Department of Geosciences
Guyot Hall
JUNIOR INDEPENDENT WORK / SENIOR THESIS
SHOPPING GUIDE

Are you shopping for a Junior or Senior Project???

Shopping for Prehistoric Ideas? OR Life on Other Planets or the Solar System

Perhaps Field Work ! OR Life in the Oceans

WHATEVER YOUR CHOICE
CHECK OUT THE GEOSCIENCES SHOPPING GUIDE FOR IDEAS

Department of Geosciences
Guyot Hall

JUNIOR INDEPENDENT WORK / SENIOR THESIS SHOPPING GUIDE

NOTES

1. Projects suggested by the faculty members and research staff are listed here. Contact these researchers for further information.

2. In many cases topics suggested are general areas of research. Discussion will be needed to decide on a specific problem and the scope of the project, particularly those which have both Junior Paper and Senior Thesis potential.

3. Feel free to discuss ideas of your own with any faculty member, even those not listed (who had no ideas or did not meet the deadline).

CODES IN LEFT-HAND MARGIN

JP	=	suitable for Junior Independent Work.
ST	=	suitable for Senior Thesis research.
JP or ST	**=**	could be scaled for either Junior Independent Work or Senior Thesis Research.

Prof. Michael Bender, Room M48 - University Ext. 8-2936
E-mail: bender@princeton.edu

JP 1. Respiration Rates in the Dark Ocean.

Characterizing rates of photosynthesis and respiration in the ocean is a major task of ocean biogeochemistry. Rates are estimated from chemical changes observed in the water and ages of waters in which these changes occur. A "toy model" for estimating water ages assumes that, below the sea surface, ocean mixing occurs only between waters of the same density (which results from compensating changes of temperature and salinity). This project would involve a literature survey of such models, and could include original calculations that extend present approaches.

JP 2. Radiocarbon Ages of Sinking Organic Matter in the Deep Sea.

The production of organic matter in the sunlit ocean (roughly the upper 100m), and its sinking and decay at depth, is the main process causing chemical gradients in the sea. With depth, waters become older and have a greater radiocarbon age. If sinking organic matter originates only at the sea surface, it would have the young surface age. Production of organic matter lower down in the sunlit ocean, or addition of organic matter synthesized at depth, will lead to older ages. This project involves reviewing the literature with an eye to understanding the sources of organic matter settling in the thermocline (upper 1000 meters) and the deep sea.

ST 3. Helium Uranium Dating of Calcites.

In principle, minerals can be radiometrically dated by measuring the amount of helium they have accumulated from radioactive decay of uranium. In practice, this method sometimes works poorly because helium is small enough to leak out of crystals. The mineral calcite is fairly leaky, but large crystal sizes promote retention, so that it may be possible to date various calcites. If so, it could provide a tool for dating sedimentary and metamorphic deposits of interest in various studies. This project would involve helium-uranium dating calcites of known ages in order to determine conditions under which the method works well.

ST 4. Changes in the Earth's Fertility During Glacial-Interglacial Transitions.

The isotopic composition of O_2 in air depends on competing reactions in the stratosphere and the biosphere (photosynthesis and respiration). We can measure changes in the isotopic composition of atmospheric O_2 through time by studying gases trapped in ice cores. Then, with insights about the chemistry of the ancient stratosphere, one can estimate glacial-interglacial changes in the fertility of the planet, as well as changes during the transition from glacial to interglacial conditions. This project would involve detailed studies of the isotopic composition O_2 across glacial "terminations" with the aim of understanding how the biosphere responded to these events, and influenced them.

Prof. Thomas Duffy, Room 218 - University Ext. 8-6769
E-mail: duffy@princeton.edu

Professor Duffy will be on sabbatical during the Fall Semester 2013-2014

My primary research involves understanding the structure, composition, and evolution of planets through experimental study of minerals at high pressures and temperatures. Other interests include: mineralogy, high-pressure physics and chemistry, planetary science, and superhard materials.

ST 1. Raman Spectroscopy in Mineralogy

Raman spectroscopy is a laser-based non-destructive analysis tool for minerals that has wide applications in geoscience. We have a number of laboratory projects that would enable you to learn to use and apply Raman spectroscopy to some interesting mineral or rock samples.

JP or ST 2. Extrasolar Planets

The discovery and characterization of extrasolar planets is one of the most exciting recent developments in planetary science. In this project you will use experimental data and theory to model possible interior structures for different possible type of extrasolar planets including giant terrestrial planets (~10 earth masses) or so-called ocean planets which are thought to be giant versions of Jupiter's moon Ganymede (~50% H_2O, ~50% silicate and metal). What minerals will exist in these bodies? What will be the pressure and temperature distribution in the interior? What will be the density, mass, and moment of inertia? How might geophysical processes on such bodies differ from those in Earth.

ST or JP 3. High Pressure Equations of State

The elastic properties of geological materials are of prime importance for interpreting seismic data for the deep Earth in terms of composition and mineralogy. There are several competing methods for extrapolating laboratory measurements of sound velocities to deep Earth conditions. This project will involve determining which methods are most reliable. In doing so, you will learn about elasticity and mechanical properties of solids. Involves spreadsheet calculations and some basic computer programming. Requires math through linear algebra.

JP 4. Composition of Earth’s Core

The Earth’s core is one of the most enigmatic regions of the planet. The composition of the core is about 90% iron, and 10% of some lighter element(s). The nature of the light element is important for understanding the growth of the inner core, the rate of cooling of the Earth, and the evolution of the geodynamo and Earth’s magnetic field. The project will involve evaluating geophysical evidence (phase diagram, density, sound velocity) for and against one or more of the major candidates (Si, S, H, O) for the light element of the core.

ST 5. **Computer-based Control System for Optical Spectroscopy**
Develop a computer interface for a Raman spectrometer using the LabVIEW software package. LabVIEW is a powerful and widely used software environment with built-in functionality for data acquisition, instrument control, measurement, and analysis. In this project you will gain experience in creating a software interface to control the operation of a laser and spectrometer, and to perform real time analysis of measured data. Skill developed here will be applicable to a wide range of laboratory projects.

ST. 6. **Plasma-Based Synthesis of Graphene**
In collaboration with: Yevgeny Raitses (PPPL) Graphene is a one-atom-thick planar sheet of sp^2-bonded carbon atoms that are densely packed in a honeycomb crystal lattice. This new material, which combines aspects of semiconductors and metals, could be a leading candidate to replace silicon in applications ranging from high-speed computer chips to biochemical sensors. However, before graphene sheets can be applied to commercial applications, it is necessary to find lower cost methods of mass production. Recently, a new method of graphene synthesis in magnetically enhanced arc discharge was proposed and demonstrated by a collaborative team of the Princeton Plasma Physics Laboratory and the George Washington University. This project will focus on experimental studies of this new method with emphasis on characterization of effects of magnetic and electric fields on plasma-based synthesis of graphene. A student will participate in upgrade of an arc experimental setup, development and use of plasma and laser diagnostic tools and data analysis. The project will include analysis of post-arc samples using electron microscopes (SEM, TEM) and micro-Raman spectroscopy.

Prof. John Higgins, Room 212, Guyot Hall, University Ext. 8-7024
E-mail: jahiggin@princeton.edu

JP or ST 1. **Modern analogues for snowball Earth cap dolostone?**
Learn how to measure a recently developed proxy (magnesium isotope ratios) in recent and ancient dolomites to gain insight into the mechanisms of dolomite formation. Explore implications for the interpretation of snowball Earth cap carbonates. Are recent dolomites an appropriate analogue for snowball Earth cap dolostones? How does the origin of the cap dolostone affect our understanding of the aftermath of a snowball Earth?

JP or ST 2. **Investigating Earth's CO_2 thermostat**
Learn about the role of silicate weathering in the global carbon cycle on million year timescales. Carry out experiments in the lab reacting seawater with basalt at low temperatures. Quantify rates of alteration using mass spectrometry and explore implications for the role of seafloor weathering in Earth's CO_2 thermostat. How does seafloor weathering affect planetary habitability?

JP or ST 3. Records of ancient seawater chemistry from deep-sea pore fluids

Learn how fluid in the pores of deep sea sediments retain a memory of past ocean chemistry and how we access these records using geochemical measurements and numerical models. Develop and upgrade a database of global pore fluid profiles to identify pristine records. Make state-of-the-art geochemical measurements of the pore fluid and sediment to reconstruct seawater chemistry. Explore implications for our understanding of the global carbon cycle and climate over the last 10-20 million years.

Prof. Jessica C. E. Irving, Room 321C – University Ext. 8-4536
E-mail: jirving@princeton.edu

My interests are centered around discovering and interpreting the seismic structure of the deep Earth. Both high frequency body wave seismology and low frequency normal mode seismology can be used to image the mantle, the outer core and the inner core.

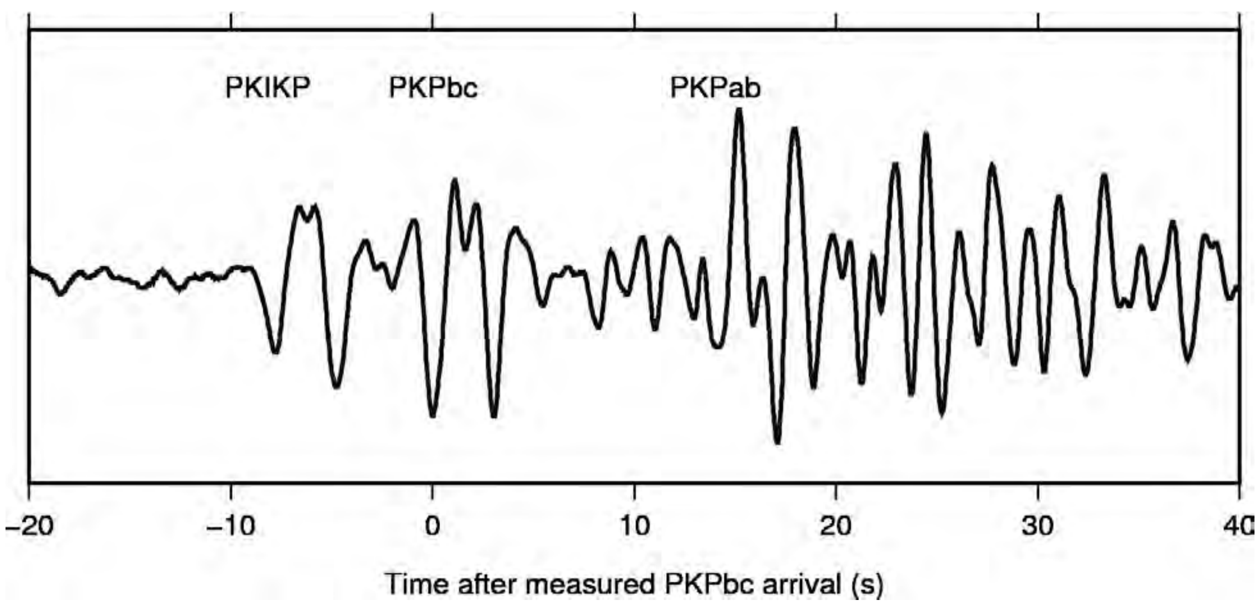
Possible projects include:

JP or ST 1. Regional studies of the inner core using PKIKP arrivals - the first waves to arrive at the far side of the world after an earthquake

JP or ST 2. Studying the lowermost mantle using precursors to the ScS phase, which reflects from the Core-Mantle Boundary (CMB).

JP or ST 3. A topic in deep Earth observational seismology which particularly interests you.

These are very brief outlines. If you would like to discuss potential ideas for either JP or ST projects please get in touch



Prof. Gerta Keller, Room 308 – University Ext. 4117
E-mail: gkeller@princeton.edu

JP or ST **Analysis of the environmental and biological effects of Deccan volcanism in marine environments**. This study evaluates the global effects of volcanism in marine microfossils (planktic foraminifera) and the climatic changes associated with it (stable isotopes) in an effort to determine the role volcanism played in mass extinctions.

There are two intervals of Deccan volcanism – each is suitable for a research topic:

1) The main Deccan volcanism phase ended with the mass extinction 66 m.y. ago and is associated with major climate changes, species dwarfing and opportunistic species blooms. Investigate this event based on the response of marine microfossils, planktic foraminifera, and stable isotopes.

2) The last volcanic eruptions began about 300 ky after the mass extinction and are also associated with climate warming, opportunistic species blooms, but no mass extinctions. Investigate this event based on the response of marine microfossils, planktic foraminifera, and stable isotopes.

3) The kill-mechanism of the end-Cretaceous mass extinction is likely ocean acidification as a result of SO2 and CO2 from volcanism and/or the Chicxulub impact. Investigate whether this is a likely hypothesis based on recent ocean acidification studies. Evaluate ocean acidification in sediments near Deccan Traps and in between lava flows, as well as in marine sections across the world. Involves microfossil analysis, SEM work, stable isotope analysis.

Prof. Adam Maloof, Room 215/213 – University Ext. 8-2844
E-mail: maloof@princeton.edu

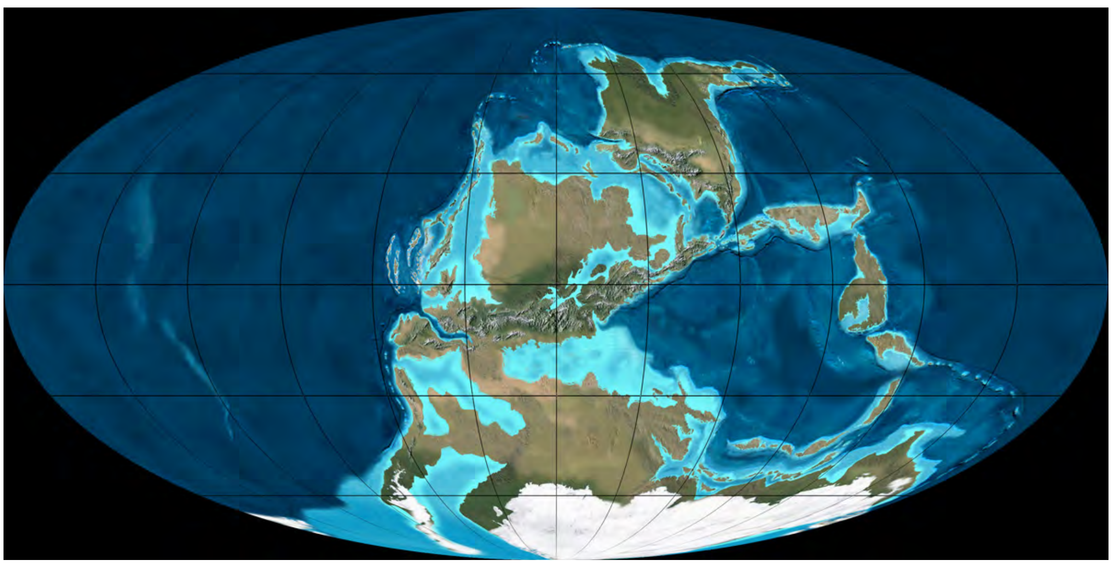
I am a field geologist studying Earth history and the limits of global change. My current work involves using sedimentary and volcanic rocks to extract information about Earth's ancient magnetic field and the relative motion of continents, perturbations to the global carbon cycle, and the coevolution of life and climate change.

JP or ST 1. Geography and climate during the Late Paleozoic Ice Age

Pre-Mesozoic paleogeographies are constructed by using paleomagnetic data to constrain the latitude and orientation of individual continents. During the Carboniferous, large forests finally began to cover the land, Pangaean mountain belts formed, and big perturbations to the carbon cycle were recorded in the ocean. At the same time, the Gondwana supercontinent moved over the south pole and was variably covered in ice sheets (see image below). This glacial interval is known as the Late Paleozoic Ice Age (LPIA) and is the most recent analogue to the glacial-interglacial cycles that characterize the most recent 3 million years.

Does the paleogeography of ice sheets determined from the geological record really match the paleomagnetic record of latitudes for drifing Gondwanaland? Do geographic extents of ancient ice sheets really match the tropical sedimentary record of sea level (and thus ice volume) changes? With what amplitude and frequency did the LPIA glaciers wax and wane—did they respond to the same astronomical forcings that the modern ice sheets do?

JP or ST projects can tackle these questions through either (1) reanalysis of paleomagnetic and glacio-geologic data to tackle the questions of paleogeography, or (2) study of the geochemistry of carbonate and phosphate fossils from tropical sedimentary rocks to test current interpretations of sea level change. This project could lead to senior thesis field work in Utah and Nevada.

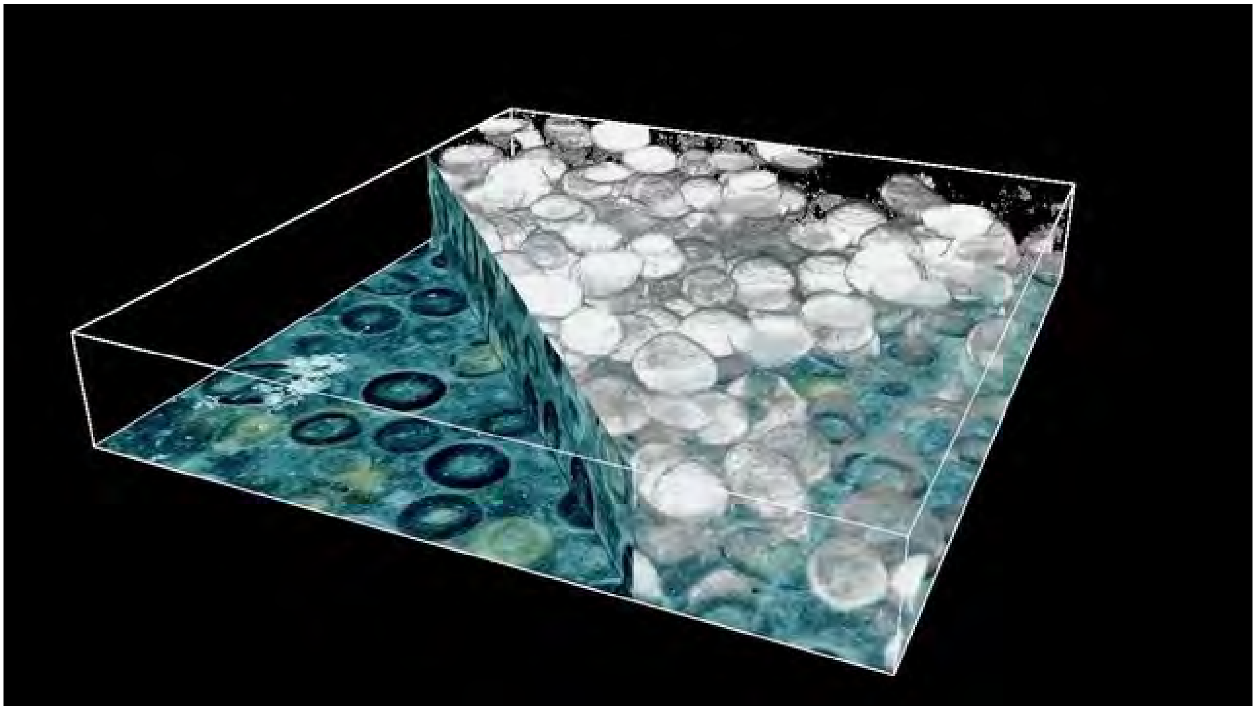


JP or ST 2. Pleistocene Climate in Ethiopia

Most records of Pleistocene climate change (i.e., the last few million years of ice ages and interglacials) come from drill cores, either through polar ice sheets or deep sea sediment. Very few continuous records of climate change have been retrieved from land in the tropics, despite the fact that the tropics are very important for driving global change. In this JP or ST, you will glue together a large stalactite from Northern Ethiopia. Next, you will slice, grind, photograph, count annual layers, drill, and initiate a suite of geochemical measurements. With this data, you will tell a story of how climate was different between glacials and interglacials in East Africa. You may even determine whether the drought of the past forty years that has had such a large impact on humans there is unique, or if similar droughts occurred earlier in Earth history.

JP or ST 3. 3D digital reconstruction of embedded objects in rocks

Using new technology housed in the Princeton Grinder Lab (http://giri.princeton.edu/), the student can choose a subject of interest and investigate it with the Grinding, Imaging and Reconstruction Instrument (GIRI). For example, the student could examine an ancient fossil, modern bones or teeth, 3D sedimentary bedforms like stromatolites or ripples, or petroleum reservoir rocks and targets for carbon sequestration like oolites and sandstones. The idea is to study an object or the interior of an object of geoscientific that is not readily modeled by simplying photographing or scanning the surface. The project involves image analysis and 3D modeling using languages like Matlab, Python and Java, and software such as Avizo, Envi and Imagine.



Prof. David Medvigy, Room 418B - University Ext. 8-9017
E-mail: dmedvigy@princeton.edu

JP or ST 1. Plant respiration in a changing climate. The amount of CO_2 emitted to the atmosphere by terrestrial vegetation strongly depends on the balance between respiration and photosynthesis. For example, if respiration increases and photosynthesis stays the same, atmospheric CO_2 will increase. Current-day global climate models attempt to account for changes in respiration and photosynthesis. However, evidence is mounting that the models' representations of leaf respiration may not include the correct sensitivity to environmental conditions, especially light. In this project, the student will assess the implications of this potential error using computer simulations of the carbon cycle. Two types of simulations will be explored. In the first type, respiration will be independent of whether it is day or night. In the second type, daytime respiration values will be reduced relative to nighttime values. Simulations will be forced by both current-day climate and projections of future climate. Previous computer modeling experience is not necessary as long as there is a strong desire to learn.

JP or ST 2. Response of California vegetation to climate change. Most of the state of California lies within a biodiversity hotspot called the California Floristic Province, an area of extremely diverse vegetation. This biodiversity is under threat from climate change, population pressures, and other factors. In particular, California's native grassland today is among the state's most threatened ecosystems. In this project, the student will explore the sensitivity of California grassland to climate change. Computer simulations of current-day grasslands will be conducted. The results of the simulations will be compared to observations of grassland productivity. Then, projections of future California climate will be incorporated into the simulations, and the sensitivity of the grassland to changing climate will be assessed. Previous computer modeling experience is not necessary as long as there is a strong desire to learn.

JP or ST 3. Water budget of the New Jersey Pinelands. The Pinelands National Reserve in southern New Jersey is the largest continuous forested landscape on the Northeastern coastal plain, and covers about 23% of New Jersey. In recent years, the Pinelands has been affected by insect attacks, fires, hurricanes, and severe droughts. In this project, the student will investigate how the water budget of a forested stand in the Pinelands has been changing over the past few years. The particular focus will be on transpiration, the process by which plants move water from their roots to their leaves, where it then evaporates to the atmosphere. Existing measurements of whole-tree transpiration will be used and analyzed. Relationships between transpiration and environmental conditions, including daily weather fluctuations and soil moisture, will be developed. Transpiration of different tree species will be compared. The overall goal of the project will be to develop an empirical relationship between transpiration and environmental conditions.

JP or ST 4. **The seasonality of deciduous needleleaf trees and implications for the carbon cycle.** One of the most intriguing trees on the Princeton campus is a dawn redwood, located near the Princeton University Art Museum. It is a needleleaf tree, but it sheds its needles each fall and grows new needles each spring. Such deciduous needleleaf trees are not particularly common in New Jersey, but they are the dominant tree type in some higher-latitude forests. In this project, the student will investigate what environmental factors control the timing of spring needle emergence and/or fall needle drop. To do this, the student will analyze an existing dataset. The student will develop empirical relationships between temperature (and possibly other environmental factors) and the seasonality of deciduous evergreen trees. These relationships will then be used to assess the potential sensitivity of deciduous evergreen trees to climate change in the 21st century. This issue may have important implications for the global carbon cycle. For example, if warmer temperatures lead to a longer growing season, the carbon uptake of deciduous evergreen may be substantially enhanced.

Prof. Francois Morel, Room 153 - University Ext. 8-2416
E-mail: morel@princeton.edu

Opportunities for research on the interaction of chemicals with microorganisms.

JP or ST 1. Specific research projects include measurements of various metal-binding ligands in algae when exposed to metal pollution. Laboratory studies would include the study of biochemical responses of marine or freshwater phytoplankton to individual metals such as cadmium, copper, lead, mercury, and zinc. Field studies might involve measurements of these biological markers of metal stress in Lake Carnegie.

JP or ST 2. Will increasing carbon dioxide concentrations in the atmosphere promote increased productivity in marine ecosystems? Projects related to an ongoing study of the interaction between trace metal availability and carbon utilization and limitation in marine phytoplankton are also available.

Prof. Satish Myneni, Room M51 – University Ext. 8-5848
E-mail: smyneni@princeton.edu

Research webpages: http://geoweb.princeton.edu/research/geochemistry

Water is essential for the origin and survival of life on our planet and perhaps plays a pivotal role on the existence of life on other planetary bodies as well. In several different forms, water mediates the physical and chemical interactions between various components of the Earth's surface environment, which includes mineral oxides, biota and their byproducts, and the atmosphere. One of the challenges in environmental sciences is to gain a better understanding of interactions between these different components in nature, and to use it to predict a variety of biogeochemical processes such as elemental cycling, biological chemistry of elements, and the fate and transport of contaminants in the environment. This area of research is gaining importance, and researchers from different disciplines began conducting studies to explore these interactions in greater detail. I am interested in exploring one of these fundamental interactions, which include the evaluation of the chemical state of water in different geologic media and how this modifies the biogeochemical behavior of different inorganic and organic moieties in the natural systems. I am also interested in evaluating the chemical state(s) of important geochemical species to develop predictive patterns for explaining their macroscale behavior

All of my projects are related to environmental chemistry, and the research focus is on the macroscale and molecular level observations of various biogeochemical reactions. Background in chemistry is useful for these projects. For senior thesis, these projects involve experimental work with microscopy and spectroscopy tools in my laboratory, Princeton Materials Institute, and those available at the X-ray synchrotrons (such as National Synchrotron Light Source, Brookhaven, NY; Advanced Light Source, Berkeley, CA), and theoretical studies for chemical speciation and spectral analysis. Details of these research projects and results from senior theses submitted by my group members can be obtained from my research group web pages. Some of the available topics for senior thesis and summer research are as follows:

JP or ST 1. Naturally formed halocarbons (halogen containing organic molecules) in the environment. Focus: Characterization; evaluation of biogeochemical parameters that influence the formation of halocarbons and their behavior in the environment; role of halocarbons in C- and other elemental cycles. Research includes field trips for water, soil and sediment sampling in Pine Barrens (NJ) and the nearby estuarine environments, detailed analysis either in our laboratory or in the campus. The following picture shows one of our field sites in Pine Barrens, NJ.

JP or ST 2. Chemistry of naturally occurring organic compounds in the environment. Chemistry; molecular structure; reactions with minerals in soils and sediments, and their role in interfacial reactions in the natural systems.

JP or ST 3. Environmental chemistry of contaminants.
Biogeochemistry of selected contaminant metals in soil, sediment and aquatic systems, and their biological accumulation.

JP or ST 4. CO_2 reactions with geologic media.
The focus is on the influence of elevated atmospheric- and soil/sediment-CO_2 on mineral weathering and carbon storage in terrestrial systems, water quality, and biogeochemistry. This study involves prediction of mineral-fluid equilibria from thermodynamic speciation, and conduct laboratory investigations to verify these predictions for reactions at different time scales (direct laboratory experiments for reactions at short time scales, and observations from mineral weathering for long time scales). Field sampling is necessary at the Mammoth Mountain (CA).

Prof. T.C. Onstott, Room B-79 - University Ext. 8-7678
Email: tullis@princeton.edu

Microbiology and Biogeochemistry of the Arctic, the Deep Subsurface and of Mars

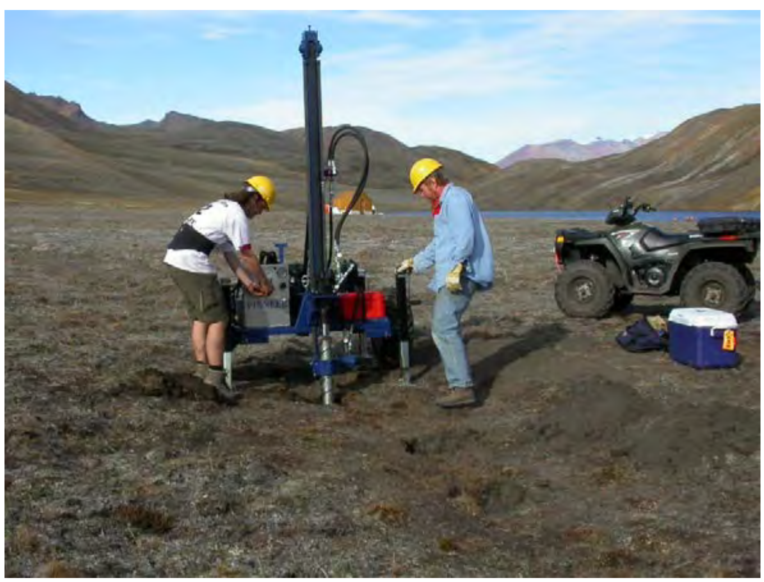
JP or ST 1. **Is the Arctic a Methane Sink?** Global climate models project the strongest future warming in the Northern Hemisphere to occur at high latitudes with some models predicting a 4-8°C warming over these regions by the end of this century. As a consequence, thawing permafrost and the resulting microbial decomposition of previously frozen organic C are believed to lead to the production of CH_4 at rates that will make it a significant potential positive feedback. Yet certain types of permafrost soils consume atmospheric CH_4. Could the latter offset the former? A JP would involve surveying the published literature on Arctic CH_4 fluxes and transfer the measured fluxes to an Arctic soil map using GIS. The student would then determine which soils are CH_4 sinks versus CH_4 sources and derive a new estimate of the regional CH_4 emission rate in the Arctic that can be compared to estimates made by inverse modeling of the atmospheric CH_4. A senior thesis would extend this analysis to future global warming models.

JP or ST 2. **Who is oxidizing all the Earth's atmospheric CH_4?** Some unknown species belonging to the aerobic methane oxidizing bacteria are capable of oxidizing the CH_4 in the Earth's atmosphere at very high rates. These species, known as the high-affinity methanotrophs, are responsible for the uptake of atmospheric CH_4 in soils and rocks globally yet their phylogenetic identity remains a mystery because they have never been isolated. A potential JP project would be to test DNA primers that target the functional gene responsible for high affinity methane oxidation. This work could be extended to a senior thesis to quantify the activity of these high-affinity methanotrophs by quantifying their abundance through the DNA/RNA concentration under different growth conditions and, with luck, perhaps lead to isolation of this mysterious organism.

JP or ST 3. **The Impact of Carbon Cycling in Arctic Permafrost on Global Warming.**

Permafrost, or perennially frozen ground, underlies about 22-24% of the Earth's surface and covers the Arctic landscape. Global climate models project the strongest future warming in the Northern Hemisphere high latitudes, with some models predicting a 4-8°C warming over these regions by the end of this century. As a consequence, thawing permafrost and the resulting microbial decomposition of previously frozen organic C is one of the most significant potential feedbacks from terrestrial ecosystems to the atmosphere. To study this process intact permafrost cores have been collected from Axel Heiberg Island in the Canadian High Arctic and returned to the lab for long-term thawing experiments. The cores will be analyzed using metagenomics, transcriptomics, and proteomics during the thawing experiment while measuring the flux of greenhouse gases, CH_4, CO_2 and N_2O. A student's JP's or senior theses would involve detecting and quantifying rates of CH_4 production and consumption in the permafrost cores and identifying which microorganisms dominate the carbon cycling and how their rates are affected by temperature, light, water saturation and nutrient amendments.

Another JP topic would be to isolate methanotrophic and methanogenic microorganisms from permafrost cores for characterization and 16S rRNA gene sequencing. A senior thesis could extend to examine protein expression profile at different incubation conditions. Depending upon the quality of the JP, the student will have an opportunity to travel to the Canadian High Arctic the following summer to perform field work collecting samples for microbiology, aqueous and dissolved gas chemistry and isotopic analyses.



Coring permafrost from ice-wedge polygons on Axel Heiberg Island in the Canadian high Arctic.

JP or ST 4. **CH_4 isotopic composition in the field as a life detection method for Mars.**

A newly funded NASA project focuses on the CH_4 gas isotopic composition and dynamics and microbiology of a Martian analog site located around and in lakes bordering the Greenland ice sheet, and includes a borehole that has been drilled beneath the Greenland ice sheet. JP research includes analyzing samples collected from this site for CH_4 consumption and production and the molecular signatures of CH_4 cycling. Depending upon the quality of the JP, the student will have an opportunity to travel to the Greenland the following summer to perform field work collecting samples for microbiology and aqueous and dissolved gas chemistry and perform isotopic analyses using the CRDS. These samples would provide the basis for a senior thesis. A senior thesis could involve anything from DNA extraction and sequencing, the cultivation and characterization of new bacterial isolates, the use of microscopy and *in situ* hybridization techniques to image bacterial cells in permafrost samples, to testing for biological activity *in situ* using a CRDS.

JP or ST 5. **Methane oxidizing bacteria in mutualistic symbiosis with flora?**

Recent published results suggest that aerobic methane oxidizing bacteria, MOB, exist in close association with moss. This has significant implications for global warming as tundra surfaces in the Arctic become increasingly vegetated and has implications for current global climate models. The nature of the relationship has yet to be solved however. A JP or ST would involve searching for this association of MOB with moss from other Arctic sites in Canada and Greenland and determining what benefits the moss derive from the MOB.

Atleigh Forden ’16 collecting CH_4 gas Samples from polygon troughs in western Greenland.

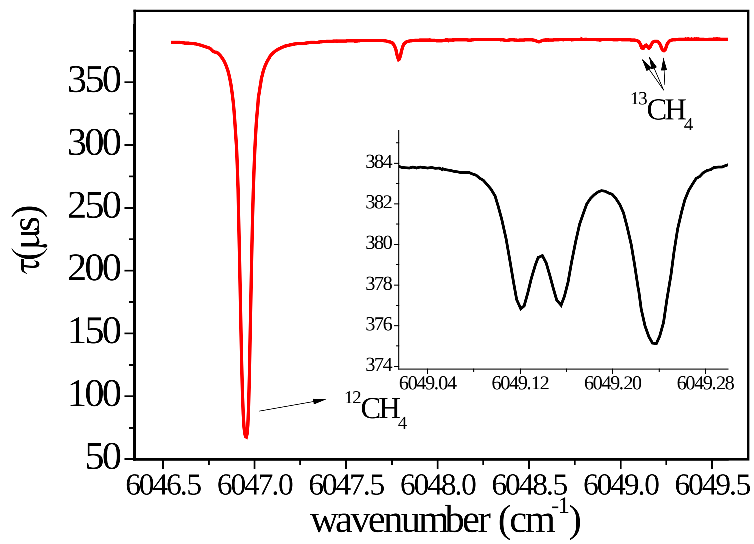
JP or ST 6. **Carbon Cycling in the Deep Crustal Biosphere.** One of the most exciting scientific endeavors of the past 25 years has been the exploration of the subsurface biosphere. Based on the many marine and few continental sites being studied, the subsurface biosphere has been estimated to harbor a large fraction of the Earth's prokaryotic biomass. Broad and compelling research questions continue to drive this field, including:

1. How large is the subsurface biosphere and how deeply does life extend into the Earth?
2. What fuels the deep biosphere?
3. How does the interplay between biology and geology shape the lithosphere?
4. What are subsurface genomes telling us?
5. Did today's surface biosphere originate underground?
6. Is there life as we don't know it in the deep subsurface?

Graduate student Cara Magnabosco (GEO) and senior Melody Lindsay (EEB) were collecting in situ geochemical data and molecular samples at Beatrix Gold Mine (1.3 km below surface).

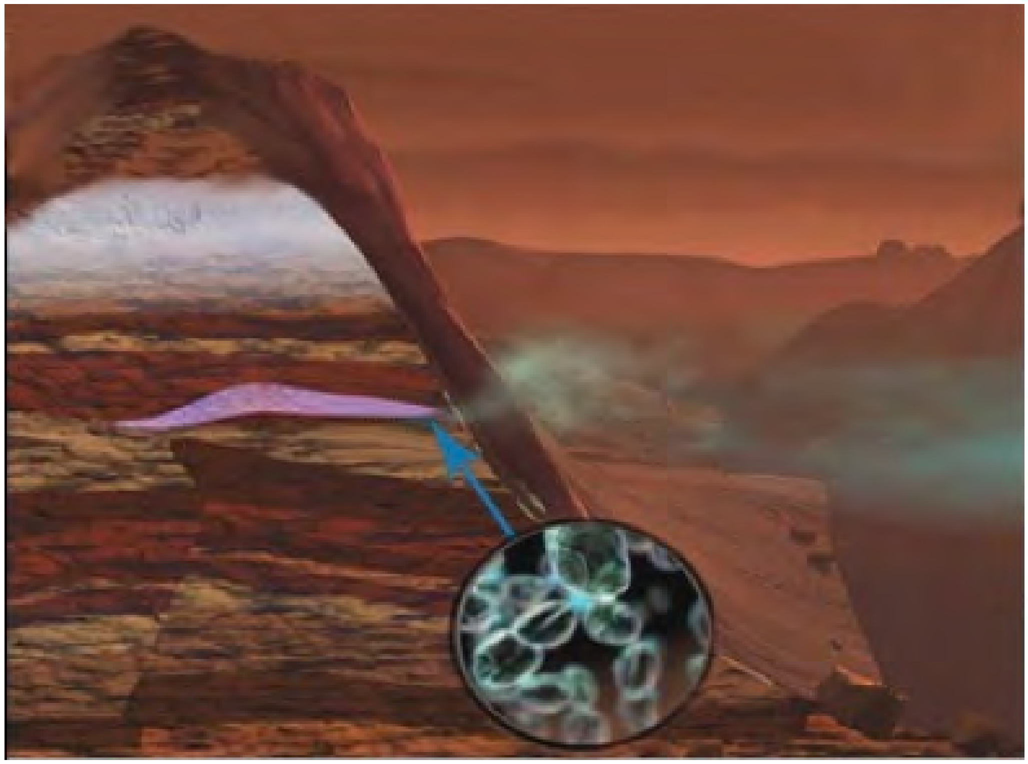
This project will focus on the second question and, more specifically, how the deep biosphere cycles carbon compounds. Various JP and ST projects include: DNA/RNA extraction and sequencing, analyses of genomic datasets, the cultivation and characterization of new bacterial isolates from the mines, the use of microscopy and *in situ* hybridization techniques to image bacterial cells in rock and water samples, geochemical measurements and modeling, and measuring *in situ* biological activity using stable and radioactive isotopes of carbon. The student will also be able to travel to South Africa during the summer/winter for fieldwork several kilometers beneath the Earth's surface.

JP or ST 7. **Stable Isotopes of CH_4 and CO_2 by CRDS.** The stable isotope compositions of CH_4, CO and CO_2 have significant implications for the global carbon cycle on Earth and on Mars. The Cavity Ringdown Spectrometer (CRDS) is a new technology for rapidly measuring the isotopic composition of these gases and others without using a mass spectrometer. Our lab has developed a CRDS for C and H isotopes of CH_4 and has a commercial Picarro CRDS for C isotopes of CO_2 and for organic and inorganic carbon in rocks, water and biofilms. The CRDS can be applied to terrestrial ecosystems, marine samples, ice cores and is also being developed for space flight. A JP or senior thesis would involve learning about CRDS technology and using the CRDS in the lab to study microbial carbon cycling and isotopic fractionation or in the field to make real time measurements of trace gas isotopic compositions during diurnal cycles and model gas fluxes. Potential field sites include the high Canadian Arctic and Greenland. Another senior thesis topic would be to measure the rate of microbial CH_4 production or oxidation under Martian environmental conditions.



CRDS spectrum of CH_4 isotope absorption peaks in the near-IR.

JP or ST 8. **Biomarkers in the Martian Atmosphere.** The recent discovery of CH_4 in the Martian atmosphere suggests that subsurface gases are actively being released by tectonic or hydrothermal processes. Such gases may be biomarkers for subsurface life. JP or ST would involve modeling of what is known about the trace gas chemistry of the Martian atmosphere and the photolytic reactions involved in the Martian C, N, H and S cycle and advance to include subsurface gas flux to determine what type of spacecraft measurements would be required to detect trace subsurface gas release. The research may be augmented by initial reports from the Mars Surface Laboratory. The student will also interact with Prof. David Medvigy and Dr. John Wilson at GFDL.



NASA cartoon of hypothetical Martian CH_4 seeps into the atmosphere.

JP 9. Alternative Phylogenetic Markers.

Ribosomal RNA has been a dominant target gene for biodiversity assessment. The main advantages are its universal distribution in life forms, conservativeness and large databases for comparative purpose. Yet the presence of multiple operons is a bit problematic for accurate quantitative analysis. In past decades, protein-encoding genes have been proposed as alternatives, for instance ribosomal polymerase subunits (rpo). A JP would do a survey on genes across sequenced microbial genomes and assess the potential of alternative biomarker(s) based on its genetic properties, distribution and phylogenetic resolution.

JP or ST 10. Evaluation and design of oligonucleotide probes for biodiversity studies.

Rapid advances in theories and technologies have made it plausible to collect a complete suite of genes (metagenomics and transcriptomics), proteins (proteomics) and metabolites (metabolomics) for an environmental sample. Nonetheless, oligonucleotide-based molecular techniques (e.g. fluorescence *in situ* hybridization, quantitative PCR, microarray and pyrosequencing) in combination with the universal biomarker for life, rRNA genes, provide indispensable proxies for studying the ecological roles of community members and their functional dynamics in an ecosystem. The student could take the approaches of reviewing the literature and/or performing computational analyses to evaluate, design and recommend oligonucleotide probes (or primers) for specific technique or general purpose. This approach could be applied to the genes directly involved with carbon metabolism in permafrost and deep subsurface microbial studies.

Prof. Michael Oppenheimer - University Ext. 8-2338, 448 Robertson Hall
E-mail: omichael@princeton.edu

JP or ST 1. Constraining Ice-Sheet Driven Sea Level Rise Projections

Continental ice sheets influence sea level via changes in their mass balance. Our group recently developed a Bayesian framework that allows uncertainty in ice sheet mass balance projections to be better-characterized and updated over time. In its current incarnation, this framework utilizes observations at the continental scale to constrain current and future rates of sea level rise from Antarctic ice loss.

This approach can be improved by employing smaller scale observations (e.g. satellite-derived gravity and ice flux measurements) as additional constraints on the spatial pattern and rate of ice mass change. However, it is unclear how observations would be combined and weighted. This project entails collecting and synthesizing mass balance observations via a careful literature review. Using actual or synthetic observations, we will then test the ability of these constraints to reduce uncertainty in observations and/or projections using a MATLAB model.

Prof. S. George Philander, Room M47 - University Ext. 8-5683
E-Mail: gphlder@princeton.edu

My projects involve phenomena and social issues related to the Earth's climate, including El Nino, global warming and paleo-climates. The following are two examples.

JP or ST 1. The present is a most unusual moment in the history of our planet. How do we know that? In what way is the present unusual? Answers to these questions, which give the present a context that helps us prepare for the future, require a study of the amplifying climate fluctuations of the past several million years. Those fluctuations have thus far been associated with the Recurrent Ice Ages, but the waxing and waning of glaciers are now emerging as members of a suit of very different phenomena in different parts of the globe, all interacting. For example, the glaciers over North America were strongly affected by conditions in the tropical Pacific, and around Antarctica. What other regions influenced North America?

JP or ST 2. Planet Earth is a special place – the only planet known to be habitable – at a special time in its long and eventful history. Why is it habitable? What are the highlights of this eventful history? In South Africa I am trying to use these questions to develop curricula, including field trips, that will attract the youth to science. (Education, the key to the alleviation of poverty, is a dire need in that country.) Some Princeton students are involved in this effort.

Prof. Allan Rubin, Room 319 - University Ext. 8-1506
E-mail: arubin@princeton.edu

JP or ST 1. Earthquake catalogs include many features, including mainshocks, foreshocks, aftershocks, and swarms. These can potentially teach us, for example, about how the properties of the crust vary in space, where faults are "creeping" or "locked", and how to refine earthquake forecasts (i.e., using foreshocks). But first one must be able to recognize which earthquake belongs in which category, given that catalogs consists only of a string of numbers (earthquake origin time; location; magnitude). Recently, new methods for this classification have been proposed, but it is not clear that these are the best. For a JP or ST, work with high-quality catalogs from California, Japan, or elsewhere, to compare existing classification schemes, devise your own, and compare the results to what is known about the local geology, heat flow, etc.

JP or ST 2. Within the last decade, new styles of fault behavior have been discovered at depth within subduction zones and along the San Andreas fault. Rather than undergoing "stick-slip" (earthquake) behavior or creeping steadily at the plate rate, these regions exhibit "episodic slow slip", where every year or so the fault speeds up to about 100 times the plate rate, producing the equivalent of a magnitude 6+ earthquake over a period of days to weeks. Simultaneously, they produce a "chatter" that is observed on seismometers but that looks nothing like regular earthquakes. This "tectonic tremor" is a low-amplitude signal, continuous in time for minutes to hours, that lacks clear P-wave and S-wave arrivals but that nonetheless provides us with out best chance of mapping out the progression of slow fault slip at depth, if we can learn top locate it. I have been working with a new method that gives tremor locations beneath southern Vancouver Island that are much more accurate than have been obtained previously. We would like to know if this method works as well in other parts of Cascadia or in Japan, which also have dense seismometer networks. For a JP or ST, get available data from one of these regions and explore.

Prof. Jorge Sarmiento, 306A Sayre Hall, Forrestal Campus - University Ext. 8-6585
E-Mail: jls@splash.princeton.edu

JP 1. A global carbon cycle update

Observations of the various components of the global carbon cycle are obtained on a regular basis. What has been happening to the carbon cycle over time, for example in response to the recent recession, and a recent proposed reduction in terrestrial Net Primary Production over the past decade? This project will examine the most recent data to determine if these changes can be observed.

ST 1. What can changes in the ocean's heat content tell us about ocean deoxygenation?

Ocean warming is closely linked with the loss of oxygen. This loss is larger than expected from solubility alone, because of the ocean warming induced stratification causing a reduction in the transport of oxygen into the ocean's interior. This project will examine the linkage between oceanic changes in heat and oxygen content using results from the GFDL Earth System Model. In particular, the regional and water-mass specific ratios of heat gain/oxygen loss over the past few decades will be investigated and compared with estimates based from observational analysis.

ST 2. **What do the latest climate models tell us about ocean biogeochemistry over the next century?**
As the scientific community prepares for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, GFDL and many groups around the world are performing multiple earth system simulations of possible climate scenarios over the next century. What do these simulations predict will happen to the distribution of carbon and nutrients in the ocean?

ST 3. **How important is the Southern Ocean in the uptake of fossil fuel carbon dioxide from the atmosphere?**
The ocean takes up almost 1/3rd of the carbon dioxide emitted by fossil fuel burning each year. Model simulations suggest that the Southern Ocean accounts for about 30 to 50% of this uptake. The higher values are out of proportion to the surface area of the Southern Ocean. A global data set of oceanic observations obtained over the past decades gives us an unprecedented overview of the global distribution of a wide variety of tracers of ocean circulation. This project would involve analysis of these tracers to determine the extent to which the model simulations could be correct, and could include as well a literature and model examination of the mechanisms by which this uptake occurs.

ST 4. **How does absorption of light by seawater affect phytoplankton in the ocean?**
The absorption of light by the ocean typically captures 50% or more of the photosynthetically active radiation, and forces phytoplankton to live in the top 100 to 200 m of the ocean or shallower. What would the ocean look like if seawater did not absorb light? We can use ocean biogeochemistry models to simulate the behavior of the system if this were the case.

Prof. Blair Schoene, Room 219 - University Ext. 8-5747
E-mail: bschoene@princeton.edu

I am interested in the physical and geochemical evolution of Earth's crust and mantle. My research pulls from methods in geochemistry, geochronology, structural geology and petrology. A few ideas for projects are listed below, but if you find your interests fall within my broad interests and want to discuss other options, please come see me or send an email.

JP or ST 1. **Isotopic mapping of the Kaapvaal craton.** Radiogenic isotopes, unlike other geochemical tracers, provide time-sensitive information about the sources of magmas and fluids. Nd isotopes are important in the study of the formation of continental crust throughout Earth history because they can provide not only information about when a rock formed, but also about the age of sources of the rock. This project involves compiling and synthesizing a large database of unpublished Nd isotopic data from the Kaapvaal craton, southern Africa, in order to deduce the timescales of construction and stabilization of the one of our best preserved pieces of Archean (>2.5 Ga) continental lithosphere. Results from this project could have implications for the formation of continents early in Earth history.

JP or ST 2. **Trace elements in the mantle.** Trace element cycling between the lithosphere and asthenosphere is controlled by the concentration of trace elements into the crust by mantle melting and their subsequent recycling into the mantle via subduction and/or crustal/lithospheric delamination. This process is important not only for studying mantle processes by monitoring trace elements in volcanic rocks but also in controlling the distribution of heat-producing elements (U, Th, K) in the mantle. This project involves a literature survey of how trace elements are transported into the mantle (i.e. in what minerals), and could be extended to integrate numerical modeling of petrogenetic processes pending initial findings.

JP or ST 3. **The volcanic-plutonic connection.** A proper geochemical balance of the crust and mantle requires knowledge of how the geochemistry of volcanic rocks relates to their unerupted counterparts. This is partly important because volcanic rocks are more easily eroded and transported back into the mantle via subduction. Large freely accessible geochemical databases are now available and allow us to investigate trends in geochemistry based on geography, tectonic setting, and composition with greater ease. Some such compilations in the literature show that subduction related volcanic rocks are equivalent in composition to their plutonic counterparts, suggesting that differentiation via fractional crystallization is unimportant in silicic magmatic systems, which contrasts some observations. This project involves utilizing these new databases to expand such comparisons to other tectonic settings and geographic areas.

ST 4. **The importance of volatiles in flood basalts and their relationship to mass extinction.** Princeton University sits on the evidence for one of the largest mass extinction events in all of Earth history, the ca. 200 Ma end-Triassic extinction and environmental crisis. Volatile gasses and heavy metal emissions associated with the Central Atlantic Magmatic Province (CAMP), one of the largest volcanic provinces ever, has been hypothesized as the cause of the extinction. However, the contrasting affects and residence times of CO_2 and SO_2 in the atmosphere are poorly understood, as are their abundance in the CAMP. This project involves the collection of local samples of CAMP volcanics and using fluid inclusions in phenocrysts as a measure of volatiles in the CAMP. This information is required to build effective numerical models for the relationship between volcanic out-gassing and the environmental consequences.

ST 5. **Applications of field geology and geochemistry/geochronology to Appalachian tectonics.** The Appalachians are one of the world's oldest persisting mountain belts, and record a rich history of continental formation, amalgamation and subsequent destruction. Numerous unanswered questions pertaining to the 1.3 Ga crust and ore-deposit formation and the 200 Ma rifting event can be addressed with field-based projects in the New Jersey highlands and surrounding areas. Such projects involve the enthusiastic assistance of experts on the local geology from the New Jersey Geologic Survey. **Juniors**: it is nearly required that you begin field-work either the spring of junior year and/or summer before senior year for these projects to work out.

Prof. Daniel Sigman, Room M52 - University Ext. 8-2194
E-mail: sigman@princeton.edu

Website: http://www.princeton.edu/sigman

JP or ST 1. **Modern nitrogen cycle.** Biologically available nitrogen is a critical nutrient for the algae and plants that represent the base of all foodwebs, but its inputs, outputs and cycling are poorly understood in many environments, and the global nitrogen budget remains extremely uncertain. The stable isotopic composition of nitrogen and oxygen in bio-available nitrogen compounds is a promising tool for providing an integrative picture of the nitrogen cycle. Apply novel methods developed at Princeton to analyze liquid and solid nitrogen samples collected from the environment. Identify your own field site and collect your own samples, or analyze samples collected by the Sigman group during their fieldwork in the ocean.

JP or ST 2. **Organic matter trapped in fossils.** The Sigman group has developed methods for studying the isotopic composition of the trace organic matter trapped within the fossils of organisms and micro-organisms. Our focus is on the use of fossils from the ocean (diatoms, foraminifera, stony corals, shark teeth, and others), especially for studying biological, chemical, and physical changes in the ocean over ice age cycles and their role in changing the concentration of carbon dioxide in the atmosphere. Identify your own fossils and questions, or ask for suggestions.

JP or ST 3. **Dissolved organic N in the ocean.** Dissolved organic nitrogen is a dynamic component of the nitrogen cycle in the surface ocean, yet its composition, origin, and fate are a mystery. Work with water samples from different ocean basins to investigate where dissolved organic nitrogen is produced and destroyed and the role that it plays in supplying nitrogen to upper ocean biology.

JP or ST 4. **Novel microbiological tools for geochemistry.** Microorganisms can be good chemists. Contribute to the development of new, microbe-based methods for the isotopic analysis of trace quantities of bioavailable nitrogen in the environment. This project requires prior experience in microbiological lab techniques.

JP or ST 5. **Numerical models of biogeochemistry in the present and past ocean.** Studies of environmental geochemistry and Earth history are aided greatly by the use of numerical models that include the circulation of the ocean. A student with the appropriate background could use one of our spectrum of numerical models or build their own to address key questions regarding the biology, chemistry, and physics of the ocean over Earth history.

Prof. Frederik J. Simons, Room 321B - University Ext. 8-2598
E-mail: fjsimons@princeton.edu

Interests: Geophysics; structure and evolution of continents; seismic waveform analysis and tomography; topography and gravity anomalies; satellite measurements; development of oceanic instrumentation; earthquake early-warning studies; inverse problems; wavelet analysis; image analysis; potential fields; sea level variation.

JP 1. Make a database of large earthquakes recorded in Japan for the purposes of analyzing their waveforms. It's probably helpful if you read Japanese. The goal is a wavelet analysis of the waveforms of large events in the context of an early-warning study.

JP 2. Compare normal-mode predictions of gravitational changes due to large earthquakes with time-series records from superconducting gravimeters.

JP 3. Benchmark seismograms and gravity perturbations from a normal-mode summation package against the results produced by an iterative direct solution method.

JP 4. Derive bounds on the local average density structure of the Earth when averaged over a line connecting two points in the crust – such as required to interpret geoneutrino physics experiments.

JP 5. Come talk to me for ideas. Past Junior Papers with me have been on the analysis of tree rings; the use of localizing basis functions to study geomagnetic satellite data; the analysis of hydrophone records in the oceans; the study of acoustic wave speeds in the oceans; the creation of new computer algorithms for the synthesis of seismograms via normal-mode summation; the influence of earthquakes on the Earth's gravity field over the last three decades; the study of gravity hills in New Jersey using relative gravimetry and GPS positioning and geological mapping of the Venusian lithosphere.

ST 1. Study of ocean floor roughness via a parameterized spectral approach and a maximum-likelihood estimation procedure.

ST 2. Study of lunar topography roughness via a parameterized spectral approach and a maximum-likelihood estimation procedure.

ST 3. Derive a crustal thickness model for Mars from the localized analysis of gravity and topography data.

ST 4. Past Senior Thesis with me has been on normal-mode based calculation of gravitational potential differences due to large earthquakes. Suggest your own in my area of expertise (also see my webpage, www.frederik.net). Come talk to me for ideas.

Prof. Bess Ward, Room 217 - University Ext. 8-5150
E-mail: bbw@princeton.edu

JP or ST 1. **Investigate nitrogen cycling in marine environments.** Several different approaches possible, including microbiology (grow microorganisms, measure biogeochemically important transformations in relation to nutrients and oxygen conditions), molecular biology (use PCR, cloning, sequencing and microarrays to investigate diversity of different microbial groups), stable isotopes (learn to run a mass spec to measure rates of nitrogen transformations). Analyze cruise samples using mass spectrometry.

JP or ST 2. **Nitrogen assimilation by phytoplankton.** Use flow cytometry and molecular biological methods (quantitative PCR, microarrays, cloning and sequencing) to investigate the diversity of algae involved in nitrate assimilation in seawater, and to investigate the regulation of nitrate assimilation at the genetic level. Potential field work opportunities on oceanographic research cruises. Analyze cruise samples using flow cytometry.

JP or ST 3. **Microbial processes in salt marshes and estuaries.** Help with sediment incubations and measure the rates of nitrogen transformations. Learn isotope geochemistry, using stable isotopes to investigate microbial transformations including nitrification, denitrification and anammox. Field trips to marshes/bays on the east coast of the US.

Associated Scientists

David Parris - Paleontological Staff, NJ State Museum, Trenton
E-mail: david.parris@sos.state.nj.us
Telephone: (609) 292-6330, FAX: (609) 599-4098

JP or ST Both junior paper and senior thesis projects may be arranged , using the collections and field research projects of the New Jersey State Museum. Past projects have included both vertebrate and invertebrate paleontology, most frequently in New Jersey (Cambrian-Pleistocene), but also in the marine Cretaceous of South Dakota, and the terrestrial Cretaceous of the Bighorn Basin of Montana and Wyoming.