Arctic Ocean
Beaufort Sea
ALASKA (USA)
Bering Sea
Gulf of Alaska
CANADA
Hudson Bay
Baffin Bay
Davis Strait
Labrador Sea
GREENLAND (DENMARK)
ICELAND
Norwegian Sea
SVALBARD (NORWAY)
Barents Sea
Kara Sea
Laptev Sea
East Siberian Sea
Bering Sea
Sea of Okhotsk
RUSSIA
NORWAY
SWEDEN
FINLAND
UNITED KINGDOM
North Sea
BELARUS
POLAND
UKRAINE
FRANCE
ROMANIA
SPAIN
ITALY
GREECE
TURKEY
SYRIA
KAZAKHSTAN
MONGOLIA
UZBEKISTAN
TURKMENISTAN
NORTH KOREA
SOUTH KOREA
Sea of Japan
JAPAN
North Pacific Ocean
CHINA
IRAN
AFGHANISTAN
PAKISTAN
INDIA
Caspian Sea
Black Sea
Mediterranean Sea
UNITED STATES
MEXICO
Gulf of Mexico
CUBA
Caribbean Sea
North Pacific Ocean
MOROCCO
ALGERIA
TUNISIA
LIBYA
EGYPT
SAUDI ARABIA
OMAN
YEMEN
MAURITANIA
MALI
NIGER
CHAD
SUDAN
SENEGAL
GUINEA
NIGERIA
GHANA
CENTRAL AFRICAN REPUBLIC
SOUTH SUDAN
ETHIOPIA
SOMALIA
CAMEROON
GABON
DEMOCRATIC REPUBLIC OF THE CONGO
UGANDA
KENYA
TANZANIA
ANGOLA
ZAMBIA
ZIMBABWE
NAMIBIA
BOTSWANA
SOUTH AFRICA
MADAGASCAR
Arabian Sea
Bay of Bengal
MYANMAR (BURMA)
LAOS
THAILAND
South China Sea
PHILIPPINES
MALAYSIA
INDONESIA
PAPUA NEW GUINEA
AUSTRALIA
NEW ZEALAND
Indian Ocean
VENEZUELA
COLOMBIA
ECUADOR
PERU
BRAZIL
BOLIVIA
PARAGUAY
CHILE
ARGENTINA
URUGUAY
South Atlantic Ocean
South Pacific Ocean
Southern Ocean
Great Australian Bight
Tasman Sea
Coral Sea
South Pacific Ocean

Microbial Induced Calcite Precipitation as Sustainable Ground Improvement Method

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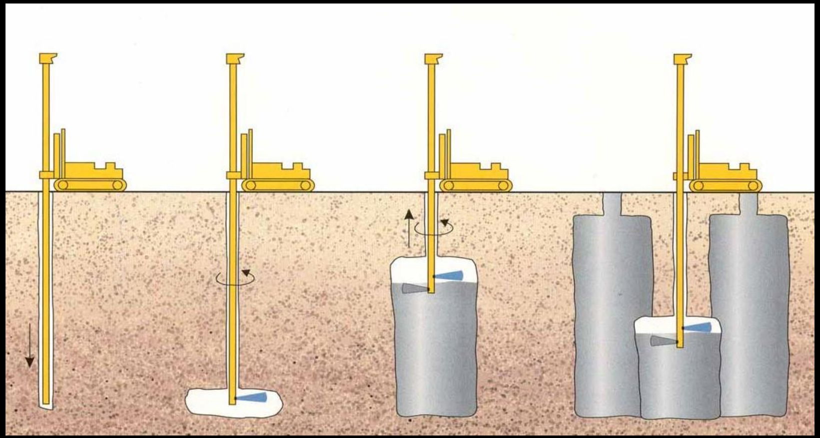
GLOBAL
WARMING



Microbial Induced Calcite Precipitation (MICP)

$$(NH_2)_2CO + 2\,H_2O \xrightarrow{\text{Urease}} CO_2 \uparrow + 2NH_4OH,$$

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \xrightarrow{\text{Carbonicanhydrase}} H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-},$$

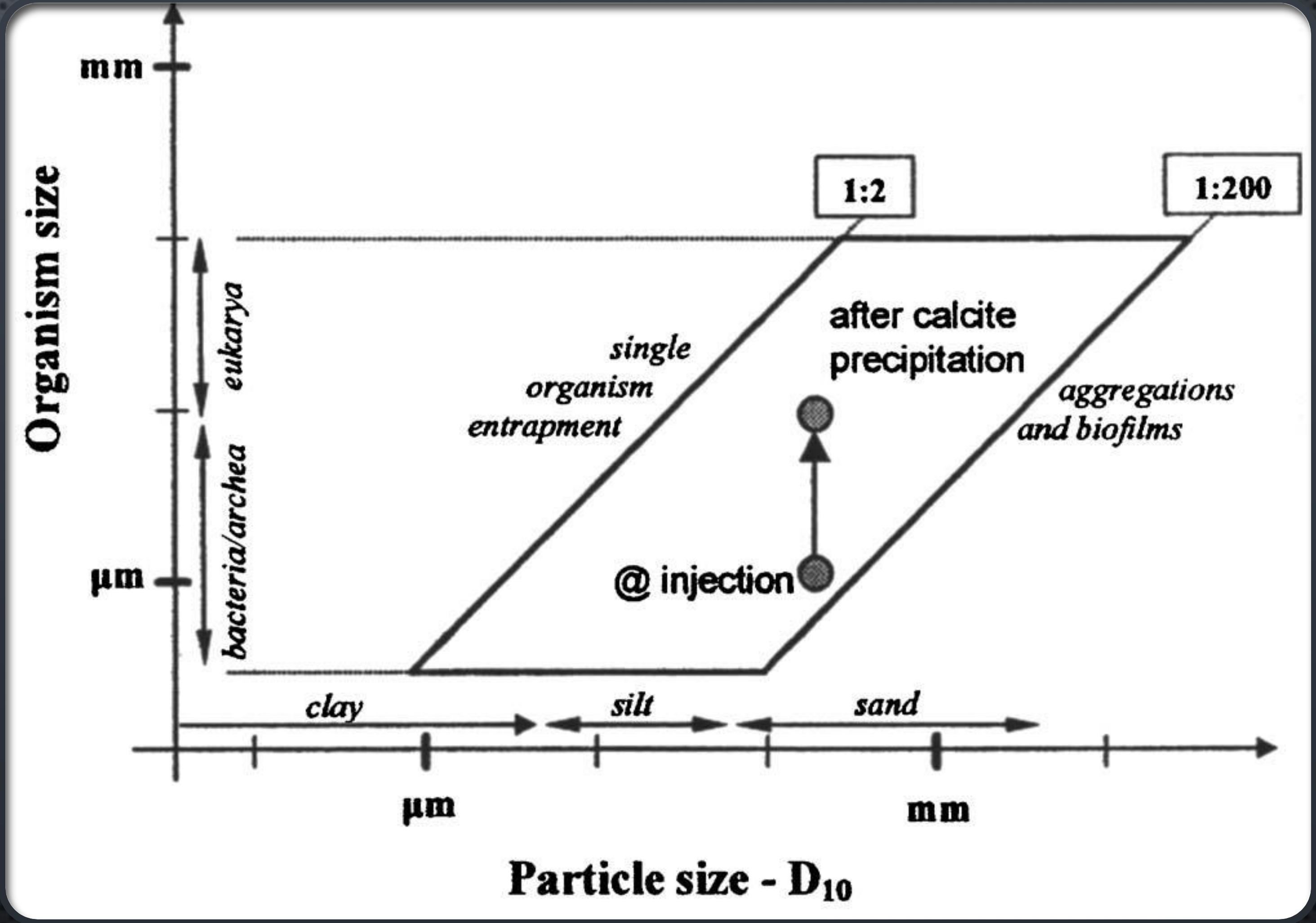
$$CaCl_2 + H_2CO_3 \rightarrow CaCO_3 \downarrow + 2HCl,$$

$$2\,HCl + 2\,NH_4OH \rightarrow 2\,NH_4Cl + 2\,H_2O,$$

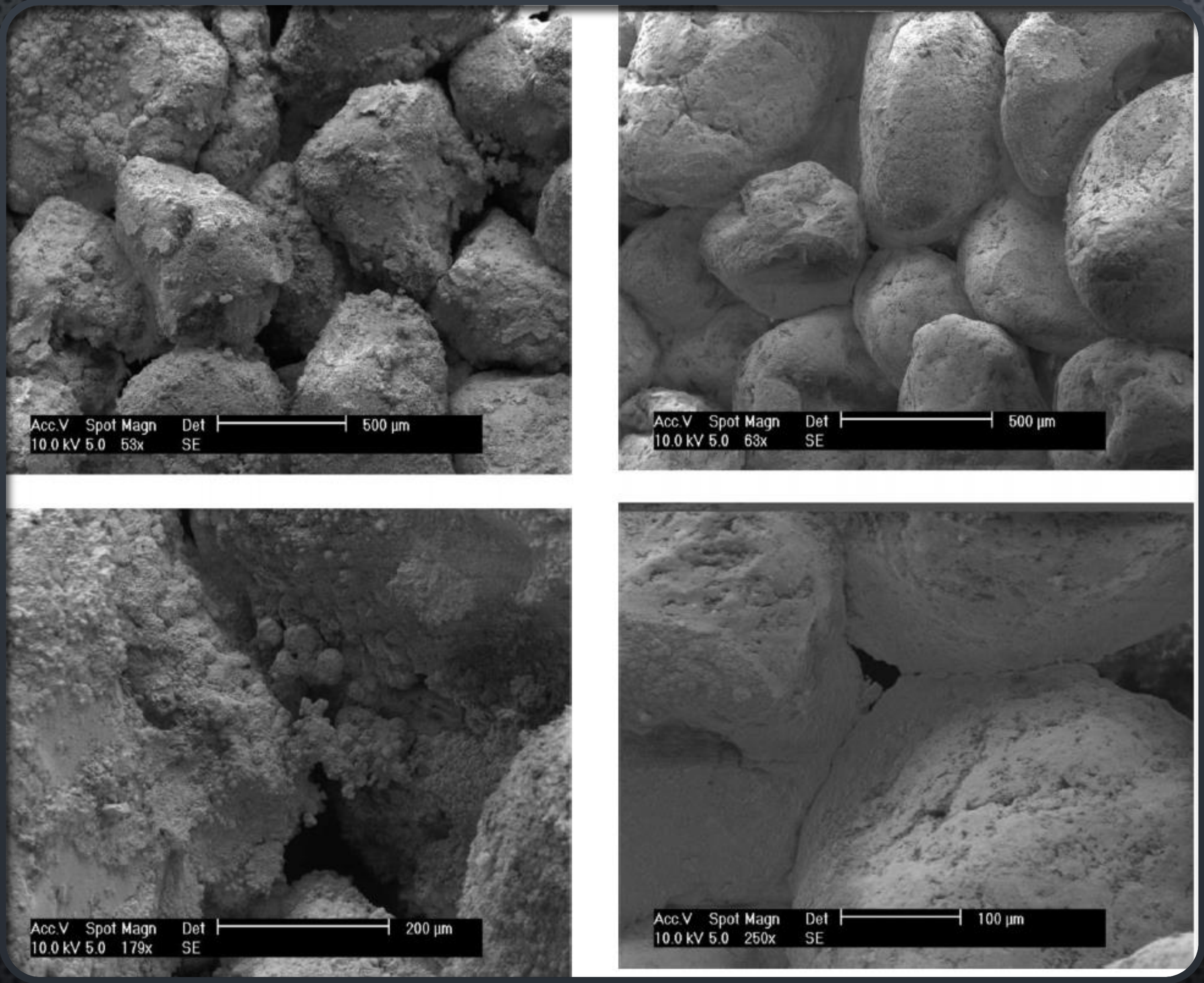
$$(NH_2)_2CO + 2\,H_2O + CaCl_2 \xrightarrow{\text{Urease and carbonicanhydrase}} CaCO_3 \downarrow + 2NH_4Cl.$$

MICROORGANISM SIZE- SOIL TYPE COMPATIBILITY.

-MAINLY SUITABLE FOR SAND DUE TO THE SIZE OF THE PORES THAT ALLOW THE BACTERIAL AND CEMENTATION AGENT TO SPREAD OUT THROUGH THE SOIL MATRIX.



Reference: Mitchell, J. K., and Santamarina, J. C. _2005_. "Biological considerations in geotechnical engineering." J. Geotech. Geoenviron. Eng., 131_10_, 1222–1233.



MICROBIAL INDUCED CALCITE PRECIPITATION AS SUSTAINABLE GROUND IMPROVEMENT METHOD (CONTINUED)

BIO TREATED SAND WITH MICP UNDER SCANNING ELECTRONIC MICROSCOPE (SEM).

- MICP COVERING THE SAND PARTICLES, BUT IT ALSO ACTS AS CEMENTATION BRIDGING THE GAPS BETWEEN PARTICLES.

MICROBIAL INDUCED CALCITE PRECIPITATION AS SUSTAINABLE GROUND IMPROVEMENT METHOD (CONTINUED)

Site class	Soil Profile	Shear wave velocity, V_s (m/s)
A	Hard rock	$V_s > 1524$
B	Rock	$762 < V_s \leq 1524$
C	Very dense soil and soft rock	$366 < V_s \leq 762$
D	Stiff soil	$183 < V_s < 366$
E	Soft soil	$V_s < 183$
F	Problematic soil	Site spec. eval.

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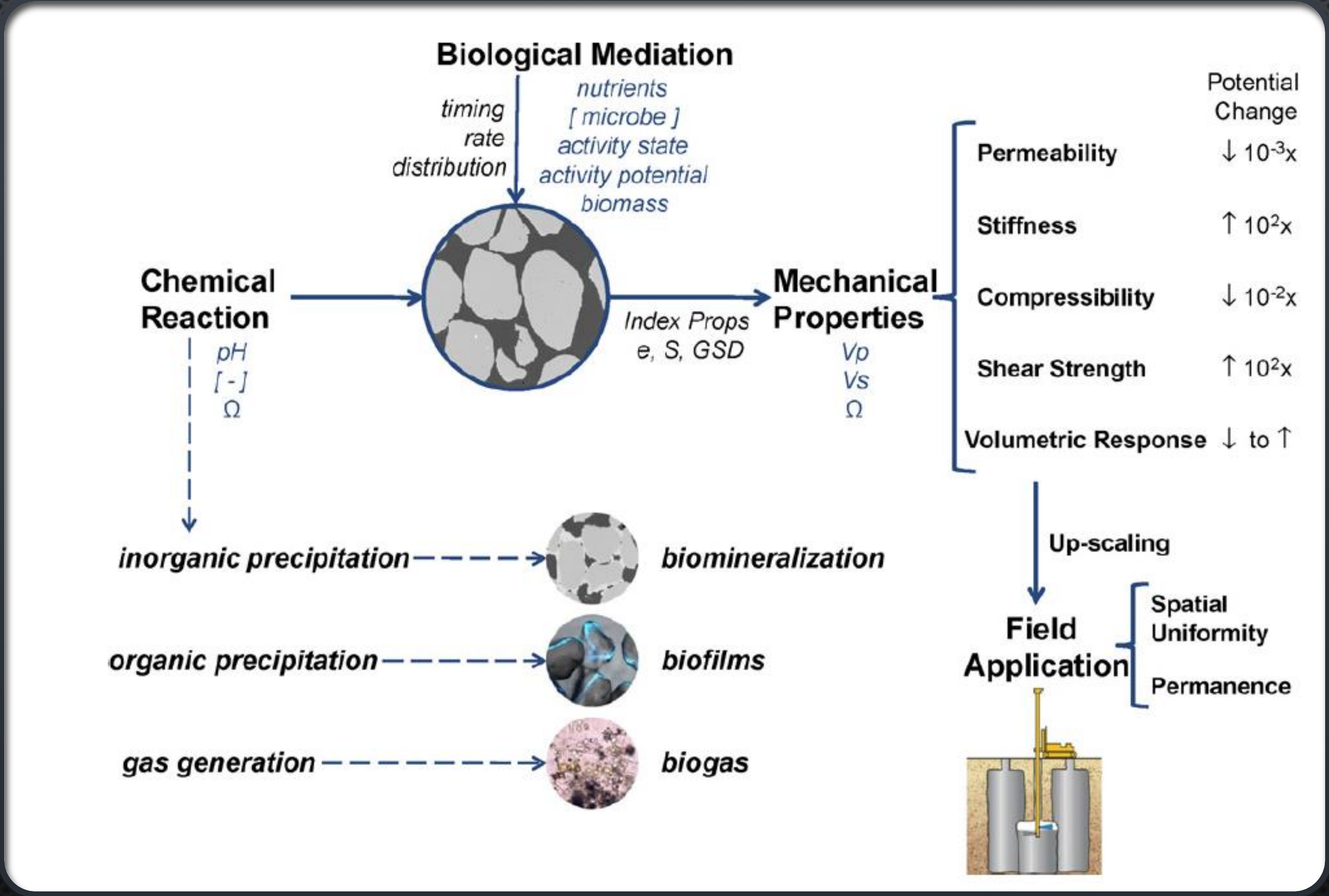
Microbial Induced Calcite Precipitation as Sustainable Ground Improvement Method (continued) DeJong e al. (2006)



MICROBIAL INDUCED CALCITE PRECIPITATION AS SUSTAINABLE GROUND IMPROVEMENT METHOD (CONTINUED)

- THE FIRST FULL SCALE FIELD TRIAL ON MID FOR LIQUEFACTION MITIGATION IN THE WORLD, AND FIELD DEMONSTRATION TO SIMULATE EARTHQUAKE LIQUEFACTION (CREATE FAKE EARTHQUAKE).
- THE TARGETED SITE IS HARBORTON , A 62-ACRE HABITAT RESTORATION PROJECT OWNED BY PORTLAND GENERATE ELECTRIC IN NORTHWEST PORTLAND. IT'S LOCATED WITHIN THE CRITICAL ENERGY INFRASTRUCTURE HUB AND NEXT TO A PGE SUBSTATION WHERE 90% OF OREGON'S LIQUID FUEL AND ALL JET FUELS FOR PORTLAND'S AIRPORT ARE HANDLED.

CONCLUSIONS

- The research approved that MICP is an effective method that improved the engineering properties of the soil such us shear strength and the stiffness.
- Shear wave velocity can be used to monitor the cementation process and can be used as indicator to the change in the soil behavior after the cementation.
- The MICP method has two effects on the biotreated sand, cementation and densification. The cementation between the particles may broke under the high value of loading however, the densification will not be lost even after the failure is occurred.

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THANK YOU