Watanabe Laboratory

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We conducted various research in energy resources, environmental sciences, and engineering. They include environmental risk assessments, geosciences and geoengineering in light of energy resource production, and geo-informatics for a sustainable future. Recently, our work has focused on the sustainable and profitable production of petroleum and geothermal energy, as well as CO_2 sequestration and mineralization.

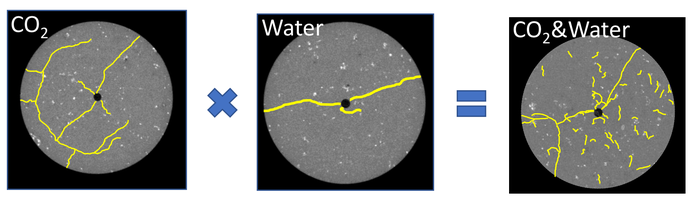




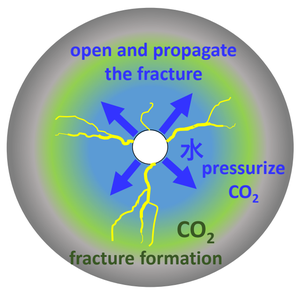


Carbon Recycle CO_2 Geothermal Power Generation

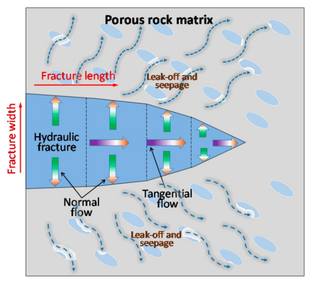
New fracturing method combining CO_2 & water injection

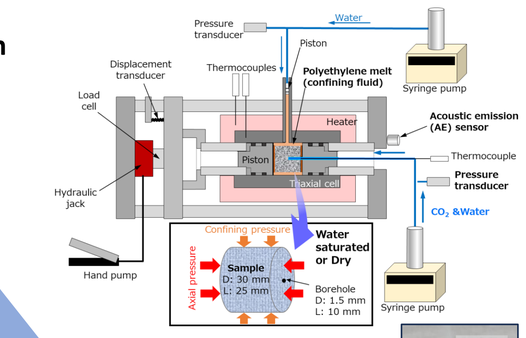


CO_2 & water fracturing mechanism

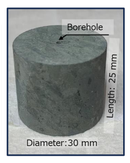


pore water in rocks inhibits fractures opening and propagation

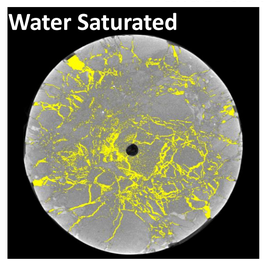


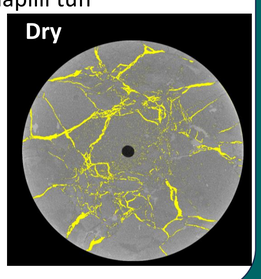


- Is it effective in the presence of pore water?
- Does it work on porous volcanic rocks?



andesitic lapilli tuff

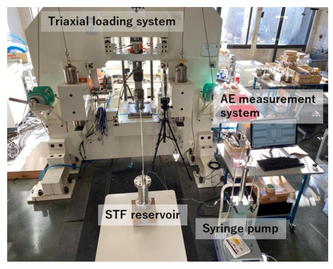


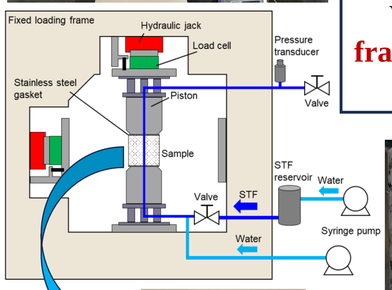


CO_2 & water fracturing is still effective with the pre-existing pore water and is particularly effective in porous volcanic rocks.

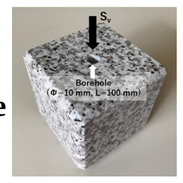
Multidirectional fracturing of rock using shear thickening fluid

Experiment System



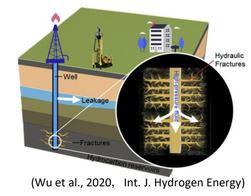


Granite



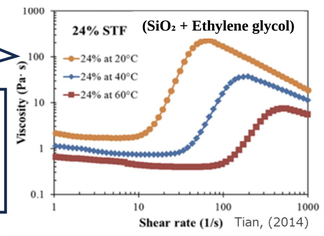
Hydraulic fracturing

Fracture nucleation improves the permeability only in a certain direction.
➡How does the fracturing manner change by the **shear thickening fluid (STF)**?

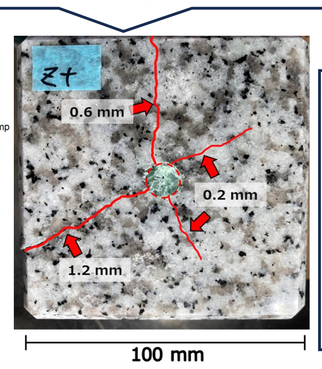


(Wu et al., 2020, Int. J. Hydrogen Energy)

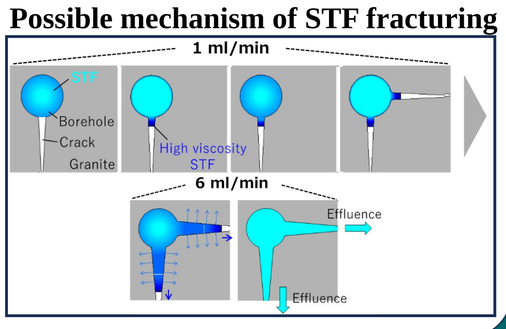
High flow rate and **narrow** fracture width
➡**Increase in viscosity**



We have produced **multidirectional fractures and larger aperture fractures**, which improve rock permeability.

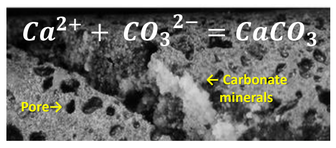


Possible mechanism of STF fracturing



Enhanced CO_2 geological storage and mineralization using biodegradable chelating agents

CCS, in which CO_2 is injected into underground rocks and fixed as a carbonate mineral, has been attracting attention in recent years.



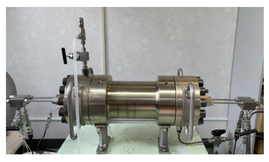
In order to utilize reservoirs in the most efficient, safe, and secure manner, **we invented a method to promote CO2 geological storage and mineral fixation.** [patent application2023-51335]

What is the applicability to basaltic volcanic sandstone containing clay minerals?

Challenge: Clay minerals clogging channels and poor permeability

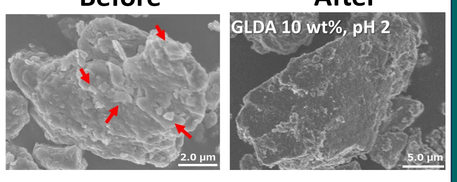
👈Rocks that have undergone clayey alteration and oxidative alteration
Contains the clay mineral montmorillonite

Biodegradable chelating agent GLDA dissolves minerals to improve permeability

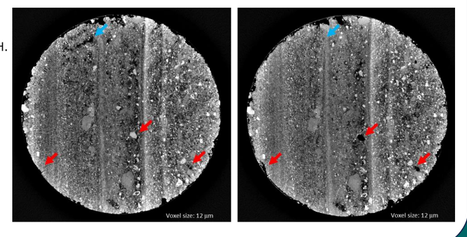


👈 **Chelating agent injector into rock**

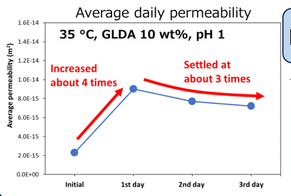
Before **After**



Montmorillonite dissolved in GLDA
Confirmation of pore formation



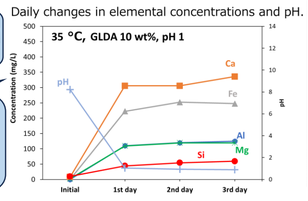
Average daily permeability



Permeability UP !

Aids in the dissolution of minerals!

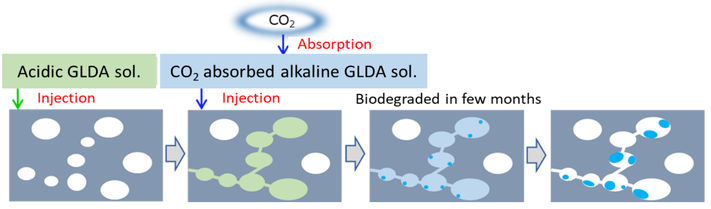
Daily changes in elemental concentrations and pH.



Modeling of accelerated mineral dissolution for enhanced CO_2 geological storage and mineralization using biodegradable chelating agents

Challenges of CO_2 geological storage and mineralization in basaltic rocks:
Porosity, pore connectivity, permeability and reactivity of basalts are not always high enough

New approach for enhanced CO_2 geological storage and mineralization



Effectiveness of the method is…
Proved by lab experiments
→Actual space-time scale evaluation is necessary
Let's create a simulator!!

1st step:
accelerated mineral dissolution modeling

Equilibrium

Mg :

Y: GLDA **Complex formation**

$Mg^{2+} + OH^- \leftrightarrow MgOH^+$

$4Mg^{2+} + 4OH^- \leftrightarrow Mg_4(OH)_4{}^{2-}$

$Mg^{2+} + Y^{4-} \leftrightarrow MgY^{2-}$

Long-term mineral dissolution modelling is possible!

Kinetics

$R = K([X]_{total,sat} - [X]_{total})$

Dissolution is driven by the difference in concentration

A T-swing process for enhanced CO_2 capture and storage using recyclable chelating agent

CCUS【Carbon dioxide Capture, Utilization and Storage】→ CO_2 mineralization

CO_2 mineralization assisted by chelating agents

- **Low cost**: industrial waste utilization, chelating agent recycling, low to moderate temperature
- **High returns**: valuable products (e.g., $CaCO_3$)
- **Environmentally friendly**: without wastewater

❶ Minerals dissolution enhanced in chelating agents even at neutral to alkaline conditions

❷ Morphologies of $CaCO_3$ can be controlled

Aragonite ($CaCO_3$)

❶ Ca extraction
$CaSiO_3 + H_2\text{-}GLDA^{2-} + 2H^+ \rightarrow$ **$Ca\text{-}GLDA^{2-}$** $+ H_4SiO_4$

❷ Ca carbonation
$Ca\text{-}GLDA^{2-} + HCO_3^- + H^+ \rightarrow$ **$CaCO_3$** ↓ $+ H_2\text{-}GLDA^{2-}$

❸ pH recovery CO_2 capture
CO_2 $+ H_2O \rightarrow H^+ + HCO_3^-$

❶+❷+❸ $CaSiO_3 + CO_2 + H_2O \rightarrow CaCO_3 + H_4SiO_4$

Joint research with earth development and environmental studies

Development of construction and quarrying systems with intelligent construction equipment using sensing technology such as work tools of construction equipment and on-board cameras

Estimation of ground strength

2024 Earthquake

✓ Increasing severity of landslides
✓ Labor shortage and low productivity
➡ Achieving safe and efficient work with intelligent

Estimation of crushed rock grain size

Blasting → Grade evaluation → Blasting plan → Blasting

Realization of safe and reliable blasting through blasting cycles

Segment video of excavating into frame images and extract conto