University of Minnesota / College of Science & Engineering
Department of Earth Sciences
2016 Strategic Plan

INTRODUCTION: The Earth Sciences are at the center of understanding how our dynamic planet works, from the core to the surface and from the nanoscale structure of Earth materials to planetary-scale dynamics. Earth scientists address problems fundamental to the habitability and sustainability of the planet, from the origin of life in "deep time" to the interaction of humans and the environment today. The Earth Sciences are central to understanding and solving the world's most difficult environmental issues involving global climate, the oceans, freshwater on the surface and underground, natural resources (including minerals and energy), land use, and natural disasters. Earth scientists will discover solutions to the planet's environmental problems by integrating geoscience knowledge with engineering and public policy.

The research of Earth scientists at the University of Minnesota advances knowledge in applied and basic research of Earth-systems. Societally relevant research topics include bioremediation of pollution; the dynamics of water in rivers, lakes, and groundwater systems; the history, causes and consequences of climate change; and feedbacks among Earth systems involving life, water, air, and minerals. We are also leaders in basic research topics such as the magnetic behavior of Earth materials, the evolution of Earth's surface, the composition and flow of the crust and mantle, and the linked processes of biogeochemical cycles in the oceans, atmosphere and land. Our research spans the processes that led to the formation of the planet and the forces that continue to shape our oceans and landmasses, as well as processes operating on human time scales at the local and regional levels and beyond.

Our research priorities are well aligned with the University of Minnesota's Grand Challenges Research Areas, including the aim of "Assuring Clean Water and Sustainable Ecosystems". Because global change – past, present, and future – is central to the Earth Sciences, we contribute to understanding interactions of humans and the environment, thereby helping build societal resilience in the face of natural disasters (such as earthquakes, floods) and changes in availability of resources (water, mineral, energy).

MISSION: The Department of Earth Sciences addresses vital societal problems from global to regional levels and conducts curiosity-driven basic science research that forms the foundation of 21st century discoveries and innovation in the Earth Sciences. Our research focus is integrated with our teaching and service activities, creating strengths in all of our core missions.

VISION: Through highly collaborative and interdisciplinary research, we will be global and regional leaders in Earth Science research and education, contributing to solutions of societal problems and fundamental questions involving Earth systems, and training a new generation of creative scientists.

Overview of the Department of Earth Sciences at the University of Minnesota

The Department of Earth Sciences is one component of the Newton Horace Winchell School of Earth Sciences, along with several research centers and the Minnesota Geological Survey (MGS). We have a longstanding tradition of collaborative science in research and teaching within the department, with other departments in the College of Science and Engineering (such as Civil, Environmental, & Geo-Engineering; Chemistry; Physics and Astronomy; Chemical Engineering & Materials Science) and across the University (School of Dentistry; Soil, Water, and Climate; Microbiology; Anthropology), and with colleagues across the country and the world.

In this spirit of collaboration, the School of Earth Sciences hosts three national facilities that are global hubs for researchers: Institute for Rock Magnetism (IRM), Limnological Research Center (LRC)/National Lacustrine Core Facility (LacCore)/Continental Scientific Drilling Coordination Office (CSDCO), and the Polar Geospatial Center (PGC). The Department is also deeply involved with other major centers in the College of Science and Engineering (St. Anthony Falls Laboratory (SAFL); National Center for Earth-surface Dynamics; Characterization Facility) and in the broader university (Minnesota Supercomputing Institute, Institute on the Environment).

Our research activities are global. We foster this trend by pursuing unconventional opportunities, such as joint grants (for example, NSF-DFG, NSF-NERC, and non-European agencies) and major research initiatives (Earth-Life Transitions, Continental Dynamics, EarthScope, Paleo Perspectives of Climate Change); most of these involve global collaboration. Our faculty are successful at securing funding from a diverse set of federal agencies (NSF, DOE, NIH, NASA) as well as from the state (LCCMR). In 2015, researchers in the Department of Earth Sciences (including the IRM, LacCore/CSDCO, and PGC)) brought in $7.2M in sponsored research funding to the University of Minnesota, in addition to other funding awarded through other affiliated centers (MGS, SAFL).

In August 2017, the Department and two of its research centers (IRM, LRC/LacCore/CSDCO) will move into the newly renovated Tate Hall. This will provide the opportunity for enhanced research and teaching in modern facilities.

<u>The Department, by the numbers:</u>

- 26 tenured or tenure-track faculty members: 22 conduct research and teach in the Earth Sciences, one is the Director of the Minnesota Geological Survey, one is a Professor in the History of Science and Technology Program; and one is the Dean of the College of Science and Engineering
    - 17 are Professors, three are Associate Professors, five are Assistant Professors; and one position is currently open (search in progress);
    - 10 are members of groups underrepresented in STEM fields.

- two Research Professors: one in the Institute for Rock Magnetism, one in the Limnological Research Center;
- one Teaching Professor;
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- ~35-40 research associates;
- ~55 graduate students (2/3 of whom are typically PhD students); and
- ~60 undergraduate majors (BS, BA).

The excellence of our faculty has been recognized at the early-career level through McKnight Land-Grant professorships (7), a Sloan Research Fellowship, NSF CAREER awards (3), and a Guillermo E. Borja Career Development Award (2016). At the senior level, our faculty have been awarded Distinguished McKnight University Professorships (3) and CSE Distinguished Professorships (2). Our faculty includes one Regents Professor and two of the College of Science and Engineering's current four members of the National Academy of Science.

Faculty have also received significant teaching awards, including the Morse-Alumni Distinguished Teaching Award for excellence in undergraduate education (3) and the Award for Outstanding Contributions to Graduate and Professional Education (2), and have participated in national initiatives to improve teaching and learning in the Earth Sciences. We successfully recruit graduate students from top programs in US and international institutions.

The Department of Earth Sciences at the University of Minnesota is globally recognized for the quality of our research and education programs. The strength of our research programs resulted in the University of Minnesota's achieving 11th place in the global ranking of Universities in the "Earth and Environmental Sciences" category in the latest *Nature* index.

STRATEGIC PRIORITIES

Our fundamental goal is to develop and sustain a vibrant intellectual community in Earth Sciences at the University of Minnesota. This encompasses two core elements:

(1) programs of undergraduate and graduate teaching and learning that emphasize rigorous application of basic and applied sciences to the Earth and prepare students for careers in different employment sectors: academia, private industry, non-profit organizations, and government;

(2) a strong program of research that competes at the highest levels nationally and internationally;

Both of these goals involve a broad spectrum of service to the public, the University, the state of Minnesota, and the national and international Earth Sciences research community.

This document presents our plan for accomplishing these goals in the next ~5 years.

Goal 1 : Undergraduate and graduate education / student career-development

Approximately 1/3 of our undergraduate majors pursue graduate study in the Earth Sciences and related fields, and most of our graduate students pursue academic careers. We prepare our students for graduate programs and research careers through rigorous coursework and by providing a broad range of opportunities to participate in frontier-level research. Our undergraduate three-course sequence in 'geodynamics' (solid-earth, fluid-earth, and earth-surface) and our multi-faceted field courses are innovative. We believe that these aspects of our program are extremely strong.

Our preparation of students for careers in Earth Sciences outside of research and academia needs improvement. This important issue lies at the intersection of teaching and service to the community. Although we provide a solid foundation of coursework for students pursuing any Earth Science related career, we nevertheless believe that this is an area where we can do better. Our plan for improvement includes the following:

1. Increase communication with the local geo-community; that is, with companies and agencies that hire, or could potentially hire, our students. We will accomplish this in part by establishing an Advisory Board that will visit the Department, interact with faculty and students, and provide suggestions on our student preparation for non-academic careers. The Board will consist primarily, but not exclusively, of Department alumni who work in the regional geoscience community (industry, government, education, non-profit).

2. Increase the number of students who participate in internships as part of their undergraduate or graduate studies. We will explore ways to integrate internship experiences with our curriculum, and we will encourage all students to participate in either a research experience or an internship.

3. Evaluate and improve applied sciences aspects of our undergraduate and MS programs, including the coursework-only (Plan C) MS program, the Environmental Geoscience minor, and courses that can include more practical experiences in labs and in the field.

We are considering whether we can best achieve this overall goal by hiring one or more contract faculty member(s) with experience in and connections with the regional geoscience community. Such a person's job activities could include (1) teaching or co-teaching classes with an applied component; (2) helping students prepare for an exam that is part of the State's process of certification for Professional Geologist; (3) overseeing our professional MS program

(Plan C Master's); and (4) connecting students to internships and integrating their experiences with their academic studies.

Providing an excellent introduction to the Earth Sciences to non-majors is also an important priority for our Department. We plan to revise and expand our course offerings for non-majors and for Earth Sciences minors so as to maximize the number of students who learn about important issues and concepts related to Earth and Environmental Sciences.

Goal 2 : Research (hiring plan)

Context: The Department of Earth Sciences has done well in recent years by combining energetic pursuit of outstanding hires in priority hiring areas with the flexibility to recognize and take advantage of unexpected and/or new opportunities (such as a new hire in geobiology via the MnDRIVE initiative). In the last three years, five new faculty members joined the Department, strengthening our research programs in geodynamics, geobiology, hydrogeology, seismology, and surface processes. In 2016-17, we are conducting a search for a Gibson Professor of Hydrogeology. In the next 3-5 years, we anticipate losing at least two faculty members through retirement, primarily in solid-earth geoscience fields.

As part of our strategic planning process, we have considered questions of frontier areas of Earth Science research, the importance of continuing strengths in established research areas, and the impact of future hires on our education mission. We recognize the synergy between research and teaching and are committed to continuing to build and foster a diverse faculty.

In the following sections, we present areas in which we see great potential for novel research and effective teaching/advising, and which therefore represent priority areas for future hires, informed by factors including our ideas for critical new directions, existing strengths, areas where our location and/or facilities give us a natural advantage, the University's strategic priorities, and opportunities for collaboration with other parts of CSE and the University.

The following five general areas have enormous potential as fields of enquiry in the Earth Sciences and represent priority fields for future hires. These areas build strength in critical areas of research and education and will allow us to recruit and retain scientists working on major questions in basic and applied Earth Sciences. There are many commonalities among the fields described.

The different fields described in the following sections are **not ranked by priority**. When we have the opportunity for searches in the future, we will revisit this plan. Key topics for future discussion will include maintaining strength in current areas of research excellence and expanding into new fields.

GEOCHEMISTRY OF THE EARTH'S SURFACE AND NEAR-SURFACE ENVIRONMENTS

Geochemists determine and explain the causes of environmental changes over the >4 billion years of Earth history and extending into the future. We propose to hire one or more geochemists who employ new and emerging methodologies and approaches to study environments at and near the Earth's surface. Topics of interest include climate change, the critical zone*, the atmosphere, the oceans, ice sheets, life history, environmental history, and organisms that affect the surface environment. Strategic hires in this broad field will place Minnesota in an excellent position to take advantage of rapidly expanding areas of research, including:

Geochronology. Major advances in the Earth sciences depend on our ability to date Earth materials precisely and accurately. This includes advances in the dating of surfaces (exposure dating) and paleosurfaces (low-T thermochronology), and in dating high-T processes using uranium-lead and argon-argon dating, among other isotopic systems.

Clumped Isotope Geochemistry. This relatively new area in isotope geochemistry has already made significant contributions to the Earth Sciences, with the potential for expansion. For example, oxygen isotope clumped thermometry of carbonates addresses questions regarding the temperature and oxygen isotopic composition of the oceans and lakes at key times in Earth history, as well as questions as to whether or not animals are endothermic or ectothermic. Clumped isotope thermometry of gases (e.g. methane) can answer questions about their formation temperature.

Aqueous Geochemistry: mineral surfaces and kinetics. The reactions that occur at the mineral–water interface are central to most geochemical processes. Examples include weathering and soil formation, nutrient availability, biomineralization, acid mine drainage, the fate of contaminants, and minor element incorporation and partitioning during mineral growth. These processes, and their rates, are ultimately controlled by reactions that occur at mineral surfaces. Through the development of advanced analytical methods, direct observations of mineral reactions at the nano-scale have enabled exciting new possibilities for determining the rate and mechanism of mineral dissolution and precipitation, with implications for the chemical evolution of natural fluids.

Non-traditional metal isotope geochemistry, including both mass-dependent and mass independent processes. Recent advances in analytical geochemistry and mass spectrometry have allowed determination of stable isotope variations of trace sulfur species (^{33}S, ^{36}S) and metallic elements (e.g., Fe, Cr, Mo, Hg). Biologically influenced and truly inorganic isotope fractionation processes have been experimentally and theoretically confirmed and used to reconstruct how the oxygenation of the Earth's surface environment has changed through time and has affected the evolution of life on our planet.

Organic Geochemistry. Organic compounds play an integral role in the geochemical cycling of nutrients and elements as well as in the formation, evolution, and sustenance of life.

Signatures of life and environmental change are preserved in these compounds, in the rock and fossil record (such as mass extinctions), in the atmosphere, and in marine and lacustrine sediments. Analyses of these organic compounds and related geological and chemical signatures (e.g., stable isotope) can give insight into the biological, abiotic, and anthropogenic processes that have and continue to shape our planet and beyond.

Paleoceanography and Chemical Oceanography. The oceans have an outsized role in the evolution of climate and in elemental cycles. Geochemical proxies of nutrient cycling, deep ocean chemistry, and ocean circulation are central to chemical oceanography. In paleoceanography, the same proxies are applied to marine sediments to understand the history of the oceans and climate; many of these are also applicable to lake sediments.

Summary and goals

Strategic hires in this broad field will place Minnesota in an excellent position to take advantage of rapidly expanding areas of research. When combined with our existing strengths in other aspects of isotope geochemistry, aqueous geochemistry, geochronology, and geobiology, one or more hires in these sub-disciplines would strengthen Minnesota as an international center of excellence in geochemistry. Many of the subdisciplines of interest would also strongly support our research and teaching missions as a department of Earth and Environmental Sciences.

*The Earth's **critical zone** is the "heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources" (National Research Council, 2001, Basic research opportunities in Earth science: Washington, D.C., National Academies Press, 153 p.)

EARTH-SURFACE RESPONSE TO GLOBAL CHANGE

The University of Minnesota is an international leader in studying the Earth's surface. The one-of-a-kind St. Anthony Falls Laboratory draws researchers across the world to study fluid dynamics, geomorphology, sedimentary geology, hydrologic sciences, and ecology – all centered around water and the forces that shape Earth's surface environment. The Polar Geospatial Center, based in the N.H. Winchell School of Earth Sciences, is improving Earth-observation data access in some of the most remote and rapidly changing parts of the world. The National Center for Earth-Surface dynamics has nucleated a community of scientists that looks to Minnesota as a worldwide leader. At this time of critical global change, our department is strategically positioned to leverage and expand upon the resources and prestige of these facilities to be a world leader in understanding impacts to the Earth's surface.

Building on the success of the NSF-sponsored National Center for Earth-surface Dynamics, we propose the University of Minnesota as the ideal place to build strength in surface response to global change, including climate and land-use change. Increased water consumption, declining snowpack, more extreme precipitation events, an intensified hydrologic cycle, and human modification of the landscape have strongly affected Earth's surface morphology and water resources and will continue to do so into the future. We propose an interdisciplinary team of hydrologists, cryospheric scientists, geomorphologists, geochemists, ecologists, sedimentologists, and climate scientists to lead this effort, including those in the Department of Earth Sciences and collaborators from across the University of Minnesota.

New hires to complement existing strengths and support this effort could include leading experts such as:

- **Glaciologists** or **cryospheric scientists**;
- **Geochemists** applying novel techniques to understand past, and future environments (see previous section);
- **Physical hydrologists** interested in the evolution of coupled geomorphic–hydrologic systems;
- **Process-based climatologists** focused on the interface between the atmosphere and hydrologic and Earth-surface processes.

Summary and goals

Many of these hiring options have the potential for synergy in other subfields of the Earth sciences, with the Earth's surface and global change as the focus. As a cross-cutting discipline, Earth-surface processes has the potential to link areas of strength across the department. This possible future hiring direction will be further refined pending the results of the ongoing search for a Gibson Professor of Hydrogeology and possible future hires (e.g., in geochemistry and/or tectonics).

Expansion of the department into global change and its impact on the surface environment will open opportunities to apply our rigorous Earth Science research to some of the most pressing questions of the 21st century. These include water scarcity, water quality, melting permafrost, global biogeochemical cycling, flood hazard, erosion, sea-level, climate change, river delta stability, global food supply, and energy resources. Each of these issues includes connections to existing faculty research, and all would benefit from a new hire that integrates existing intellectual capacity into a functional network of knowledge to aggressively tackle pressing global problems.

Hiring in a field related to the surface response to global change is well aligned with several of the University's Grand Challenges, with the mission of the Institute on the Environment, and with ongoing research in other units of the University (e.g. the Department of Soil, Water, and Climate). We would be interested in pursuing options for a cluster hire with another department to increase the impact of global change research and education.

MINERAL & ROCK PHYSICS

Mineral and rock physics is a highly interdisciplinary field that focuses on observational, experimental, and theoretical investigations of the physical and chemical properties of geological materials and their bearing on understanding the state, evolution, and dynamics of the surfaces and interiors of Earth and other planets. It provides fundamental information necessary to interpret geological and geophysical observations and pose models in tectonics and geodynamics; it thereby provides crucial constraints into the workings of plate tectonics, mantle convection, the geodynamo, and related large-scale phenomena. It is also directly relevant to understanding surface processes and environmental geochemistry.

Research in mineral and rocks physics emphasizes studies of macroscopic behavior in terms of microscale properties, requiring observations over a range of scales. It provides experimental observations and theoretical models that bridge from laboratory observations to processes occurring over geological time and length scales. Mineral and rock physics – particularly experimental mineral and rock physics – is a relatively small field, yet it provides data and paradigms that are critical to understanding a broad range of observations in geophysics, tectonics, and other fields.

Summary and goals

Because the University of Minnesota has an exceptional research reputation in mineral and rock physics and because it is the site of premier experimental facilities, we are poised to take extraordinary advantage of these conditions by further fostering and developing this singular strength. It is an ideal area for continued excellence in our Department's otherwise small program in solid-earth geophysics.

A faculty member hired into this position would meet a critical need in our undergraduate and graduate curricula, which require the expertise of solid-earth geophysicists. For example, core classes in Solid-Earth Geodynamics and Fluid-Earth Geodynamics, as well as elective courses in geophysics, are taught by a small group of faculty.

In particular, the Mineral and Rock Physics class (ESCI 5203) at UMN has been a fundamental contribution to training of solid Earth graduate and undergraduate students. This class, developed by David Kohlstedt, was among the first of its kind taught at any US university, and numerous similar courses around the country are now taught using syllabi and lecture notes developed by Kohlstedt. Continued offering of this class or its updated equivalent will help maintain UMN as a premier institution for training of solid earth geophysicists. In our department, this field has served as a major point of connection with materials scientists at the University and the private sector, so maintaining a strength in this field has a positive impact beyond the Department of Earth Sciences.

PLANETARY SCIENCE

Planetary science is a large and diverse area of study with strong connections to fields that are also of interest in Earth sciences, including tectonics, geomagnetism, rock and mineral physics, high- and low- temperature geochemistry, sedimentology, geomorphology, cryosphere studies, climatology, atmospheric sciences, and geobiology. Hiring in planetary science would expand our Department's research into fields and topics that have many unanswered questions and that generate substantial public and student interest. Unexpected discoveries in recent missions to Mercury, Pluto, and the moons of Saturn highlight scientific opportunities and public excitement of exploration studies.

In many cases, comparative studies of Earth and planetary examples allow insight into problems of great interest. Three important examples include the differences in tectonic styles between the Earth, Venus and Mars; the distinct histories of climate and habitability between Earth and Mars; and the possible origin of life in diverse planetary environments, including on ancient Mars or associated with seafloor hydrothermal systems in the ice-covered oceans of Europa. Further, many planetary processes have important influence on Earth sciences. Examples of these include

- the role of accretion, giant impacts, core formation, the geomagnetic field, and the formation of the Moon on Earth's early geochemical and geophysical evolutions;

- the influence of smaller impacts on more recent catastrophic events such as mass extinctions; and

- the importance in variations in orbital parameters to climatic variations in the Quaternary and before.

Summary and goals

Increasing departmental research activities in planetary science would be an opportunity to enhance connections with the astronomers with whom we will co-reside in Tate Hall. Following the great success of the Kepler mission and consequent plans for numerous satellite and terrestrial-telescope initiatives, exoplanet studies are now a large component of astronomical sciences, comprising ~1/3 of the sessions in recent American Astronomical Society meetings. Studies of exoplanets require new collaborations between astronomers and planetary scientists, and present considerable opportunities for cross-disciplinary research. This field is therefore a natural connection between our department and our new astronomy neighbors in John T. Tate Hall.

Another opportunity exists for closer connection to the University's Bell Museum of Natural History. This opportunity would center on specimen-based study and take advantage of the fact that the University of Minnesota has a large collection of meteorites (140) on long-term loan to the Smithsonian Institution. We are interested in exploring the possibility of a joint hire that involved physics/astronomy, the Bell Museum, and Earth Sciences.

There is at present a dearth of planetary science taught in the UMN curriculum. One course, ESCI 3006 (Planets of the Solar System) is the only course in any department that specifically focuses on planetary science. Although originally intended for non-science majors, it attracts a student base that ranges from interested students without a science background to earth science and astrophysics majors. There is a clear need to expand our offerings to include both a service course that takes advantage of the wide interest in planetary science among non-specialists and that helps train future earth and astronomical scientists in the fundamentals of planetary science.

LITHOSPHERE, LANDSCAPES, AND LIFE (TECTONICS)

Tectonics is inherently broad, ranging from field-based geological research to geodynamic modeling, so there are many opportunities for collaborative, interdisciplinary research. Two frontier research areas that complement other components of the hiring plan in this document are:

Formation and evolution of continents on planetary timescales (billions of years). Continental growth and evolution can be interrogated by many aspects of the Earth sciences, including geochemistry, petrology, sedimentology, structural geology, geochronology, and geophysics (seismology, paleomagnetism), and can be linked to fundamental questions about the origin of plate tectonics, the dynamics of the Earth's interior (core formation, deep mantle processes), and the co-evolution of the lithosphere/hydrosphere/ atmosphere.

Tectonics, landscape dynamics, and biodiversity. The forces of plate tectonics constantly modify the landscape. Mountains rise, hydrographic networks and climate zones are modified, and ecological gradients develop; in some cases mountain regions become hot spots for biodiversity. Advances in molecular phylogenetic analyses, cutting-edge monitoring of Earth surface processes, and a growing interest in combining geology and biology are opening new research avenues for understanding how tectonic phenomena interact with climate evolution and biological diversification. A new faculty member in this general area would study active/recent processes and would also have an opportunity to decipher the geologic record in which evidence of paleo-elevation and paleo-landscape in relation to tectonic forcing is preserved. This individual would benefit from the growing strength in our Department in Earth surface dynamics and paleobiological/ molecular geobiological research.

Summary and goals

The Earth's tectonic system affects many aspects of life as a result of its role in the geochemical and geophysical evolution of the planet over long time scales as well as a driver of natural hazards on a human time scale. It is therefore an essential component of Earth and Environmental Sciences research, teaching, and outreach.

Hiring in the broad field of tectonics is essential for maintaining our strong component of field-based education and research as a basis for training undergraduate and graduate students and for solving fundamental geoscience questions and societal challenges. Therefore, given the current faculty configuration of the Department, a scientist with strong interests in field-based tectonics (broadly defined) would best fulfill our education mission (which includes required field courses for undergraduates), complement existing research, and explore novel aspects of tectonic systems. In particular, integration of field and analytical expertise (such as in geochronology or other analytical technique) would meet a significant need in our department, with anticipated positive impacts for graduate training and faculty collaboration.

SUMMARY

Our strategic priorities are aimed at distinction in education, research, and service at local to global levels. We will enhance our teaching program by improving opportunities for student research and internships, including developing new ways to provide career-development opportunities for undergraduate and graduate students, and we will pursue an ambitious plan of excellence in frontier areas of Earth Science research – some of which are current fields of strength and some of which represent new directions for our Department.

We are a small, excellent department within the College of Science and Engineering at the University of Minnesota. This strategic plan presents our priorities for developing strengths while being alert to new opportunities for collaboration and cooperation in research and education. Implementation of this plan will further our aim of being leaders in the broad, interdisciplinary field of Earth Sciences in both basic and applied research, innovating in education of undergraduate and graduate students, helping solve some of the world's most pressing environmental problems, and answering first-order questions about the origin and evolution of the planet.