Towards Reducing Wellbore Leakage via a Novel Wellbore Biomineralization Technology based on Microbially Induced Carbonate Precipitation (MICP)

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Outline

- Oil and Gas Wells
  - Build and Leakage
  - Typical Repair
- Biomineralization
  - MICP
    - Shallow Depth
    - Deep Depth

Oil and Gas Wells

Build and Leakage

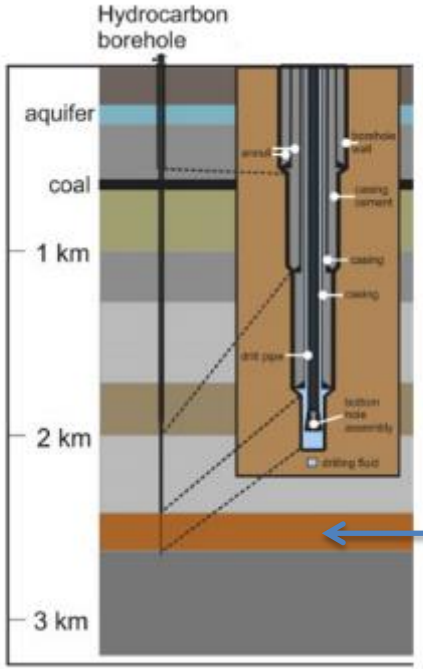


Fig 1. Hydrocarbon well drilling (*Modified from Davies et al., 2015*)

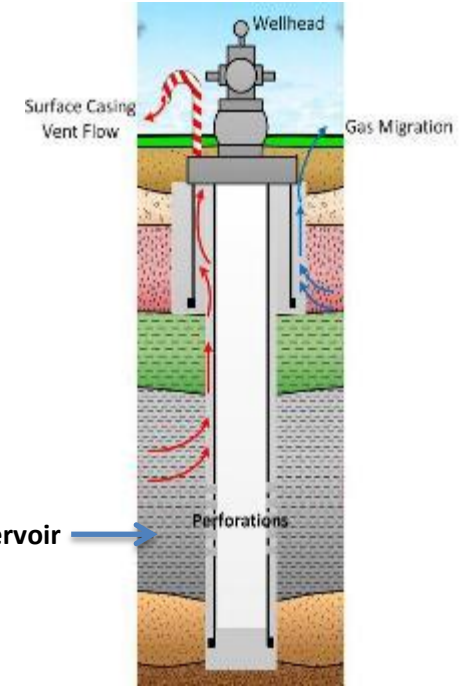


Fig 2. Hydrocarbon and gas migration (*Modified from Hardie & Lewis, 2015*)

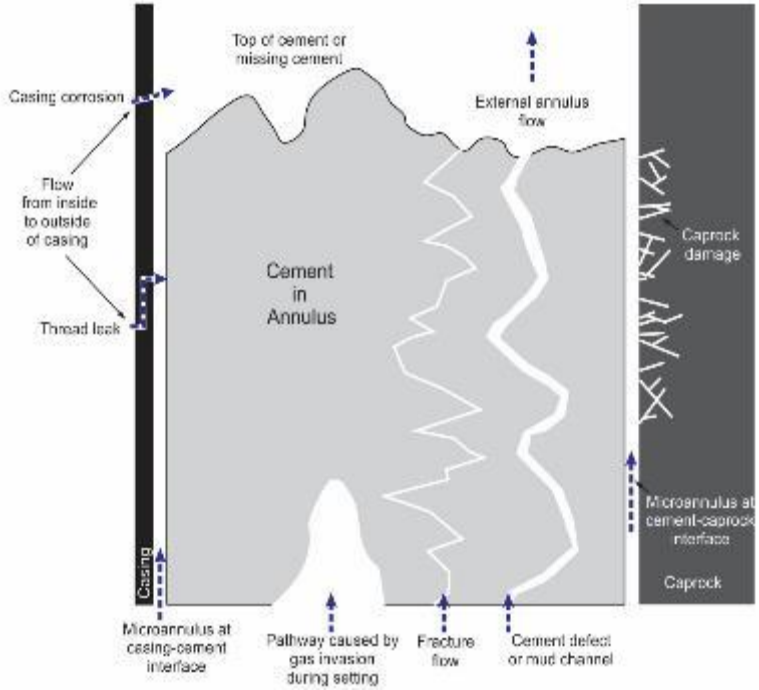


Fig 3. Wellbore damage and routes for fluid leak (*Carrol, Int. J. Greenh. Gas Con., 2016*)

Oil and Gas Wells

Build and Leakage

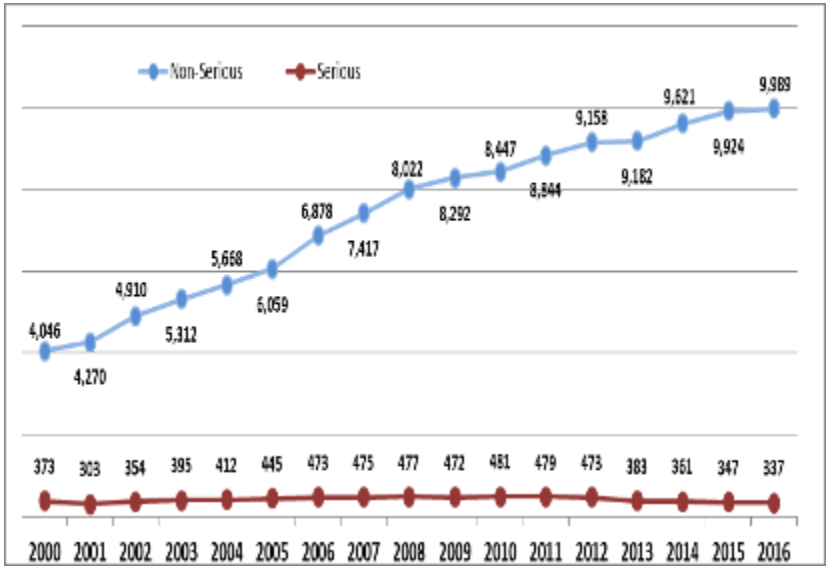


Fig 4. Hydrocarbon well drilling (*Alberta Energy, 2016*)

Fig 5. Hydrocarbon well drilling (*Noomen et al., Ecol. Inform., 2012*)

Oil and Gas Wells

Typical Repair

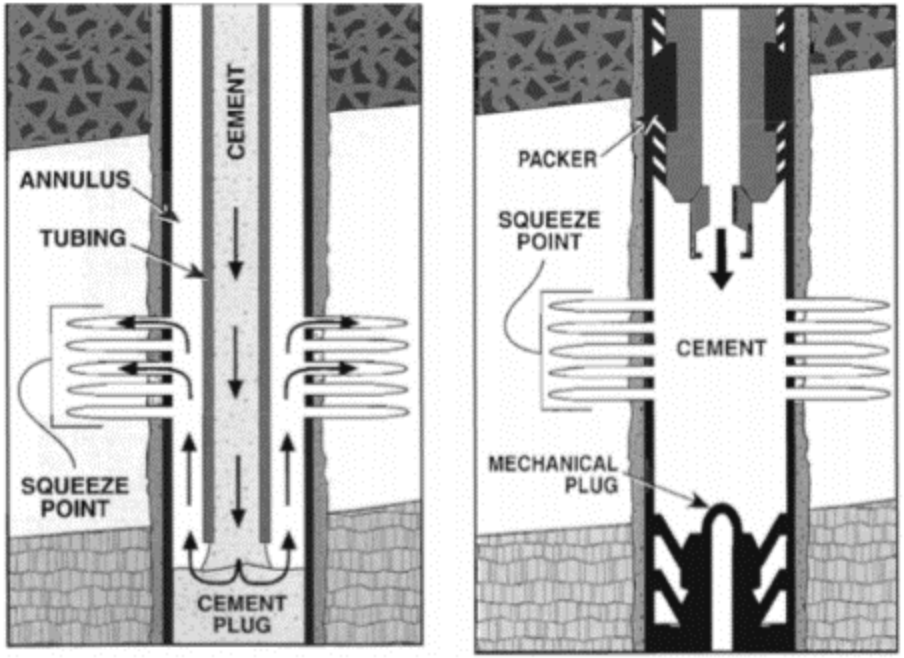


Fig 6. Bradenhead (left) and packer (right) squeeze (*Van Dyke, 1997*)

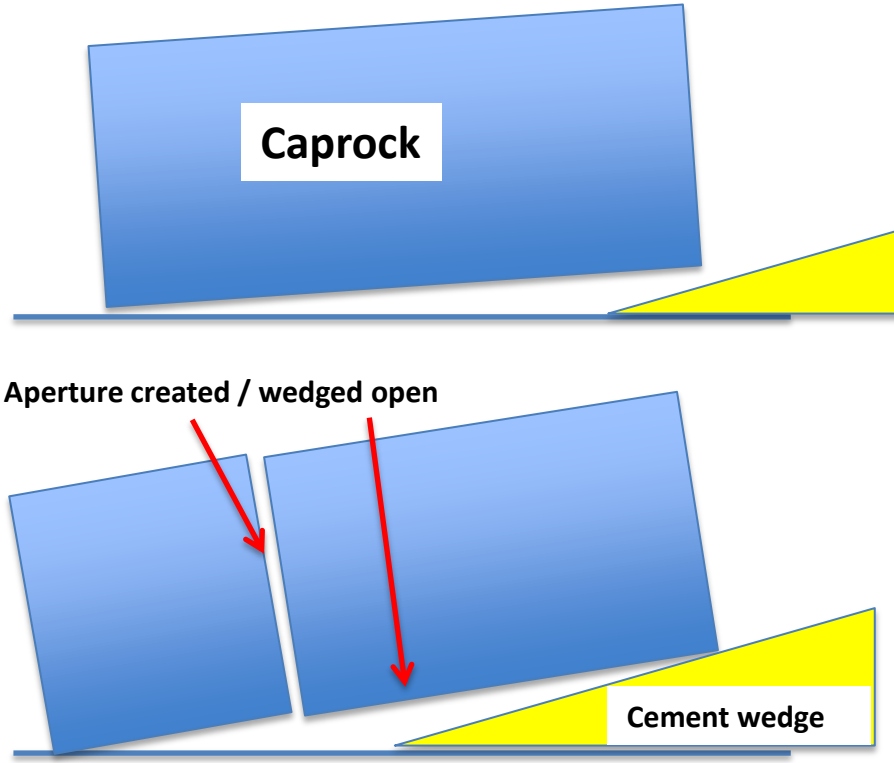
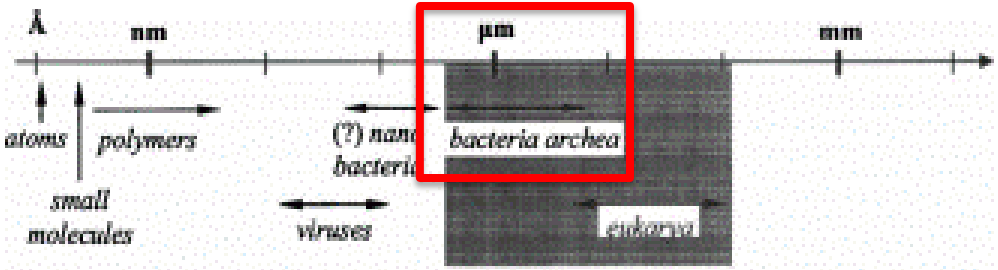
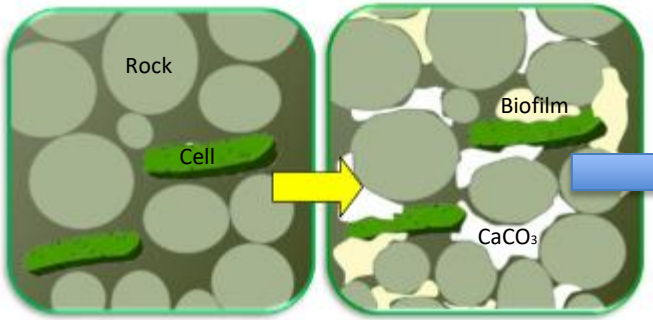


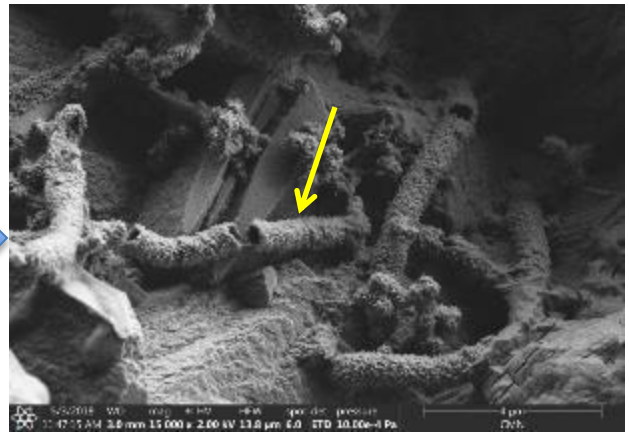
Fig 7. Cement 'wedge' effect (*Modified from Dusseault et al., 2014*))

Biomineralization

MICP







Vs. Amorphous Formation

https://www.youtube.com/watch?v=hq_k3QNwwfg

Biomineralization MICP

Reaction	Substrate	Product
Ureolysis	Urea	$2NH_4 + CO_3$
Denitrification	NO_3	N_2
Sulfate Reduction	SO_4	H_2S
Iron Reduction	Fe(III)	Fe(II)
Photosynthesis	HCO_3	CO_3

Table 1. Alkalinity and CO_3 generating microbial processes (*Adapted from Graddy, et. al., ES&T, 2018*)

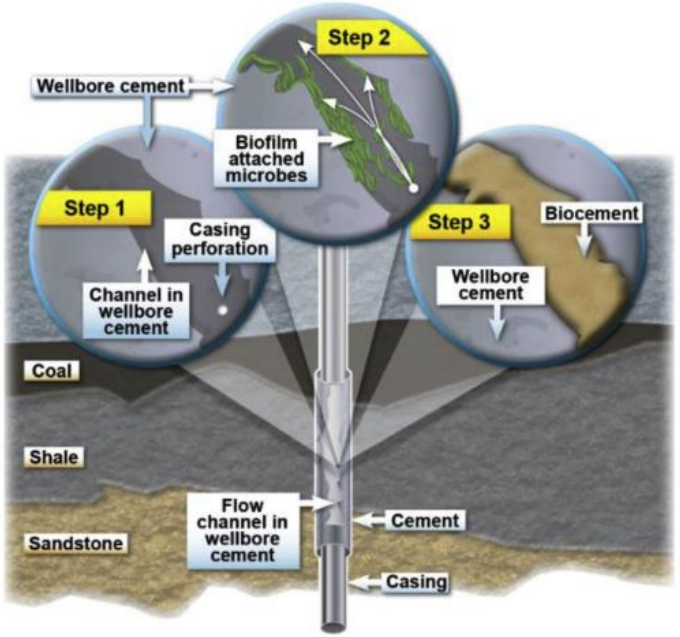


Fig 10. Biomineralization of wellbore (*Phillips et al., ES&T, 2018*)

Biomineralization

MICP – Shallow Depth

Fig 8. Analog fractured wellbore system (*Phillips et al., 2015*)

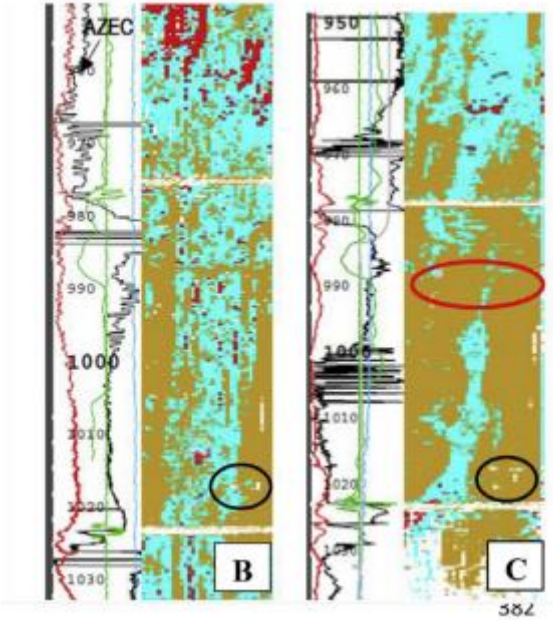


Fig 9. Field-scale wellbore repair before (b) and after (c) MICP injection *(Modified from Phillips et al., J. Pet. Sci. Eng.,2018)*

Biomineralization

MICP – Deep Depth

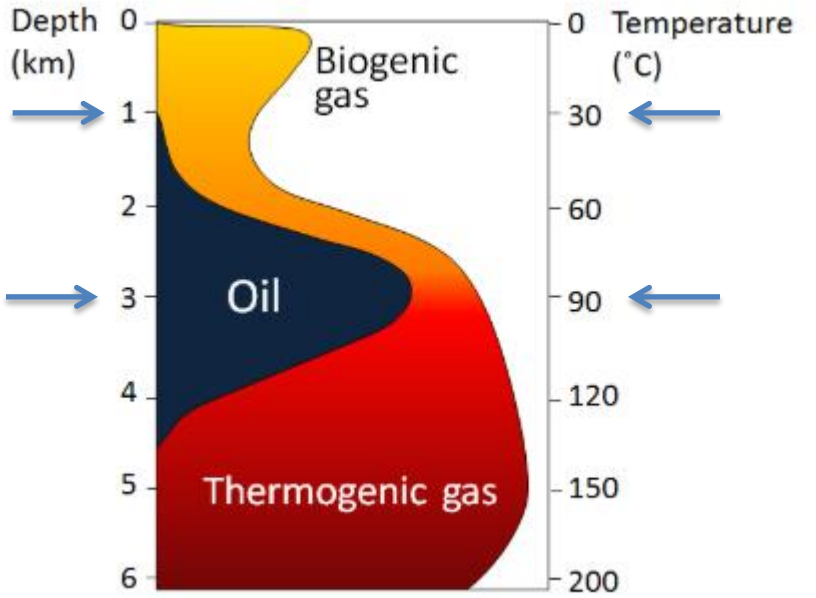


Fig 10. Hydrocarbon distribution at depth and temperature (*Steven Earle, Physical Geology, Chapter 20.3*)

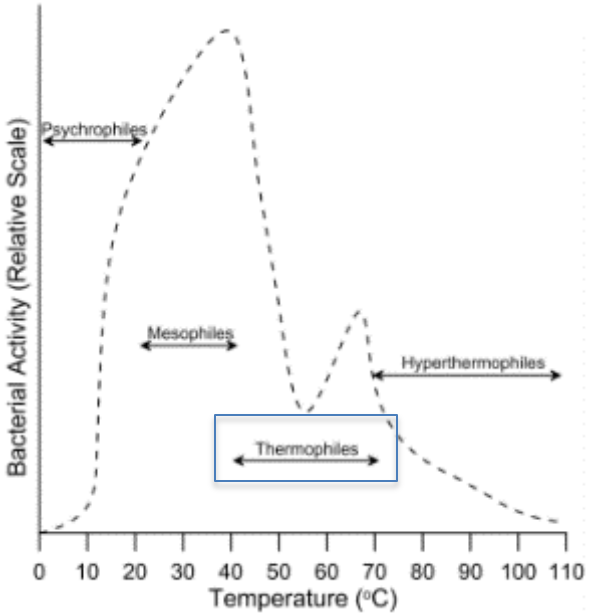


Fig 11. Bacterial activity in wells as a function of temperature (*Katz, Open Geology Journal, 2011*)

Biomineralization

MICP – Deep Depth

- Identify candidate bacteria for deep depth MICP
- Test candidates at elevated temperatures and salinities
- Confirm top candidate(s) for carbonate mineral production
- Explore growth under pressure

Biomineralization

MICP – Deep Depth

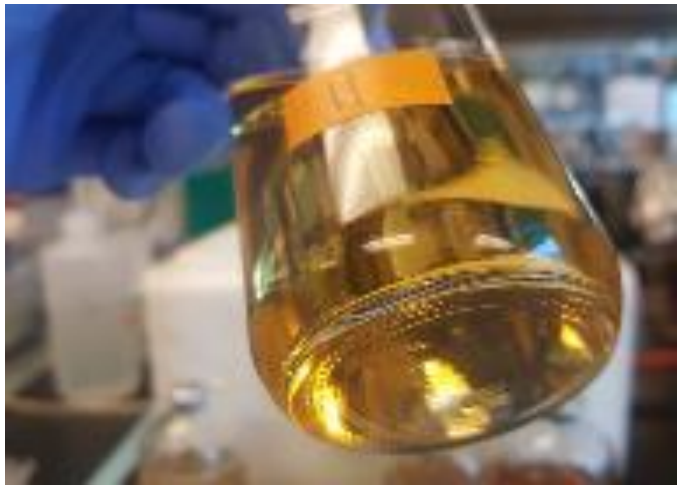
Character	1	2	3	4	5	6	7	8	9	10	11	12	13
Temperature Range (°C):													
Liquid	10-35	10-35	40-65	40-65	45-65	40-70	45-70	45-70	40-65	10-50	45-65	30-65	20-40
Solid	10-35	10-35	45-65	40-70	40-70	40-70	40-75	40-70	40-70	10-50	40-65	30-65	15-40
Optimal	25	25	55	60	55	60	60	60	60	45	60	60	35
NaCl range (%)	0-5	0-5	0-3	0-1	0-3	0-3	0-5	0-3	0-5	0-20	0-3	0-5	0-3
Hydrolysis of Urea:													
Stuart's Broth (Strong)	+	+	-	-	-	-	-	-	-	w	-	-	-
Christensen's Broth (Weak)	+	+	-	v	v	v	-	-	-	w	-	w	-
Reduction of Nitrate	+	+	+	+	+	+	+	+	+	-	+	+	+
Gas Produced	-	-	-	-	v	v	+	+	-	-	-	-	+
Anaerobic growth	-	-	+	+	+	+	+	+	+	-	+	+	+
Final pH with NO_3^*	6.70	6.85	6.40	6.40	6.75	6.90	7.90	7.15	6.10	6.70	6.25	6.20	8.20

* DNB pH = 6.5-6.7 ; *Escherichia coli* pH = 5.5-5.6

Table 2. Physiological characteristics of *Geobacillus, Sporosarcina, Gracilibacillus and Anoxybacillus*

Biomineralization

MICP – Deep Depth



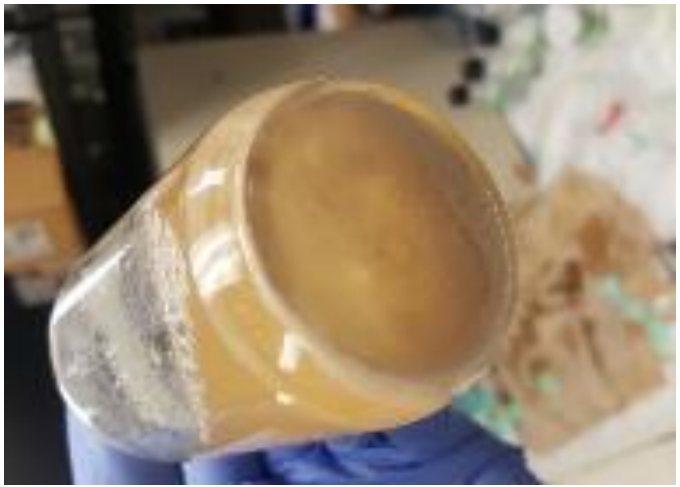


Fig 12. $CaCO_3$ production trials with *G. subterraneus* and *G. thermodentrificans* (60°C, 48h)

Biomineralization

MICP – Deep Depth

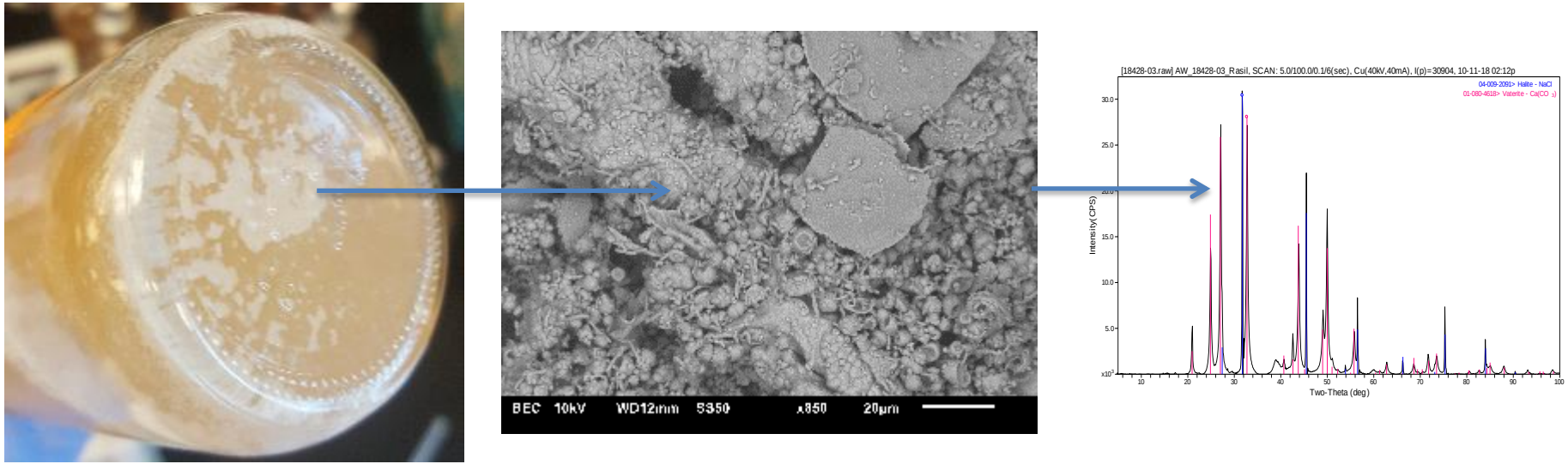


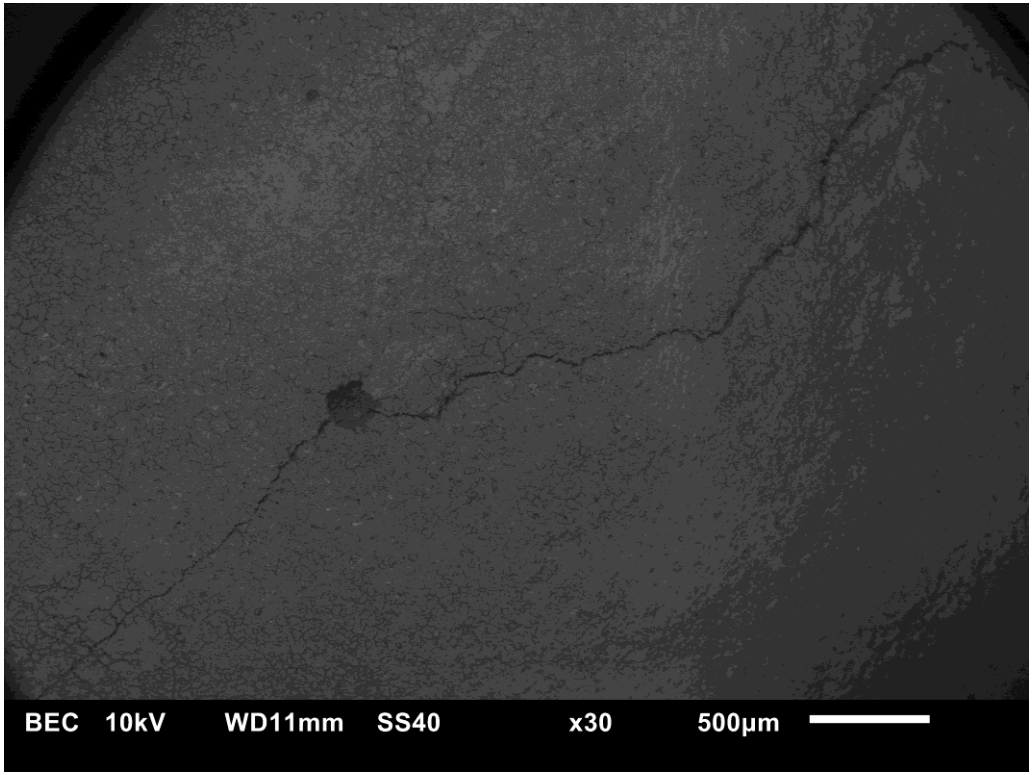
Fig 13. $CaCO_3$ production trials with *G. subterraneus* and *G. thermodentrificans.*

Biomineralization

MICP – Deep Depth

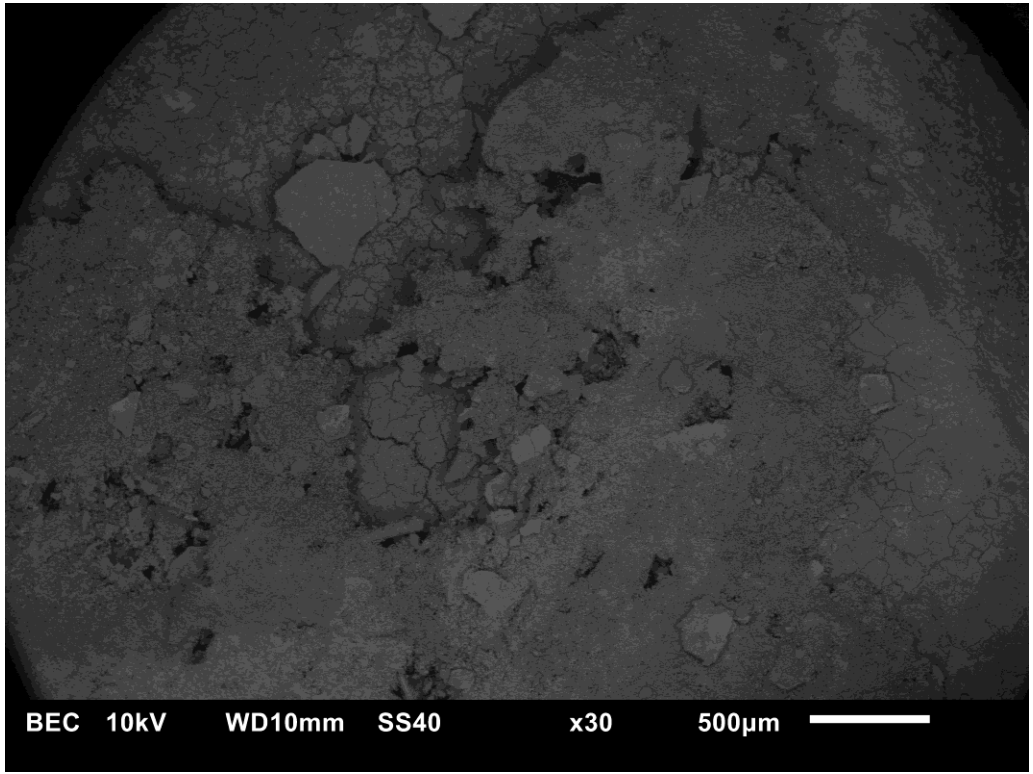
Biomineralization

MICP – Deep Depth



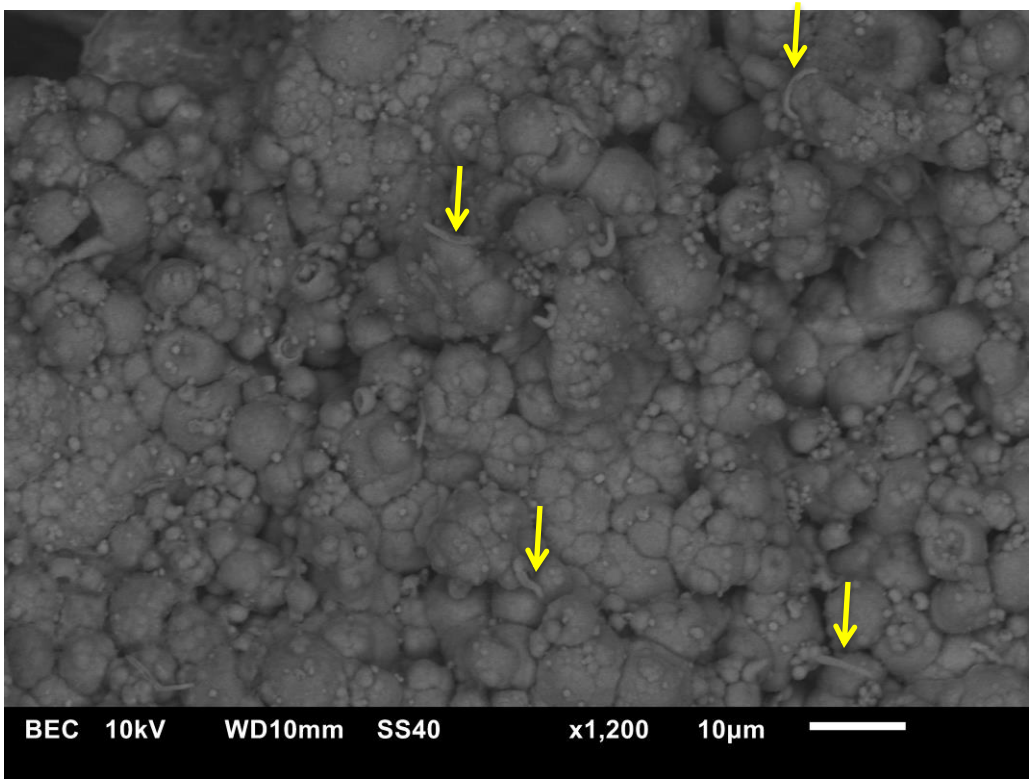
Biomineralization

MICP – Deep Depth



Biomineralization

MICP – Deep Depth



Biomineralization

MICP – Deep Depth

Fig 14. Pressure reactor apparatus

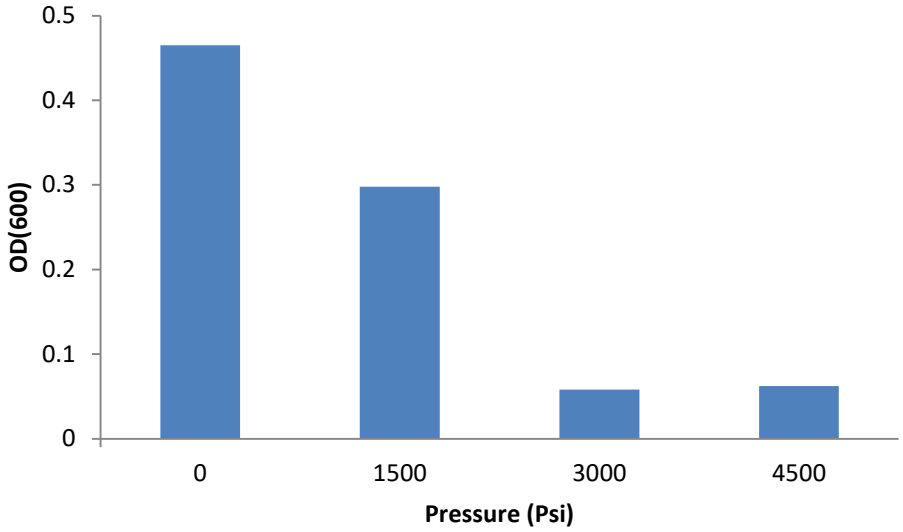


Fig 15. Growth of *G. thermodentrificans* at wellbore-like pressures (50°C, 48h)

Biomineralization

MICP – Deep Depth

- Identify candidate bacteria for deep depth MICP
- Test candidates at elevated temperatures and salinities
- Confirm top candidate(s) for carbonate mineral production
- Explore growth under pressure
- Investigate metabolic pathway and quantify byproducts overtime (optimize MICP)
- Test in wellbore analog system

Questions?

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