Personal History:

When I was in second grade, my father commenced his master's degree. Some of my fondest memories involve him coming home and working on his calculus homework with me. **This motivated my interests in mathematics at an early age.** To foster my interests, my father gave me Steven Hawking's *A Brief History of Time.* I spent weeks reading through the pages, barely understanding a word but being fascinated with everything in the universe. Black holes in particular were amazing to me as they epitomized the unknown. My father encouraged me to not limit myself and to dream. I carried these lessons with me as I grew up mainly with my mother in the Detroit metropolitan area. I watched her do everything in her power to support my brother and I. The only role model that I had known had left my life and I was devastated. I isolated myself from others, which led me to a state of depression. My one solace was knowing that no matter what, I had a vast universe around me. This was my escape from everyday life. The universe had an infinite number of possibilities and I wanted to learn about all of them as my father had once inspired me to do. **These experiences enhanced my curiosity in the universe and made me want to pursue a career in astronomy.**

Motivation for Pursuing Astrophysics:

My passion for math and physics was fostered in high school. I loved the challenges I was faced with every day in AP Calculus and how we were encouraged to work in groups to solve problems in AP Physics. At the time, I was the accountant for our school store which led me to major in accounting at Michigan State University (MSU) and delay my dreams of focusing on astronomy. Even though I excelled, I was not engaged and I knew this path was not my own. I remembered my dream, and that the only thing preventing it from coming to fruition was myself. **Thus, following my freshman year, I became an astrophysics major.**

In the first year as an astrophysics major, I was met with a rush of anticipation. This was the beginning on a path that was completely foreign to me. I chose to skip many introductory level courses and obtained overrides for higher level courses so that I could graduate in a timely manner. Much of my time was spent catching up to those that had already overcome the challenges I faced and as the only black astrophysicist in the program (the second in the history of MSU) I felt utterly alone. I joined a mentoring program and was paired with a graduate student. We garnered support from the department, and the Astronomy Club was born. We organized department cook-outs, public observing nights, and faculty seminars. This social environment encouraged my astronomical pursuits.

With my college debt increasing, I worked 20+ hour weeks at a cafeteria on campus. To support myself, in 2013 I became a teaching assistant for a physics class intended for non-physics majors known as *Mystery of the Physical World*. I was able to connect with students that had no passion for science and share my enthusiasm with them. To this end, I was pleased to discover I had instilled in these non-majors an interest in science outside of their usual field. In early 2014, I became a teaching assistant for the second level astronomy class, *Planets & Telescopes*. I assisted astronomy majors in their understanding of how objects within the solar system behave. This was an opportunity to mentor those not far behind me in the major. **I was able to gain perspective for how far I had come as well as impart wisdom from what I had learned in my time in the major.** I graded coursework and used my free time to establish tutoring hours for the students. I enjoyed helping students understand difficult concepts as well as watching them grow over the course of the semester. This bolstered my confidence in what I had learned and allowed me to become comfortable teaching and relating those concepts to others.

The theme of my undergraduate experience was challenge and thus I chose to take upper level physics classes such as particle and nuclear physics in order to gain an additional degree in physics. I also took it upon myself to enroll in a radiation transfer graduate class during the final year of my undergraduate studies. This class was a tremendous opportunity to gain insight into the graduate level.

Research Background:

In 2014, I began my first research experience which focused on cataclysmic variable (CV) stars, binary star systems that consist of an accreting white dwarf and a companion star. This mass accretion causes a periodic rise in brightness as infalling gas forms a bright accretion disk around the white dwarf. My original interests revolved around dark matter and cosmology, however, there were no opportunities to conduct research on these topics and thus chose to study stars instead. I had the opportunity to use the MSU 24” telescope in order to gather data on various American Association for Variable Star Observers targets including V1974 Cyg, Nova Per 1889, and many more. From this opportunity, I learned how to operate telescopes proficiently as well as develop an understanding for the physics involved in CV systems. In the conclusion of this experience, I presented on magnetic versus non-magnetic CV’s for a student focused research seminar at MSU. This was the first time I was in front of an audience presenting on an astronomy topic.

I wished to conduct research that involved cosmology and specifically wanted to do so with Dr. Mark Voit due to his talent in teaching and expertise in the field. My senior thesis focused on galaxy cluster simulations. **I used an existing galaxy cluster simulation code to constrain the cosmological parameters which would allow the optimization of future galaxy cluster surveys conducted by the Wide Field Infrared Survey Telescope (WFIRST).** For this project, I learned the physics that govern galaxy clusters, further develop my programming skills, and statistical methods in cosmology. I varied the matter density parameter, Ω_M, cosmological constant, w, the parameterized relation between cluster mass and number of galaxies residing in a galaxy cluster, Λ_0, and the amplitude of perturbations in the power spectrum, σ_8, in order to simulate galaxy cluster counts. We used statistical analysis in order to constrain these parameters. We found that fluctuating σ_8 produced the most variance, meaning it was the most constrained, while w resulted in the least, thereby making it the least constrained. We also found that additional gravitational lensing data will yield modest improvement to the uncertainties of Ω_M, σ_8, and Λ_0. I concluded my senior thesis by presenting these findings to the faculty of MSU in 2016. I was also awarded the Lawrence Hantel Fellowship for my research.

Through all of my research experiences, I learned how to better manage my time between working multiple jobs and focusing on a demanding major. I learned how to efficiently use my time; when my research experienced temporary setbacks, instead of faltering, I was able to adapt and focus on other facets of the research in order to maintain overall progress. These skills are essential to the success of a scientist.

Current & Future Goals:

Being a first generation college graduate, I have learned not to waste the opportunities I am given. Currently, I attend Arizona State University (ASU), where **I strive to be the first in my family to obtain a Ph.D.; but not only that, I want to impact the world.**

The NSF fellowship will provide me with essential support for pursuing my research and continuing onto become a leader in academia. Becoming an NSF fellow would also be prestigious and would allow me to network with well-respected scholars. I hope to take these dreams and make them into a reality. Some of my goals when coming to graduate school were to vastly enhance my programming skills and be challenged, and thus I chose to work with Dr. Evan Scannapieco. **Currently we are working to solve the problem of highly ionized heavy elements that are present in gas surrounding isolated galaxies through rigorous modeling.** We will accomplish this by accounting for the non-thermal random motions that are commonly observed in this gas. My background lies in galaxy clusters and so **I will continue on to model the emission properties of the medium around galaxies located in cool-core galaxy clusters.** These clusters are defined as having an intracluster medium with low to intermediate entropy and either a flat or inwardly decreasing temperature profile**.** The medium located in the center of these clusters emits radiation and cools hydrostatically. This results in the compression of inner gas by the overlying layers. Hot gas from the outer zones of this medium flows inward to replace the cold gas, creating a cooling flow. This will allow me to combine my previous knowledge of clusters and my newfound knowledge of gaseous systems.

As a child I had only a handful of inspirational mentors in my life. My father was the man I aspired to become. I want to pass on those lessons that he instilled in me. I want to inspire children that come from a troubled upbringing. **There needs to be more people of color in higher fields of science and we need to encourage children who are eager to engage in STEM fields.** This lack of people of color in higher education is highlighted by my own graduate study experience, as I am the only black astrophysicist in my program. I take pride in the fact that I came from a low-income background where society taught us not to dream, but instead, I am currently attending graduate school. Due to societal influence, we were expected to either go to jail or follow the trend of becoming a low income, high school graduate. I have had teachers tell me that I would not amount to anything. I took what my father taught me and exceeded every expectation of me. I want to take my experiences as well as my love for science and convey them to those who are in similar situations as I was. At ASU there are many opportunities to accomplish this such as our department Open House, where the public engages with graduates and faculty on the many projects we participate in, and the Annual School of Space and Exploration (SESE) day, another event which allows the department to show off its multitude of projects to children and parents. Upon admission to ASU, I was also awarded the Doctoral Enrichment Fellowship for my first academic year. As part of this fellowship, I am a participant in the Changemaker challenge in which graduate students from a variety of disciplines come together in order to find innovative solutions to problems in the world. This allows me to gain interdisciplinary perspective on the problems that plague the world. I want to inspire a shift in society where disadvantaged children are given every opportunity to be actively involved in science and moreover aspire to go into a STEM field.

As children, we are able to nurture our curiosity. However, as we grow older we tend to stray away from this. Being researchers, we are in a unique position to take advantage of that curiosity and use it to understand the world around us. I believe that it is our duty to remain engaged with youth and keep them involved in STEM fields. **I want to become a leader that encourages the growth of these fields and changes the world.** We must change the mindset of every child that does not see a future in science, and through this, we will change the world.

Proposed Plan of Research

Most of the elements from which life is composed are formed within stars and supernovae. As these stars die, the material they produce is expelled by galactic winds into the circumgalactic medium (CGM), the ionized gas that envelops galaxies. The history of the CGM directly impacts the chemical composition of all galaxies, the properties of the first stars that formed after the big bang, and the relation between the stellar mass and gas-phase heavy-element content of all galaxies (Martin et al. 2010).

Recently, there has been a substantial effort to work towards analyzing the amounts of heavy elements present in the CGM (Peeples 2015). However, the observed properties of many ionized species remain unexplained by current ionization models, with the most puzzling species being five times ionized oxygen, O_{VI}, (Werk et al. 2016). **Thus it is my proposed plan of research to use supercomputer simulations to investigate these ionized states of heavy elements and help understand how the observed CGM species may arise.**

Currently, I am an Astrophysics Ph.D. student working with Dr. Evan Scannapieco at Arizona State University. I have begun to analyze previous data acquired by a former Ph.D. student, William Gray. The code used to obtain these results includes the detailed FLASH cooling & chemistry package developed in Gray et al. (2015, 2016) and the **results will enlighten astronomers' understanding of the key physical processes within the CGM.**

Motivation

Attempts to explain the amounts of O_{VI} and other ionized heavy elements have failed completely. Absorption by O_{VI} with column densities above $N = 10^{14}cm^{-2}$ is ubiquitous at a distance of 150 kpc from star forming galaxies, and is present, but less common, around quiescent galaxies (Peeples et al. 2014). This implies that a large portion of oxygen must exist in the form of O_{VI}. This is extremely problematic since the opportunity for collisional ionization is low, and phoionization requires extremely low densities (10^{-3} - 10^{-4} cm^{-3}). Also, accounting for the large O_{VI} column densities with such low density gas requires unphysically long path lengths (Werk et al. 2014).

Furthermore, the pressure in such low density gas would be extremely low, and therefore it should return to the galaxy or leave its gravitational influence. There is something clearly missing from our current understanding, and we believe this missing piece to be turbulence. In fact, large non-thermal random motions are detected in almost all CGM observations, but these are ignored when interpreting the ionization states. **Through the proposed research, we will be able to provide a definitive answer for the role these motions play, accounting for the turbulence within the CGM and how it influences the species present.**

Methods

- ***Testing and Application to Isolated Galaxies (1st year of research):***

For verification, I will first test our code against CLOUDY, a widely used open-source ionization code (Ferland et al. 1998). After verifying that our code without turbulence agrees with CLOUDY, I will test whether a turbulent CGM can account for the various abundances as well as different scenarios that may result in a photoionized CGM around isolated galaxies. Recent work by Werk et al. (2016) considered various line ratios for multiple low redshift galaxies and attempted to explain the observations through modeling. I will be able to directly test the spread in turbulence (20 km/s $< b <$ 200 km/s) and make comparisons with these observations. We predict that a lower ionization parameter, defined as the ratio of ionizing photons to hydrogen density, will be sufficient to describe the CGM.

- ***Modification and Testing (2nd year of research):***

Next, I will look at the emission properties of the medium around galaxies located in cool-core galaxy clusters. These clusters are defined as having a circumgalactic medium with low to intermediate entropy and either a flat or inwardly decreasing temperature profile (Hudson et al. 2010). Significant advances have been made in the understanding of cold fronts that develop within these cores (Zinger et al. 2016), however there has not yet been an analysis performed on the resulting emission lines of these systems. By expanding the parameters of our existing code, I will be able to simulate these emergent lines and characterize the abundances of heavy elements. To obtain these results, I will first modify and test our code against other simulations of the dynamics in the galaxy clusters. Once this is completed, I will begin to model the chemical structures of the medium that surround such galaxies.

- ***Further Modeling and Comparative Analysis (3rd year of research):***

Once testing is completed, I will begin to model the chemical structures of the medium that surrounds galaxies in clusters. I will compare my simulations of the media in cool-core clusters with observational data of low redshift clusters. This data will be taken from X-ray observations and will allow for the development of a cohesive model for these observations.

Anticipated Results and Discussion

Simple ionization models are unable to explain the complex CGM. We believe that in order to accurately model such a system, one must consider turbulence. If we find that this addition drastically changes the agreement between the model and observations, then we know that previous treatments of this problem were not sufficient. We predict, however, that accounting for turbulence will change the picture dramatically. This is a profound mystery that requires rigorous modeling in order to be solved.

Our code will track collisional and photo-ionizations, recombinations, and collisional cooling for hydrogen, helium, carbon, nitrogen, oxygen, neon, sodium, magnesium, silicon, and iron. We will be able to simulate whether highly ionized species that are observed in the CGM can be caused by turbulence rather than high ionization parameters and whether turbulence can explain the abundances of these species that are sensitive to collisional excitation, such as O_{VI}. Furthermore, by expanding the capacity of our program we will gain insight into emission lines that present themselves in cool-core clusters. **This research has the potential to dramatically change our understanding of the medium that surrounds galaxies.**

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Modeling Impact-Driven Komatiite Generation on Mercury

Keywords: komatiite, ultramafic, basalt, mantle, Late Heavy Bombardment, Mercury, model

Introduction: I propose to model the cumulative thermal effects of the Late Heavy Bombardment (LHB) on Mercury's mantle to explain the unexpected presence of komatiites on Mercury, and to use the results to produce a comprehensive model for transferring heat into the mantles of silicate planets through impacts.

One of the greatest mysteries in the geologic history of our planet is what conditions were responsible for the emplacement of komatiites—rare, magnesium-rich rocks found in only a few locations on Earth. Komatiites formed mostly during the Archean, when a time of increased heat production allowed Earth's mantle to reach temperatures in excess of 1500ºC. Because the mantle has long since cooled by ~200ºC, all the specimens on Earth are very old and highly modified. Consequently, the mechanics of komatiite generation—and the related interior dynamics of early Earth—are poorly understood.

However, these ostensibly rare terrestrial rocks may exist on other planets and moons in our solar system; komatiites have been proposed as an analog for crater basalts on Mars[1] and as a material in present-day volcanic eruptions on Jupiter's moon, Io.[2] Recently, remote geochemical analyses suggest volcanic rocks of a komatiitic composition are also present on Mercury.[3]

The potential existence of komatiites on Mercury is surprising, and suggests a new approach to understanding the evolution of the planet's interior. The most popular hypothesis for komatiite formation on Earth proposes that they were created as a result of deep, hot plumes in the mantle. However, Mercury's anomalously high density suggests a core-mantle boundary depth of only ~420 km, which would imply a mantle too shallow for hot plume generation. I posit that an external heat source, such as large asteroid impacts, could have triggered high-temperature melting in Mercury's mantle;[4] the increased impact flux of the LHB may have added enough energy to generate komatiitic melts. Internal heat modeling will determine whether or not this could be the case and will inform my future efforts to investigate bombardment-induced mantle heating and melt generation on other silicate worlds. The results of this project will also shed light on the genesis of terrestrial komatiites, contributing to our knowledge of the geologic history of early Earth.

Project Structure: This project is comprised of three tasks. Task (1) involves the comparison of terrestrial komatiite data with remotely sensed geochemical data from Mercury. Task (2) consists of modeling LHB-related temperature effects on Mercury's interior. The project culminates in task (3): construction of a model for bombardment-enhanced mantle heating of silicate planets.

(1) The goals of the first stage of the project are to corroborate the existence of komatiites on Mercury and to quantify the mineralogy of komatiites. Using Earth-based instruments equivalent to those of the currently operating Mercury orbiter, MESSENGER, I will work with Dr. N. Arndt (Grenoble, France) and Dr. W. Maier (Cardiff, UK) to assemble a collection of komatiite samples and spectroscopic data. Because MESSENGER has identified unusual trace metal abundances in putative komatiites on Mercury,[3] I will gather x-ray fluorescence (XRF) data from the Barberton and Munro komatiites under controlled laboratory conditions, so as to quantify komatiites' major-trace chemistry and compare the results with MESSENGER's recently returned element chemistry data. This study will be one of the first to take full advantage of new MESSENGER data. Past research and classes in petrology and igneous and

metamorphic field methods have prepared me to use the required instruments, map isolated study sites, and collect and analyze samples. Since the composition of komatiite varies and many outcrops are relatively inaccessible, I will examine additional samples of komatiite from South Africa via the Smithsonian's sample loan program.

(2) After confirming MESSENGER's data, I will model the cumulative thermal effects of the LHB on Mercury's mantle. Dr. O. Abramov and Dr. S. Mojzsis have developed an analytical model of the effects of the LHB on Hadean Earth.[5,6] I will adapt this technique to conditions on Mercury with the help of a recently published impact flux model for the planet.[7] My IT skills, programming background, and past classes on scientific computing and geophysics will be invaluable during this phase of the project. In addition, I will travel to the USGS Astrogeology Science Center in Arizona so I can collaborate with Dr. Abramov in person. The resulting simulation will determine if the LHB could have added sufficient heat to trigger the generation of komatiitic lava on Mercury, which also has implications for thermal mechanics of early Earth.

(3) Tasks 1 and 2 serve as the preamble to my ultimate goal of generating a comprehensive model for emplacement of heat into the mantles of silicate worlds by impact bombardments. This final product will help us better understand the thermal history of young silicate planets.

Intellectual Merit: Once completed, this research may provide a new explanation for the generation of komatiites, and will reveal the relative importance of accretion to mantle heat production. The results of this project will expand our understanding of komatiites, and help us interpret high-temperature lavas in our solar system, thus also clarifying an enigmatic period of Earth's history. Komatiites appear to be currently erupting on Io, are apparently present on Mercury, and could also exist on Mars, which provides an opportunity many geologists long for: the chance to study a terrestrially-extinct geologic process in action. I suspect my research will also allow me to posit the presence of komatiites on Venus and propose possible search methods.

Broader Impacts: Since first learning about komatiites, I have been fascinated by how they provide a window to a part of Earth's past that is still largely unknown. I naturally plan to share my research with the scientific community through conference presentations and publications, but I also intend to include undergraduate researchers in this project, with the hope that they will feel inspired as I did. They will have the chance to study a rare rock type and work with relatively untouched data. I have mentored students in the past, and I am motivated to continue to do so.

Furthermore, I plan to use my professional experience in web programming, design, and social media, in collaboration with educators in my professional network, to create an online classroom where anyone can follow my fieldwork. This website will document the entire project via video and text blogs, and will also include cartoons and animations to help explain project ideas and the scientific method to kids. While I believe all ages will enjoy this online experience, my target audience is junior high school girls; I want to show them what female scientists can do. My goal is to use this study of komatiite generation on Mercury to nurture students' interest in Earth's geologic history, and ultimately help cultivate future scientists.

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Intellectual Merit: The transfer of energy from rainfall impacting the surface is responsible for contributing to changes in landforms across the Earth. Specifically, the rainfall kinetic energy (KE) that is directly related to the drop size distribution (DSD) is recognized to play a significant role in erosion processes. The KE of rainfall is also responsible for widespread damage to infrastructure and loss of human life during flood events, in particular debris flows and mudslides. Societal hazards related to flooding are expected to grow as urban areas continue to expand and storm systems respond to global climate change. As one of the fastest growing urban regions, the Phoenix metropolitan area had a reported $16.3 million in damages associated with summer storms in September 2014 alone[1]. My previous industry experience has provided first-hand experience in assessment of the damages caused and the implementation of solutions related to extreme storm events. The cost of rebuilding infrastructure and reducing future flood-related catastrophes prioritizes the need for detailed precipitation research. Unfortunately, the high spatiotemporal variability of storm systems impedes the proper characterization of rainfall properties. For example, the southwestern US is subjected to a bimodal precipitation regime marked by two maxima during the summer (July–September) and winter (November–March), which vary dramatically in their rainfall properties[2]. This diversity of meteorological conditions offers a unique opportunity to characterize precipitation across this region from direct measurements of DSD and KE and to quantify their relation to erosion.

Understandably, the process of falling rain leading to soil particle movement has received prior interest[3,4,5,6]. The most commonly collected rainfall characteristic, intensity, is typically gathered from rain gauges, from which the parameters affecting erosion (DSD and KE) are derived. However, as a bulk parameter, rainfall intensity does not accurately capture KE due to intra-storm variability of the DSD. Early efforts to relate intensity to the mean DSD were made by Laws and Parsons[7] by collecting falling raindrops into pans of sifted flour. As point measurements in time, these efforts fall short in describing the temporal changes in DSD and thus also KE over a storm's lifespan. Efforts to collect continuous measurements of the DSD are critical, as the rainstorm KE is directly related to the spatiotemporal variability of the mass, velocity, and number of drops. Many studies have aimed to express the mean DSD as a probability distribution related to the storm intensity. Marshal and Palmer[8] first concluded via empirical study that the mean DSD is well represented by a negative exponential function. However, there is significant disagreement between the theoretical solutions and empirical observations, including the unresolved discrepancy between mean and spatiotemporally variable DSDs. Later studies have confirmed that additional effort is needed for gathering direct measurement of the DSD from many storm types throughout their lifetimes with differing intensities, durations, altitudes, wind updrafts, and geographical regions to understand the relation between the observed erosion values and calculated rainfall KE[5,9,10].

In this proposed effort, I will coordinate the collection of rainfall DSD, sediment yield, and meteorological data from three sites in a climatic region subjected to a bimodal precipitation regime. The three sites have been selected based on the well-known variations in annual rainfall and the percentage received during the more intense summer season. Two rural sites in the Sonoran (Green Valley, AZ) and Chihuahuan (Las Cruces, NM) deserts subject to natural rainfall complement an experimental facility in a developed area with a physical rainfall simulator (Mesa, AZ). Each site will consist of a weather station, runoff and sediment collection system, and optical disdrometer. Collected data at each site will include rainfall rate, air temperature/humidity, wind speed/direction, solar radiation, soil water content, DSD, KE, and runoff and sediment yield. The combination of rural field sites and an experimental facility will enable a comparison between meteorological conditions, precipitation characteristics, and erosion values across many natural and synthetic storms over different seasons to elucidate storm system type dependencies. At each site, local soil, plant and antecedent wetness conditions will be characterized during initial reconnaissance and tracked over time to inform the sampled runoff and sediment yield observations. Automated sediment and runoff collection systems will vary between the sites to accommodate varying dimensions between a large soil test bed at the experimental facility and smaller sampling plots at the rural sites. Continuously collected DSD data will allow the resultant KE to be accurately determined across a large population of storm events at each site, allowing cross-site comparisons to elucidate general features and site-specific variations. Statistical analyses of winter and summer storm events will elucidate variability in the characteristics of rainfall and assist in constraining the erosive potential of each regime.

Broader Impacts: Assessment of rainfall characteristics at the three representative sites in the southwestern US will lead to a greater understanding of regional geomorphological processes. Specifically, this effort will add to the sparse network of disdrometers and measured DSDs across the Sonoran and Chihuahuan deserts. Anticipated results will fuse science and engineering by extending experimental observations of precipitation characteristics to the design and testing of soil and geotechnical materials used in the built environment to meet current and future storm hazards. Results from the sites will be combined to inform how urban areas in the southwestern US could continue to grow under increasing threats from extreme flooding events.

I am currently engaged in the design and construction of the rainfall simulator and soil test bed at ASU's Center for Bio-mediated and Bio-inspired Geotechnics in Mesa, AZ. The anticipated DSD, KE, and erosion values collected at the experimental and rural sites will provide information regarding the contribution by each precipitation regime to the overall sediment erosion hazard in the region. DSD data from the rural sites will also serve as a benchmark to evaluate the rainfall produced at the experimental facility. This community facility will be used to test the effectiveness of rolled erosion control products (RECP) and other engineering solutions used in the built environment for erosion control.

I also aim to make use of the experimental facility as an educational tool open to all. ASU is well known for its community outreach efforts, such as Night of the Open Door. This facility in Mesa, AZ, will provide an accessible opportunity for the public to learn about regional flood hazards during rainfall events with hands-on demonstrations of rainfall and erosion processes. The utility of this facility is also geared towards interdisciplinary research efforts. I will be actively involved in the training of visiting researchers as well as maintaining QA/QC standards. The cooperative nature of this experimental facility will allow me to implement a rainfall simulator and runoff and sediment collection system that will naturally facilitate future interdisciplinary research.

Havoc caused by extreme flooding events leave the underrepresented communities in urban and rural areas at greater risk. The GRFP will allow me to advance our knowledge of precipitation that enables the development of engineered solutions to floods, and provides the flexibility to engage in dialogue with those who are most vulnerable to illuminate their specific concerns. My leadership in communicating the risks associated by floods will produce communities that can self-assess and adapt to the best of their ability with new understanding.

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Subduction-related volcanism constitutes ~25% of the total magma erupted on Earth annually (*1*). A wide variety of processes contribute to the production of arc magmas including: the transfer of elements from the subducting slab to the mantle, mantle melting and the interaction of mantle melts with continental crust. However, there is no cogent model to explain the formation of arc magmas (see reviews of debate in *2, 3, 4*). It is still unclear whether the primary mechanism of melt generation at subduction zones is: 1) the addition of an H_2O-rich component released from the subducted slab and associated sediments to the mantle wedge, 2) melting of the slab and/or sediments, or 3) a combination of both. Understanding the production of arc magmas is also a crucial step in answering broader geologic questions such as how the continental crust formed or how crust is recycled in the mantle.

Previous experimental studies have examined the pressure/temperature (P/T) conditions necessary to partially melt hydrous natural basalts (i.e., the subducted slab), as well as the composition of the first melt produced (*5, 6, 7*). At one time slab melting was thought to be the mechanism to produce arc volcanism, however this hypothesis lost popularity. This was due to the scarcity of a magma type interpreted as pristine slab melts (i.e., "adakites": *8, 9*) and because estimates of the *d*T/*d*P slopes for subducting slabs suggested the P/T conditions required were restricted to cases of subducting of a very young hot oceanic plate (*10*). Now, revised models of the thermal regime in the mantle wedge, which use a temperature-dependant viscosity for the mantle (*11*) and the newly determined vapor-saturated solidus of the mantle wedge (*12*), together provide mounting evidence that the solidi for the slab and the vapor-saturated mantle may overlap at P/T conditions of the slab/wedge interface. In other words, *both* vapor-saturated mantle and slab melting may be common in the formation of "typical" arc magmas. Recent work may also reduce or remove the correlation between slab melting and adakite formation. Adakites may represent an especially high extent of melting of the slab or partial melting of eroded material from the lower crust of the overriding plate, not the slab (*13, 14*). Similarly, a number of important studies address the isotopic and trace element contribution to arc magmas from subducted sediments (e.g., *15, 16*) and experimentally determine the pressure, temperature and composition of partial melts of subducted sediments (*17, 18, 19*). However there has been very little done to explore the consequences equilibrating sediment melts with the mantle wedge (*17*).

Experimental petrology can provide new insight into how the chemical composition of typical arc magmas is produced. I propose to use experimental techniques to determine the melting behavior of the hydrous mantle wedge when small degrees of partial melt of the oceanic slab and/or subducted sediment are added. I will conduct piston cylinder experiments on a synthetic oxide mixture of a primitive undepleted peridotite composition (*20*) and partial melts of the slab or sediments determined in earlier published experiments (*17, 18, 19*). The experiments will be conducted at a range of pressures (1.2-3.2 GPa), temperatures (800-1400°C) and oxygen fugacities (QFM-NNO) relevant to the mantle wedge to determine the solidus for this mixture. Electron microprobe analysis of the chemical composition of the partial melts and crystalline residues produced by these experiments will be conducted at the Massachusetts Institute of Technology. I can then compare the results of these experiments to vapor-saturated melting experiments on undepleted mantle compositions conducted by Gaetani and Grove (*21*) and Grove et al. (*12*) to determine how phase stability and melting behavior changes with the addition of siliceous partial melts to the mantle. In order to develop an integrated model for subduction zone magma production, our experimental results will be tested against the observed compositional range of arc magmas on Earth today. Work by Grove et al. (*22, 23*) on the major-element, trace-element, and H_2O content, as well as the depths of melting of primitive magnesian andesites and quenched magmatic inclusions from Mt. Shasta, will provide an important first comparison of modern subduction-related stratocone lavas to our experiments.

This research will determine whether typical arc magmas are formed by the addition of a siliceous melt of the subducted slab and/or sediments to the mantle wedge or if they are formed by the addition of a water-rich component alone. It will use well-established techniques in experimental petrology and build on previous studies to test new hypotheses regarding the origin of arc magmas.

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Personal Statement, L.W. Raming

1 Relevant Background

In 2007, just before completing my senior year as an economics major, I accepted a summer job as a river guide in the Grand Canyon. Being a river guide is exciting and fun. It is also challenging. I had to ensure the safety and well-being of 28 guests over a 10-day period, learn to navigate class 4+ rapids, and provide entertainment and lessons on the history and geology of the Grand Canyon.

It was this latter challenge that changed my destiny. Learning to understand and share the geology of the Grand Canyon truly delighted me. As I continued to guide, my interest in geology became more than just a hobby or something with which to entertain guests. I became possessed with understanding how something as soft and fluid as the Colorado River could shape something as hard and rigid as the Grand Canyon. My fascination with these geological forces motivated me to return to the University of Utah to pursue and complete a degree in the geosciences.

1.1 Intellectual Merit

In 2015, I graduated with a degree in geology and a minor in physics. My course work had given context to my earlier observations in the Grand Canyon. The Mohr-Coulomb theory explained the structural patterns found in the western Grand Canyon and the dramatic and sudden transition from the Grand Wash Cliffs to the Basin and Range. Sedimentology linked observation of modern beaches along the Colorado River to the ancient beaches of the Tapeats sandstone. Geophysics explained why isostasy could be used in theories on uplift of the Colorado Plateau. Courses in physics helped me develop useful tools for rigorously tackling quantitative scientific problems. In Intro to Computational Physics I learned how to use C++ to solve numerical solutions, to model the motions of complex physical systems, and use Monte Carlo methods to simulate nuclear chain reactions. In my physics labs, I learned the importance of the propagation of analytical error, while in my energy and sustainability course I learned about the tradeoff between work and entropy and the challenges that face sustainable systems.

1.2 Broader Impacts

The inspiration of my course work and the accumulation of academic success had been a personal validation for me in learning that success in the sciences is not about genius, instead it is about passion and hard work. This awareness inspired me to volunteer at a local elementary school teaching lessons on rocks and fossils. I wanted to make science accessible and inspiring to students at a young age. Additionally, as an undergraduate I co-taught the geophysics lab and helped 40+ students learn challenging topics. These experiences, including time as a river guide has reinforced the importance of clear communication as a way of making science accessible to everyone.

2 Research Experience

During my undergraduate years, I would often attend the weekly geoscience colloquium where visiting professors presented innovative and inspiring research. I was excited by these talks and wanted to learn how to conduct scientific research. In the Spring of 2013, Professor Brenda Bowen offered me a research position with her group studying the Bonneville Salt Flats, a saline playa located in the Great Salt Lake Desert, Utah. The Bonneville Salt Flats (BSF), while being a unique landform, also serves as a significant economic resource and a valuable recreational area. Over the past century, documented decreases in the thickness of the halite crust (which has been largely attributed to the local evaporative mines) has caused significant alarm. Efforts to mitigate the depletion of the crust began in the late 90s. While several studies had documented a possible increase in halite thickness and extent, there had been no significant studies documenting the areal extent of the crust nor the influences of seasonal and climatic cycles on BSF.

2.1 Intellectual Merit and Broader Impact

The programming language R and the spatial analyst software ENVI enabled me to analyze and process metrological data and Landsat imagery of BSF from the past 30 years. What was surprising about the analysis was the apparent ineffectiveness of efforts to mitigate the crust depletion through pumping halite rich solutions onto BSF during the winter months. The complex interaction of the halite solution and seasonal cycles led us to propose that these mitigation efforts could potentially have a negative impact on the halite crust. From this preliminary work, the project received funding from the NSF Coupled Natural Human Systems Award and has been a good example of applied geomorphology.

I have worked hard to communicate the results of our research to the public and the scientific community. I was interviewed by a local news channel on the impact of our research, co-authored a peer review paper, co-authored a book chapter, and presented a poster at GSA Fall Meeting 2014. Through these efforts I received an Excellence in Undergraduate Research Award from the Geology and Geophysics department at the University of Utah.

My work on playas continued with a summer internship at the Space Science Institute. Working with Dr. William Farrand and Professor Bowen, I used remote sensing to classify playas and assess their hazards as a dust source. Playas are defined as wet or dry based on the frequency and extent groundwater interacts with the playa surface. Importantly these interactions influence how susceptible a playa is to dust generation and the minerals that develop on a playas surface. Characteristic minerals for dry and wet playas have unique spectral signatures. Subsequently, minerals such as gypsum (typical of wet playas) and montmorillonite (found in dry playas) are identifiable in hyperspectral data sets through principle component analysis and multi-spectral feature fitting. I designed a system, using these tools, to classify playas based on the abundance of these characteristic minerals. The classification system provides a framework for remotely identifying hazards associated with the different playa types something that will be useful in areas of increasing aridification. I presented our research at the AGU Fall meeting 2015.

While my undergraduate research experience was in remote sensing of arid-playa environments, I was still eager to follow the inspiration of the Grand Canyon, and the processes that created it. I knew a PhD in geomorphology would allow me to pursue these inspirations and I knew that working with Professor Kelin Whipple and the surface processes group at Arizona State University could provide me with the training and skills to address fundamental questions of fluvial processes and the evolution of the Earth's surface. For those reasons, I was elated when I was accepted to the School of Earth and Space Exploration at Arizona

State University.

In recognition of my scholastic achievements and my future potential as an incoming PhD student, I was honored with the School of Earth and Space Exploration First Year Award. In order to live up to this award I have worked hard to develop the tools and knowledge necessary to conduct research in geomorphology. This past year I have learned the fundamentals of transport, hydraulic and hydrologic models. I have developed a proficiency in MATLAB, Python and ArcGIS. Over the summer working as research intern at JE Fuller Hydrology and Geomorphology, I put these skills to use by conducting research on erosional thresholds in bedrock channels. I shared the results of my research at a JE Fuller brown bag series, to the employees of JE Fuller and other members in the industry.

3 Future Goals

The Earth currently is on an unprecedented path with dramatic changes in climate, land cover, and the human population. All three components interact at the surface of the Earth where vital processes operate to maintain a habitable planet. Understanding the complex nature of these interactions and lessening their potential negative impacts presents significant challenges. These challenges motivate my two major goals as a scientist: (1) The first is to conduct research on erosional thresholds in landscapes and develop understanding of how stochastic climate driven events shape the Earth's surface. (2) The second is to develop public support and literacy for the sciences.

Currently I am working hard to fulfill these goals. At the school of Space and Earth Exploration I am conducting two research projects in fulfillment of my PhD. My primary project utilizes data analysis and numerical models to examine erosional thresholds as a function of climate. My second project is to design and develop a smart particle sensor that can be used for measuring vibrations and incipient motion in cobbles. Both approaches are necessary to help untangle the signals of landscape dynamics. Research also requires rigorous communication; an aspect I continue to work on. I will be traveling to the AGU Fall meeting in December to present my current research.

Public support for science is vital for addressing the above-mentioned challenges, however, science can be exclusive and confusing for many people. As scientists, it is our responsibility to clearly and routinely communicate the relevant and exciting aspects of science to people of all backgrounds. Through experiences as a river guide, teaching assistant, and volunteer I realize that communicating effectively and inspiring people takes significant effort. To refine these skills and to improve access and relevancy of science to students of diverse backgrounds I am working with earth science teachers at the Tempe Union High School District. The focus is on developing lab activities that use Google Earth to explore landforms derived from fluvial processes. These exercises will be paired with stream table labs where students can re-create similar land forms and observe small scale models of sediment transport.

My ultimate intention is to be a professor where I can focus on research and education. My goals will continue to address the impacts of climate change on surface processes and the importance of science education for a responsive and engaged public. With the aid of the NSF GRFP I will be able to pursue and complete these goals.

Vibration and Incipient Motion of Fluvial Sediment

Intellectual Merit

Predicting incipient motion of fluvial sediment has presented significant challenges to scientists and engineers. In homogenous low gradient settings, relative success has been achieved by relying on reach averaged shear stress and a constant non-dimensional bed shear stress to predict movement of a given grain size. This approach however, breaks down in steep streams where macro-scale turbulence becomes more pronounced and local near-bed velocity and turbulence fluctuation play a critical role in initial motion of sediment [1]. An important and likely equal player is the role of sediment vibration [2], a phenomenon that has rarely been studied but is important in describing the fluctuations in lift and drag forces (turbulence) on individual grains and subsequently the likelihood of entrainment. Fortunately, with the advent of cheap and accurate microelectromechanical systems (MEMS), sediment vibration can be studied in the flume and in the field. The research proposed here utilizes such an approach to test the roles of sediment vibration in incipient motion.

Research Plan

Validation Study and Approach

Olinde and Johnson [3] have shown the usefulness of using a MEMS 3-axis accelerometer in casts of cobbles to understand the dispersion and transport of sediment. Motivation for this project came from their observations of in-place vibration of active tracers. While these signals were a hindrance in detecting onset of transport, with an increased sampling rate and bandwidth(200-500 Hz) [4] they can be used to document and test the fundamental yet poorly constrained phenomena of sediment vibration.

Smart Grain Sensor Design

The sensors developed here, termed smart grains, will employ a similar design to Olinde and Johnson [3] where the sensor will be secured within a cast of a concrete grain. The grains will range from cobble to boulder size. An absolute orientation MEMS sensor and auxiliary hardware will be installed within the cast. The absolute orientation sensor will consist of a 3-axis accelerometer, 3 axis gyroscopes, and a geomagnetic sensor. The additional components will provide greater sensitivity for measuring in place vibration and will also allow for easier identification of downstream movement. Larger cobbles and boulders will be equipped with pressure sensors in order to measure the roles of pressure dynamics in grain vibration. Field sensors will be painted and equipped with a Radio Frequency ID chip to aid in recovery.

Hypotheses, Tests, and Predictions

Intellectual Merit

All hypotheses will be tested in the flume at Arizona State University and the field site will be picked based on discharge record, location, and gauging station.

Hypothesis 1: *For a given discharge and flow depth the magnitude of vibration will correlate with the size of the grain holding all else constant.* Results will help identify sensitivity of grain size to vibration and subsequently identifying grain sizes that can be used as markers for onset of bedload transport.

Hypothesis 2: *As the ratio of the characteristic roughness length to flow depth (i.e. relative roughness) increases, turbulence decreases [1]. Subsequently if turbulence drives sediment vibration then reduction in relative roughness should lead to increased vibration.* This will help derive mechanistic models for grain vibration and allow for correlation in non-dimensional bed shear stress, turbulence, and sediment vibration.

Hypothesis 3: *Maximum amplitude of vibration for a given smart grains occurs immediately prior to entrainment.* Using the most pronounced signal (i.e. marker grains from hypothesis 1), the pattern of vibration will be tested for correlation between absolute magnitude of vibration and entrainment. The following results will allow for empirical models where incipient motion can be predicted as a function of absolute magnitude of vibration.

Field Application: Smart grains will be deployed in the field alongside passive tracer. Data will be collected for comparison of flume experiments and to test predictions of sediment transport as a function of vibration probability.

Broader Impacts

If hypothesis 3 remains viable and correlations of vibrations and entrainment are robust, then the smart grain sensor can be further developed to create warning systems in riprap structures and other erosional control designs. The sensors could be set to trigger an alarm once an excessive amount of vibration is reached.

Select smart grains will be developed so that real time data can be transferred to a computer or smart phone through Bluetooth. Subsequently education outreach will focus on using smart grains to create real time exercises where students can instantaneously download and analyze data from their experiments. These activities will be developed in conjunction with lesson plans focused on using Google Earth and stream tables to understand fluvial processes (see personal statement).

Conclusion

The research proposed here provides a unique and viable way to measure sediment vibration and its role in fluvial processes. In addition this project takes advantage of recent advances in technology and potentially provides benefits for erosion control, flood hazards, and education outreach.

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