Will the Next Global Crisis Be Produced by a Large Volcanic Eruption? 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.

Work 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, volumes 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.

Pre-requisites: 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:
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What are the Origins of Pure SiO_2, Tailed Spherules Found in Ross Sea and Western Pacific Sediments?

Background: Many cores from the Ross Sea contain pure 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. A volcanic source is unlikely as the most silicic volcanic rocks are about 80% SiO_2. Higher SiO_2 contents require the higher temperatures characteristic of impacts. We found the spherule-bearing layer in one well-dated core from the Ross Sea. The layer has about the same age as the Younger Dryas, a time when the climate abruptly shifted from warming to glacial cold. Kennett et al., 2009 proposed that the younger Dryas was produced by an impact, but no source crater has been identified. We have not found a good prospect for a young impact crater in the Ross Sea. Based on gravity gradient maps (Sandwell et al., 2014), the southwestern Pacific has two geologically young impact crater candidates. These crater candidates could not have been detected by satellite altimetry unless they were tens of km in diameter, sufficiently large for the southernmost candidate to deposit small amounts of impact ejecta in the Ross Sea.

Work Required: Although Antarctic marine sediments are usually difficult to date, a few cores are well-dated. The student and Abbott will examine sieve fractions from more well-dated Ross Sea cores to see if they contain a layer of silicate spherules from the time of the Younger Dryas. We previously found these tailed spherules in undated cores from the equatorial western Pacific and the Arafura Sea. The student will pick marine microfossils to date the spherule bearing layers in these cores. We will also select one core close to the southernmost impact crater candidate in a site sheltered from the impact tsunami and will search for impact ejecta and tailed spherules in that core. If either is found, we will date the layer using ^{14}C ages on marine microfossils.

Pre-requisites: 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:
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References:
Kennett, D.J. et al., 2009. Shock-synthesized hexagonal diamonds in Younger Dryas boundary sediments. *Proceedings of the National Academy of Sciences*, *106*(31), pp.12623-12628.

Sandwell, D.T. et al, 2014. New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure. *Science*, *346*(6205), pp.65-67.

How Reliably Can We Estimate the Flux of Heat and Tracers Using Argo Floats?

Background: Oceans play an important role in the Earth's climate by transporting and storing carbon dioxide, oxygen, heat, salt, nutrients (we generally call these "tracers"), and in the process influence the climate at time scales or weeks to millennia. Ocean transport is achieved by both large currents and smaller scale turbulent flows that vary over a wide range of scales, and that stir tracers both laterally and from the surface to depth. The multiscale nature of this transport makes the problem of estimating the net transport a statistical one. The upper ocean (0-2000m) has been monitored using Argo floats [https://en.wikipedia.org/wiki/Argo_(oceanography)], which measure temperature, salinity, and biogeochemical tracers, since the early 21st century. This long term monitoring effort has resulted in a large dataset with the potential to explore different statistical properties of the ocean. Some of the particularly important metrics to quantify would correspond to questions like what is the amount of turbulent transport of tracers (like heat, salt, oxygen, etc) by mesoscale eddies (~100 kilometers)? Estimating the tracer variance can help us to estimate the effects of mesoscale eddies on the tracer fields. While researchers have started to explore these questions to some degree, the novelty and richness of the ever growing Argo dataset presents numerous opportunities for further exploration and discovery.

Work Required: This project will analyze spatial statistical properties (mean, variance, etc.) of temperature and salinity profiles and velocity collected by Argo floats in the global oceans, resulting in global maps of different statistical moments and their statistical significance. Motivated students can potentially extend the project in numerous novel directions, like using machine learning for prediction or doing parameter estimation to help the next generation of climate models. This project will provide the undergraduate hands-on experience in dealing with big oceanographic datasets. Most of the data analysis will be done using the Python ecosystem, with particular emphasis on using tools developed by the Pangeo community. This work will provide exposure to skills in physical oceanography, statistical analysis, open source data science, and visualization. We expect the researcher to work approximately 35-40 hours/week, splitting their time between data analysis, literature review, meetings with mentors, etc.

Pre-requisites: Some experience/coursework in statistics, data analysis, and coding (preferably in Python) will be helpful. Coursework in physics, mathematics, oceanography or fluid dynamics can also be beneficial.

Mentors:

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Monitoring Arsenic Concentrations in Drinking Water with Portable, Real-Time Electrochemical Analysis

Background: Few resources are more fundamental than water. Clean drinking water often is only available through water treatment. Current commercially available water treatment technologies are often ineffective, costly, and require regular monitoring. This failure is most severe in rural areas, where municipality-supported public water supplies are often unavailable to rural households. More than 40 million people in the US rely on private and unregulated, and usually unmonitored, water sources. In many cases, this reliance results in people using water unfit for consumption. The proposed research addresses point-of-use and small-scale water treatment plants for rural communities in Native American communities in the Great Plains affected by arsenic and uranium, two of the most widespread geogenic (naturally-sourced) contaminants. Within our proposed study region, more than 30% of rural inhabitants drink water with high arsenic or uranium concentrations. Household water treatment systems used in these environments are complex and demand significant maintenance and upkeep to be effective resulting in abundant failures for arsenic and uranium contamination.

Work Required: The proposed research will examine methods of monitoring arsenic concentrations in drinking water in near real time. Assuming research is possible in person, this project will involve experimental work in the laboratory to develop electrochemical cells, and to monitor drinking water concentrations in untreated water. If this research is conducted remotely, this research could citizen science approaches that support this research using a combination of local water sampling and monitoring. If experimental work is not possible, we will use existing data and modeling to design water treatment systems.

Pre-requisites: Some college chemistry or geochemistry. Intense interest in the problem.

Mentors:
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How Did Large Marine Volcanic Eruptions During the Holocene Influence Oceanic Productivity?

Background: The abundance of marine life is constrained by the availability of nutrients needed for phytosynthetic life to grow. Although iron is abundant on earth, it is highly insoluble. As a result, the availability of iron limits the rate of primary production (net photosynthesis) in nearly half of the world's oceans. As such, even transient additions of iron, for example from dust, potentially can stimulate life, and as a result, affect climate by removing carbon dioxide from the atmosphere. Iron is also abundant in volcanic ash. In this project, we will examine the connection between recent (Holocene) eruptions and marine productivity in nearby ocean waters. To do so, we will examine the history and locations of eruptions preserved in USSSP cores. In addition to examining how much iron is present in these sediments, we will examine its chemical form and the extent to which it may contribute to phytoplankton growth. We plan to search hydraulic piston cored sites that are downwind of arc volcanoes for shallow, Holocene age ash layers. We will focus on ODP sites in the western Pacific at tropical to midlatitudes. We can use a combination of X-ray fluorescence (XRF) and diffraction (XRD) to characterize composition and mineralogy, synchrotron-based X-ray absorption spectroscopy to establish iron mineralogy specifically, and scanning electron microscopy and electron microprobe analyses of visible ash layers to understand the potential bioavailability of specific volcanic deposits from the cores. Grain size and surface area will be used to refine estimates of mineral dissolution and nutrient availability. We will then determine the potential size of this biological stimulation on marine systems by determining the strength of the eruption (based on geometric constraints and explosivity indices). Fine ashes (<10 microns in diameter) may travel in air to be deposited in ice cores, providing an opportunity to link marine and terrestrial paleo-records of volcanic activity. Coupled to these changes, we will examine remotely sensed estimates of primary production based on contemporary chlorophyll measurements in the vicinity of recent eruptions such as the January 2022 submarine eruption in Tonga.

Work Required: The student will search USSSP cores downwind of the Ryukyu, Izu-Bonin and Tonga-Kermadec arcs for visible ash layers that are within the Holocene part of the stratigraphic section. The student will then request samples for analysis by XRF, EDS (XRF on a scanning electron microscope) and microprobe. After sieving the sample and saving the less than 38 micrometer size-fraction, the student will pick marine microfossils for dating the layer and ash shards for chemical and optical analyses on the SEM. We will analyze the less than 38 micrometer size fraction for its size distribution (or send samples out to a commercial lab) to determine how much of the ash is less than 4 to 9 micrometers in size. SEM imaging of the smallest grains will provide estimates of their surface area.

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How Does the Potent Greenhouse Gas Methane Produced in Landfills Reach the Atmosphere?

Background: Methane is a potent greenhouse gas, thirty times more potent than CO_2. Therefore, constraining methane sources can contribute to predictions of how our climate will change over time. Landfills are one of the largest sources of methane across the US, New York state and, surprisingly, New York City. Methane is produced in landfills through the microbial decomposition of biological waste. Studies have indicated that the active face of the landfill is the location of most of the methane emissions. The Freshkills Landfill in Staten Island was recently closed and the active face of the landfill was covered over in November 2021. Before the face was closed, we measured larger than expected methane emissions into the atmosphere from the landfill and found that the dominant source of methane was not from the active face, but from the leachate pumps as they send waste water to the waste water treatment plant before discharge.

Work Required: This project will collect water and air samples from around landfills in the New York city area and quantify the methane concentration and biological (BOD) and chemical oxygen demand (COD) in the samples. The fieldwork includes in field sampling at a site at various temperatures and after rain events. The Lab work includes measuring the methane and higher hydrocarbons in the samples with a gas chromatograph with a flame ionization detector (GC-FID) and calculating BOD/COD from oxygen measurements over time in sealed samples using a fluorescence oxygen probe. The concentration data will allow us to quantify the methane fluxes from the landfill and propose solutions to the landfill managers to mitigate these emissions. Field and Lab work will average 30 hrs. /wk., with the rest of the time being focused on data analysis, literature review, etc.

Pre-requisites: General chemistry and lab courses are required; Organic or analytical chemistry with interests in biological and environmental issues would be a plus.

Mentors:

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The CO_2 to SO_2 Ratio: Can It Be Used to Predict Volcanic Eruptions?

Background: The degassing of CO_2 and S from arc volcanoes is crucial to global climate, eruption forecasting, and cycling of volatiles through subduction zones. With substantial developments in volcanic gas in the past decades, the CO_2/SO_2 ratio, in particular, is recognized as a new potential precursor of volcanic eruptions. Several recent eruptions have been preceded by increases in the CO_2/SO_2 ratio several weeks prior. However, the interpretation of the CO_2/SO_2 ratio of high-temperature volcanic gas has remained tricky due to the large variability displayed by one volcano over time and between eruption cycles. San Cristóbal volcano in Nicaragua shows abnormally high CO_2/SO_2 in its volcanic gases and therefore, makes a great endmember to study the factors that control volcanic gas compositions. Microanalysis of H_2O, CO_2, and S in mineral-hosted melt inclusions can be a powerful tool for studying CO_2 and S degassing. However, the previous studies show that vapor bubbles in melt inclusions can cause a significant underestimate of CO_2 contents. We are using a high pressure laboratory technique that uses the piston-cylinder apparatus to rehomogenize olivine-hosted melt inclusions. The rehomogenized melt inclusions can reveal the CO_2 and S concentration in the least-degassed source magma and the CO_2/SO_2 evolution with changing pressures during degassing. Both can significantly improve our interpretation of the gas data. Aiming at understanding what causes the high CO_2/SO_2 ratio in the volcanic gas from San Cristóbal, this project will resorb the vapor bubble using a newly-developed high-pressure technique. It will yield glassy inclusions that record CO_2-S degassing trends for San Cristóbal volcano.

Work Required: This project will involve handpicking olivine crystals, conducting high-pressure experiments with a piston-cylinder apparatus, and preparing experimental products for Fourier-transform infrared spectroscopy, electron microprobe, and laser ablation ICP-MS analyses. Lab work will be complemented by literature review, data processing, and analyses.

Pre-requisites: Knowledge of mineralogy and geochemistry at the introductory level is needed to accomplish this project. The intern will also need to use Excel for data compilation, basic data processing and plotting, and PowerPoint for brief presentations.

Mentors:
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Did Fire Cause Grassland Expansion in Eastern Africa?

Background: C_4 grasses first appeared in East Africa around 10 million years ago, and became widespread 6 million years ago. Grassland expansion happened at different times around the globe, and while previous studies have investigated atmospheric carbon dioxide levels and regional aridity as potential drivers, results are currently inconclusive. Evidence from Pakistan suggests fire may have enabled grasses to take root at the expense of trees and other woody vegetation. However, in Australia (an already fire-prone region), fire did not play a prominent role in grassland expansion. It is unknown if fire was an important agent for grassland expansion in eastern Africa 6 million years ago.

Fossil evidence suggests our early ancestors (i.e., hominins) evolved in eastern Africa. Hominins may have relied on interactions with natural fires as early as 2 million years ago. While some scientists hypothesize that increased fire activity in Neogene East Africa sparked fire-reliant behaviors in hominins, we know little about long-term trends in fire activity in the region. For this project, we will explore fire activity and major vegetation fuel types in eastern Africa over the Neogene using organic geochemical tools. We will integrate our new records of fire in eastern Africa with other records of past ecosystem changes to explore their effects.

This project will use the molecular fingerprints of polycyclic aromatic hydrocarbons (PAHs). We will extract PAHs from marine sediment samples collected from DSDP Cores 235 and 241 from the Somali Basin. PAHs will be separated and purified in preparation for analysis using gas-chromatography mass spectrometry. Once analyzed, the PAH profiles will be identified and quantified. We will then explore how the PAH profiles from the sediments changed through time, and compare to previously published biomarker and isotope data.

Work Required: This project will involve solvent extraction of PAHs from marine sediments followed by column chromatography to separate and purify compounds. Lab work will require 20-40 hrs./wk.

Pre-requisites: None, although knowledge of organic chemistry and programming in R is a plus.

Mentor: Troy Ferland, tf2534@columbia.edu (586) 216-8401

What Drives Geochemical Variability in Terrigenous Sediments at IODP Site U1479?

Background: Terrigenous (land-derived) sediments are brought to the deep sea by various transport mechanisms, including icebergs, winds, and ocean currents. The geochemical characteristics of those sediments can provide clues to their provenance (continental source), and thereby allow us to reconstruct the pathways that transported them. One of the major goals of IODP Expedition 361 was to reconstruct changes in the Agulhas Current system, in part, by using terrigenous sediment provenance. Transport mechanisms can be grain-size specific and can cause sorting which can alter the composition compared to its source. To minimize this effect, we performed our measurements on only the finest grains, <2 microns in diameter. Previous work by our group set the stage for this provenance work by measuring a variety of radiogenic isotopes ratios and elemental concentrations in the Agulhas Current region. However, this early work was done using the <63 micron sediment fraction, not <2. Comparison of these two datasets (that of IODP Exp 361, and the earlier published data) is complicated by their differing grain size. Interpreting the results from Exp 361 can be greatly aided by reconciling these grain size differences.

Work Required: The student will make a subset of geochemical measurements using the <63 micron sediments from a subset of samples from Exp 361.

Pre-requisites: The project will involve chemical digestions and chemical separation techniques, so some experience in a chemistry laboratory is preferred.

Mentors:
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How Can Dust From Ocean Drilling Program Cores From Near Southern Africa Be Used to Fingerprint Past Climate Change?

Background: Atmospheric dust and sediment serve as valuable tracers of past Earth and ocean processes, because their geochemical compositions reflect their bedrock parent material. Moreover, dust serves as a means for fertilizing of the oceans, and glaciation is an important way that dust is created. Scientists use the isotopic compositions of sediments and dust as a 'fingerprint', linking materials at downstream sites, such as sediment cores, back to their sources. Through geochemical fingerprinting, scientists have gained insight into the causes and impacts of abrupt climate changes, the stability of ice sheets and their potential contributions to sea level rise, and changes in ocean and atmospheric circulation patterns. The planned project will use samples taken from cores recovered by the Ocean Drilling Program near Southern Africa to harness the capabilities of two different isotopic approaches used to determine where the dust comes from. The approach proposed here will allow us to address critical questions regarding past wind patterns in the South Atlantic, the roles of different dust sources in supplying nutrients there, and important questions such as *"can we see the initiation of Patagonian glaciation?"*. The approach will have widespread possibilities to solve many geologic questions on Earth and elsewhere. For example, it has the potential to be applied to extraterrestrial materials such as the Mars Mission and Moon rocks.

Project: Geochemical tracing of dust is a powerful approach that aids in reconstructing past atmospheric, oceanic, and ice sheet dynamics. However, in some regions such as the Southern Hemisphere, even multi-variate approaches such as strontium (Sr), neodymium (Nd), and lead (Pb) isotopes yield ambiguous results due to overlapping compositions of different source areas. We have found that Pb isotopes add great value in distinguishing sources and that combining these with potassium/argon (K/Ar) geochronology provides even more constraints on sediment provenance. We will develop and test an approach for combining Sr-Nd-Pb isotopes and K/Ar analyses using rock and mineral standards and fine-grained sediments recovered from the sea floor by the Ocean Drilling Program.

Work Required: The student intern will learn how to prepare samples for K/Ar analysis; operate the noble gas mass spectrometer; process and interpret the data; and process and analyze samples for radiogenic isotope analysis. The majority of the intern's time (~30 hours/week) will be spent doing lab work.

Mentors: Steven Goldstein, steveg@ldeo.columbia
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What Can Fossil Corals Tell Us
About the Evolution of Ar-40 in the Earth's Atmosphere?

Background: Argon is a noble gas that makes up 0.8% of Earth's modern atmosphere. There are 3 stable isotopes of argon: Ar-40, Ar-38 and Ar-36. Today the 40Ar/36Ar is 298.56 and the 38Ar/36Ar is 0.1885 (Lee et al., 2006, Geochimica et Cosmochimica Acta). But at the beginning of Earth's history, there was almost no Ar-40. Ar-40 in Earth's atmosphere has been produced by radioactive decay of K-40 and degassed from the solid earth. Documenting the history of increase in Ar-40 in Earth's atmosphere would provide important information about the degassing history of Earth, and would also provide constraints that would help efforts to date the oldest ice in Antarctica. There are a few measurements of ancient atmospheres from different archives (3 billion year old quartz veins by Pujol et al., 2013, Nature; 400 million year old chert by Stuart et al., 2016, Earth and Planetary Science Letters; and 0-800 thousand year old ice by Bender et al., 2008, Proceedings of the National Academy of Sciences), but there is a need to find more archives to fill in the picture of the evolution of degassing. This project would test the applicability of fossil corals that have been carefully screened by multiple methods, and found to retain the original pristine aragonite. Although the archive of screened coral specimens spans an age from 0 to 160 Ma, the project will begin with modern samples to develop and test the methods.

Work Required: This project will involve extensive experimentation in a noble gas lab. In order to achieve the goals, it will be necessary to develop protocols and tests ensuring that the values measured are reliable. Because corals incorporate some potassium, it may also be necessary to examine the samples further with microanalytical techniques, and it will be necessary to measure potassium on the same aliquots that are measured for argon. The intern will need to have good lab skills and a willingness to try new approaches and scrutinize results in preparation for further analyses.

Pre-requisites: A strong background in laboratory science coursework (Physics, Chemistry). An interest in Earth and Environmental Sciences preferred.

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How Does the Microstructure of Ice Affect its Macroscopic Behavior?

Background: Ice is a seemingly ubiquitous material in the solar system. The large-scale movement of ice on Earth and other planetary bodies is directly controlled by microscopic features inside and outside of individual ice grains. A major challenge for experimentalists is finding ways to characterize the microstructure on samples that can so easily be destroyed. We have some existing capabilities, but new methods need to be explored, in particular for trying to characterize the density of defects within grains.

Work Required: For this project, the student will investigate optimal procedures for imaging and measuring the intracrystalline and grain boundary structure in experimentally deformed ice samples. The student will use both a light microscope and a scanning electron microscope, both of which are present in our lab, and will use imaging software to quantify the features. Data generated from this project will ultimately be used to improve models of glacial movement on Earth and to gain a deeper understanding of processes on other planetary bodies. The student will work with a team of researchers focusing on ice deformation problems and will develop a variety of skills essential for laboratory research, such as sample preparation, image analysis, basic electronics and machining, maintaining a lab notebook, experimentation, data analysis, and presentation of scientific findings.

Pre-requisites: We have no expectation of prior lab knowledge or training, just a willingness to learn and an openness to getting dirty and being slightly cold (we sometimes bundle up and work in a cold room to fabricate samples). The work will be carried out in the Rock and Ice Mechanics Lab at Lamont-Doherty Earth Observatory.

Mentors:
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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.

Work 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, and 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.

Pre-requisites: None, although knowledge of basic oceanography and climate are helpful.

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

How Did Past Ice Age Cycles Affect the Climate in the Pacific Ocean?

Background: The Earth has experienced repeated and extended episodes of global glaciation over the last two million years. These past climate changes increased in magnitude during the past million years, with sea level variations of more than 120 meters and large changes in regional temperature, in association with increases and decreases in the atmospheric concentration of carbon dioxide and other greenhouse gases. Although the climate variations are very well documented in ice cores from Antarctica and in sediment cores from the Atlantic Ocean, there is less detailed information available about oceanographic and climate changes in the Pacific Ocean throughout these glacial cycles. Ocean drilling by ODP and IODP has recovered long sequences of deep-sea sediments from a range of locations that hold the promise for insights into the Pacific response to large scale climate change.

Work Required: This project is designed to allow a student to contribute to the body of knowledge that can help answer the question of how the Pacific Ocean varied through ice age climate cycles. It will involve hands-on investigation of deep-sea sediments and sedimentary constituents including microfossils from one or more Pacific Ocean drilling sites, selected in consultation with PI McManus. The selected student will work in our shared sediment laboratory and microscopy laboratory in the New Core Lab at LDEO. Training and guidance will be provided for all procedures, which will use existing equipment including microscope, freeze-dryer, ovens, microbalance, sieves and beakers. 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

Can Precariously-Perched Rocks Constrain the Maximum Post-Glacial Shaking From Earthquakes in the Northeastern United States?

Background: Although the occurrence rate of large earthquakes in northeastern United State is low, seismic risk is moderately high, due to the large population and fragile infrastructure. Several earthquakes in excess of magnitude 6 have occurred in historic times, including in southern New Hampshire (1638) and Cape Ann, Massachusetts (1755), but little is known about them because of their antiquity. A key issue is the rate at which any point on the Earth' surface experiences earthquake accelerations that are large enough to cause damage to structures. We will address this question by examining the stability of standing stones and precariously-perched rocks. The use of such stones and rocks to constrain maximum ground accelerations was pioneered by Brune and is well-established as a paleo-seismic tool. Brune's original technique assessed the stability of the stones by mechanically shaking them. However, the technique that we will use is completely hands-off. It uses use photography and advanced image-processing techniques to create 3D renderings of the stones, which can then be subject to computer-based stability analysis. Cosmogenic dating, carried out by other researchers, constrains the ages of rocks and stones deposited by Ice Age glaciers and enables the calculation of accurate rates.

Work Required: The intern(s), accompanied by the mentor, will perform about 20 days of field work in Harriman State Park to identify, characterize and photograph the rocks and stones. The intern will then use publicly-available rendering software to produce 3D models of the stones, and to subject them to static stability analysis using a Python-based analysis code.

Pre-requisites: The intern needs to be willing to learn a little seismology. As time will be split between fieldwork and computer analysis, the intern will need to be willing to invest significant time doing both. Some prior exposure to the physics of vibrations and waves and to data analysis would be helpful, but is not required.

Mentor: William Menke: menke@ldeo.columbia.edu

What Clues Do Zircon Crystals Provide About the Sources of Gigantic, Climate-Changing Volcanic Eruptions and Their Transit From the Mantle to the Surface?

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) is causally linked to the End Triassic Extinction (ETE) at about 202 million years ago. Recent geochronological on zircons from the CAMP established very precise time constraints on the emplacement of the oldest basalt flows and their correlation to the extinction level using the U-Pb, CA-ID-TIMS method. These crystals formed in the lava flows and related intrusions feeding the flows. But, there are other, older zircons, referred to as 'detrital zircons', that are found within all units of the CAMP that represent a nearly 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? Most workers agree that CAMP magmas contain a significant component of older, recycled, crust that was subducted during the early Paleozoic or earlier. But there is no agreement on whether the magma formed from multiple local melts that then moved vertically, recycling local subducted material varying from place to place, or if they moved laterally over large distances from a mantle plume that recycled one huge recycled subducted mass. The zircons present should reflect assimilated crust with varying in age depending where the magmas formed. The present plan is for the intern to pick the spots on the crystals for 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 sources abd 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.

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What is the Astronomical Pacing of Climate at 10,000 to Million-Year Time Scales within Mediterranean and Arctic Ocean Sediments?

Background: The seminal 1976 ,"Pacemaker of the Ice Ages" paper by Hays, Imbrie and Shackleton clearly demonstrated that gravitational interactions of masses in the Solar System produce changes in the geometry of the Earth's spin axis and orbit and consequent Milankovitch climate cycles on Earth. It is also theorized that changes in solar luminosity caused by solar 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 could help us understand Solar System and solar dynamics and how they have changed over hundreds of millions of years as well as help us understanding the pace and rhythms of climate change here on Earth. Ocean Drilling Program Sites 963 and 964 in the Mediterranean Sea, and Site 302 in the Arctic Ocean exhibit sedimentary cycles caused by climate-driven environmental changes on Milankovitch timescales of tens of thousands to millions of years. There are also very intriguing larger cycles at decadal to millennial sub-Milankovitch-scales. These cycles at multiple time scales 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 fast, high density, and high quality data that can be input into mathematical timeseries and processed to reveal the frequencies at which ancient climates responded to astronomical effects.

Analysis Required: The intern will obtain XRF scan data from a variety of cores taken by the Ocean Drilling Program and twill hen 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 climate, 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 useful but not essential.

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What Controls Shallow Earthquakes in Subduction Zones?

Background: Observations around the world have been rapidly identifying and characterizing earthquakes and faulting behavior at subduction zones in unprecedented detail. In particular, the shallow regions of subduction zones have been revealed to be areas where a rich and complex variety of earthquake behavior occur. There are many aspects of shallow earthquakes that are poorly understood. The goal of this project is to study shallow earthquakes in subduction zones using a MATLAB code for simulating the physics of earthquake behavior. Two important shallow slip behaviors are tsunami earthquakes and slow slip events. Tsunami earthquakes are shallow events that produce larger tsunamis than expected given their surface wave magnitudes. These are rare and destructive events that to date have been observed in several locations including northeast Japan, the Kuril Islands, Alaska, Nicaragua, Indonesia, Peru, and New Zealand. Slow slip events, or "slow earthquakes", are periods of slow fault movement that can last for weeks or months, and do not cause ground motion. We currently do not have a good understanding of how or if slow slip events and shallow tsunami earthquakes are related. Simulations that reproduce these types of earthquakes could help us to identify what parts of the world these earthquakes are most likely to occur.

Work Required: This project focuses on conducting numerical simulations of the earthquake cycle in subduction zones. The simulations will be performed using an existing MATLAB software package that includes a graphical user interface. This package has been written specifically to increase the ease of running simulations, without the need to read or edit the code. A minimal amount of code editing will be required, although additional time spent on coding is an option if the intern wants to develop code. The work involves: (1) setting up and running simulations (this involves some literature review to identify relevant data to include in simulations); (2) analyzing simulation output for a set of key observables, such as the size and frequency of simulated earthquakes; and (3) comparing simulation results to observed earthquake behavior in New Zealand and/or Japan.

Pre-requisites: Three college level physics courses and/or calculus and differential equations are required. Experience with MATLAB or python would be a plus, but not essential.

Mentor: Rob Skarbek, rskarbek@ldeo.columbia.edu, Tel: 845-365-8337

What Controls the Phytoplankton Community in the Tropical Atlantic Ocean?

Background: Phytoplankton are a key component of the Earth system – they play a critical role in regulating climate by drawing down atmospheric CO_2, producing 50% of the oxygen we breathe and also make up the base of the food web that ultimately contributes to about 20% of animal protein consumed by humans. Thus understanding how the phytoplankton community responds to perturbations – both anthropogenic and climate related is essential to interpreting the past and predicting future change and to answering questions such as "What are the forces that shape the phytoplankton community (and subsequently the community of higher trophic levels)?" i.e. How does phytoplankton community structure respond to physical, chemical, and biological perturbations? Our knowledge is hampered by inadequate observational tools at the appropriate scales and consequently our ability to answer questions like "Will there be more harmful algal blooms? How will fisheries change in response to climate change?"

Work Required: The intern will learn to use CLASS, a novel spectrofluorometric instrument that was developed at LDEO, and a flow cytometer to study phytoplankton community structure in the Tropical Atlantic Ocean. The CLASS can be used to measure the concentration of different types of phytoplankton. The flow cytometer can be used to count cells of *Prochlorococcus, Synechococcus*, and picoeukaryotes. While the CLASS data has already been collected, the samples for the flow cytometer have to yet be run in the laboratory. If COVID protocols do not allow in-person presence in the lab, the intern will focus on analysis of data already collected. The intern will learn to use these measurements to describe changes in the phytoplankton community as a response to varying environmental drivers.

Pre-requisites: The intern should have taken basic calculus, statistics, biology, chemistry, and physics courses. The student should be familiar with data analysis using software such as Excel and basic statistics. Familiarity with R and/or programming languages such as Python will be a plus.

Mentor: Ajit Subramaniam: ajit@ldeo.columbia.edu Tel: 845-365-8641

What Is the Impact of Environmental Change on Oyster Reefs?

Background: As global climate change accelerates, accurate predictions of biological responses to climate and human-caused disturbances are critical to mitigate likely damage to the biosphere. However, our ability to predict responses of species and ecosystems to multiple stressors is severely constrained by models largely drawn from controlled experiments. Large-scale assessments of mechanisms shaping biotic variations in real-world ecosystems are scarce but essential for building the theoretical framework necessary to anticipate the scope of biological responses. Organisms producing calcified skeletons are predicted to face the greatest challenges under rapidly changing environments. The eastern oyster *Crassostrea virginica* is a calcifying foundation species producing intertidal reefs that once were a dominant structural and ecological component of many estuaries in the Northwest Atlantic. Eastern oyster reefs provide key ecosystem goods and services, enhance biodiversity, improve water quality, and protect shorelines from storms and sea levels rise. However, *C. virginica* reefs have declined dramatically because of climate and anthropogenic impacts. Calcareous shells perform vital functions for oysters and create reef habitat supporting marine communities. Although climate changes are known to impact oyster survival, their consequences on oyster shell and reef structural integrity in natural systems across climate regions remain a major research gap.

Work Required: The project will characterize and model large-scale geographic patterns of oyster shell structure, composition, and mechanical properties across latitudinal gradients. This work will analyze wild and cultured *C. virginica* populations collected from different climatic regions in the Northwest Atlantic from Canada to Texas. Laboratory work includes oyster shell samples cleaning, collection of shell morphology and density data, sample preparation (grinding and polishing) for compositional analyses, microscopy and mechanical testing. Laboratory work will average 25hrs. /wk., with the rest of the time being focused on datasets organization, data analysis, and literature review.

Pre-requisites: Background in environmental/biological sciences; the candidate should feel comfortable commuting to the Lamont-Doherty Earth Observatory for most of laboratory work; the candidate should be well-organized with good time management ability.

Mentor: Dr. Luca Telesca, ltelesca@ldeo.columbia.edu, (845) 365-8738

What Are the Impacts of Extreme Episodic Events on the Health and Ecology of the Long Island Sound Ecosystem and How Do These Influence Vulnerable Coastal Communities?

Background: This is an opportunity for an undergraduate student to participate in exciting field research that examines how human activities, seasonal processes, and episodic events impact the water quality and ecology of Long Island Sound. Like many similar highly populated estuaries, the Long Island Sound suffers from water quality problems, including hypoxia, anoxia, eutrophication, and recurrent harmful algal blooms (HABs). Within the past twenty-five years, harmful algal blooms have devastated New York coastal waters, disrupting food chains for many marine species and impacting economically viable fisheries, aquaculture, and recreation activities. These environmental hazards are expected to intensify as the Sound is becoming increasingly vulnerable to climate change. This project aims to quantify how human activities and episodic events impact seasonal and spatial transitions in phytoplankton assemblages across Long Island Sound, and how these transitions are linked to changes in the amount and quality of nutrients and dissolved organic matter entering the system. We also aim to understand impacts on coastal communities, especially low-income communities who appear to be disproportionately impacted by eutrophication hypoxia and harmful algal blooms. The project integrates satellite observations of both the terrestrial and aquatic domains with multi-disciplinary ecological and paleo-ecological datasets, demographic information, hydrodynamic-biogeochemical ecosystem models, and socioeconomic/population dynamics models.

Work Required: The student will build skills in diverse field and laboratory techniques, data analysis and the use of analytical instruments. Water samples collected from rivers, coastal marshes, and the Sound's estuarine waters will be characterized chemically and optically. In-situ measurements of water physicochemical and bio-optical properties will be collected during one-day cruises to study estuarine biogeochemical and ecological processes. The student will collect and process samples, analyze data, and generate quantitative analyses of how natural and anthropogenic disturbances affect water quality and ecological processes in Long Island Sound. Additionally, the student will develop skills in critical analysis, problem solving and scientific communication, and will have the opportunity to link results from this work to projects within the tri-state area aiming at assessing coastal ecosystem vulnerability to climate change. Results from this work may lead to important insights for long-term water quality management and improvement, with important benefits for vulnerable populations.

Pre-requisites: We are looking for highly motivated undergraduate students with strong background and interest in environmental sciences, quantitative skills, and willingness to be part of an interdisciplinary team effort. Experience in programming, field data collection methods, and/or remote-sensing data analysis preferred, but not required.

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