Environment and Natural Resources Trust Fund
2018 Request for Proposals (RFP)

Project Title: **ENRTF ID: 071-B**

Sulfide Mineral-Eating Microbes to Improve Water Quality

Category: B. Water Resources

Total Project Budget: $ 339,667

Proposed Project Time Period for the Funding Requested: 3 years, July 2018 to June 2021

Summary:

Naturally occurring microorganisms break down sulfide minerals from Minnesota's copper-nickel deposits. If we can understand this process, we can use microorganisms to improve management of mine waste and water.

Name: Daniel Jones

Sponsoring Organization: U of MN

Address: 310 Pillsbury Drive SE
Minneapolis MN 55455-0231

Telephone Number: (651) 245-2775

Email dsjones@umn.edu

Web Address

Location

Region: Northeast

County Name: Statewide

City / Township:

Alternate Text for Visual:

In Minnesota's copper-nickel deposits, the valuable metals are bound to sulfur in a class of minerals called sulfide minerals. Certain naturally occurring microorganisms break down sulfide minerals to gather the energy necessary for life. This process releases metals and acid, which can degrade water quality. If we can understand how and why these microbes "eat" sulfide minerals from Minnesota's copper-nickel deposits, we can use this knowledge to speed up or slow down sulfide mineral oxidation and improve management of waste rock and water from future mines in the state.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Sulfide mineral-eating microbes to improve water quality

I. PROJECT STATEMENT

Naturally occurring microorganisms break down sulfide minerals in rocks from Minnesota's copper-nickel deposits. If we can understand this process, we can use microorganisms to speed up or slow down sulfide mineral oxidation and improve management of waste rock and water from future mines in the state.

Background

Microorganisms are important for mining. Approximately 15% of the world's copper is extracted by "biomining," a process in which microbes are used to break down minerals and release copper. Microbes are also widely used for the remediation and management of contaminated mine water and waste rock. **But because rocks from Minnesota's copper-nickel deposits are unique, most of these advances in the microbiological treatment of ores and mine waste cannot yet be applied to these economically important mineral deposits.**

- In Minnesota's copper-nickel deposits, the valuable metals occur in minerals called sulfide minerals. When sulfide minerals break down, they release metals, sulfate, and acid, which can degrade local water quality if not properly managed.
- Certain microorganisms naturally live off the chemical energy in sulfide minerals. By "eating" the minerals, those microbes can speed up sulfide mineral breakdown.
- But, we don't know if this is the case for rocks from Minnesota's copper-nickel deposits. Because of specific characteristics of these rocks (moderately acidic leaching, certain sulfide minerals), we don't know which microbes are important for Minnesota's copper-nickel deposits or how they behave.
- If we can understand which microbes are important and why, we could either prevent their growth to slow down acid and sulfate release, or alternatively, use them to speed up and control sulfide breakdown.
- Our experiments will focus on pyrrhotite. Pyrrhotite is most abundant sulfide mineral in Minnesota's copper-nickel deposits and would be the primary source of acid and sulfate from mine waste rock. The abundance of pyrrhotite is partly what makes Minnesota's deposits unique.

If we can learn how microbes affect sulfide minerals from Minnesota's copper-nickel deposits, this knowledge will open the door to a host of new ways to economically manage waste rock, tailings, and water from future mines in the state. But first, basic science is needed to understand how microbes affect sulfide minerals in Minnesota's copper-nickel deposits. We are proposing to do that basic science.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Map and analyze the sulfide mineral pyrrhotite in Minnesota's deposits* **Budget: $95,474**

Minnesota's copper-nickel deposits are unique, partly because while most other mines in the world are dominated by the sulfide mineral pyrite (fool's gold), the most common sulfide in Minnesota's deposits is pyrrhotite. But, pyrrhotite is complex. Pyrrhotite occurs in different forms (different crystal structures), and those different forms can break down at very different rates.

We will therefore first map and analyze the different forms of pyrrhotite in Minnesota's copper nickel deposits. Little is currently known about the extent and concentration of the different pyrrhotite forms in these deposits. Knowing the types of pyrrhotite and their distribution will improve water quality predictions and allow us to apply our experimental work (Activity 2) to the specific situation in Minnesota.

Outcome	Completion Date
1. Development of a protocol for accurate pyrrhotite analysis in Minnesota's rocks.	*12/31/2018*
2. Mapping and quantification of the pyrrhotite forms in rock samples from Minnesota's copper nickel deposits.	*12/31/2019*

Activity 2: *Measure rates of sulfide mineral breakdown under chemical and microbial conditions common to Minnesota's copper nickel deposits* **Budget: $244,193**

The ultimate goal is to determine how microorganisms affect the sulfide mineral pyrrhotite under conditions that would occur if Minnesota's copper-nickel deposits were mined. To accomplish this activity, we will first synthesize the different forms of pyrrhotite that occur in Minnesota's rocks (identified in Activity 1) and use those in carefully controlled experiments designed to quantify and compare rates of pyrrhotite breakdown with and without different microorganisms. We will use microorganisms that are naturally found in Minnesota's rocks.

Rocks from Minnesota's copper-nickel deposits weather under "moderately acidic" conditions (pH 4-7). But to date, pyrrhotite breakdown rates (oxidation kinetics) have only been carefully measured below pH 4. We will therefore quantify those breakdown rates under "Minnesota conditions" (pH 4-7), then determine how microbes alter them and why. Then, we will extend these results and measure microbially-influenced pyrrhotite breakdown in a more complex but also more realistic scenario using rocks that would represent mine waste from Minnesota's copper nickel deposits.

Outcome	Completion Date
1. Development of a protocol for pyrrhotite synthesis.	*6/30/2019*
2. Quantification of pyrrhotite breakdown rates for different varieties of pure pyrrhotite identified in Activity 1 at pH 4-7 ("Minnesota conditions").	*6/30/2020*
3. Quantification of microbially-influenced pyrrhotite breakdown rates (using specific microorganisms that naturally occur in rocks from Minnesota's copper nickel deposits).	*12/31/2020*
4. Quantification of microbially-influenced pyrrhotite breakdown rates in rocks from Minnesota's copper nickel deposits, and develop recommendations for large scale testing.	*6/30/2021*
4. Final data analysis, reporting, and publication.	*6/30/2021*

III. PROJECT STRATEGY

A. Project Team/Partners

The core team will consist of Principle Investigator (PI) Daniel Jones, Co-PIs Joshua Feinberg and Lee Penn, and Kathryn Hobart (graduate student), all from the University of Minnesota. Co-PI Feinberg (Dept. of Earth Sciences) is an expert in mineralogy with several published studies on pyrrhotite and will direct Activity 1. PI Jones (BioTechnology Inst. and Dept. of Earth Sciences) is an expert in environmental microbiology, and will direct Activity 2. Co-PI Lee Penn (Dept. of Chemistry) is an expert in mineral synthesis and will supervise the synthesis of pure pyrrhotite samples and certain kinetic analyses (Outcome 2). Jones and Feinberg will jointly advise Kathryn Hobart, a graduate student supported by this project who will work on both activities. Jones and Feinberg also request funds to partially support a technician and undergraduate researcher, who will assist with all aspects of the project. Penn requests support for a graduate student to work on pyrrhotite synthesis and analysis.

B. Project Impact and Long-Term Strategy

We are proposing basic research that will open the door to new ways to economically maintain and improve water quality and manage waste rock and tailings from future nonferrous mines in Minnesota. At the end of this project, we will be able to make recommendations for large-scale testing of new mine waste management strategies. The mineral breakdown rates measured in this study will also inform kinetic testing procedures used by state regulatory agencies and industries working on water quality predictions for permitting purposes. Longer term, this project will pave the way for new microbially-based technologies and treatment strategies to improve water quality and environmental outcomes associated with mining in Minnesota.

C. Timeline Requirements

The project will be completed in three years, starting in July 2018 and ending in June 2021.

2018 Detailed Project Budget

Project Title: Sulfide mineral-eating microbes to improve water quality

IV. TOTAL ENRTF REQUEST BUDGET 3 years

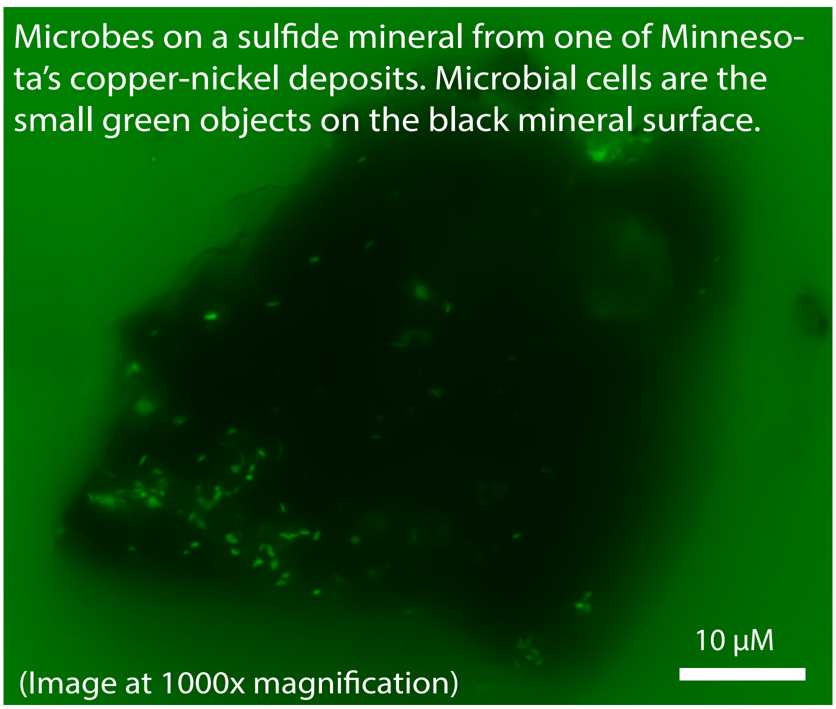
BUDGET ITEM *(See "Guidance on Allowable Expenses", p. 13)*	**AMOUNT**
Personnel: Dr. Josh Feinberg, U of Minnesota, co-Investigator (2 weeks/years 1 and 2 of salary and benefits, 4% of total salary). Feinberg is jointly responsible for Activities 1 and 2 with Jones, and will oversee and coordinate mineralogical analyses.	$ 13,626
Personnel: Dr. Lee Penn, U of Minnesota, co-Investigator (2 weeks/years 1 and 2 of salary and benefits, 4% of total salary). Penn supervise the synthesis of pure pyrrhotite samples and certain kinetic analyses related to Activity 2.	$ 15,873
Personnel: Graduate student (Kathryn Hobart, UMN) (0.5 FTE, 3 yrs, 100% of total salary for those years). Hobart will work with Feinberg and Jones on Activities 1 and 2.	$ 112,958
Personnel: Graduate student (unidentified, UMN) (0.5 FTE, 2 yrs, 100% of total salary for those years). The graduate student will work with Penn on the pyrrhotite synthesis and reaction kinetics (Activity 2).	$ 67,762
Personnel: Undergraduate researcher (40 hours/week summer, 10 hours/week semester, 2 yrs). The undergraduate student assist with fieldwork (Activity 1) and work with Jones and Hobart.	$ 20,846
Personnel: Peter Solheid, UMN, laboratory technician (2 mo./yr, 2 yrs, 16.7% of total salary). Peat is a technician in the Institute for Rock Magnetism, who will work with Feinberg and Hobart on magnetic characterization methods for Activities 1 and 2.	$ 33,864
Professional/Technical/Service Contracts: Analytical costs for mineralogical and chemical analysis at the University of Minnesota Characterization facility ($14K, for scanning electron microscopy, transmission electron microscopy, and Raman microscopy) and the University of Minnesota Genomics Center (DNA sequencing, 2 MiSeq lanes, $6.5K).	$ 20,500
Equipment/Tools/Supplies: Laboratory equipment for mineral synthesis ($5000, benchtop muffle furnace, Thermo Scientific™ Thermolyne™ or similar) and for pH control during mineral breakdown experiments ($9000 for supplies for custom pH stat setup, $4000 for small volume peristaltic pump and heads).	$ 18,000
Equipment/Tools/Supplies: Laboratory supplies include supplies for DNA based and microscopic microbiological analysis ($8K total, including DNA extraction kits, PCR reagents including Taq, agarose, dyes, buffers, fluorescent probes, preservatives, slides and coverslips, anti-fade mounting media), chemical and mineralogical analyses ($11K total, including maintenance costs for Penn's X-ray diffractometer ($4K), supplies and maintenance for ion chromatograph ($3K), liquid helium ($2K/yr for 2 years)), and general laboratory consumables for Jones and Feinberg's labs ($3K total, including gloves and other personal protective equipment, centrifuge tubes, pipet tips, serum bottles, kimwipes, culture media and other chemical reagents, non-magnetic glue, sample holders), and supplies for pyrrhotite synthesis ($3K) and laboratory consumables ($3K) for Penn's lab (chemicals (including iron precursors, elemental sulfur and other sulfur containing precursors, solvents), standards, and lab supplies including reactor liners, glassware, TEM grids, single crystal slides for XRD, supplies for anaerobic and dry storage of synthesized materials).	$ 25,000
Acquisition (Fee Title or Permanent Easements): N/A	$ -
Travel: Travel costs for 5 trips/year for 2 years to NE Minnesota for fieldwork to collect rock sample (400 miles/round trip by personal auto), and travel, lodging, and registration costs for two individuals to present at the regional Society for Mining, Metallugy, and Extraction (SME) conference in Duluth each year.	$ 6,238
Additional Budget Items: We request funds to publish 2 articles containing results from this study in peer reviewed journals,, including costs associated with publication of color images.	$ 5,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 339,667

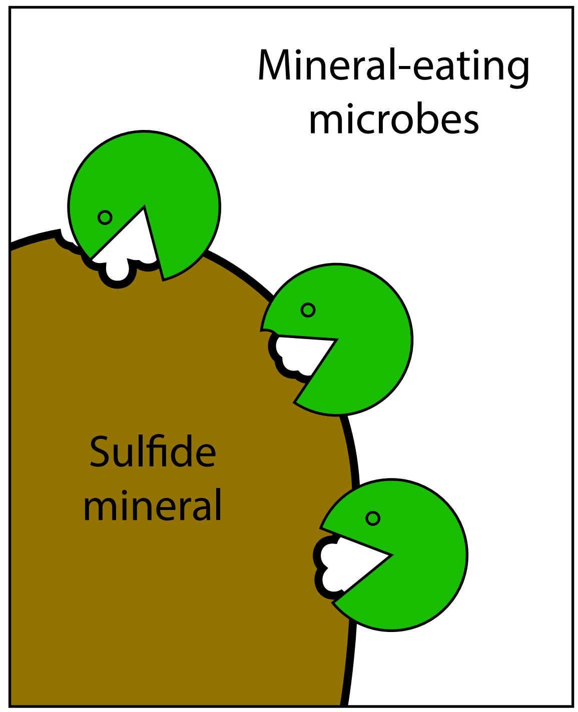
V. OTHER FUNDS

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ To Be Applied To Project During Project Period	N/A	N/A
Other State $ To Be Applied To Project During Project Period	N/A	N/A
In-kind Services To Be Applied To Project During Project Period: Dr. Daniel Jones, PI, University of Minnesota, is not requesting any salary, and will be donating 3 mo./year of his time to the project (25% of his total salary and benefits) in yrs 1 and 2.	$ 37,937	*Secured*
In-kind Services To Be Applied To Project During Project Period: The University of Minnesota does not charge the State of Minnesota overhead (54%; estimate is based on total costs excluding graduate student tuition)	$ 170,112	*Secured*
Past and Current ENRTF Appropriation:	N/A	N/A
Other Funding History: University of Minnesota MnDRIVE seed grant (Assessing microbial contributions to sulfide mineral oxidation in Cu-Ni ores of the Midcontinent Rift, NE Minnesota, $40,000)	$ 50,000	

Sulfide mineral-eating microbes to improve water quality

Certain naturally occurring microorganisms break down sulfide minerals to gather the energy necessary for life.
This process releases metals and acid, which can degrade water quality.





If we can understand how and why these microbes "eat" sulfide minerals from Minnesota's copper-nickel deposits, we can use this knowledge to speed up or slow down sulfide mineral oxidation and improve management of waste rock and water from future mines in the state.

Project manager qualifications and organizational description

Daniel S. Jones, Ph.D., is a Research Associate in the University of Minnesota BioTechnology Institute, with affiliate and graduate faculty status in the Department of Earth Sciences. Jones is an expert in environmental microbiology and microbial ecology, with multiple publications on microbial ecology and microbial sulfur cycling in natural and mining-impacted environments, including recent work on the microbiology of rocks from Minnesota's economic mineral deposits. Jones also serves as an industry liaison for the University of Minnesota MnDRIVE initiative Advancing Industry, Conserving Our Environment, where he works to facilitate interactions among University of Minnesota researchers, industry representatives, and state agencies.

Prof. Joshua Feinberg, has over 19 years of experience working as a geoscience professional for state and federal natural resource agencies, for private environmental consulting corporations, and as a university professor overseeing federally funded scientific research. Feinberg is currently a tenured Associate Professor in the Department of Earth Sciences at the University of Minnesota and the Associate Director of the Institute for Rock Magnetism (IRM), which is a National Multi-User Facility funded primarily by the National Science Foundation. Feinberg's research uses a combination of geophysical approaches (e.g., rock magnetism, paleomagnetism, gravity) and material characterization techniques (e.g., scanning and transmission electron microscopy, scanning force microscopy, X-ray diffraction) to characterize magnetic minerals (which includes pyrrhotite, on which he has several published studies).

Prof. Lee Penn is a co-PI and has extensive experience developing synthetic methods for the production of mineral particles, including a wide range of sulfide minerals, of specific compositions and narrow size and shape distributions. In addition, the Penn research group uses electron microscopy and other advanced methods to holistically characterize materials in order to elucidate the links between size and shape and materials' properties (including electrical, optical, and magnetic). Finally, the group has numerous publications describing how mineral particles participate in chemical reactions, with particular focus on how minerals dissolve. Penn is a Distinguished University Teaching Professor, who has won numerous awards, including the Charlotte Stribel Equity Award from the University Office for Equity and Diversity's Women's Center (2016-2017) and Horace T. Morse University of Minnesota Alumni Association Award for Outstanding Contributions to Undergraduate Education in 2015. Finally, Prof. Penn is an Institute on the Environment Resident Fellow.

Organization Description. The University of Minnesota is a prestigious public university and the state of Minnesota's land-grant university. In addition to the laboratory facilities available to the PIs, the university includes multiple core facilities (including the Characterization Facility, the University of Minnesota Genomics Center, and the Minnesota Supercomputing Institute) that have the equipment and instruments necessary for the proposed studies.