequency of such large eruptions in the Pleistocene, which begun 2.6 million years ago and is characterized by global cooling and the waxing and waning of the ice cycles. In this project, we instead establish a time series of such large eruptions that was left behind in the form of centimeter-thick volcanic ash beds in the marine sediments of the Northwest Pacific ocean basin. Drill cores from ODP Sites 881 and 882 are rich in ash beds and uniquely record major volcanic explosive eruptions (VEI ~6-7) during the 2.6 million years long archive of past major volcanic eruptions. Is there a link between glacial cycles and large-scale volcanic eruptions that also started to increase at 2.6 Ma

Analysis Required: This is a data mining project. All data are at hand. The student will identify ash bed layers from ODP Hole 881 (NW Pacific) from high-quality core images (Section-half image logger) and other existing ODP expedition data, compile them into a database and calculate their ages. This will be followed by modeling minimum eruption sizes using existing (simple) algorithms, and a range of potential sources and ash distribution patterns. Ideally, there will be an assessment about fluctuations of volcanic eruptions through time. Work will require ~25 to 30 hours per week (this is flexible).

Prerequisites: The student should be familiar with Excel. Interest in programming is a plus. The project a great learning opportunity about the capabilities of the International Ocean Discovery Program (IODP).

Thesis Mentor: Susanne Straub: smstraub@ldeo.columbia.edu, 845-365-8464

What Determines the Abundance of Chemical Species in the Upper Troposphere and Lower Stratosphere Over the Region of the Asian Summer Monsoon?

Background: The Asian summer monsoon is the dominant feature of the global atmospheric circulation during Northern Hemisphere summer. The monsoon consists of intense, deep convection and adiabatic heating that are strongly coupled to a near-surface cyclone and an anticyclone in the upper troposphere and lower stratosphere. Recent studies have found that the Asian summer monsoon circulation provides an effective transport pathway for pollutants such as carbon monoxide, black and organic carbon, sulfur dioxide, and short-lived halogen compounds derived from the Asian landmass to enter the global stratosphere and affect the chemistry and climate of the stratosphere.

Analysis Required: This project will analyze satellite measurements of various chemical species including carbon monoxide and black carbon in the upper troposphere and lower stratosphere over the Asian summer monsoon region. In particular, the project will investigate how the abundances of chemical species are affected by surface emission, convective activity, large-scale ascent, and chemical processes. In addition, the project will involve the analysis of model output of a state-of-the-art global model of chemical species and climate. We will assess the models ability to correctly simulate the concentration and abundance of chemical species in the upper troposphere and lower stratosphere. .

Prerequisites: General physics, interest and experience in atmospheric science. Statistics courses and programming experience would be a plus.

Mentors: Yutian Wu yutianwu@ldeo.columbia.edu, 845-365-8353

What Was the Timing and Magnitude of Abrupt Climate Changes in the Past?

Background:: Abrupt climate change designates events that took place over centuries, if not decades, making them relevant to the human life time scale. Studying past abrupt climate change events may shed light on how the rapid global warming we experience currently could unfold. One type of abrupt climate change is a Heinrich event. Heinrich events are the discharges of armadas of icebergs into the North Atlantic Ocean during the last glacial period. The icebergs' melting may have freshened the surface ocean, slowed down the overturning circulation, and impacted the global climate. While the timing and magnitude of Heinrich events were previously thought to be well-known, a core archived at the Lamont-Doherty Core Repository may reignite the debate about these once 'settled' questions with its preliminary magnetic susceptibility data. This proposed project will use radiocarbon dating techniques to ascertain the chronology of events.

Analysis Required: This project will strategically sample the identified deep-sea sediment core at 8-12 centimeter depth intervals, spaced out between the Heinrich layers. The intern will wash the sediment, so the coarse fraction is separated from the fine. These steps will be carried out with the Lamont-Doherty Core Repository's state-of-the-art sediment processing equipment. The intern will analyze the coarse fraction under a microscope and pick shells of planktic (surface-dwelling) foraminifera in a specified quantity. The shells will be sonicated to clean out any debris. They will then be sent to the National Ocean Sciences Accelerator Mass Spectrometry Facility at Woods Hole Oceanographic Institution for radiocarbon analysis. Lastly, the analysis results will be converted to calendar year dates and interpreted. Professor Jerry McManus and PhD student Yuxin Zhou will guide the intern's ,lab work and interpretation of results. The project will be put into the larger context of the discourse on abrupt climate change, which is ongoing and attracts great interest from the community.

Skills Required: Training will be provided for all specific tasks and instrument use. It is important that the student be diligent, careful, and willing to learn. Although not necessary, it would be helpful if they have some familiarity with the Earth's climate system, oceanography, and/or basic laboratory practices. The student and project will benefit most from the right intern's combination of independence and ability to work well with others.

Mentors: ,Yuxin Zhou yzhou@ldeo.columbia.edu
Jerry McManus, jmcmanus@ldeo.columbia.edu