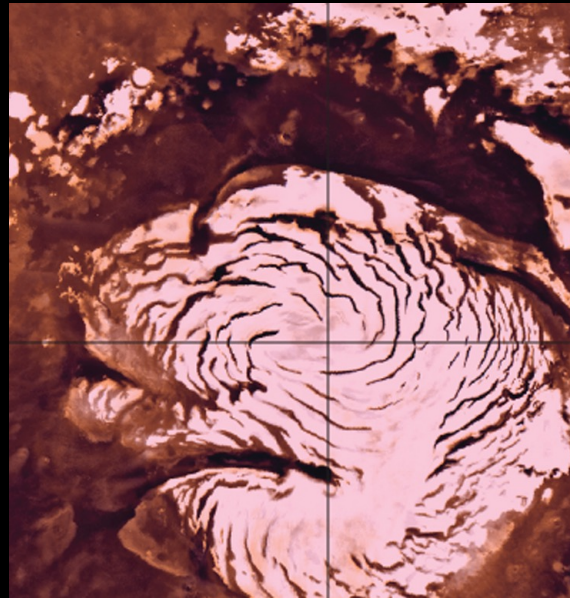


Engineered bioremediation of water obtained from *in situ* resources on Mars



Garrett A. Roberts Kingman

NASA Postdoctoral Program, Ames Research Center

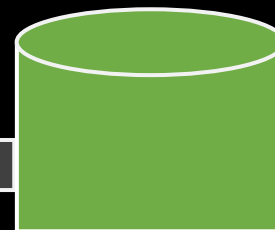
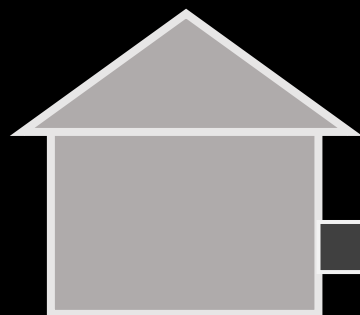
With Lynn Rothschild and Carol Stoker

Ice
mining
system

Water
with
dissolved
salts

Purification
system

Usable
water



Martian surface

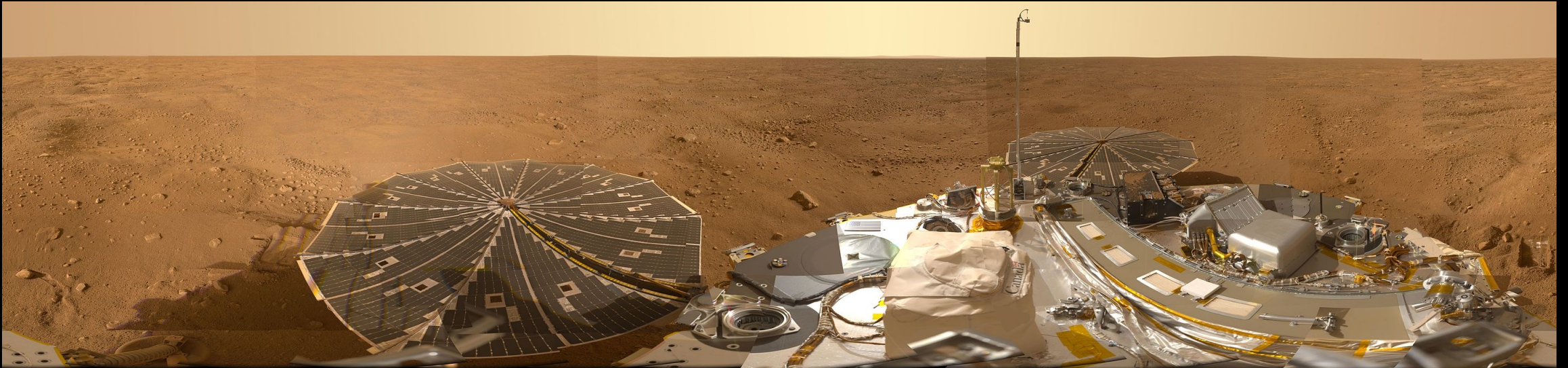
Liquid water
pumped out

Heat generated
to melt ice

Subterranean ice



Dissolved salts: perchlorate and chlorate



- Martian regolith is $\sim 0.6\%$ perchlorates/chlorates by mass
(Hecht et al. 2009, Elsenousy et al. 2015, Chevrier et al. 2022)
- Estimate concentrations in extracted water on order of 1%

Why are perchlorate and chlorate important?

- Acute toxicity at ~15g for both molecules via hemolysis, hemoglobin oxidation, and renal failure
- Effects of chronic exposure include thyroid inhibition and lung toxicity

	Water Limit (Agency)
Perchlorate	6 ppb (CA)
Chlorate	800 ppb (CA notification level)

- **Must reduce perchlorate/chlorate levels approximately 100,000 fold**

Traditional engineering solutions

A shrinking problem

Years of pumping groundwater and cleaning it, along with dilution from rainwater, have shrunk the size of the perchlorate plume between Morgan Hill and Gilroy from 10 miles long to 1.75 miles long.

Perchlorate levels (micrograms per liter)

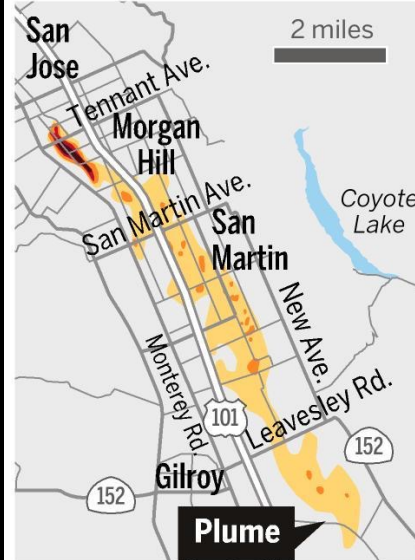
4.0 to 6.0

6.1 to 11

11.1 to 24.5

24.6 and up

2007 Third quarter



2012 Third quarter

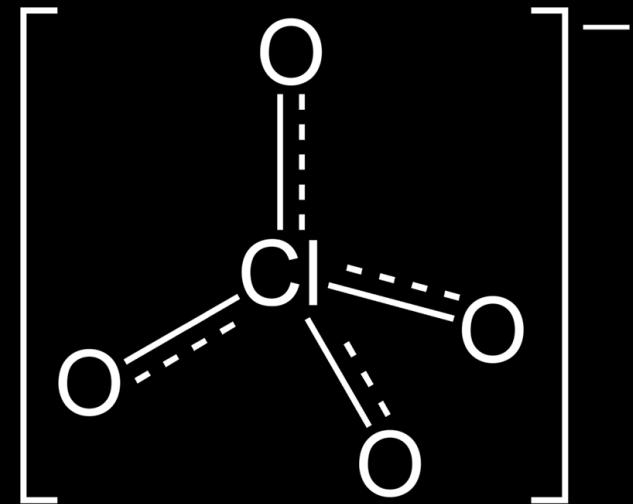


Source: Central Coast Regional Water Quality Control Board
BAY AREA NEWS GROUP

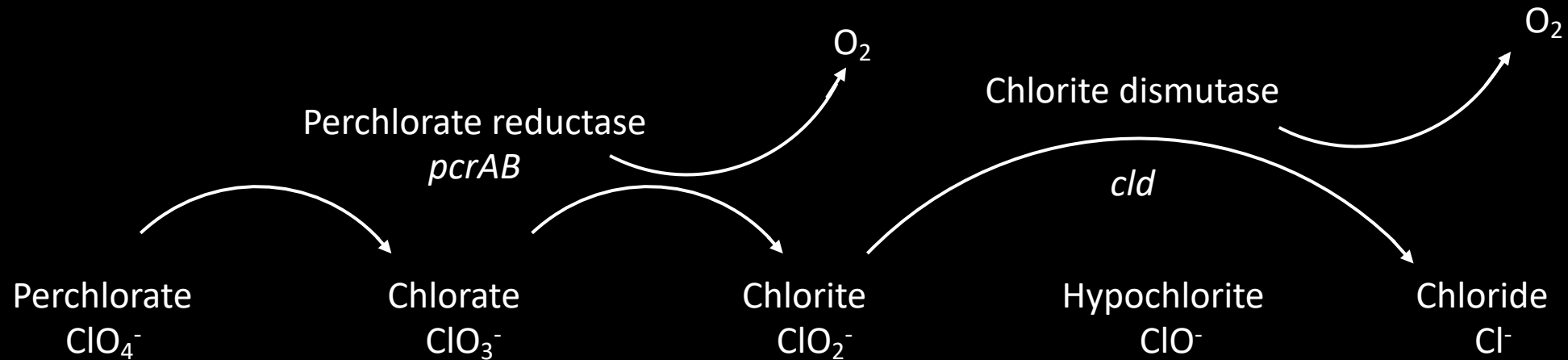
- Anion exchange resins
- Reverse osmosis
- Adsorption
- Distillation

Challenges for traditional approaches

- Perchlorates are potent oxidizers and increase wear on equipment and membranes
- Desalination creates concentrated brines
 - Water wasted
 - Dump locally or transport?
- The stricter the requirements, the more challenging the design (and higher power/mass)



Solution: controlled reduction of perchlorates



Reduction of perchlorates is thermodynamically favorable

Microbes and enzymes to catalyze these reactions are known



Image: *Dechloromonas aromatica*, DoE JGI

Natural perchlorate reduction

> [Curr Microbiol.](#) 2002 Oct;45(4):287-92. doi: 10.1007/s00284-002-3751-4.

Bioremediation of chlorate or perchlorate contaminated water using permeable barriers containing vegetable oil

William J Hunter ¹

Affiliations + expand

PMID: 12192528 DOI: [10.1007/s00284-002-3751-4](#)  Paperpile

Abstract

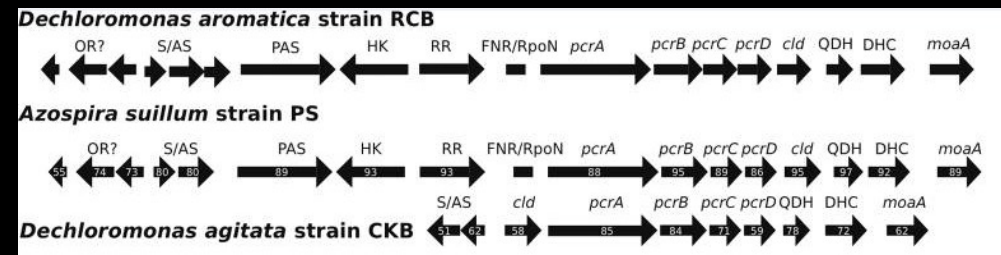
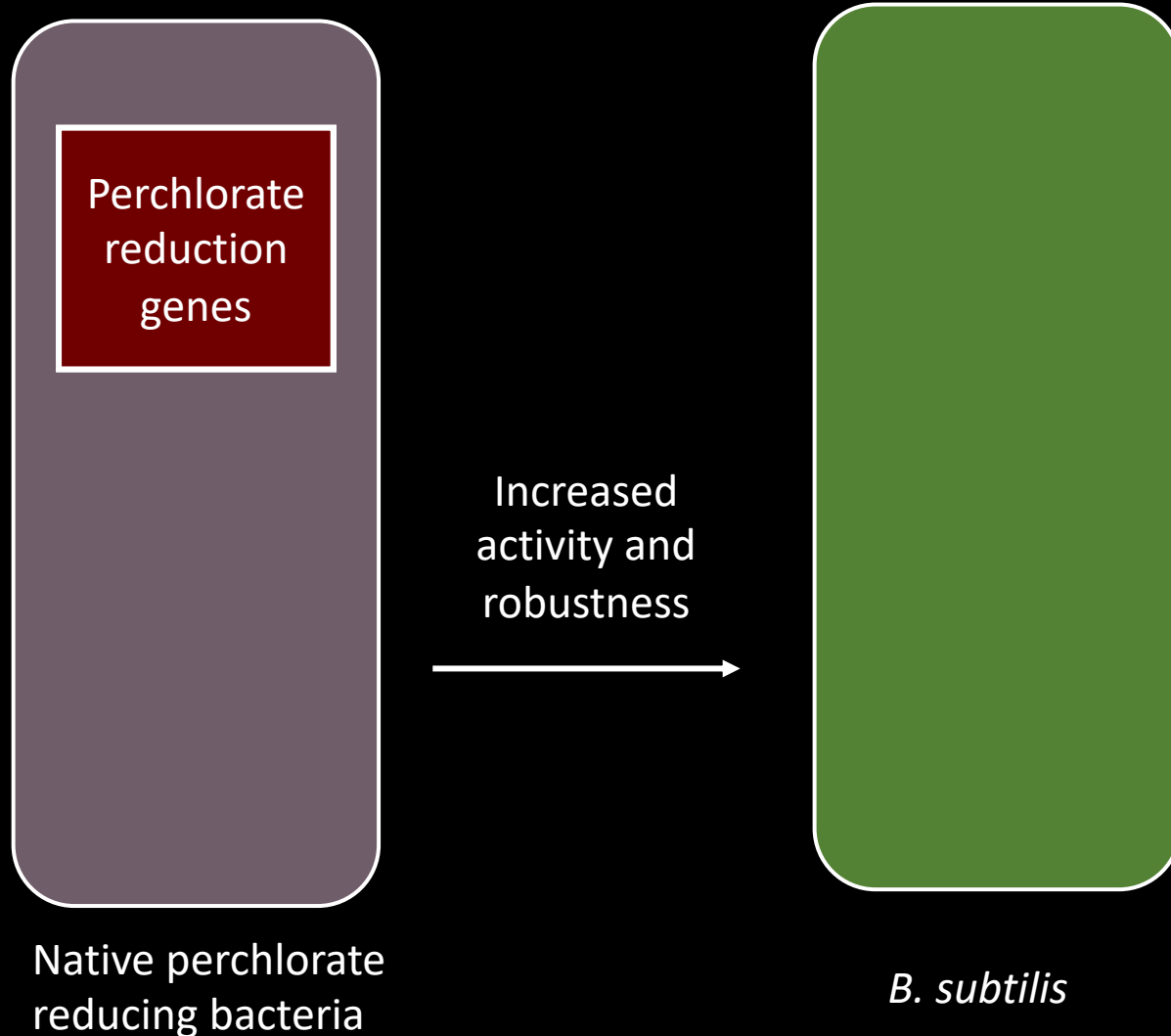
A scale model of an in situ permeable barrier, formed by injecting vegetable oil onto laboratory soil columns, was used to remove chlorate and perchlorate from flowing groundwater. The hypothesis that trapped oil would serve as a substrate enabling native microorganisms to reduce chlorate or perchlorate to chloride as water flowed through the oil-rich zone had merit. Approximately 96% of the 0.2 mM chlorate and 99% of the 0.2 mM perchlorate present in the water was removed as water was pumped through columns containing vegetable oil barriers. The product formed was chloride. When nitrate at 1.4 mM was added to the water, both nitrate and chlorate were removed. High concentrations of chlorate or perchlorate can be treated; 24 mM chlorate and 6 mM perchlorate were completely reduced to chloride during microcosm incubations. Microorganisms capable of reducing perchlorate are plentiful in the environment.

- Natural perchlorate reducing bacteria are abundant on Earth
- Research over several decades has identified environmental conditions most conducive to promoting native microbial perchlorate reduction
- Now considered as a standard option for perchlorate detoxification

Controlled reduction of perchlorates

Problem	Solution

Perchlorate reduction: a transferable application



Overall goal: use microbes for controlled reduction of perchlorates

- Integrate perchlorate reduction genes to *B. subtilis* strain 168 with strong, continuous expression
- Test efficacy and speed of reducing perchlorate & chlorate
- Engineer elevated reaction rate and robustness
- Explore possibility of extracellular and purified proteins (leveraging AstroPharmacy and BioMining)



 Tolerance to treated media

Additional genes for error handling?

