Exploring the Feasibility of Biocementation for ISRU Construction on Mars

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Introduction

- Martian exploration will require construction using local materials (ISRU)
  - Launch/landing pads, habitats and shelters, roads, berms, etc.
- Biomineralization offers a low-energy construction method [1]
  - Microbes mediate mineral formation
  - Can leverage natural regolith chemistry
- Assess biocementation feasibility for Mars in terms of composition, mineralization pathways, environmental constraints, and implementation methods

Biocementation

- Uses microorganisms to precipitate minerals to produce carbonate minerals that bind grains together (Figure 1)
  - Increases strength/stability
  - Common for soils on Earth
- Most common pathway is Microbially-Induced Calcium Carbonate Precipitation (MICP) (e.g., ureolysis, Table 1)

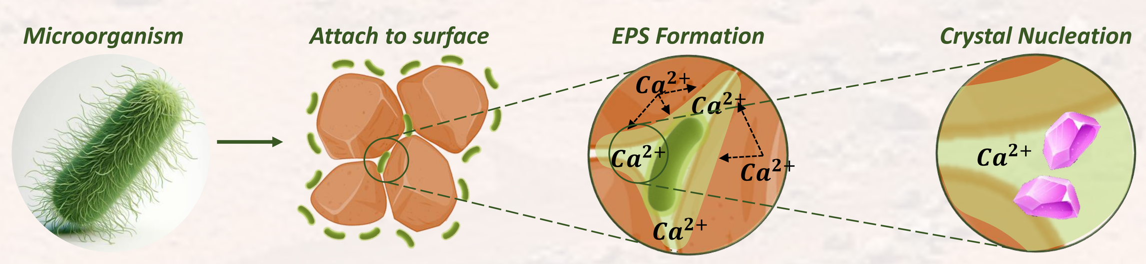

Figure 1. Depiction of the biocementation process.

Table 1. Comparison of biocementation pathways.

Pathway	Speed	Resources	Byproducts	Conditions
Ureolysis	Fast	Urea (urine), Ca^{2+} (regolith)	NH_3 (manageable)	Aerobic/ Anaerobic
Ammonification	Slow	Amino Acids, O_2 Ca^{2+} (regolith)	NH_3 (manageable)	Aerobic/ Anaerobic
Photosynthesis	Slow	CO_2 (atmosphere), light, water	O_2	Anaerobic
Denitrification	Slow	Nitrates (regolith), organic carbon	N_2	Anaerobic
Sulphate Reduction	Slow	Sulphates (regolith), organic carbon	H_2S (toxic)	Anaerobic
Methanogenesis	Slow	CO_2, organic carbon	CH4 (usable)	Anaerobic

Considerations for Biocementation Construction on Mars

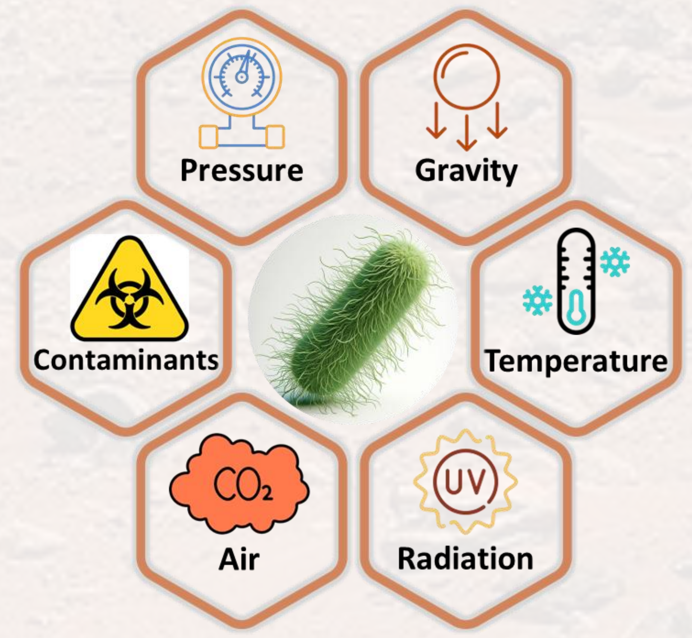

Figure 2. Factors affecting microbial activity and biocementation feasibility/efficiency.

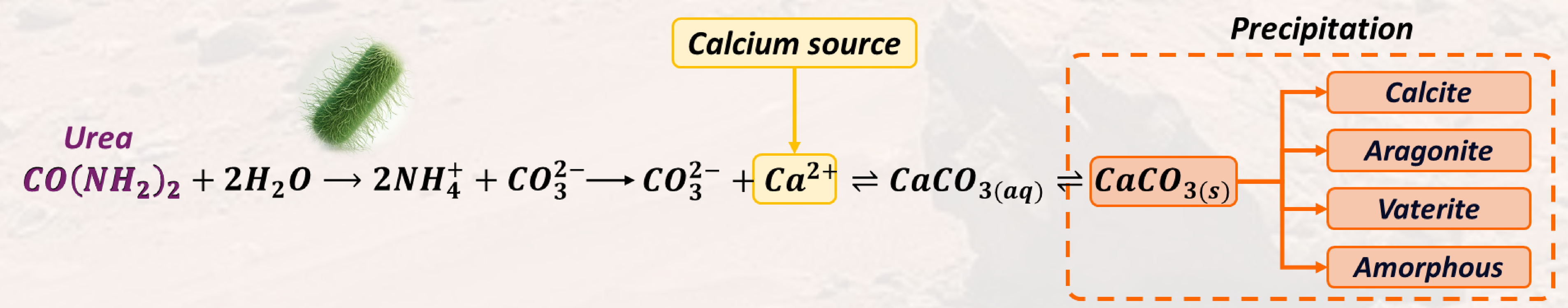

Figure 3. MICP reaction and precipitates

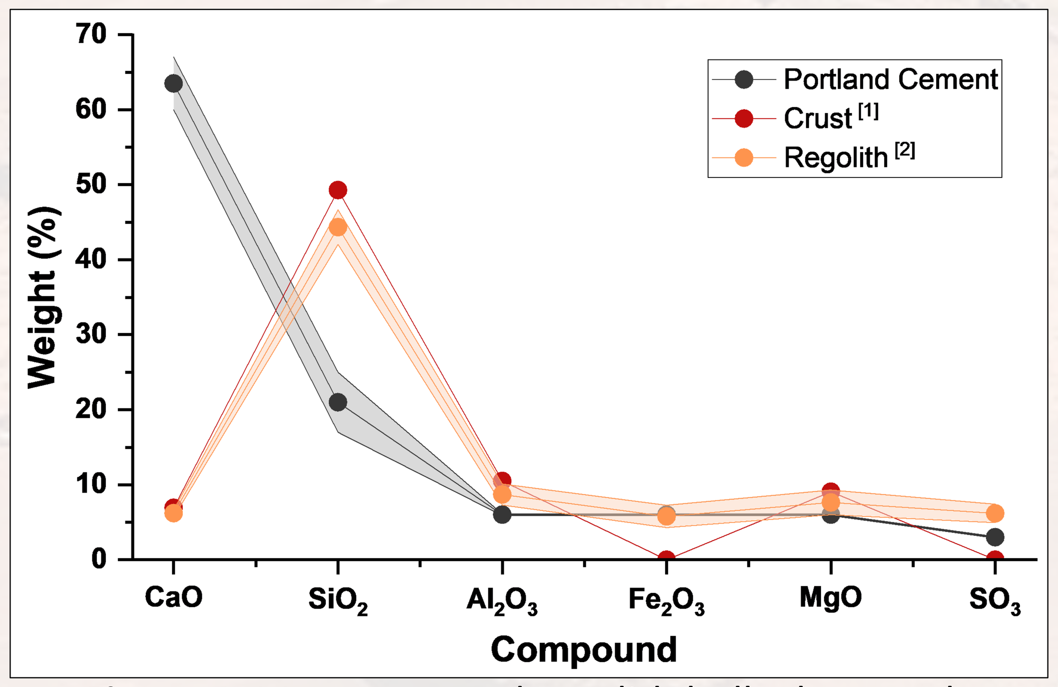

Figure 4. Mars crust and regolith bulk elemental composition [2,3] compared to standard Portland Cement.

Table 2. Environmental parameters of Earth compared to those of Mars, detailing the extreme Martian environment.

Parameters		Earth	Mars
Gravitational acceleration [m/s²]		9.81	3.72
Diurnal cycle [Earth days]		1	1.02
Surface temperature range [°C]		-89 to 58	-153 to 26
Magnetic vector field (A/m)		24 –56	0
Atmospheric pressure [bar]		1	6×10^{-3}
Atmospheric Composition	O_2	20.9 %	0.16 %
	CO_2	0.03 %	95 %
	CO		0.06
	N_2	78.1 %	2.6 %
	Ar	-	1.9 %
Daily surface radiation [mSv/day]		2 –3	200

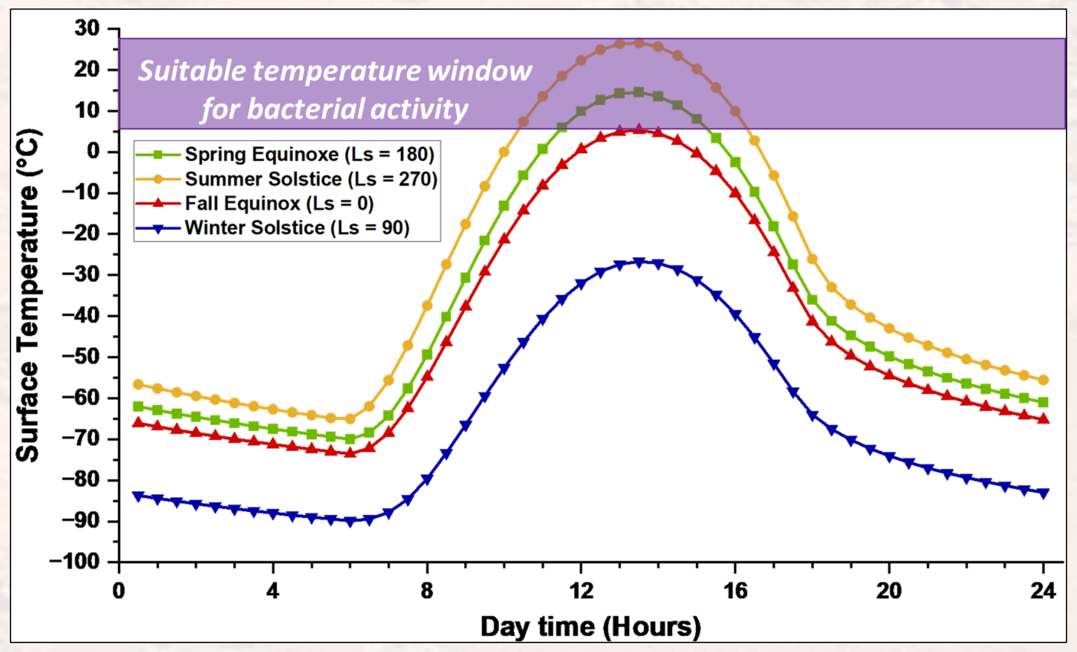

Figure 5. Mars surface diurnal temperatures as a function of position along orbit (retrieved from KRC Software) indicating that for portions of the year, the temperature is suitable for biocementation activity.

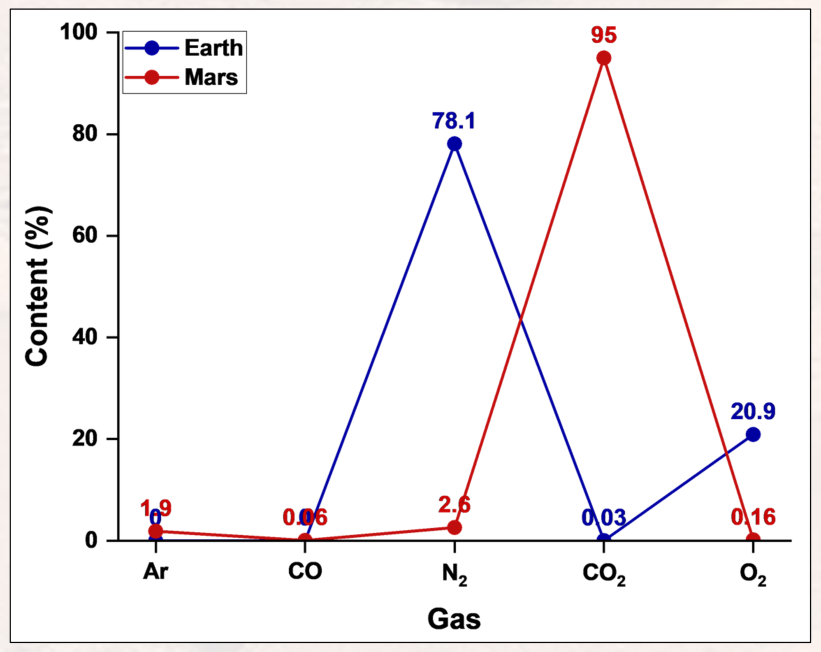

Figure 6. Atmospheric compositions of Mars and Earth showing that Mars does not have sufficient oxygen concentration for aerobic bacterial activity.

Discussion

- Biocementation for construction on Mars is promising but still largely conceptual
- Highly integrable with robotic and human exploration and ISRU [1]
  - Robotic, 3D printing-like biocementation reactors in contained habitats [1]
- Major unknowns:
  - Bacterial survival in Martian conditions and effects on biocementation efficiency
  - Containment methods for planetary protection
- Low energy requirements reduce mission demands [1]

Conclusion

- Martian regolith chemistry supports biomineralization, CaCO3 precipitation is most promising pathway
- Main advantages are low energy and ISRU system integration
- Performance needs validated in Mars environmental conditions

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References

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