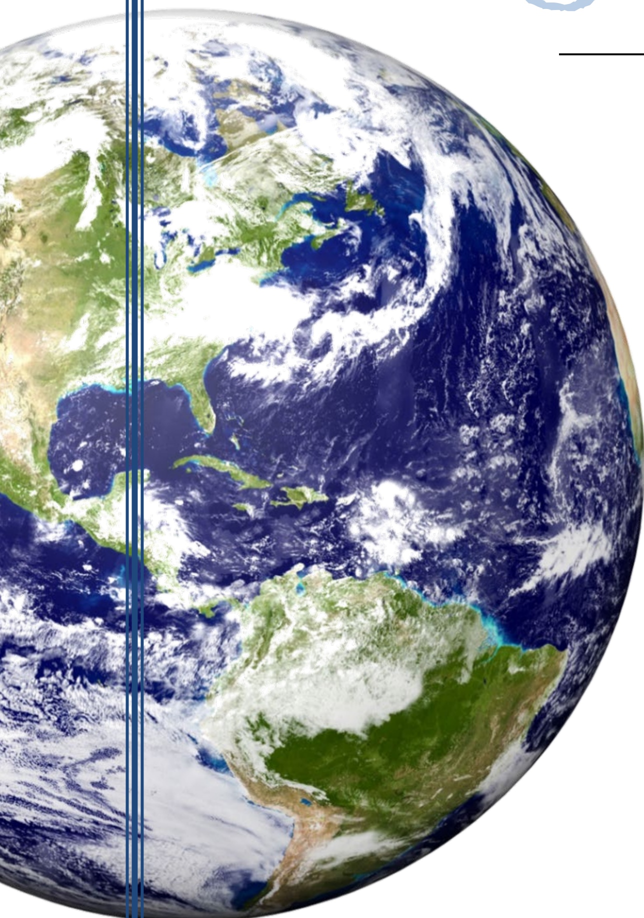
EARTH & PLANETARY SCIENCES

AT HARVARD UNIVERSITY



2020 Senior Thesis Presentations

Josh Grossman

Jacob Ott

Jamie Weisenberg

Joseph Winters

Friday, May 1st, 2020 11:30 am-1:00 pm
Zoom: https://harvard.zoom.us/j/91880817636

Please join us for a celebratory video for the EPS senior following the thesis presentations

WELCOME

Message from the Head Tutor 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 first hand 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. This year's students faced unprecedented challenges as the last half of their final semester was disrupted by the COVID-19 global pandemic. Even as their academic and social lives were turned inside out, these students pushed through to complete their theses.

Their efforts would not be possible without the support of faculty advisors, graduate students, post docs, and fellow undergraduate students. We thank these mentors and friends and congratulate our seniors on their achievement.

Miaki Ishi
Head Tutor

Esther James and Annika Quick
EPS Preceptors

Jim Anderson, Roger Fu, Miaki Ishii, Zhiming Kuang, Marianna Linz
Undergraduate Curriculum Committee

Chenoweth Moffatt
Academic Program Manager

Josh Grossman

Concentrations: Earth and Planetary Sciences and East Asian Studies

A Novel 3D Model-Based Petroleum Resource Estimate of the Qaidam Basin in Northwest China, and Implications for the Future of China's Energy Economy

Advisors: **John Shaw,** Harry C. Dudley Professor of Structural and Economic Geology and Harvard College Professor
Mike McElroy, Gilbert Butler Professor of Environmental Studies, Harvard University
Ryuichi Abe, Reischauer Institute Professor of Japanese Religions, Department of East Asian Languages and Civilizations, Harvard University

The Qaidam Basin is one of China's seven largest inland petroliferous basins and has been a center of the nation's petroleum production since the 1950s. The basin is located in Northwestern China and contains several petroleum systems. Three of these systems account for the vast majority of the total basin resources: The Quaternary petroleum system in the northeast of the basin, the Paleogene petroleum system in the northwest of the basin, and the Jurassic petroleum system to the southern basin. This study models these three petroleum systems in a 3-dimesional evolutionary model built in Schlumberger's state-of-the-art Petrel 2019 and PetroMOD 2019 software. This model incorporates geologic, well, and seismic reflection data that constrains the 3D subsurface geometry, lithologic facies, hydrocarbon chemical properties, heat flow, hydrogen index, and total organic carbon content. The hydrocarbon resource estimates (7.69 gigatons of oil and natural gas) produced from this model are substantially higher (from 25 to >200%) than previously published results. Specifically, this study confirms the largest prior estimates of the basin's natural gas resources and suggests an ≈ 40% greater total oil resource than previous estimates. The spatial distribution of petroleum accumulations generated by the model indicates the possibility of increased gas potential in the northwestern Mangya depression and greater potential for oil extraction in the southern Qaidam Basin. Natural gas produced from the basin will almost certainly be consumed domestically given China's ever-growing demand for natural gas, which is driven in part by government policies encouraging citizens and towns to switch from coal-powered heating systems to natural gas-powered heating systems in an attempt to curb pollution. However, the future of the basin's oil resources is much less clear. As transportation costs remain high given the basin's remote location, it is possible some of the oil resources in Qaidam will eventually become exports along China's Belt and Road Initiative or go to plastics manufacturing in the area. This model's results are significant in helping build a greater understanding of the relative contribution of each distinct petroleum system to the total resources present within the Qaidam basin as well as in helping guide future exploration toward several target areas.

Jacob Ott

Concentration: Earth and Planetary Sciences

Investigating the Chemistry of Archean Asteroid Impact Debris

Advisors: **Roger Fu**, Assistant Professor of Earth and Planetary Sciences, Harvard University

Large asteroid impacts in Earth's early history excavated enough of the surface to generate global scale debris clouds. The condensates from some of the earliest known impacts' debris clouds, called impact spherules, can be found today in South Africa's Kaapvaal craton. Spherules were originally composed of a combination of the impacting asteroid and the material it excavated, so the chemistry of spherules provides potential clues to the compositions of the early Earth's crust and mantle, which in turn constrain the growth of continental crust and the evolution of plate tectonics. This study builds upon previous bulk chemical analysis of a 3.24 Ga spherule bed in Kaapvaal craton called S3. Here, we investigate samples of S3 using Laser-Ablation Inductively-Coupled-Plasma Mass Spectrometry (LA-ICP-MS). This precise analytical method reveals signicant heterogeneity and varying degrees of alteration throughout S3. Evidence of baritization and silicication is observed; however, the extent of alteration is limited. Impactor- and target rock-derived chemistries are distributed unevenly amongst and within spherules and are subject to nugget effects, with impactor-sourced Ir residing primarily within pockets <100 m in scale. Based on rare earth element (REE) trends, target rock material likely consists of oceanic as well as continental crust. The presence of the latter within the excavation radius of the S3 asteroid impact supports greater land coverage on the surface of the ancient Earth than has been previously inferred from the geologic record.

Jamie Weisenberg

Concentrations: Astrophysics and Earth and Planetary Sciences

Using Protostellar Outflow Chemistry to Probe Extraterrestrial Ice Abundances

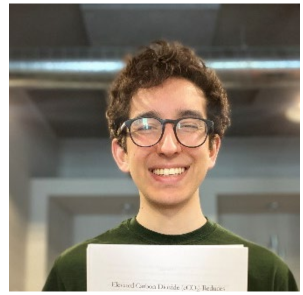
Advisors: **Karin Öberg,** Professor of Astronomy
Director of Undergraduate Studies, Harvard University
Andrew Burkhardt, SMA Postdoctoral Fellow, Harvard-Smithsonian Center for Astrophysics

Understanding the chemistry that occurs during solar system formation can give insight to how life on earth developed. Most of this chemistry develops on the icy mantles of interstellar grains. To study it we can either observe the species directly in other star systems (in the gas or ice phase) or use models to simulate the process. To detect molecules in space, we can observe emission spectra when a molecule emits a photon or absorption spectra as a molecule absorbs a photon. While the most complex chemistry in space occurs on icy dust grains, it is difficult to detect molecules in the ice phase due to observational limitations. Specifically, the absorption features of ice chemistry are harder to detect than gas phase spectra. While we see complex molecules in the icy interstellar medium and comets, the most complex molecule we can confidently identify in the ice phase using vibrational spectroscopy is methanol (CH_3OH). Thus to observe more complex molecules than methanol, we look to and alternative methods of constraining interstellar ice abundances. We present one such alternative approach, using protostellar outflows as a proxy for ice chemistry. These outflows can sputter and sublimate ice into the gas phase without inducing thermal chemical changes. We can thus observe this gas as a measurement of the material that has left the solid phase. Recent studies suggest that L1551 IRS5 shows evidence of chemically rich outflows. Here we use an interferometric survey at radio wavelengths that spans 50 GHz of bandwidth from around 290-365 GHz to examine the chemical morphology of the outflow regions. Specifically, we analyze the spectra of L1551 IRS5 to determine molecular abundances throughout the outflow of the protostar, and image the emission locations to compare the chemistry and morphology of different molecules in the region. We then compare abundances of different regions to other protostellar systems and comets. We compare these outflows to the chemical complexity in comets to test the validity of using shocks to probe the ice cloud of L1551 IRS5. We find a rich chemical profile of many species in the outflow of L1551 IRS5 consistent with previous structural studies of the region. Our analysis shows significant variation in chemical richness and column densities along the outflow as a function of radial distance from the center protostar. Additionally, six of the nine most abundant species present in the outflow are also present in comet 67P/C-G. We conclude that this similarity may suggest that by probing the outflow in L1551 IRS5, we are indeed able to proxy the ice chemistry of the surrounding molecular cloud to better understand the overall chemistry of stellar evolution.

Joseph Winters

Concentration: Earth and Planetary Sciences

Elevated Carbon Dioxide (eCO_2) Reduces Pollen Protein Concentration in Three Floral Species Important for Pollinators



Advisor: **Ann Pearson**, Department Chair; Murray and Martha Ross Professor of Environmental Sciences; Harvard College Professor
James Crall, Postdoctoral Researcher, Organismic and Evolutionary Biology Department, Harvard University

Since the beginning of the industrial revolution, global CO_2 concentrations have risen by nearly 50% from a pre-industrial average near 280 ppm to modern day concentrations above 410 ppm.1 Beyond the planet-warming effects of this buildup of greenhouse gas, elevated CO_2 (eCO_2) has been extensively shown to cause micronutrient and protein reductions in staple agricultural crops, from wheat to barley to rice. The consequences of nutrient reduction for human populations have similarly been documented — Meyers et al. (2015) find that even marginal decreases in zinc, iron, and protein concentrations in human food sources may place at risk those communities already living at the cusp of nutrient deficiency.

However, the consequences of eCO_2 for non-human species remain relatively undocumented, in part because few studies have examined the effects of eCO_2 on non-human food sources. Pollen is of particular interest, as it serves as the principle protein source for pollinators like bees, upon which much of the human food system depends — bees pollinate one third of agricultural food crops3 and the majority of all flowering plants globally. However, bee populations are in rapid decline, threatened by environmental stressors like toxic agrichemicals7 and habitat loss. Now, recent research by Ziska et al. (2016) finds that eCO_2 may cause reductions floral species' protein content. If this is indeed the case, researchers worry that protein scarcity will exacerbate environmental stressors and could lead to further pollinator population collapse.

Ziska et al. (2016) have documented a strong negative correlation between rising CO_2 and pollen protein concentration for a single floral species, "*Solidago canadensis*" (goldenrod). Goldenrod serves as an important source of pollen, but bees' dietary protein derives from a number sources, and it is unknown whether CO_2-induced protein reductions occur in a broader array of floral species. To better understand how eCO_2 might affect a wider variety of floral species important to bees, we grew *C. tinctoria* (plains coreopsis), *H. annuus* (dwarf sunflower), and *L. inflata* (Indian tobacco) at two different CO_2 concentrations, one representing the modern atmosphere (400 ppm CO_2) and one simulating an enriched future CO_2 atmosphere (600 ppm CO2, a concentration well within the Intergovernmental Panel on Climate Change's projections for atmospheric CO_2 levels reachable by the year 2100). We then investigated these species' pollen protein concentrations using a colorimetric protein assay and elemental analysis.

(Continued on next page.)

(Continued)

Ziska et al. (2016) used an elemental analysis to detect nitrogen (N) content in *S. canadensis* across a range of CO_2 concentrations, using % N composition as a proxy for protein content. Because this technique requires the use of a proxy and a conversion factor, both of which may introduce uncertainty into protein calculations, we decided to verify the results of elemental analysis within our study with alternative methods. Due to historical precedence, we settled on an adapted Bradford microassay.

We developed a Bradford microassay protocol appropriate for detecting small concentrations of protein extracted from whole anthers and discuss the method's limitations. With elemental analysis, we observed that neither the pollen's C:N ratio nor its % C composition changed significantly across CO2 treatments. However, we observed significant % N reductions for each species: 15.72% for *C. tinctoria*, 21.93% for *H. annuus*, and 29.37% for *L. inflata*, from flowers grown at 400 ppm to 600 ppm. These findings are consistent with Ziska et al.'s findings for S. canadensis in suggesting that CO2 causes protein reductions and increased starch and carbohydrate content, although they raise questions about the mechanisms underlying CO_2-driven protein reduction. More broadly, our findings highlight the importance of further investigation of the effects of eCO_2 on non-agricultural flora and their reverberating effects on the food system and consequences for bees.