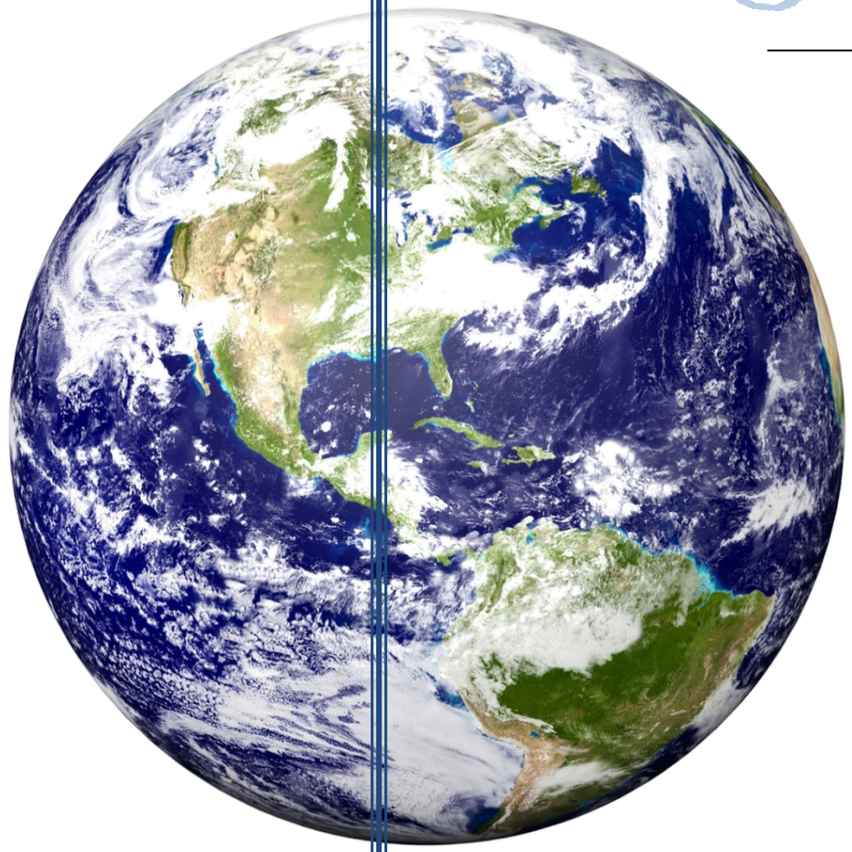
EARTH & PLANETARY SCIENCES

AT HARVARD UNIVERSITY



2024 Senior Thesis Presentations

Ben Freudenberg

Lucy Jacobsen

Klara Kuemmerle

Emily Launderville

Gabriel Maxemin

Lorelei Wolf

Beatrice Youd

Thursday, April 25th, 2024 11:30 am-1:50 pm
Haller Hall, Geological Museum 102

Please join us for an Undergraduate End-of-Year Reception beginning at 2:00 pm in the Student Lounge (4th Floor, Hoffman Labs).

Please join us for a reception honoring
all of our EPS Undergraduates
2:00 pm
Student Lounge
4th Floor, Hoffman Labs

Thank you for your support!

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WELCOME

Message from the co-Head Tutors and Preceptors:

Thank you for joining us as we celebrate the accomplishments of our senior thesis writers who spent much of their senior year tackling an exciting range of scientific problems. The senior thesis provides an opportunity for students to gain firsthand experience in the full scope of research, from in-depth background study, to identification of core questions, design of a research plan, collection and analysis of data, and formation of rigorous conclusions. These theses and today's presentations reflect the academic excellence and dedication of these students. Their efforts would not be possible without the support of faculty advisors, graduate students, post docs, fellow undergraduate students, and family. We thank these mentors and friends and congratulate our seniors on their achievement.

Roger Fu and Ann Pearson
Co-Head Tutors

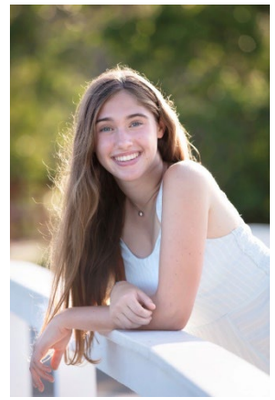
Chloe Anderson and Esther James
EPS Preceptors

Roger Fu, Ann Pearson, Marianna Linz, Jim Anderson
Undergraduate Curriculum Committee

Campbell Halligan
Academic Programs Manager

Beatrice Youd

Concentration: Intergrative Biology



Structural Variation in Congolese Marantaceae Forest Drives Differences in Biodiversity and Above-Ground Carbon Stocks

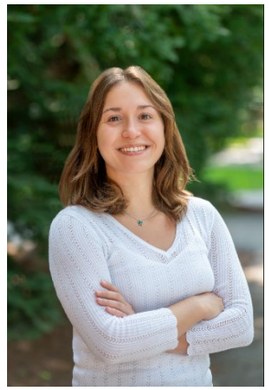
Advisor: **Andrew Davies**, Assistant Professor of Organismic and Evolutionary Biology

Marantaceae forest, a subtype, of Afrotropical rainforest located in the northern Republic of Congo has been historically understudied. In fact, above-ground carbon (AGC) calculations for rainforests in the northern Republic of Congo rely on AGC estimates for all Central African rainforests, which overlook the Marantaceae forest present in Congolese rainforests. In my thesis, I improve the precision and understanding of both ecological and AGC dynamics for Afrotropical rainforests in the Republic of Congo by examining the biodiversity, community structure, and physical forest composition of Marantaceae forest and comparing it to the common Congolese forest types of flooded forest and terra firma forest. To examine the biodiversity and ecological communities in each of these forest types, I collected tree species and tree size plot sampling data in Odzala-Kokoua National Park in the Republic of Congo. Analysis of tree species communities, in conjunction with species-specific wood density data, provided information helpful for the ecological understanding of the forest types along with AGC calculations. I examined forest structure using remotely sensed Light Detection and Ranging (LiDAR) drone data. I classified this data by forest type, according to a land classification approach I applied to the entirety of Odzala-Kokoua National Park. LiDAR data allows for an understanding of forest canopy gap and canopy height distributions. I complemented these remote sensing measurements with field measurements of tree stem densities and diameter at breast height (DBH). I calculated AGC values for the different forest types by incorporating forest-type-specific data on average wood density, stem density, and DBH. I then applied these values to the greater land classification for Odzala Kokoua National Park to understand AGC on a larger area's scale. Findings from this study have both conservation and carbon sequestration implications, as I found that Marantaceae forests were ecologically unique from a biodiversity and structure perspective and displayed a unique landscape of tree sapling competition in the forest understory. Marantaceae forests also stored less AGC when compared to current estimates of AGC in the northern Republic of Congo, highlighting the drawbacks of oversimplified AGC calculations.

Lorelei Wolf

Concentration: Earth and Planetary Sciences

Lipidome Remodeling of the Marine Ammonia Oxidizing Archaeon Nitrosopumilus Maritimus



Advisor: **Ann Pearson**, Murray and Martha Ross Professor of Environmental Sciences,

The TEX86 paleotemperature proxy reconstructs sea surface temperatures using isoprenoid glycerol dialkyl glycerol tetraethers (GDGTs), membrane-spanning lipid biomarkers, from the Nitrososphaerota (formerly phylum Thaumarchaeota); the model strain is Nitrosopumilus maritimus SCM1. While the TEX86 proxy assumes that temperature is the strongest control on lipid composition, several recent studies have shown that growth phase, growth rate, and electron-donor supply also affect ring synthesis. Accordingly, comprehensive study of the effects of growth stress on lipid composition is necessary to constrain more accurate sea surface paleotemperatures. Because TEX86 values have observable biases associated with ocean oxygen minimum zones and upwelling regions, this study sought to test the effects of oxidative stress on ring synthesis in N. maritimus. Batch culture experiments reflecting several permutations of oxidative stress conditions were run in triplicate and included both increases (hydrogen peroxide) and decreases (catalase) in reactive oxygen species. High-performance liquid chromatography mass-spectrometry (HPLC-MS) was used to measure the relative abundance of GDGTs and to analyze the number of cyclopentane rings resulting from each test condition.

Results showed that oxidative stress resulted in a modified lipid membrane for N. maritimus. Conditions of increasing hydrogen peroxide exposure resulted in lower biomass yield, slower growth rates, decreased cyclization of core GDGTs, and a marked cold bias associated with TEX86. Future research investigating the causal relationships between growth rate, ROS production, and membrane lipid synthesis in N. maritimus can provide insight for the interpretation of the TEX86 paleothermometer in upwelling regions throughout Earth's history, as well as for investigations into the ecological niches of Archaea through evolutionary history.

Ben Freudenberg

Concentration: Earth and Planetary Sciences

Constraining Triple Oxygen Fractionation in Speleothems due to CO2 Degassing

Advisors: **Daniel Crocker**, Postdoctoral Fellow – Johnston Group

Dave Johnston, Professor of Earth and Planetary Sciences, Harvard University

Oxygen isotopes in speleothems are useful tools reconstructing past climate, but speleothem oxygen isotope records may be strongly impacted by kinetic processes that obscure the record's valued paleoclimate signal. In recent years, many studies have identified the need to constrain a kinetic oxygen isotope effect of cave degassing. The most foundational of the studies is a model that predicts degassing behavior over several partial pressures of CO2. By isolating a degassing signal in a laboratory-simulated speleothem, we determined that while the model is largely accurate, there may be some discrepancies at low pCO2 that need further evaluation. Additionally, our results indicate that under cave-analogue conditions, a degassing signal may be easily obscured by the isotope effects due to factors such as drip rate, further underscoring the need for well-constrained speleothems for paleoclimate study. Finally, the implications of sample reservoir on our experimental results indicate that cave degassing may be constrained in-situ through sampling solution from a stalagmite surface and from a pool adjacent to the speleothem.

Emily Launderville

Concentration: Earth and Planetary Sciences

Constraining Tectonically Driven Provenance Changes Through Quartz in the Pilbara Craton, Western Australia

Advisor: **Emily Stoll**, EPS Graduate Student – Drabon Group

Nadja Drabon, Assistant Professor of Earth and Planetary Sciences

The study of Archean geology (4.0-2.5 billion years ago) provides a unique window into a complex period of Earth's history thought to be marked by the creation of early proto-continents and unique tectonic regimes no longer experienced on Earth. While much of the crust from that time has been destroyed, there are still pockets of well-preserved material that provide evidence of the Earth's surface at that time. One surviving remnant is the Pilbara Craton, in Western Australia. Here, the ~3.2 Ga Corboy Formation in the East Pilbara Terrane (EPT) is the proposed first instance of a shift in the Pilbara Craton from early earth vertical-style tectonics creating partial convective overturn (PCO) basins to horizontal-style extensional rift basins.

This investigation aims to unravel insights into the tectonic environment by tracing the provenance evolution of the Corboy Formation in the Pilgangoora Basin to determine the uplift history of the hinterland. In particular, this study aims to determine the exposed sources by analyzing the cathodoluminescence (CL) of detrital quartz, supported by titanium concentrations, thin section observations, and detrital zircon U-Pb geochronology. Quartz CL can differentiate plutonic and volcanic igneous grains, thus allowing us to develop a Craton-specific igneous source discrimination diagram and apply it to the detrital quartz samples from the Corboy Formation. We note early exposure of plutonic bedrock and variable plutonic, volcanic, and reworked siliciclastics shedding into the Corboy Formation.

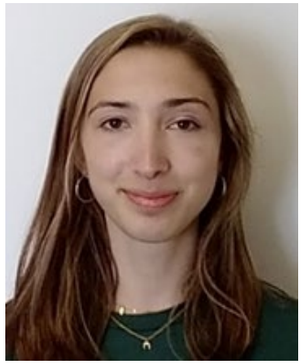
CL and detrital zircon data reflect feeding from the >3.59 Ga unknown supersuite and the Mulgandoona Supersuite early in the deposition of the Conglomerate Syncline with some exposure of the Coucal Formation from Ti-rich grains. With the beginning of reworked material and clasts, provenance shifts to suggest exposure and sedimentation of the Emu Pool and Tambina Supersuites and the influence of volcanic grains likely from limited exposure of volcanic formations and/or transported from older sedimentary units. Through the deposition of the Conglomerate Syncline, high red plutonic grains and age peaks from the Mulgandoona and >3.59 unknown supersuite decline thus likely reflecting that hinterland exposure became increasingly limited.

Clasts within the conglomerate have significant proportions of volcanic grains, suggesting volcanic souring of the older sedimentary formations that were later eroded and shed into the Conglomerate Syncline. In addition, CL and U-Pb ages suggest the proposed >3.59 Ga cryptic core of the EPT is of plutonic origin. Sourcing from both older plutonic units and supracrustal units is inconsistent with currently accepted PCO models, potentially implying a tectonic style that is not purely vertical diapirism existing in the Pilbara Craton during deposition of the Corboy Formation.

Klara Kuemmerle

Concentration: Environmental Science and Public Policy

An Analysis of Indian Monsoonal Extreme Rainfall Events and Their Correlation with Indian Ocean Sea Surface Temperature



Advisor: **Peter Huybers,** Professor of Earth and Planetary Sciences and Environmental Science and Engineering, Harvard University, and Department Chair, Earth and Planetary Sciences, Harvard University

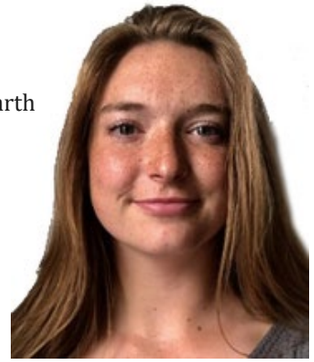
In recent decades, India has witnessed an increase in extreme precipitation events (EREs) that have had detrimental impacts on agricultural output, food security, infrastructure, and human health. While it is expected that rainfall extremes will intensify with global warming and the corresponding increase in atmospheric moisture (~7%/K), certain regions in India are experiencing stronger increases in rainfall intensities than would be expected from the Clausius-Clapeyron relationship alone. Building on previous studies that have analyzed the sources of precipitation extremes, this study explores whether sea surface temperature (SST) anomalies in the Indian Ocean are correlated with increases in daily ERE intensities and highest percentiles of hourly rainfall and whether they may be used to predict futur regional EREs. First, we cluster rain gauge stations into sub-regions according to monthly precipitation patterns. Second, we assess the temporal and spatial trends of the highest percentile daily and hourly rainfall magnitudes across individual stations and clusters. Third, we evaluate the trends in mean SST and regional patterns in the first three principal components of variability during monsoonal months. Lastly, we regress the first principal component of the highest percentiles of hourly rainfall with the first three principal components of Indian Ocean SST to determine their correlation. We find no clear spatial pattern between SST and precipitation anomalies. However, we do find a greater correspondence between EREs and the second and third principal components of SST—associated with seasonal and regional fluxes of Indian Ocean SST—than with the first principal component of SST—associated with mean global warming. We also find that this correspondence is highest in the month preceding peak rainfall. Our analysis by no means dismisses the possibility of a correlation between SST and EREs but underlines the need for more extensive research, particularly with a temporally recent and geographically broader dataset.

Lucy Jacobsen

Concentration: Earth and Planetary Sciences

Raman Analysis of Garnet at High Pressures

Advisor: **Rebecca Fischer**, Clare Boothe Luce Assistant Professor of Earth and Planetary Sciences



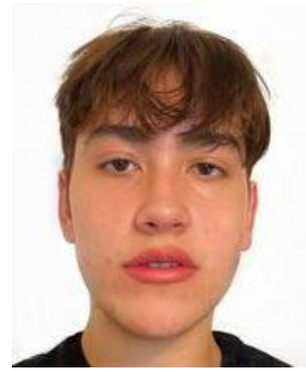
Earth's crustal distortion and movement is largely dragged along by the conduct of mantle rock. The mantle serves as a bridge through the Earth, maintaining communication with the lithosphere and the outer core. This is especially impressive when faced with how little we know about the majority of our Earth. Though we cannot access the deeper layers, we can broaden our understanding of what we do know is there. Through many disciples of Earth sciences we have set boundaries for this knowledge with which we can continue to build our understanding. One such way this can be done is to investigate the structure of minerals prominent to mantle activity. Garnets are a great example of this (Vinnik 1990). As material moves down into the mantle in eclogitic or peridotitic rock the volume fraction of garnet increases. Garnet's relative stability at high pressures allows it to become a major constituent in mantle rock. Until the seismic switch that is offered by the divide between upper and lower mantle. At this point garnet completely dissolves into denser phases. These are incredibly important processes in the movement of mantle rock (Wood et al. 2013). In this work a structural analysis of garnet under high pressure is done through Raman spectroscopy using a diamond anvil cell. This method of studying garnet is not new but has faced road blocks in the past decades as to the quality of data that can be recovered. The advancement of technology in mineral physics has allowed for five natural garnet samples to be spectroscopically analyzed up to pressures of 45 GPa. A new assignment of the Raman active modes of garnet has been made. The garnets show very similar reactions to pressures regardless of composition. They maintain alignment with assumptions of linearity in Raman shift as a function of pressure from garnets lower pressure experiments. An interesting peak splitting takes place in four of five garnets involving the rotational motion within the silicate tetrahedral of a garnets structure between 25 and 30 GPa. These mode assignments expand the ability to track Raman peaks through harsher conditions in an effort to build our understanding of the processes of deep Earth minerals.

Gabriel Maxemin

Concentration: Earth and Planetary Sciences and Chemistry and Physics

Quantifying US Landfill Methane Emissions Using TROPOMI+GOSAT Satellite Data

Advisor: **Daniel Jacob**, Vasco McCoy Family Professor of Atmospheric Chemistry and Environmental Engineering



Methane is a greenhouse gas with a short atmospheric lifetime and strong warming potential. Reduction of anthropogenic methane emissions is thus a significant way to combat climate change. Recent literature has suggested discrepancies between "top-down" and "bottom-up" estimates of landfill emissions. In this study, we explore this discrepancy through a top-down estimate that employs a blended TROPOMI+GOSAT satellite data set and focuses on landfills sources over the United States during recent years, up to 2022. Through wind rotation of methane satellite observations, oversampling, and an integrated mass enhancement method, we quantify methane emission rates. We employ these methods on eight landfills and explore associations between methane emission rates and landfill characteristics. In most cases, we see greater methane emission rates for our top-down estimates compared to the bottom-up inventory report estimates. Assuming no regional differences in landfill methane emissions reporting across the United States, we suggest that bottom-up methane emission reports are under-reported as is evidenced by the discrepancy with our top-down estimates employing TROPOMI+GOSAT data. For 2022 and compared to our top-down estimates, methane emission rates for the eight selected landfills range in how much they underestimate emissions from 1.34 Gg a−1 to 13.49 Gg a−1. Two landfill characteristics, cover type and waste-containing surface area, show strong correlations with the discrepancy in emission estimates. The top-down methane emission rate estimates, as well as the observed difference in methane emission rates, can inform the parameterization of bottom-up functions employed for emissions reporting.