Biogeophysical interactions control the formation of iron oxide microbial biofilms in acidic geothermal outflow channels of Yellowstone National Park

J. P. Beam[1,2], H. C. Bernstein[3,4], Z. J. Jay[1,2], S. C. Jay[5], M. A. Kozubal[1,2], and W. P. Inskeep[1,2,3]

[1]Thermal Biology Institute, [2]Department of Land Resources and Environmental Sciences, [3]Center for Biofilm Engineering, and [4]Department of Chemical and Biological Engineering Montana State University, Bozeman, MT, 59717, [5]Yellowstone Ecological Research Center, Bozeman, MT, 59718, United States of America

Introduction

- Mechanisms of microbial biofilm formation are widely unknown in geothermal environments.
- Fe(III)-oxide microbial mats provide an excellent opportunity to study biofilm formation *in situ*.
- Underlying biological, geochemical, and physical processes control the formation of Fe(III)-oxide microbial mats in acidic geothermal springs.

Objectives

I. Quantify *in situ* Fe(III)-oxide deposition in two acidic geothermal springs.

II. Determine temporal microbial community structure.

III. Visualize microbial cell attachment and Fe(III)-oxide production

IV. Elucidate potential mechanisms controlling the formation of Fe(III)-oxide microbial biofilms.

Methods

Glass (SiO_2) microscope slides were placed in the primary outflow channel of two acidic geothermal springs in YNP.

Analyzed for total Fe accumulated (oxalate Fe extraction, ferrozine) and DNA extracted to determine microbial community structure (e.g., 16S rRNA gene).

Scanning electron microscopy (SEM) used to visualize cell attachment and biomineralization.

Acidic Geothermal Springs

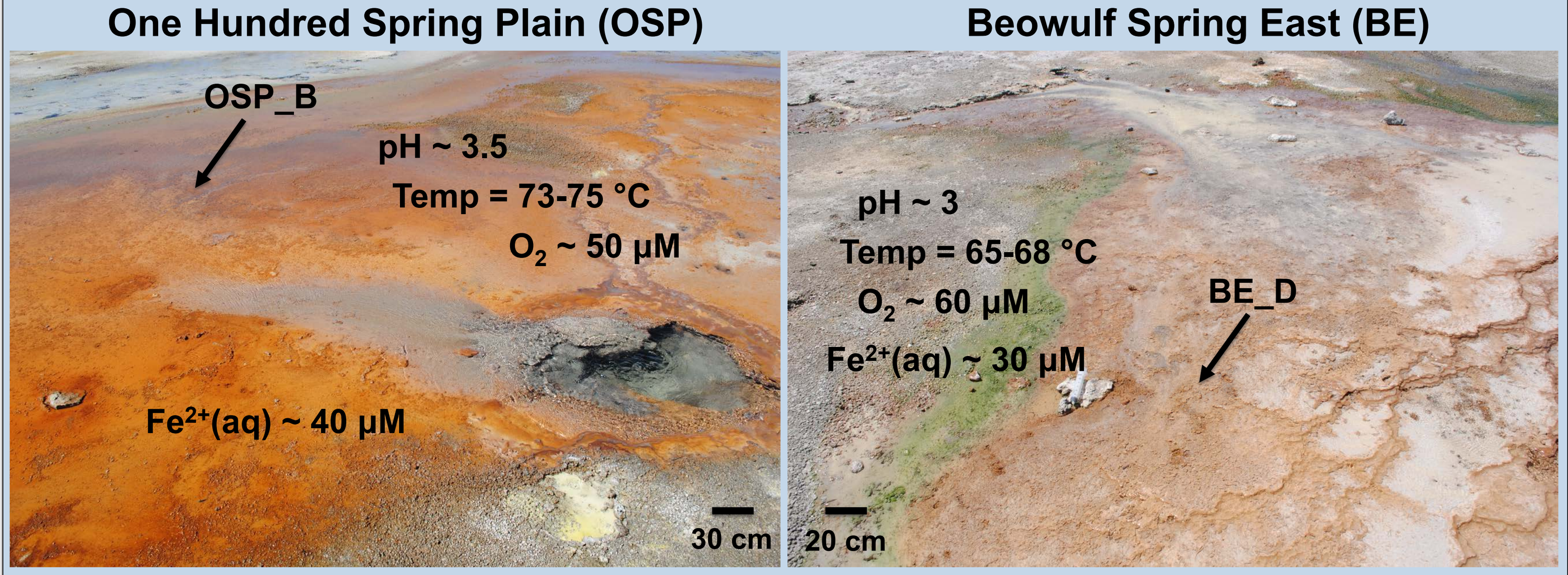

Figure 1. Photographs of One Hundred Spring Plain (OSP) and Beowulf Spring East located in Norris Geyser Basin, Yellowstone National Park, WY, USA. Flow channel velocities are approximately 0.1 – 0.2 m sec^{-1} at each site.

Relevant Archaeal Populations

Population Type	Relative Abundance	HCO	Fe(II)-oxidizer	Reference
OSP_B (T=75 °C, pH=3.5)				
M. yellowstonensis str. MK1	23	Y	Y	Kozubal et al. 2008
'Geoarchaeota'	30	Y	N	Kozubal et al., 2012
Desulfurococcales	14	N	N	Jay et al., 2011
Vulcanisaeta	31	N	N	Jay et al., 2011
BE_D (T=68 °C, pH=3.0)				
M. yellowstonensis str. MK1	12	Y	Y	Kozubal et al. 2008
Novel Archaeal Group 2	38	Y	?	Kozubal et al., 2012
Thaumarchaeota	10	Y	N	Beam et al., 2012
Novel Thermoplasmatales	12	Y	N	Kozubal et al., 2012
'Geoarchaeota'	3	Y	N	Kozubal et al., 2012
Sulfolobales_MK5	14	Y	Y	Kozubal et al., 2012

Table 1. Relative abundance of archaeal populations in BE_D and OSP_B inferred from *de novo* metagenome assemblies. HCO = heme copper oxidase. Data from Bernstein and Beam et al., 2012

Conceptual Model of Biofilm Development

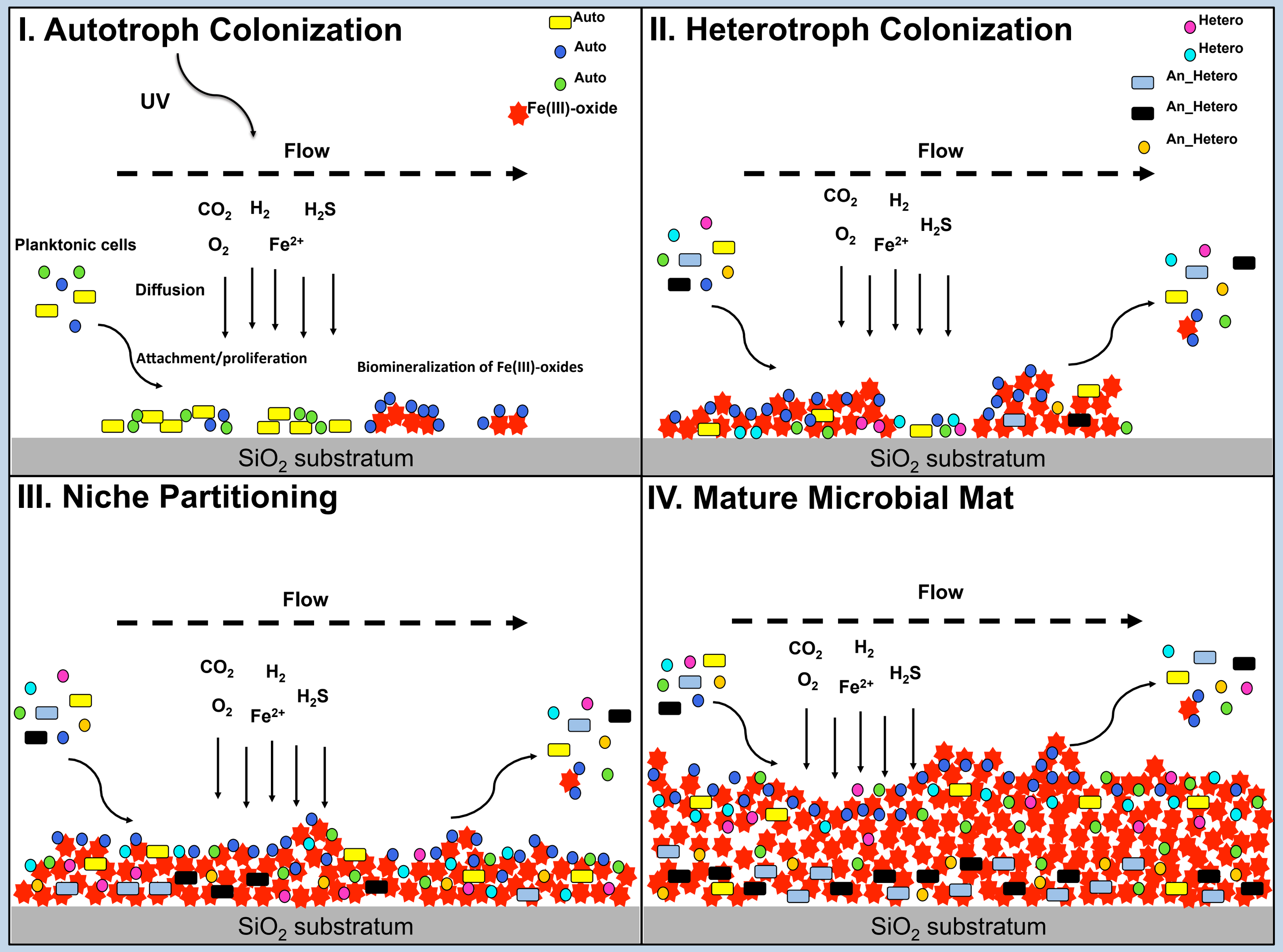

Figure 2. Conceptual model of Fe(III)-oxide microbial biofilm development

Fe(III)-oxide Accretion Rates

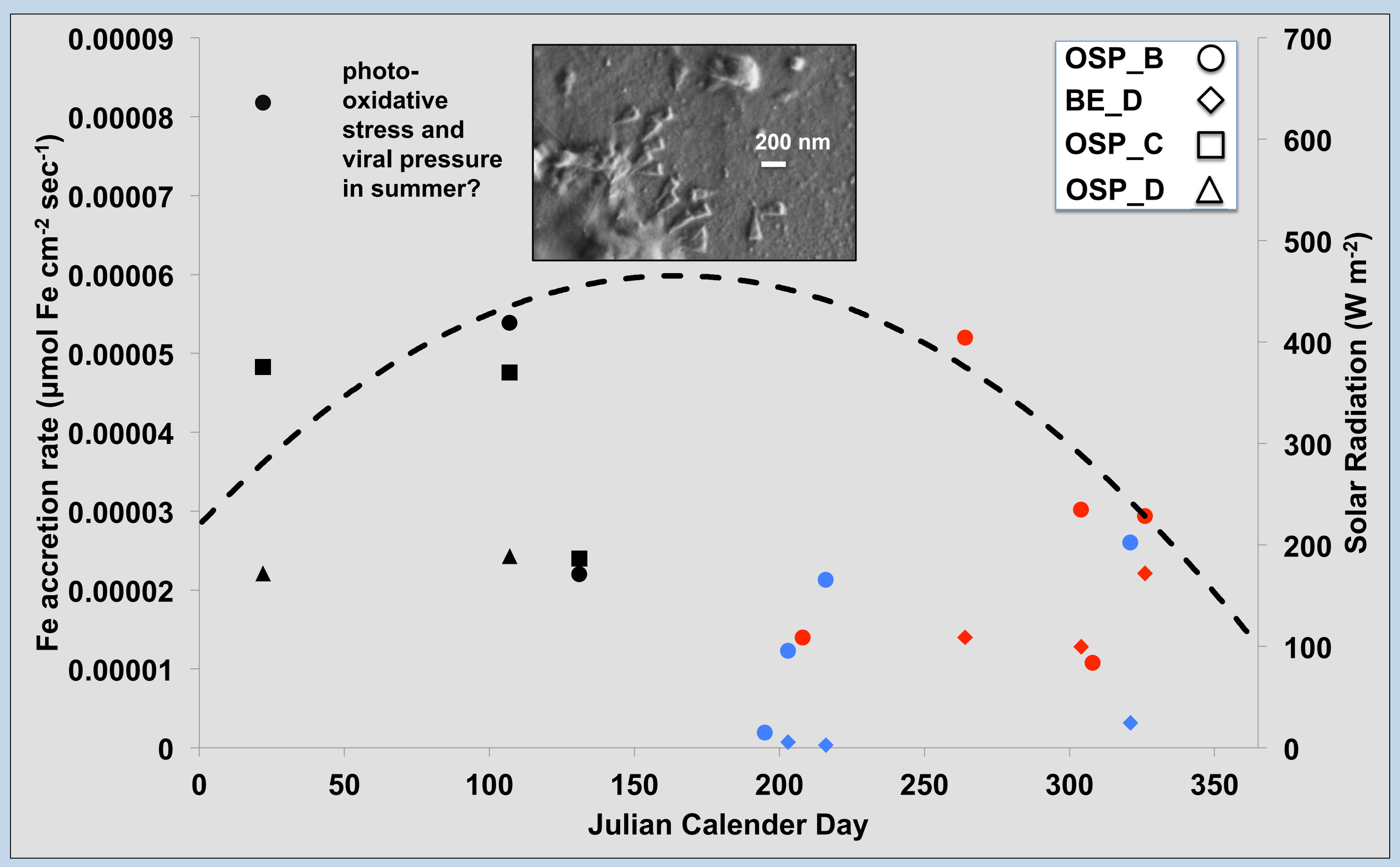

Figure 3. Yearly Fe(III)-oxide accretion rates from 2010-2012 and solar radiation data from 2009 (dotted line, http://www.ntsg.umt.edu/project/topomet#data-product). Black symbols = 2010, blue symbols = 2011, and red symbols = 2012. 2011 data from Bernstein et al., 2012.

OSP_B Temporal Community Dynamics

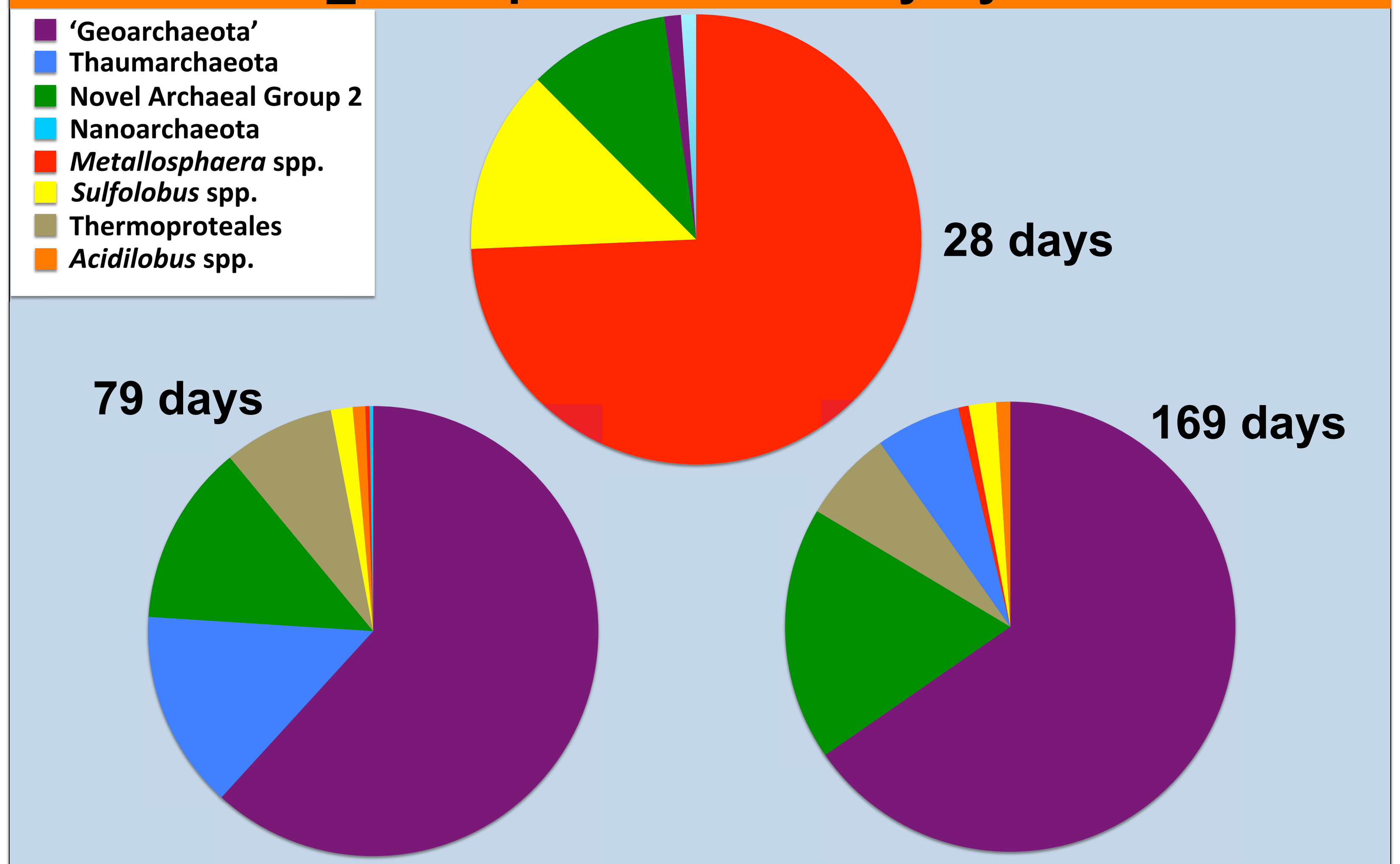

Figure 4. Community dynamics from OSP_B (2010) determined by 16S rRNA gene 454 sequencing. Phylum, order, and genus level taxon classifications based on > 97 % nucleotide identity to custom (YNP thermophiles) reference 16S rRNA gene database.

Microbial Attachment and Biomineralization

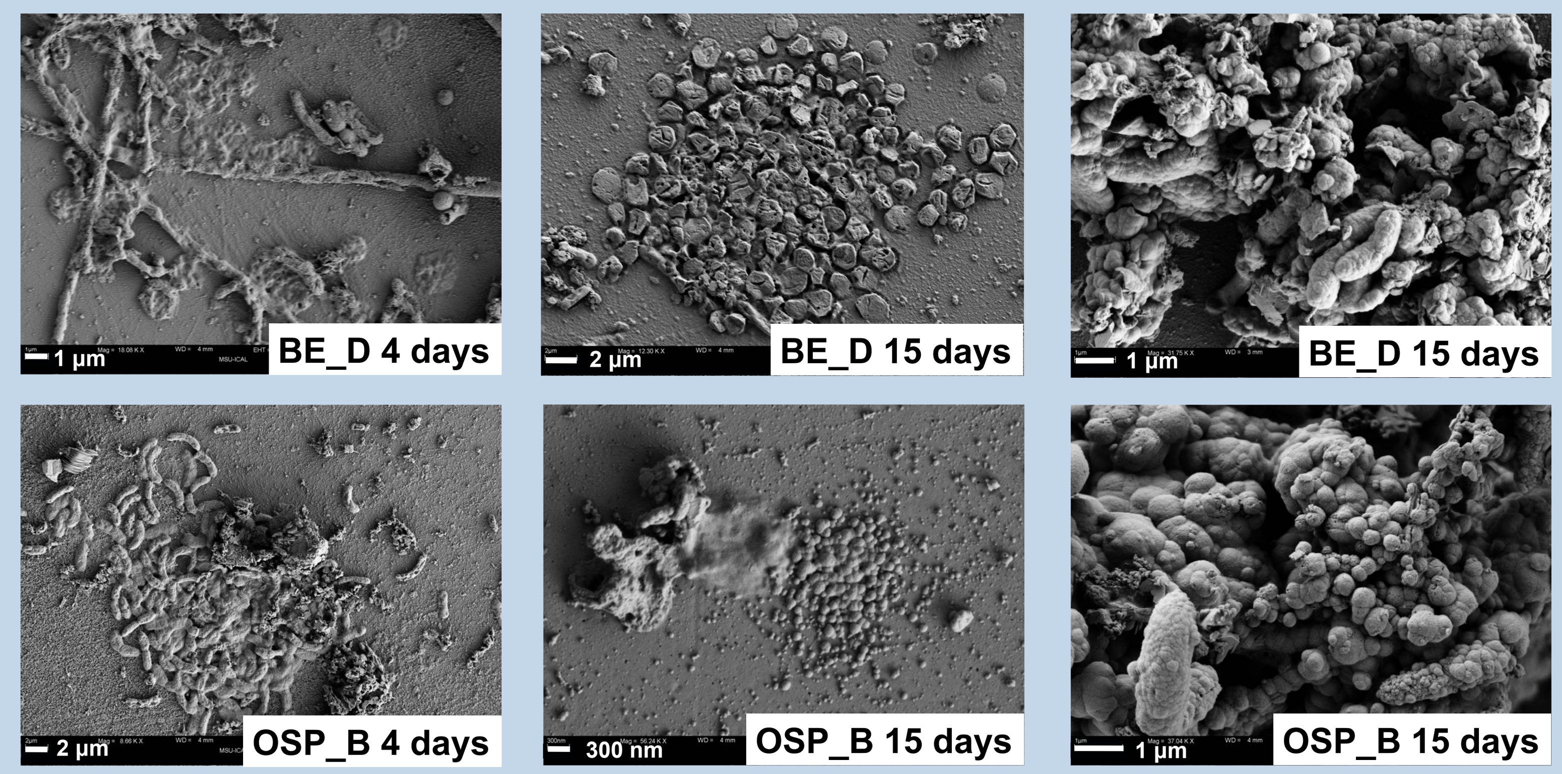

Figure 5. Scanning electron microscopy of *in situ* incubated slides revealing abundant microbial attachment and biomineralization.

Discussion

- Fe(III)-oxide biofilm formation is a **dynamic process**.
- **Photo-oxidative (e.g. UV)** stress over summer months may reduce Fe(III)-oxide formation due to **viral pressure.**
- Autotrophic, Fe(II)-oxidizing ***Metallosphaera* spp**. are **abundant** during **early** biofilm formation.
- Heterotrophic members of a new candidate phylum **'Geoarchaeota'** are more abundant in mature microbial mats.
- Microbial cells are attached and **abundant** within **4 days**.
- A combination of **biological**, **geochemical**, and **physical** processes **control** the formation of Fe(III)-oxide microbial mats.
- Future work will focus on temporal dynamics using 16S rRNA gene pyrotag sequencing, ^{13}C analysis, FISH, and nanoSIMS.

Acknowledgements

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