Dr. Paul Kelso Sabbatical Application for 2022-2023

How does the Earth work? Developing 3D geophysical models of the early Earth. Science education research and application: scientific uncertainty, digital field data and 3D modeling

Abstract

After decades of geoscience research, fundamental questions remain about the early Earth. These include understanding the timing of the origin of plate tectonics and determining the processes that created and modified the earliest continents. My sabbatical research will involve 3D data collection, processing and modelling of gravity and magnetic data collected in the best exposed example of preserved early Earth crust, the Pilbara region in northwest Australia. This will be the first detailed 3D study of early Earth tectonic plates anywhere in the world.

My sabbatical will impact LSSU students through: 1) field work in Australia; 2) field and laboratory based senior projects; 3) incorporation of 3D modeling techniques into class projects; 4) use of sabbatical data sets in course activities; 5) improving student understanding of scientific uncertainty and its impact on interpretation and communication of results; and 6) improving students' collection of complex geologic field data digitally.

Introduction

Cutting edge research

The proposed research addresses fundamental questions related to early Earth processes and how/why plate tectonics began. Answering these questions requires acquisition of high-resolution 3D data and detailed 3D modeling of this data. **Never before have I had the opportunity to be involved in a research project that has the potential to have such a significate international impact on our understanding of Earth processes.** Also, my collaborations related to geoscience education through teaching scientific uncertainty and collecting complex, digital field data will impact the teaching and learning of students at LSSU and potentially many other institutions.

Unique opportunity

I have been invited by Dr. Basil Tikoff, University of Wisconsin-Madison, to participate in a 3D field and laboratory gravity and magnetic study of the crustal structure of the Pilbara region of northwest Australia (Figure 1) and to participate with his geoscience education research (see attached letter in supporting documents). The Pilbara region of Australia is recognized as having the best preserved and best exposed example of early Earth crust. Thus, the Pilbara is the best place in the world to answer essential questions about early Earth tectonic processes and how these processes have evolved with time to create the world we inhabit today.

Timing Synergy

Dr. Tikoff currently has funding from the National Science Foundation to help support the expenses of field work in Australia during summer/fall 2022, including supporting most of the costs of my field expenses and those of one or more LSSU students. The acquisition of field data and sample collection will take place in summer/fall 2022. Conducting field work in the outback of Australia is expensive; the funding available specifically for the summer/fall 2022 makes it imperative that this field work and associated laboratory work, data processing and modeling occurs during the 2022-2023 academic year. My participation in this project, and the opportunities and benefits to LSSU students described below, is contingent on my being awarded a sabbatical for the 2022-2023 academic year.

There are several other complementary ongoing and recently completed geologic, geophysical and geochemical studies of the Pilbara. My sabbatical project will involve collaboration with some of these researchers and the incorporation of their results into my work in order to develop models of the formation of early Earth continents and understanding the associated tectonic processes. Through my work collecting 3D data of the subsurface of early Earth crust and development of 3D models incorporating the results of recent complementary research in the Pilbara we will for the first time have the data and constraints necessary to significantly improve our understanding of early Earth processes.

Dr. Tikoff has also invited me to be a part of two currently funded National Science Foundation projects related to geoscience education. The first is a project related to teaching and learning about scientific uncertainty. This is a challenge for many scientists and science professors because of the difficulty of relaying our understanding of uncertainty to students and to the public. Secondly, I was invited to be part of a project related to teaching undergraduates how to collect complex, digital field data using a newly developed geoscience application named StaboSpot.

Background

The genesis of Earth's earliest continents is one of the most fundamental questions in Earth Sciences, and is inextricably linked to the transition from pre-plate tectonic early Earth processes to the initiation of plate tectonics. The critical need for a better understanding of the early Earth has been articulated by multiple geoscience community-based documents in the last decade (e.g., Huntington & Klepeis, 2018; National Academy of Sciences, Engineering, and Medicine, 2020; National Science Foundation Advisory Committee for Geosciences, 2014). Thus, understanding the early Earth crust and early Earth processes is recognized by the geoscience community as one of the most import outstanding problems in the geosciences. The surface geology of the iconic Australia Pilbara region and other Archean cratons have been studied for decades, but multiple interpretations still exist for its 3D geologic structures. What is needed is a "game changer" and what is notably sparse is crustal-scale, high-resolution 3D geophysical studies of the subsurface for well-preserved, early Earth crust.

My proposed sabbatical research involves collecting 3D gravity data, and magnetic samples and data, and developing 3D models of the crust of the East Pilbara of west Australia (Figure 1). The East Pilbara is recognized as the best preserved and best exposed example of early Earth crust anywhere in the world. The proposed geophysical gravity and magnetic investigations will provide critical, crustal-scale evidence to evaluate both vertical gravity-driven tectonics within the crust and horizontal plate-like tectonics in the early Archean. This study has global implications for our understanding of the early Earth and the formation of continental crust. It will provide the most detailed 3D models of early Earth crust and associated tectonic processes anywhere in the world. This study will help us to resolve whether vertical or horizontal style of deformation contributed to stabilization and preservation of the first continents.

There are ongoing and recent geochemical and structural studies of the Pilbara region at the University of Wisconsin-Madison and Washington State University. My sabbatical work will involve collaboration with this research. The result will provide critical constraints related to formation of the Earth's earliest continental crust. Structural studies of the deformation this crust experienced during early Earth processes shortly after its formation will be delineated from other processes. These related studies are being coordinated by Dr. Basil Tikoff, University of Wisconsin-Madison and Dr. Jeff Vervoort, Washington State University. Dr. Tikoff and I will be working together in the field in Australia and in the laboratory at the University of Wisconsin (see attached supporting letter). Dr. Vervoort, Dr. Tikoff and I have successfully collaborated previously on a National Science Foundation funded project studying the formation and evolution of the western margin of North America with a focus on the Idaho-Oregon region (e.g., Byerly et al., 2013; Tikoff et al., 2017; Tikoff et al., 2021). We look forward to collaborating on this new study of early Earth processes.

Outcomes

Overview of Outcomes

My proposed sabbatical work will address all three of the desired sabbatical outcomes described in the LSSU faculty contract. I provide details of my proposed sabbatical activities below but to summarize:

i. *The strength of the relationship between the sabbatical leave proposal involving applied or theoretical research related to professional activities and the advancement of knowledge within disciplinary areas.*

The primary focus of my sabbatical is applied research related to understanding of the tectonic processes of the early Earth through the first integrated 3D study of the Pilbara region in northwest Australia, the best-preserved example of early Earth crust in the world (Figure 1). The results of this project have the potential to transform our basic understanding of Earth processes, the evolution of Earth and the development of plate tectonic processes. The results of this collaborative project have the potential to have the greatest impact on geoscience community of any project I have worked on in my career.

ii. *The strength of the relationship between the sabbatical leave proposal involving an external, professionally-related experience/study in a business, industrial, health care, scientific or educational setting and the improvement of instructional/professional activities at the University.*

This sabbatical project involves my collaboration with researchers and educators at both the University of Wisconsin-Madison and University of Minnesota-Twin Cities. I will work directly with a number of faculty experts collecting data in the field in Australia and collecting magnetic and gravity related data and developing 3D geophysical models at the UW-Madison and UMN-Twin Cities. Additionally we will collaboratively investigate new ways to teach geoscience to undergraduate students. The results, techniques and expertise I develop through this project will include new data sets and new skills which I can incorporate into class and laboratory activities and share with LSSU students.

iii. *The strength of the relationship between the sabbatical leave proposal involving travel or advanced study and its yield in improving the quality of instruction at the University.*

My sabbatical includes travel nearly every month to Australia for over a month of field work, to the UMN-Twin Cities to collect magnetic data and to collaborate with magnetic experts, and to UW-Madison to conduct 3D geophysical modeling, collect data in the laboratory and collaborate on geoscience education projects related to scientific uncertainty and collecting digital geoscience field data (see included timeline). Additionally, I will attend an international geoscience conference with the objective of presenting pertinent research results. This extensive travel to collect field data and samples, to conduct laboratory studies, to undertake 3D modeling, to participate in geoscience education research and to collaborate with faculty at Big Ten institutions will only be possible through the opportunities a sabbatical provides. These sabbatical activities will have a direct impact on my teaching and improve the educational experience for LSSU students.

Proposed work

Australian field work

Field work will be undertaken in the Pilbara region of Northwest Australia (Figure 1) to collect 3D gravity data, samples, magnetic and geologic data to develop 3D models of the best-preserved early Earth crust. My PhD field area was in central Australia. I have worked extensively in Australia over the years (e.g., Kelso et al., 1993, 2007; Waters-Tormey, et al., 2000; 2003, 2009, 2012, 2017; White et al., 2007) but I have not previously worked in the Pilbara region.

In part because of my previous geophysical field work in Australia, Dr. Tikoff has invited me to be help lead the field team collect samples and geophysical data from late July through early September, 2022. If I am able to participate in this project as part of my sabbatical it is likely that one or more LSSU geology students will also have the opportunity to be part of the field team collecting data and samples in Australia. LSSU students will return in time for the beginning of classes while I will remain in Australia to complete the field work in the fall. Some of the data and samples collected in Australia will likely form the basis of LSSU students senior projects.

Field work will focus on collecting 3D gravity data and associated samples and geologic and magnetic data. This detailed geophysical work requires collecting data with a highly sensitive gravimeter and high-resolution GPS (sub-centimeter Global Positioning System elevation data). We will be working with $100,000's worth of equipment while in Australia. The University of Wisconsin-Madison will provide the necessary field equipment free of charge. Dr. Tikoff will also provide training on the proper use and maintenance of UW-Madison equipment. Myself, Dr. Tikoff and students from LSSU and UW-Madison will work together as a team to collect data and samples.

My previous experience conducting geophysical studies in the Australian outback (e.g., Kelso et al., 1993, 2007; Waters-Tormey, et al., 2017) provides the background to help me lead this project with Dr. Tikoff. We typically work 6 days a week while in the field in Australia to maximize data collection during the field season. The 7th day we go to town to get supplies, groceries, maintain/repair equipment, etc. Port Headland is the closest town of any size to the study area where we can resupply.

Laboratory work

Sample preparation and initial laboratory measurements will occur during fall 2022 with follow-up detailed sample analysis during winter/spring 2023. Data processing will occur in fall 2022. After completion of data processing and initial sample analysis, detailed 3D modeling of gravity and magnetic data will occur during the winter/spring 2023. See timeline below for a more detailed and complete schedule of work planned.

Developing 3D models of the early Earth crust through magnetic and gravity modeling requires characterizing the geophysical properties of the Pilbara rock and minerals. I have been invited by Dr. Bruce Moskowitz, Director of the Institute for Rock Magnetism (IRM) at the University of Minnesota, to be a visiting scholar at the IRM (see letter in supporting documents). The IRM is a National Science Foundation supported multiuser facility which houses the largest array of equipment in North America for the collection of magnetic data on rock samples.

I plan to visit the IRM during both fall and spring semester to collect data to characterize the magnetic properties of the Pilbara rocks. The IRM rock magnetic data will provide critical constraints for the 3D magnetic modeling of the Pilbara region. As Dr. Moskowitz states in his supporting documents letter, I will have access to the array of magnetic equipment available at the IRM free of charge and they will provide an office for me during my stay there. I will work with magnetic experts at the IRM on the measurement and interpretation of the data collected. These results will provide some of the inputs need for the 3D magnetic modeling and for interpreting the modeling results.

LSSU has a geomagnetic lab where I and LSSU students will make initial magnetic measurements of samples. The magnetic measurements made at LSSU will provide a preliminary understanding of the rock's magnetic properties and will be used to select samples for more detailed magnetic analysis at the IRM, described above.

Characterization of the gravity, chemical and mineralogical properties of the Pilbara rock samples will be undertaken at the University of Wisconsin-Madison. As noted in Dr. Tikoff's supporting document letter, I will have access free of charge to UW-Madison facilities for gravity, structural, microscopy and petrologic mineral analysis and an office workspace during my visits to the UW-Madison. While at UW-Madison I will collaborate with faculty and students on data collection, processing, modeling and interpretation. The results of this work will provide critical constraints for our understanding of the 3D structure of the early Earth crust.

3D Modeling work

The primary goal of my sabbatical research is to develop 3D models of the early Earth crust in the Pilbara region. Constructing accurate 3D models of the Earth's early crust is a challenging and time-consuming task but worth the effort. Together with Dr. Tikoff's assistance and guidance, I will be developing three sets of 3D models. One 3D model will be a 3D gravity model. Further, a 3D magnetic model will be developed using the magnetic data collected at the IRM at the UMN-Twin Cities, in the LSSU magnetics lab and provided by Australian government data. I will use these data sets, in collaboration with Dr. Moskowitz and other IRM staff, to develop constraints on the magnetic models. Finally, the results of the 3D gravity modeling and 3D magnetic modeling will be integrated with field geologic data, Pilbara rock geochemical data, and other geophysical data from the region to create a 3D model of the early Earth crust in the Pilbara.

As noted in the background section and Dr. Tikoff's support letter, understanding the 3D structure and processes of the early Earth have been recognized by the geoscience community as one of the most significant outstanding problem in geoscience. Thus, this research is not just challenging and of regional interest. The results are of great interest and importance to the national and global geoscientific communities.

Instructional strategies collaboration

Improving undergraduate science education is, and has always been, the primary objective of my career path. My emphasis on teaching and mentoring undergraduates has been recognized by my being selected as the LSSU Distinguished Teacher of the Year (2018) and by my being selected as the Michigan Association of State Universities Distinguished Professor of the Year (2011).

My sabbatical will include a number of activities that will improve LSSU students educational experience in the classroom, in the laboratory and in their field experiences. These activities will

include my collaboration with Dr. Tikoff and the interdisciplinary, multi-institutional team he is working with as part of National Science Foundation funded projects to improve teach/learning/technology. As noted in Dr. Tikoff's letter in the supporting document section he has specifically invited me to be part of this education-related research as part of my sabbatical. His geoscience education research has two components in which I will participate directly: developing methods to help students understand scientific uncertainty and developing methods to digitally collect geologic field data.

Dr. Tikoff and his interdisciplinary team plan to incorporate my previous successful experiences teaching undergraduates and conducting geoscience education research (e.g., Brown et al., 2001; Kelso and Brown, 2004, 2008, 2009, 2015a, 2015b, 2018; and Kelso et al., 2000, 2001, 2012, 2014) with their research on how student learn about, understand and incorporate scientific uncertainty into their decision making and final interpretations. When working with scientific data there are nearly always uncertainties. Scientific data nearly always has inaccuracies, quantities which are unknown, and variables and relationships that are not completely understood. Yet, as scientists, we communicate our results and often make decisions knowing that there is some level of uncertainty in the data. I will collaborate with the team's cognitive scientists and science educators to develop activities and experiences to help undergraduates recognize different levels of uncertainties and to develop ways to incorporate their understanding about uncertainty into their data collection, decision making, and interpretation. This work will focus on undergraduate teaching and learning related to uncertainties in geoscience but has applications to all of the natural sciences.

Dr. Tikoff has further invited me to participate with his ongoing National Science Foundation funded project developing a mobile application, StraboSpot, to collect and record geoscience field data. The team has created and released the StaboSpot application, but currently it is primarily being used by researchers. They have asked me to collaborate with the team to help make Strabospot more useful for undergraduate students in their courses and student projects. It is exciting to have an opportunity to be part of developing this cutting-edge technology that will likely significantly change how geoscientists collect field data in the future.

Enhanced experiences for LSSU students

There are many ways that my sabbatical will enhance the educational experience of LSSU students in and out of the classroom. One obvious, direct result of my sabbatical is that one or more LSSU students will have the opportunity to conduct field work in the world-famous Pilbara region of Australia. While in the field in Australia they will work directly with me, Dr. Tikoff and students from the University of Wisconsin. Thus, they will be part of a team of faculty, undergraduate and graduate students collecting data that is of interest to the international geoscience community. LSSU students working as part of the Australian field team will collect samples and data which they will bring back to LSSU. These samples and data will likely form the basis of their senior research project. It is likely that additional LSSU students who are not part of the field team may use some of the samples and data from Australia to undertake measurements, analysis and interpretations as part of their senior research. These students will not only work with me, but they will also have the opportunity to work directly and indirectly with faculty and graduate students at University of Wisconsin and/or the University of Minnesota. LSSU students' independent research and results will be a component of the overall Pilbara research project and will be incorporated into the final project interpretation.

The enhanced 3D modeling experience I will gain from working with Dr. Tikoff and the team at UW-Madison will provide new and enhanced opportunities for LSSU students. The experience, expertise and data sets I develop as part of this sabbatical can be brought into the classroom and used as projects and examples to teach LSSU students 3D thinking and 3D modeling. Visualizing the Earth and approaching problems from a 3D perspective is not something that most students have experienced. However, these are important skills needed to address the complex problems of society related to the environment, energy, resources and land use. Thus, upon my return, my sabbatical research will impact the learning experiences of all my students.

Additionally, as described above, a component of my sabbatical will focus on undergraduate education related to scientific uncertainty and digital geoscience field data collection. This work will improve the knowledge and educational experience of LSSU students and science students at many other universities.

Summary/high impact results

I have been involved with many geologic research studies over the years but never have I been part of a study which has the potential to impact the understanding of the geologic community is such a profound way. The proposed study has the potential to fundamentally transform our understanding of how/why/when plate tectonics processes began on Earth. It is exciting to have the opportunity to participate is such cutting-edge research. As Dr. Tikoff noted in his supporting document letter, collecting and processing this geophysical data is time consuming. The only way I will have the necessary time and opportunity to participate in these studies is through a sabbatical during the entire 2022-2023 academic year. This is a large, complex geophysical study which will take part of summer 2022 plus the entire 2022-2023 academic year to complete. This amount of dedicated time is necessary in order to collect, process, model and interpret the data, and to synthesize my results with complementary studies. This project will result in the development of the first 3D model of the early Earth's crust constrained by 3D geophysical data.

As part of my sabbatical, I will develop new expertise in 3D modeling which I can share with students through course-related activities and projects and independent student research studies. Also, the collaborative, interdisciplinary geoscience education activities in which I will participate will provide new learning opportunities for LSSU students and students at other institutions. My work with the teams understanding scientific uncertainty and developing StraboSpot will provide LSSU students, and many others undergraduate geology students, new experiences to learn to collect digital field data and to incorporate scientific uncertainty as they synthesize scientific data to make improved interpretations and to communicate their results.

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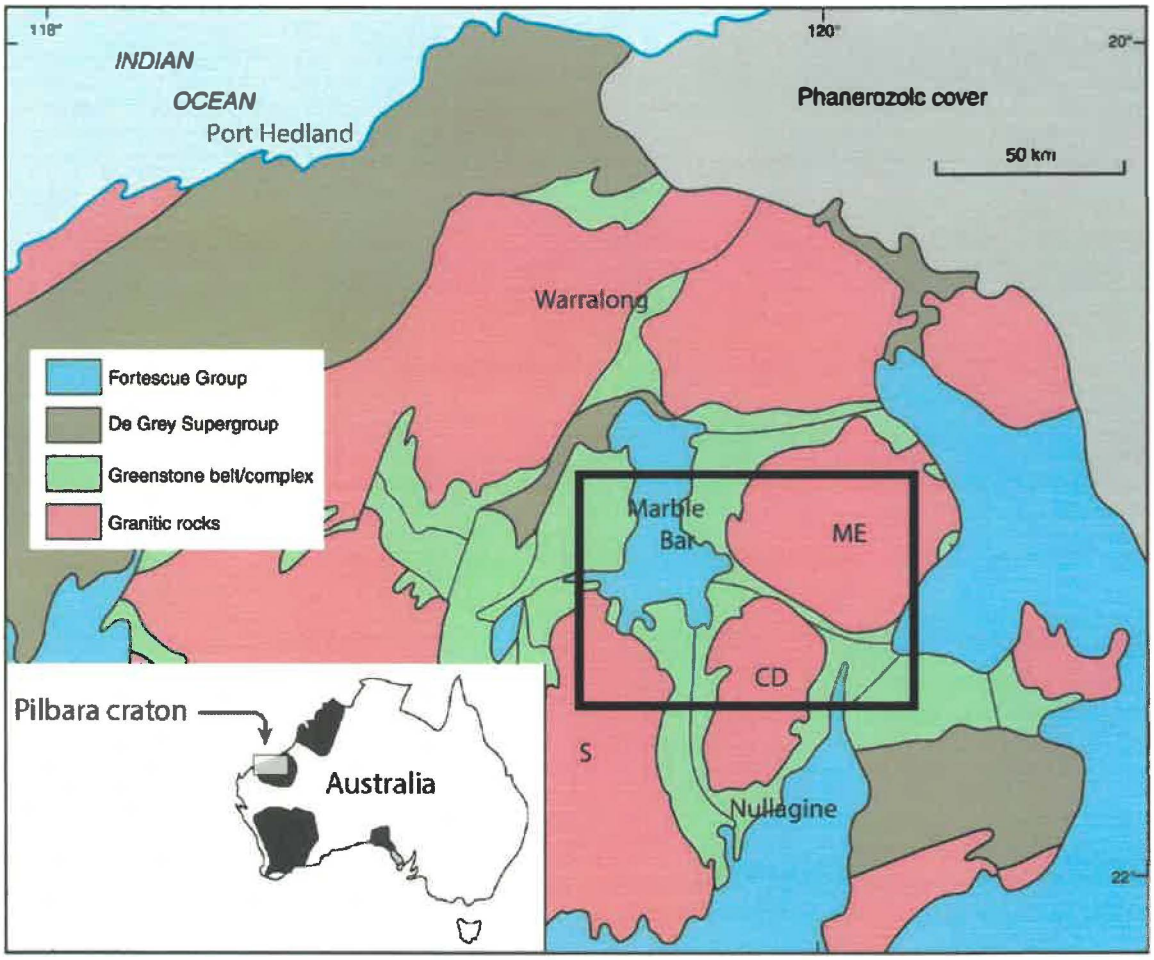

Figure 1. Generalized geologic map of the Pilbara study region in northwest Austraila (from Hickman, 2012). Black rectangle region is the focus area for the 3D geophysical studies. granitoid bodies: ME=Mt.Edgar; CD=Corunna Downs; S=Shaw

Timeline - Kelso Sabbatical 2022-2023

July-August-September 2022: Australia field work
- Collaborative: Kelso-LSSU student(s) – UW-Madison faculty and students
- Gravity data collection
- Sample collection for gravity and magnetic analysis
- Geologic field data collection

September 2022
- Complete Australian geophysical field work
- Initial data processing of Australia gravity data
- Initial data processing of Australia magnetic data
- Preliminary sample preparation and analysis at LSSU

October 2022
- Preliminary sample preparation and analysis at LSSU (continued)
- Select samples for detailed analysis at Institute for Rock Magnetism – Univ. of MN
- Complete preparation of Australian samples for detailed magnetic analysis - Univ of MN
- Visiting Scholar at Institute for Rock Magnetism (IRM) – Univ. of MN – Twin Cities
  - Magnetic data collection, characterization of magnetic mineralogy
  - Collaboration with IRM scientist on magnetic data collection and interpretation
- Data processing of Australia geophysical data (continued)

November 2022
- Visiting Scientist at UW-Madison
  - Data processing of gravity
  - Sample analysis at UW-Madison
  - Introduction to 3D Gravity Data modeling – UW-Madison
  - Discussion and characterization of challenges of teaching uncertainty and digital field skills to undergraduate students
- Analysis of magnetic data collected at Institute for Rock Magnetism

December 2022
- American Geophysical Union – Annual meeting, Chicago, IL
- Sample analysis at LSSU
- Preparation of data for 3D magnetic modeling

January 2023
- Sample analysis and data processing at LSSU
- Visiting Scientist at UW-Madison
  - 3D Gravity modeling
  - Sample analysis
  - Collaborate on ways of teaching uncertainty to science students
  - Develop familiarity with UW developed and other tools available to increasing undergraduates' competencies in collecting digital geology field data
- Initial magnetic data modeling

February 2023

- Visiting Scholar at Institute for Rock Magnetism (IRM) – Univ. of MN – Twin Cities
  - Detailed characterization of magnetic mineralogy
  - Collaboration with IRM scientists on magnetic data collection and interpretation
  - Develop constraints for magnetic modeling
    - based on data collected and collaboration with IRM scientists
- Magnetic data processing of data collected at LSSU and IRM
- 3D magnetic data modeling

March 2023

- Visiting Scientist at UW-Madison
  - 3D Gravity data modeling
  - Collaboration with UW geoscientists on
    - 3D gravity modeling constraints and interpretation
    - Teaching uncertainty to science students
    - Developing strategies to teach digital geology field data collection to undergraduates
- 3D magnetic data modeling integration with 3D gravity data modeling

April 2023

- Magnetic and gravity modeling interpretation
- Synthesis of 3D gravity and magnetic models with geochemical and structural data
- Develop 3D models of early Earth crust based on geophysical models and associated data

Summer 2023

- Write up results of sabbatical for LSSU
- Submit outcomes of sabbatical research for presentation at a geoscience conference
- Prepare presentations of sabbatical outcomes

Fall 2023

- Presentation of sabbatical outcomes to LSSU community
- Presentation of results from sabbatical at a geoscience conference
- Begin preparation of manuscript summarizing sabbatical research results