# Bacterial Biomining Rare Earth Elements in Abandoned Coal Mine Drainage: Solubilization and Sequestration

Anna Vietmeier[1,2], Bethann Wilson[1], Michelle Valkanas, PhD[3], Sam Flett[2], Sierra McDermott[2], John Stolz[1,4], Djuna Gulliver, PhD[2], Nancy Trun, PhD[1]

[1]Department of Biological Sciences, 913 Bluff St, Duquesne University, Pittsburgh, PA 15219
[2]National Energy Technology Laboratory, Department of Energy, 626 Cochrans Mill Rd, Pittsburgh, PA, 15236
[3]Department of Biology, Earth, and Environmental Science, PennWest California, 250 University Ave, California, PA 15419
[4]Center for Environmental Research and Education, 600 Forbes Ave, Duquesne University, Pittsburgh, PA 15282

American Society of Microbiology Annual Microbe Conference
Session: Microbiology of Mineral and Energy Resource Recovery
LACC 403B, Los Angeles, CA
Monday, June 23rd, 2025 @ 10:00A-10:15A

DOE: NETL Disclaimer

# Background Information

Abandoned Coal-Mine Drainage (AMD)

Critical Minerals (CM) /Rare Earth Elements (REE)

Acidogenesis Isolates that Reduce Manganese

# Abandoned Mine Drainage (AMD)

**Coal Mining in Pennsylvania**

Unregulated 1700s → 1945

Legacy mines ~11,000 mines


https://wvhistoryonview.org/catalog/004468

Sulfuric Acid → Solubilize Metals → Mn/CM/REE

**Treat AMD in Passive Remediation Systems**

Precipitate AMD Waste as Solids

# Critical Minerals and Metals (CMMs) and Rare Earth Elements (REEs)

### Modern Tech REE Demand ↑ Globally

Rechargeable Batteries, Electric Motors, Wind Turbines, Superconductors, Lasers, Optical Fibers, Aerospace Alloys

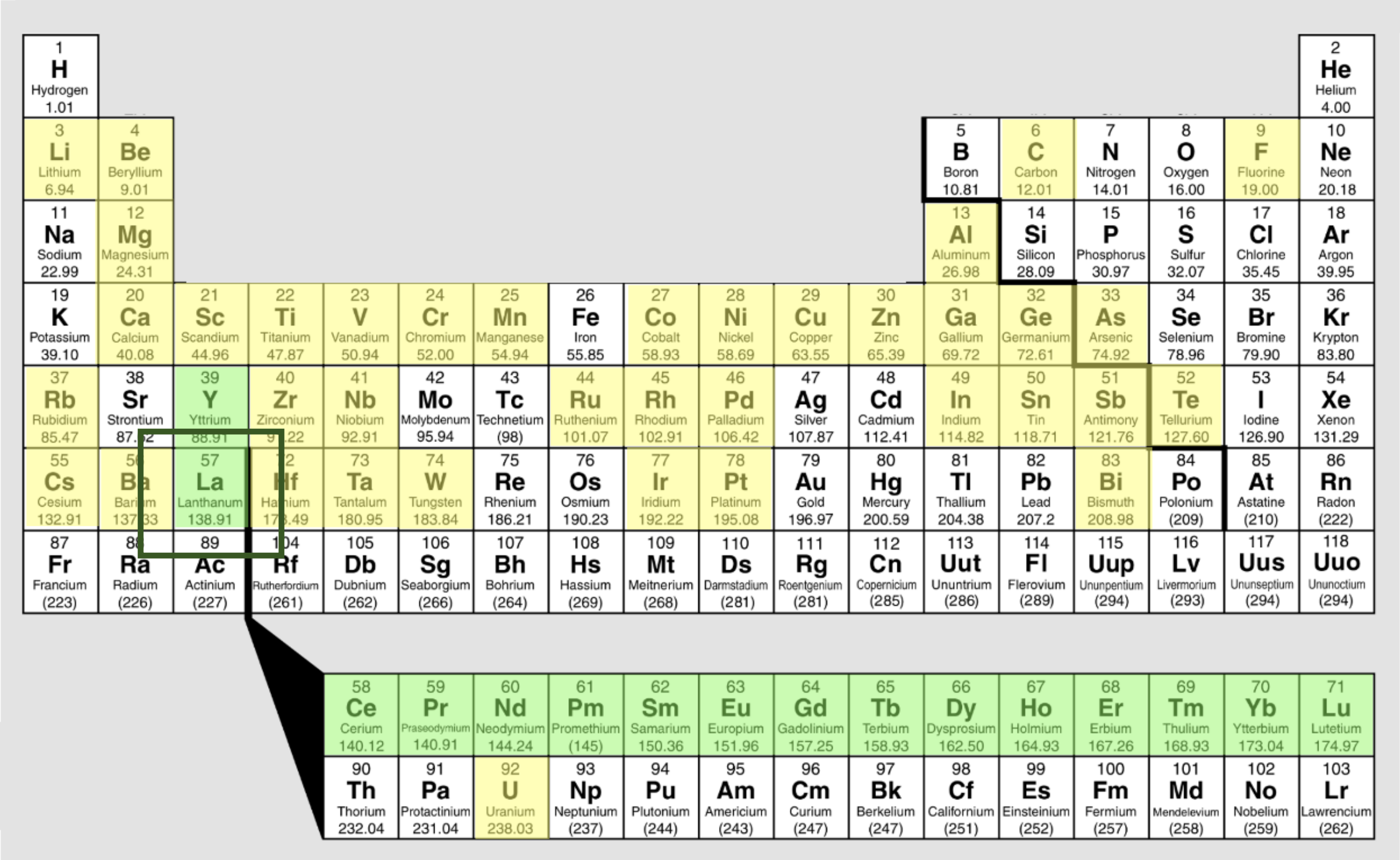
### Conventional REE Extraction

High Temp & Harsh Chemicals = Toxic Waste

### AMD as a Source of REEs

AMD REEs ~10,000 > non-AMD waters (Vo 2024)

REEs + Mn in AMD solids (Hedin, Stuckman 2024)



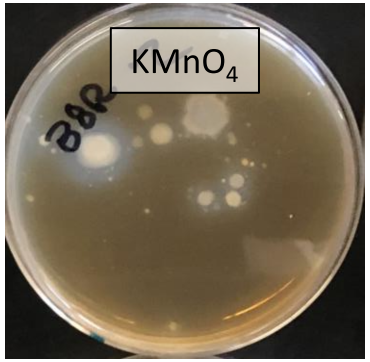
# Mn Reducing Bacteria (MnRB) Produce Acid (Acidogenesis)

| Isolate | 16S *rrn* Identity |
|---|---|
| AV20 | 90% *Bacillus cereus* |
| AV21 | 98% *Corynebacterium sp.*▽ |
| AV22 | 83% *Bacillus sp.* |
| AV23 | 90% *Bacillus thuringiensis* |
| AV24 | *98% Corynebacterium sp.* |
| KB7 | 100% *Bacillus pseudomycoides*▽ |
| JR07 | 100% *Bacillus mycoides*▽ |
| Sterile | NA |

▽Whole genome sequencing (WGS)
*Differential Manganese Reduction Media $KMnO_4$
+Differential Manganese Reduction Media $MnO_2$
✦Acid Production Determined by Phenol Red/pH probe/TSI Slants
NA = Not applicable


Kayla Brennan, Josh Robinson

# Mn Reducing Bacteria (MnRB) Produce Acid (Acidogenesis)



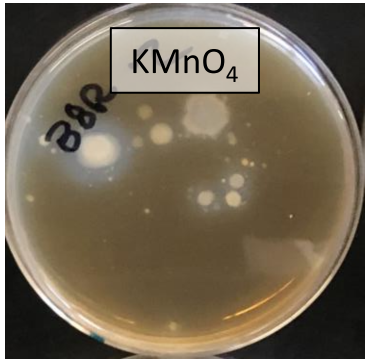

| Isolate | 16S *rrn* Identity | Reduces $KMnO_4$* |
|---|---|---|
| AV20 | 90% *Bacillus cereus* | + |
| AV21 | 98% *Corynebacterium sp.*▽ | + |
| AV22 | 83% *Bacillus sp.* | + |
| AV23 | 90% *Bacillus thuringiensis* | + |
| AV24 | *98% Corynebacterium sp.* | + |
| KB7 | 100% *Bacillus pseudomycoides*▽ | + |
| JR07 | 100% *Bacillus mycoides*▽ | + |
| Sterile | NA | - |

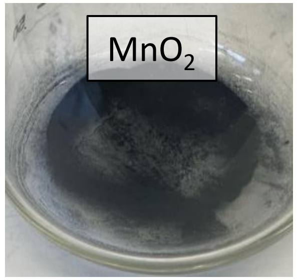
▽Whole genome sequencing (WGS)
*Differential Manganese Reduction Media $KMnO_4$
+Differential Manganese Reduction Media $MnO_2$
✦Acid Production Determined by Phenol Red/pH probe/TSI Slants
NA = Not applicable

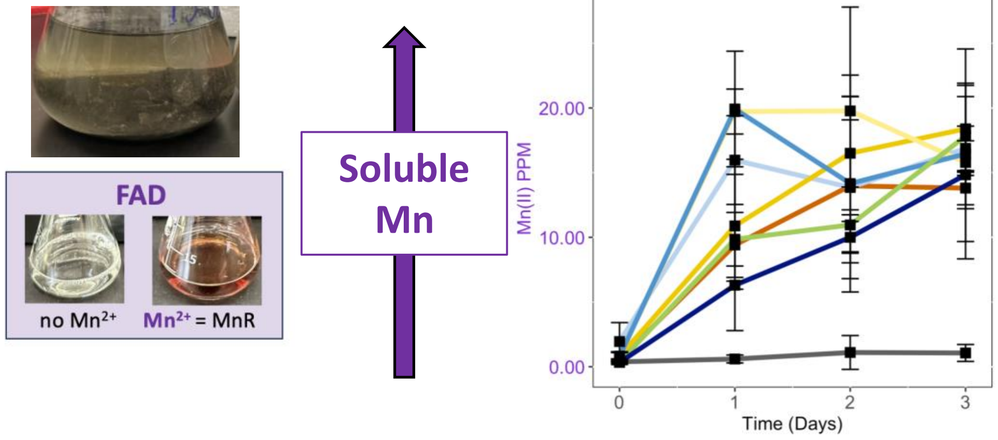
# Mn Reducing Bacteria (MnRB) Produce Acid (Acidogenesis)

| Isolate | 16S *rrn* Identity | Reduces $KMnO_4$* | Reduces $MnO_2$+ |
|---|---|---|---|
| AV20 | 90% *Bacillus cereus* | + | + |
| AV21 | 98% *Corynebacterium sp.*▽ | + | + |
| AV22 | 83% *Bacillus sp.* | + | + |
| AV23 | 90% *Bacillus thuringiensis* | + | + |
| AV24 | *98% Corynebacterium sp.* | + | + |
| KB7 | 100% *Bacillus pseudomycoides*▽ | + | + |
| JR07 | 100% *Bacillus mycoides*▽ | + | + |
| Sterile | NA | - | - |

▽Whole genome sequencing (WGS)
*Differential Manganese Reduction Media $KMnO_4$
+Differential Manganese Reduction Media $MnO_2$
✦Acid Production Determined by Phenol Red/pH probe/TSI Slants
NA = Not applicable



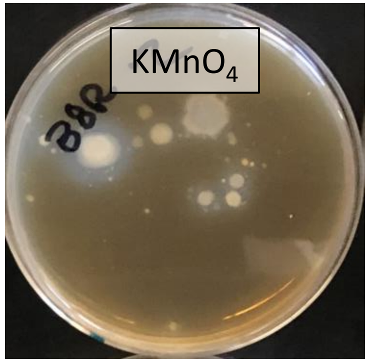



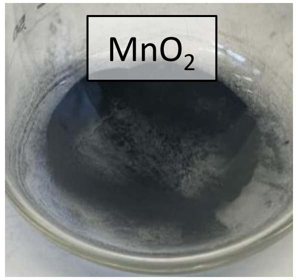



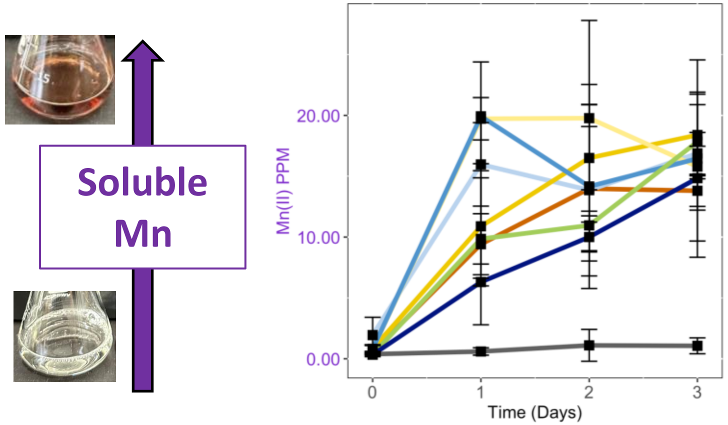
# Mn Reducing Bacteria (MnRB) Produce Acid (Acidogenesis)

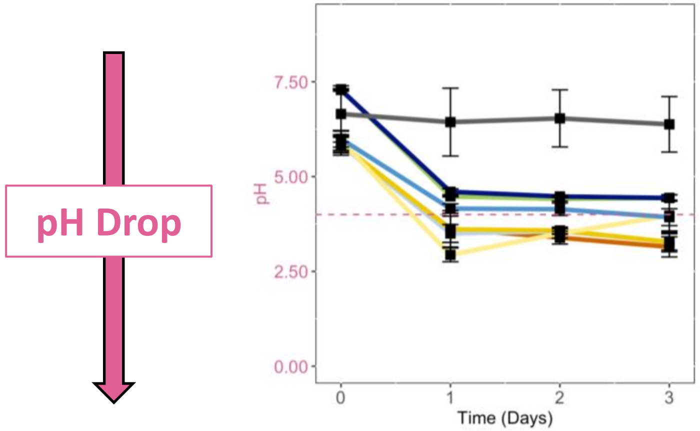
| Isolate | 16S *rrn* Identity | Reduces $KMnO_4$[*] | Reduces $MnO_2$[+] | Produces Acid[✦] |
|---|---|---|---|---|
| AV20 | 90% *Bacillus cereus* | + | + | + |
| AV21 | 98% *Corynebacterium sp.*[▽] | + | + | + |
| AV22 | 83% *Bacillus sp.* | + | + | + |
| AV23 | 90% *Bacillus thuringiensis* | + | + | + |
| AV24 | 98% *Corynebacterium sp.* | + | + | + |
| KB7 | 100% *Bacillus pseudomycoides*[▽] | + | + | + |
| JR07 | 100% *Bacillus mycoides*[▽] | + | + | + |
| Sterile | NA | - | - | - |

[▽]Whole genome sequencing (WGS)
[*]Differential Manganese Reduction Media $KMnO_4$
[+]Differential Manganese Reduction Media $MnO_2$
[✦]Acid Production Determined by Phenol Red/pH probe/TSI Slants
NA = Not applicable



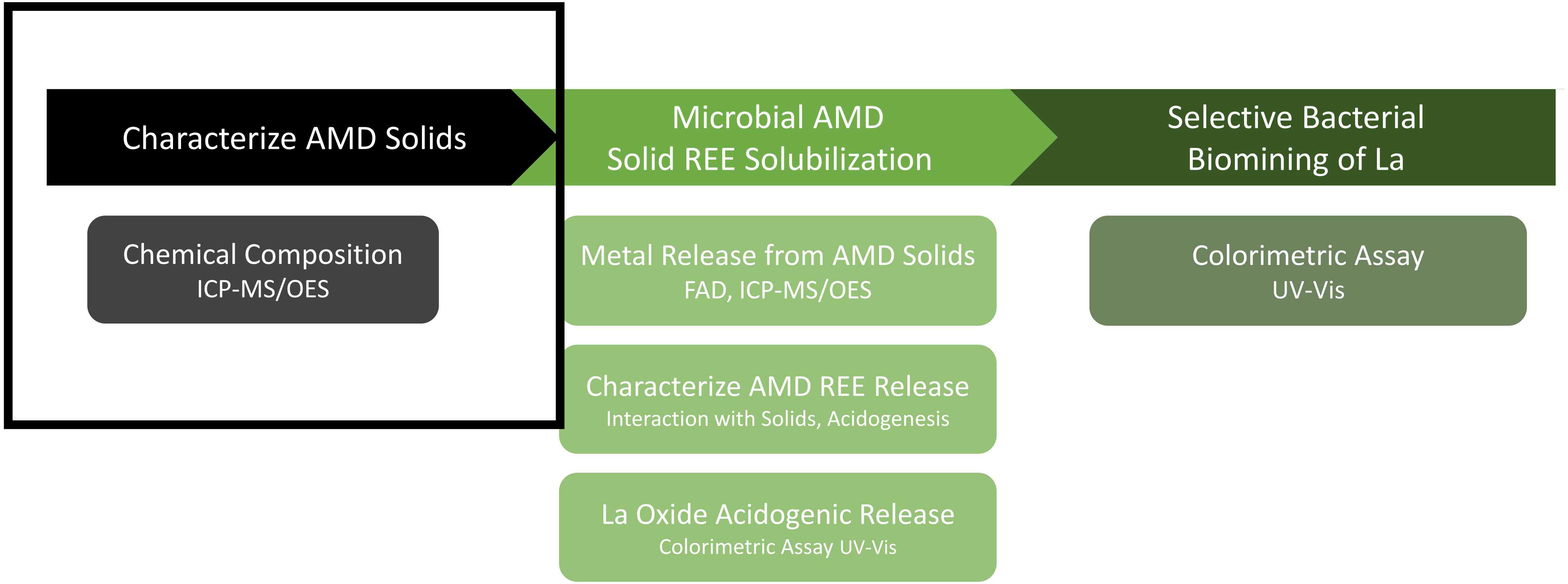






Kayla Brennan, Josh Robinson



Characterize AMD Solids
Microbial AMD
Solid REE Solubilization
Selective Bacterial
Biomining of La
Chemical Composition
ICP-MS/OES
Metal Release from AMD Solids
FAD, ICP-MS/OES
Characterize AMD REE Release
Interaction with Solids, Acidogenesis
La Oxide Acidogenic Release
Colorimetric Assay UV-Vis
Colorimetric Assay
UV-Vis

# AMD Systems to Target for Biomining

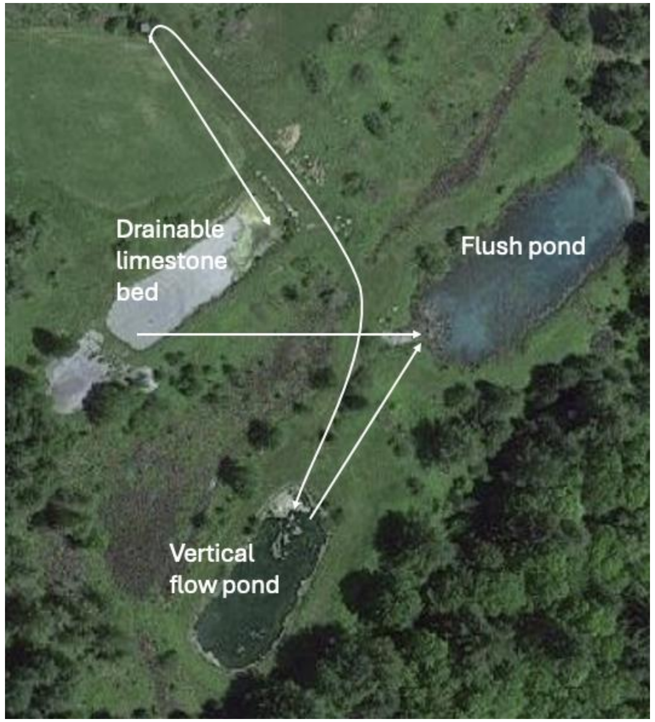
Recommended by NETL based on previous work by Ben Hedin, PhD

**Wingfield Pines**


**Sterrett**

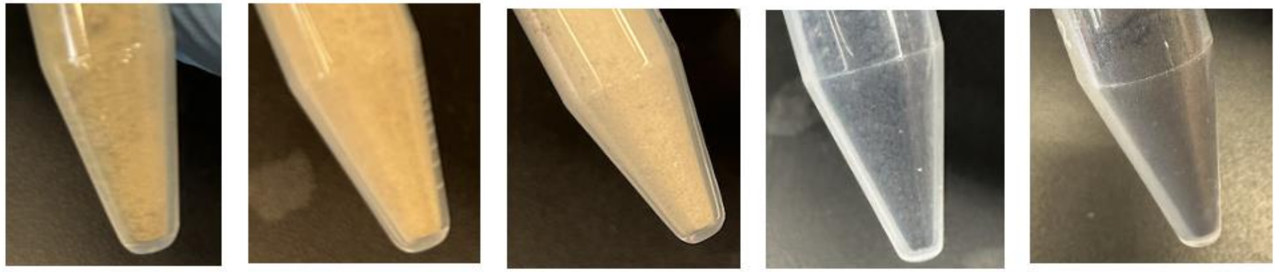

**Kentucky Hollow**


**Scootac**




**Glasgow**

# Chemical Comparisons of AMD Solids



Wingfield Pines | Sterrett | Kentucky Hollow | Scootac | Glasgow

| | Mn | Fe | Al | Li | Sc | V | Cr | Co | Ni | Cu | Zn | Ga | As | Zr | Sn | Sb | Y | La | Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WP | 3434.00 | 81,110 | 39,500 | 34 | 9 | 61 | 68 | 17 | 35 | 7 | 128 | 12 | 15 | 121 | 4 | 1 | 21 | 22 | 48 | 6 | 22 | 5 | 1 | 4 | 1 | 4 | 1 | 2 | 0 | 2 | 0 | 2 |
| St | 78,727 | 93,623 | 78,010 | 104 | 7 | 36 | 27 | 1,187 | 917 | 52 | 1,888 | 13 | 31 | 57 | 1 | 1 | 272 | 89 | 259 | 36 | 173 | 55 | 14 | 71 | 11 | 55 | 10 | 27 | 3 | 19 | 3 | 11 |
| KH | 14,627 | 50,640 | 91,280 | 61 | 15 | 91 | 66 | 613 | 858 | 151 | 954 | 18 | 61 | 73 | 2 | 1 | 144 | 69 | 246 | 33 | 151 | 41 | 9 | 45 | 7 | 31 | 6 | 15 | 2 | 10 | 1 | 11 |
| Sc | 108,900 | 3,294 | 19,388 | 60 | 3 | 3 | 18 | 3,962 | 4,746 | 59 | 7,794 | 20 | 7 | 14 | 6 | 0 | 261 | 80 | 131 | 26 | 110 | 27 | 7 | 41 | 6 | 36 | 8 | 20 | 2 | 13 | 2 | 1 |
| G | 13,750 | 6,805 | 9,555 | 9 | 2 | 4 | 14 | 912 | 149 | 41 | 207 | 4 | 2 | 6 | 2 | 0 | 28 | 11 | 26 | 4 | 16 | 4 | 1 | 5 | 1 | 5 | 1 | 2 | 0 | 1 | 0 | 0 |

ICP-MS & ICP-OES

PPM values reported

High Low

<DL 0



Colleen Hoffman, Sam Flett, Sierra McDermott, PAL

Characterize AMD Solids

Chemical Composition
ICP-MS/OES

Microbial AMD
Solid REE Solubilization

Metal Release from AMD Solids
FAD, ICP-MS/OES

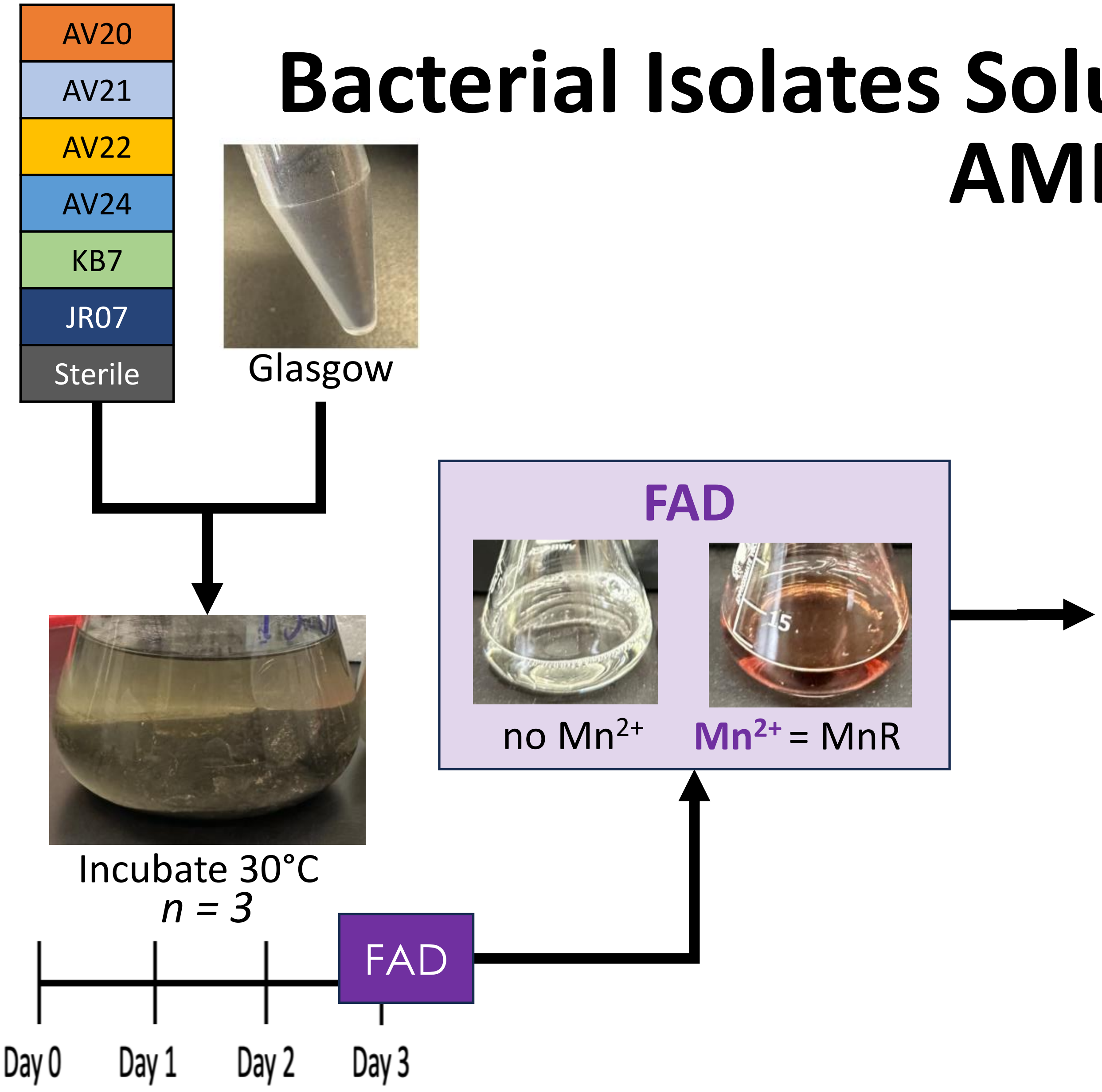
Characterize AMD REE Release
Interaction with Solids, Acidogenesis

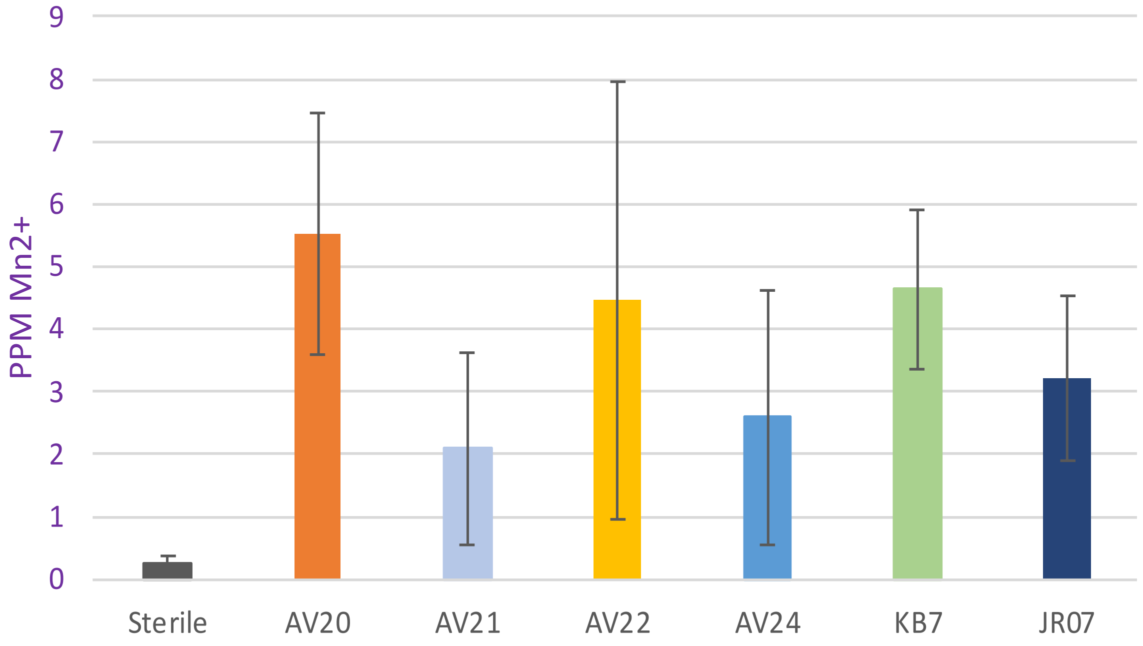
La Oxide Acidogenic Release
Colorimetric Assay UV-Vis

Selective Bacterial
Biomining of La

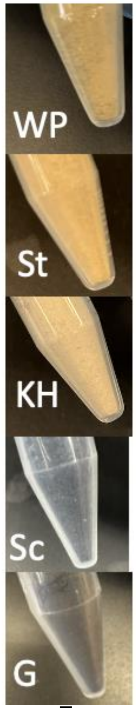
Colorimetric Assay
UV-Vis

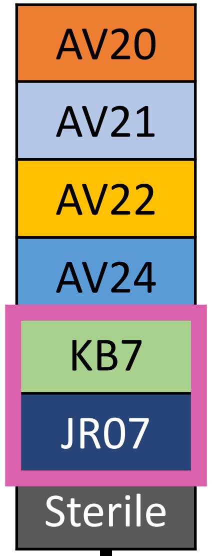
# Bacterial Isolates Solubilize Mn From Glasgow AMD Solids



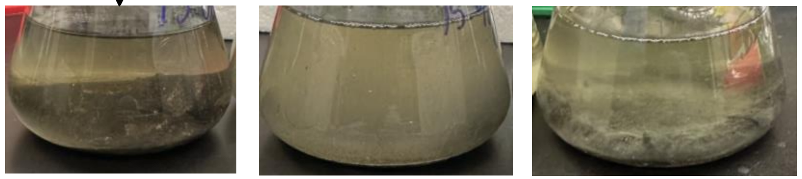



# Solubilization of REEs from AMD Solids with Bacterial Isolates

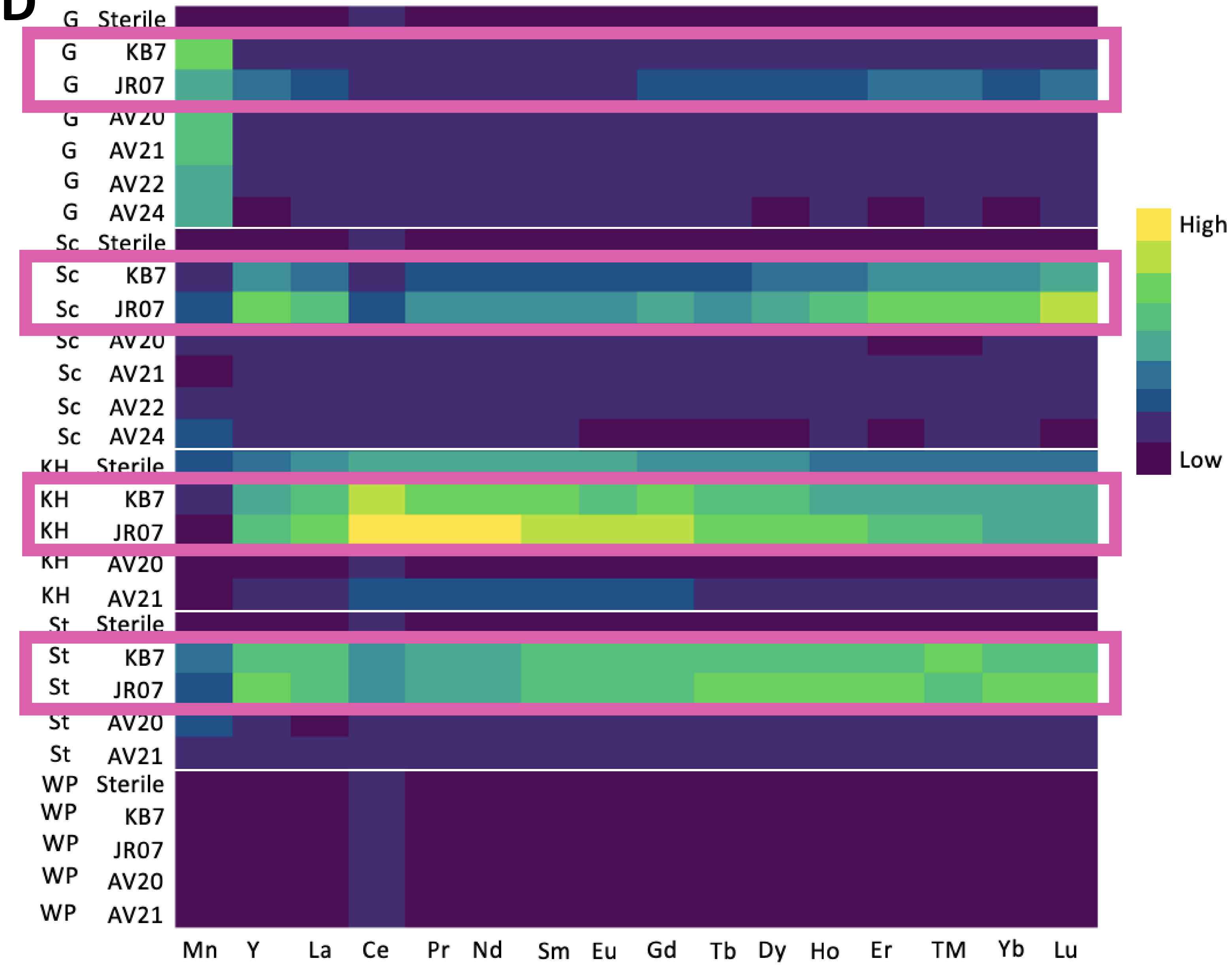



KB7 & JR07 best @ ↑soluble REEs



Sterile AV20 KB7






Sam Flett, Sierra McDermott, & PAL

Characterize AMD Solids

Microbial AMD
Solid REE Solubilization

Selective Bacterial
Biomining of La

Chemical Composition
ICP-MS/OES

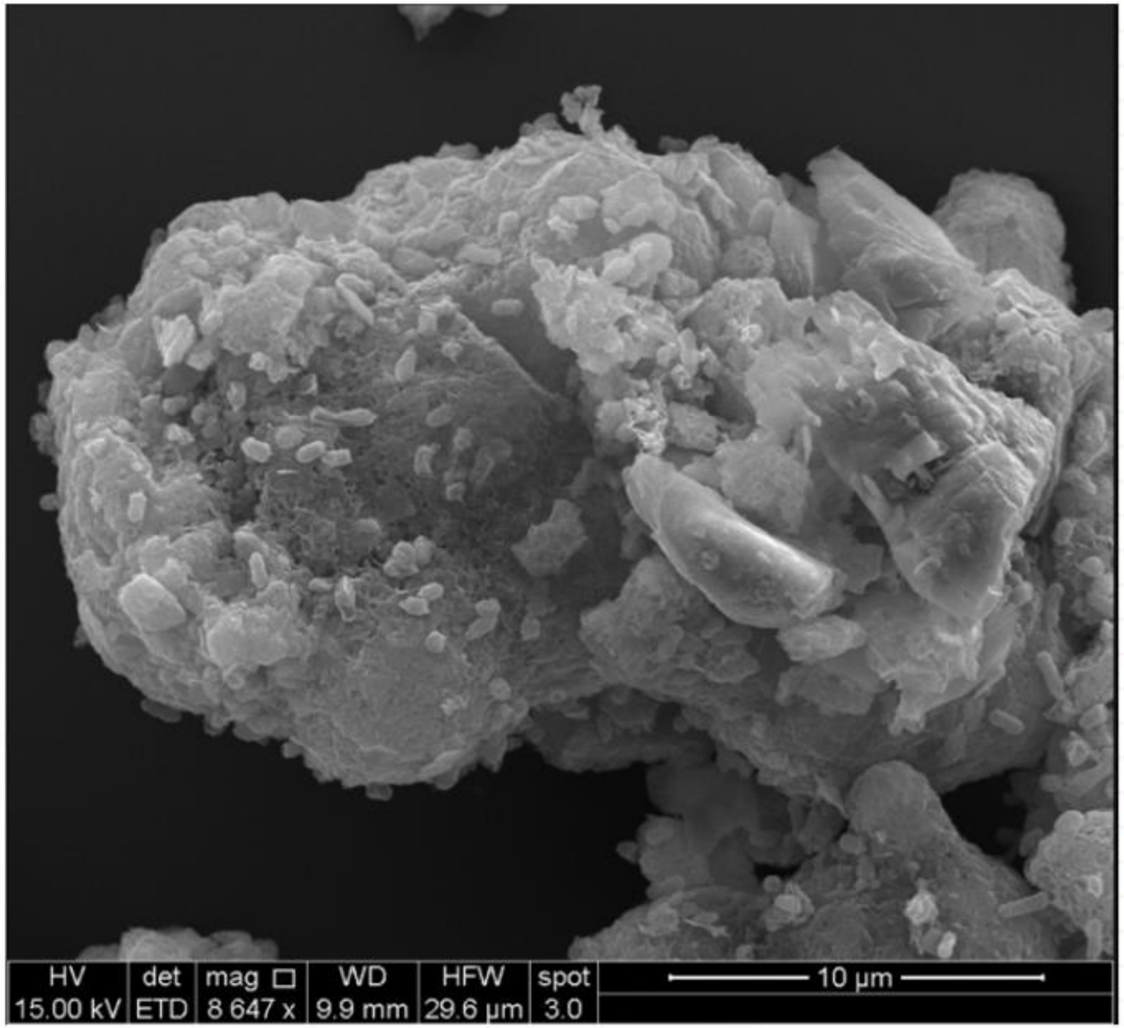
Metal Release from AMD Solids
FAD, ICP-MS/OES

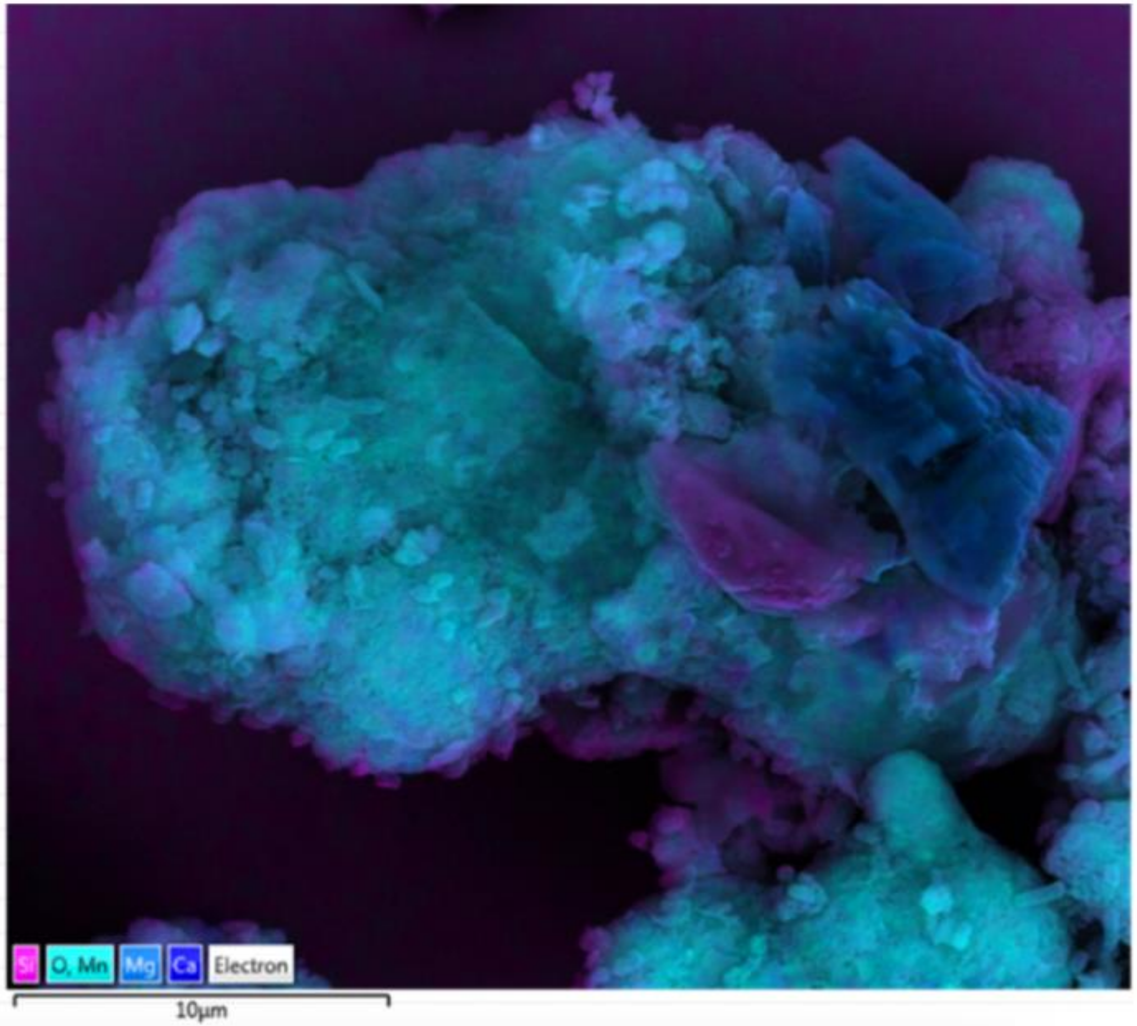
Colorimetric Assay
UV-Vis

Characterize AMD REE Release
Interaction with Solids, Acidogenesis

La Oxide Acidogenic Release
Colorimetric Assay UV-Vis

# SEM of KB7 with Glasgow AMD Solids




Mn oxides from Glasgow AMD covered in rod shaped bacteria KB7
consistent with these isolates being *Bacillus sp.*

# KB7 & JR07 are the stronger solubilizers of AMD solids (REEs)

| Isolate | 16S *rrn* Identity | Biofilm | Lactic Acid |
|---|---|---|---|
| AV20 | 90% *Bacillus cereus* | - | - |
| AV21 | 98% *Corynebacterium sp.* | - | - |
| AV22 | 83% *Bacillus sp.* | - | - |
| AV24 | 98% *Corynebacterium sp.* | - | - |
| **KB7** | **100% *Bacillus pseudomycoides*** | **+** | **+** |
| **JR07** | **100% *Bacillus mycoides*** | **+** | **+** |

Both isolates

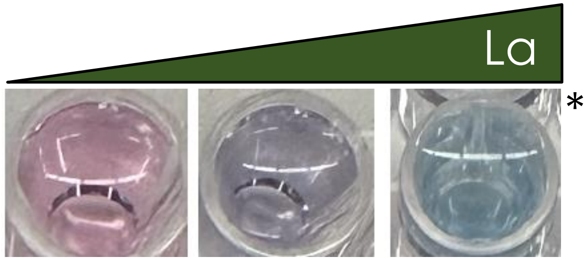
Direct interactions with AMD solids (SEM)

Form Biofilms

Produce Lactic Acid

| Characterize AMD Solids | Microbial AMD Solid REE Solubilization | Selective Bacterial Biomining of La |
| --- | --- | --- |
| **Chemical Composition**<br>ICP-MS/OES | **Metal Release from AMD Solids**<br>FAD, ICP-MS/OES | **Colorimetric Assay**<br>UV-Vis |
| | **Characterize AMD REE Release**<br>Interaction with Solids, Acidogenesis | |
| | $\boxed{\text{La Oxide Acidogenic Release}}$<br>Colorimetric Assay UV-Vis | |

# Acidogenesis Isolates KB7 & JR07 ↑Soluble La(III) from LaOx

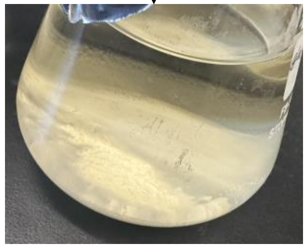




KB7

JR07

Sterile



n = 3
Incubate 30°C

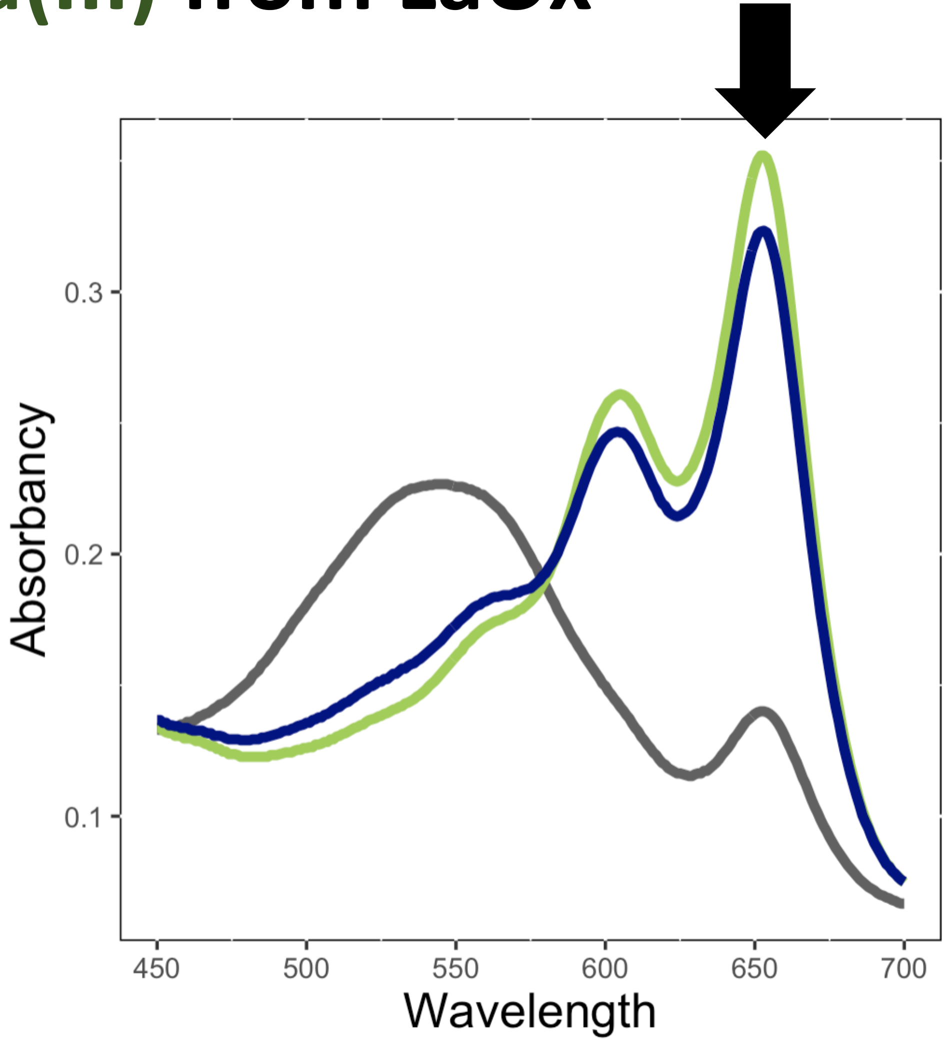
Day 0 Day 1 Day 2 Day 3

La

**REE: La**

Sterile

Inoc.






*Bethann Wilson

## Characterize AMD Solids

**Chemical Composition**
ICP-MS/OES

## Microbial AMD Solid REE Solubilization

**Metal Release from AMD Solids**
FAD, ICP-MS/OES

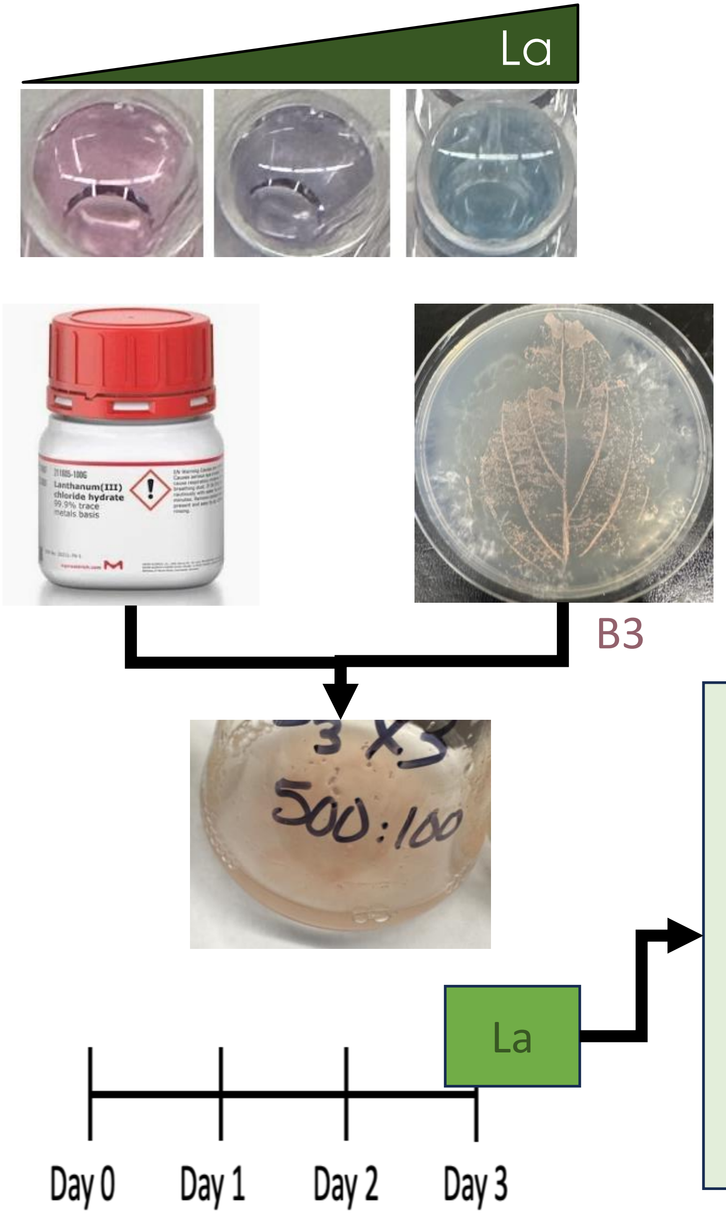
**Characterize AMD REE Release**
Interaction with Solids, Acidogenesis

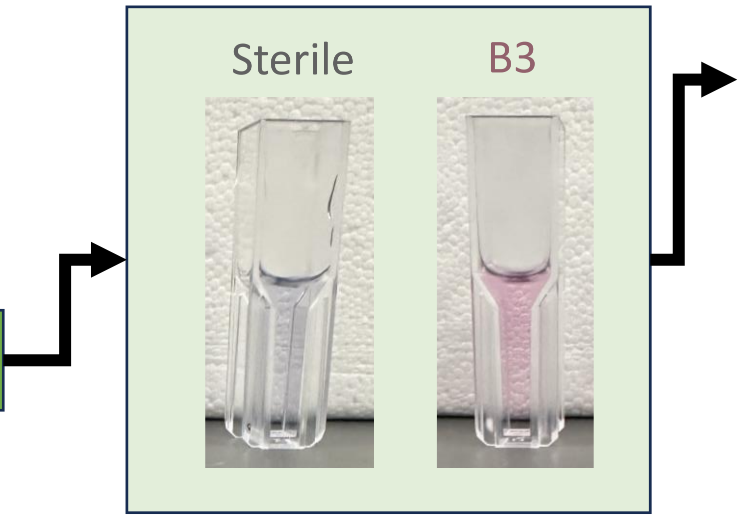
**La Oxide Acidogenic Release**
Colorimetric Assay UV-Vis

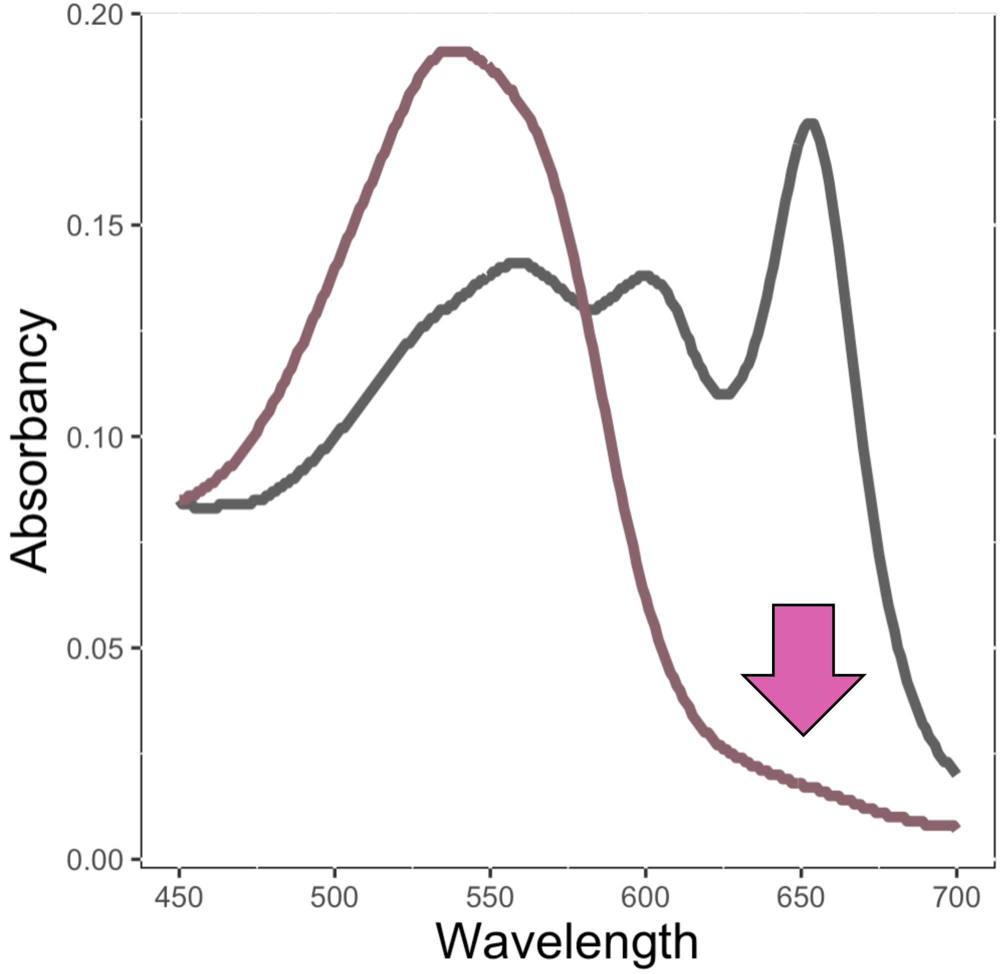
## Selective Bacterial Biomining of La

**Colorimetric Assay**
UV-Vis

# Decrease in Soluble La(III) when Bacterial Isolate B3 is Present



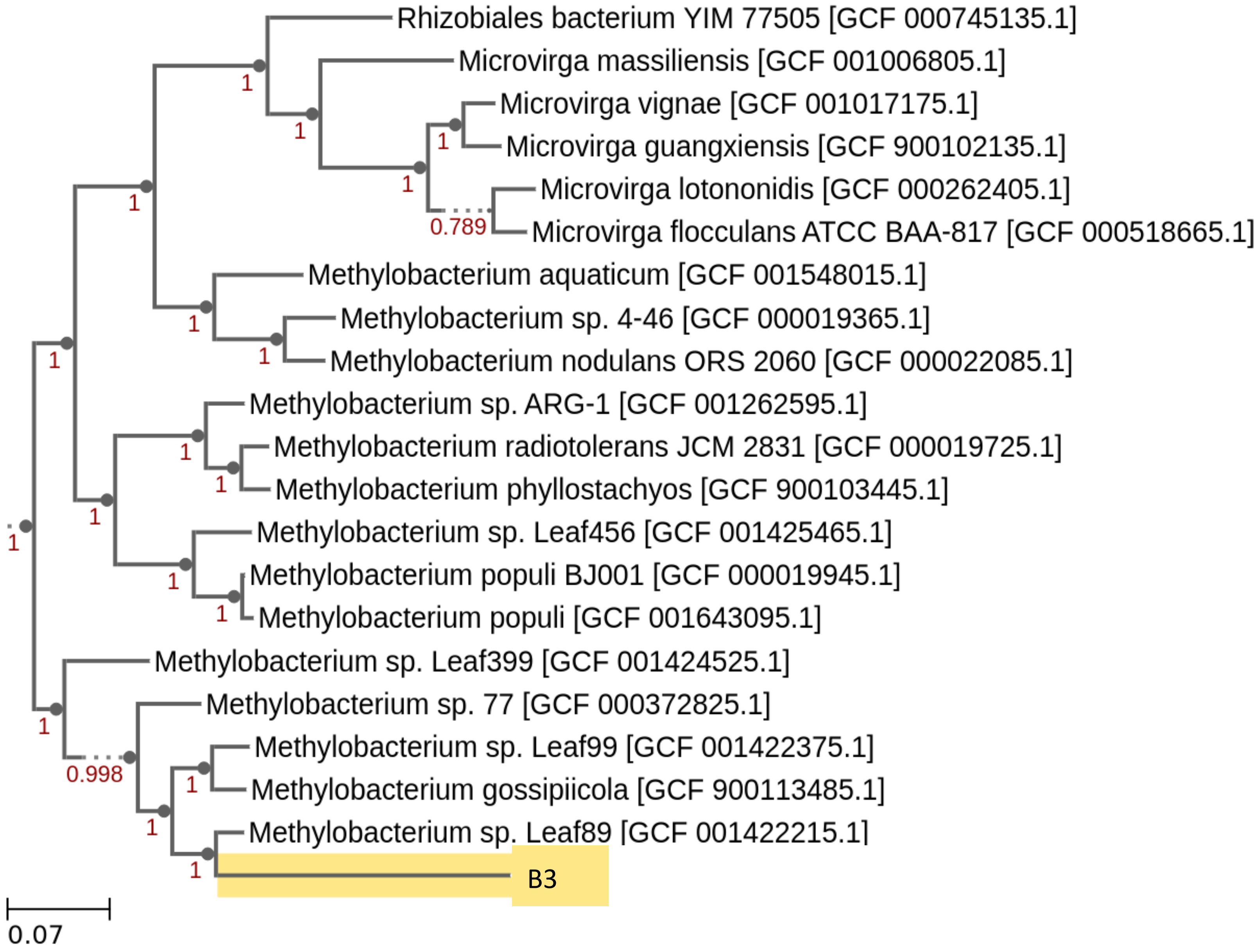






Martinez-Gomez 2015
Bethann Wilson, Cassandra Ziegler

# Characterizing B3



# Future Directions

Publish / Patent Work

Scale-up Biomining Process for In-Field Applications

# Thank You!!

PhD Advisor
**<u>Nancy Trun, PhD</u>**

PhD Committee
**John Stolz, PhD**
**Jan Janecka, PhD**
**John Senko, PhD**

NETL
**<u>Djuna Gulliver, PhD</u>**
**Kara Tinker, PhD**
**Colleen Hoffman, PhD**
Preom Sarkar
**Sam Flett**
**Meghan Beebe**
Dan Ross, PhD
Sierra McDermott
Mengling Stuckman
Christina Lopano
Kelly Albenze
PAL

Duquesne
**Bethann Wilson**
Cassie Ziegler
Meghan Wells

Trun Lab Past
**Michelle Valkanas, PhD**
**Natalie Lamagna, MS**
**Taylor Russo**
**Josh Robinson**
**Kayla Brennan**
**Alexa Lovelace**
Amber Zimmerman
Micheala Bosworth

**I'm looking for opportunities post-doctorate.**

**Let's connect!**

vietmeiera1@gmail.com

**CV**

**LinkedIn**

DUQUESNE UNIVERSITY
**School of Science and Engineering**
**Dept. Biological Sciences**
**Bayer Fellowship**
**Duquesne Women in STEM (WIS)**

## Funding

U.S. DEPARTMENT OF ENERGY

OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

NSF

ASRS AMERICAN SOCIETY OF RECLAMATION SCIENCES

NATIONAL ENERGY TECHNOLOGY LABORATORY

THE GEOLOGICAL SOCIETY OF AMERICA

AMERICAN SOCIETY FOR MICROBIOLOGY
**ASM Future Leaders Program**
**ASM Allegheny Branch**

NASLR NATIONAL ASSOCIATION OF STATE LAND RECLAMATIONISTS