Watanabe Laboratory

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Environmental and Energy Engineering, Department of Mechanical and Aerospace Engineering, School of Engineering
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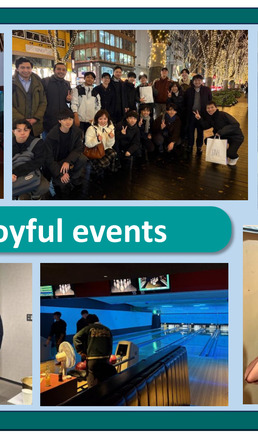
We conducted various studies in sciences and engineering related to energy resources and environments, such as environmental risk assessments and reduction, and geosciences and geoengineering, in light of energy resource developments and environmental protections for a sustainable future. We have investigated hydraulic, mechanical, and chemical properties of geomaterial, such as rocks, at a wide range of temperature and pressure conditions as well as ways to control and utilize them. Our work focuses on the sustainable and profitable production of petroleum and geothermal resources, atmospheric CO_2 removal, and CO_2 geological storage and mineralization.








Various joyful events

Domestic and international conferences

Reactive viscous fluid fracturing of volcanic reservoirs

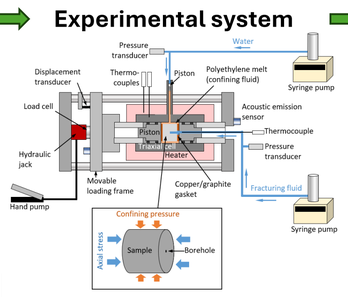
In volcanic rock reservoirs, fluid leakage into pores and microfractures limits fracture opening.

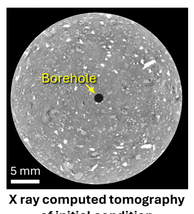
Main challenge: Suppressing fluid infiltration into the rock while limiting increase in pressure caused by viscosity.

We tested a reactive viscous fluid combining the **biopolymer scleroglucan (SCGL)** and **chelating agent GLDA** to reduce fluid loss and chemically weaken the rock, helping offset the pressure increase cause by high viscosity.

Sample → **Experimental system** → **Fractures created using different fluids**

Diameter: 30 mm
Andesitic tuff (Emochi andesite)

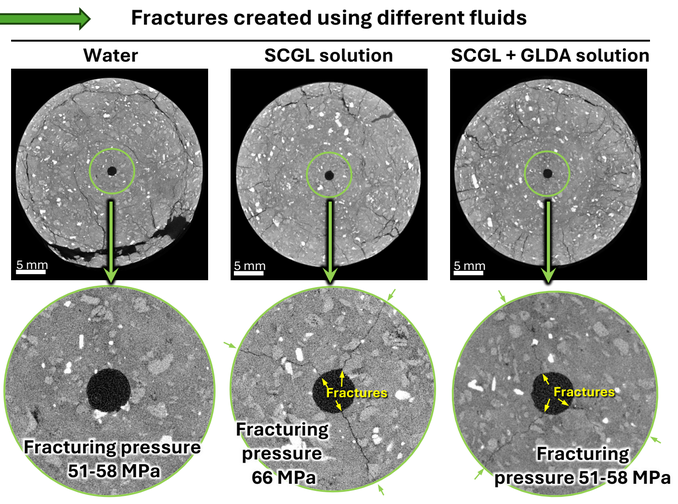




X ray computed tomography of initial condition

Controlled comparison
180 °C, 30 MPa confining pressure, 80 MPa axial stress. Holding time of 20 min then constant flow rate injection at 1 mL/min

Only the fracturing fluid was changed
Water → SCGL solution → SCGL + GLDA solution



Reactive viscous fluid promoted wider borehole-connected fractures while avoiding most of the pressure increase caused by viscosity alone.

Limited fracture opening from borehole

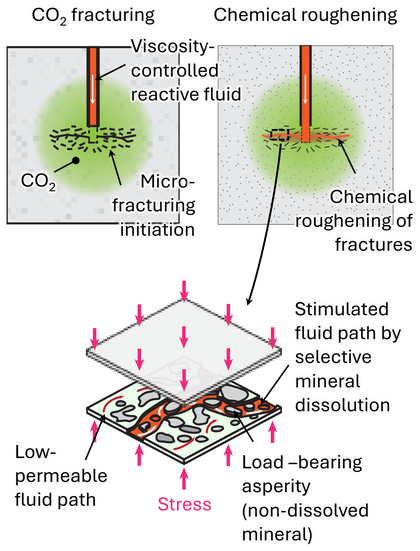
Borehole-connected fractures, **but at high pressure**

Wider borehole-connected fractures, at lower pressure than SCGL alone.

CO_2 reactive fracturing for geothermal reservoir stimulation

Efficient geothermal power generation requires permeable flow paths in hot rocks, but fractures can remain narrow or close under stress, especially in porous volcanic reservoirs.

CO_2 reactive fracturing concept

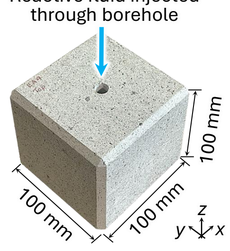


We combined **CO_2 fracturing** with a **viscosity-controlled reactive fluid** that chemically roughens fracture surfaces.

CO_2	Viscosity-controlled reactive fluid		
	GLDA	HF source	Scleroglucan
Microfracturing initiation	**Metal ion chelation**	**Silicate dissolution**	**Viscosity control Limits leak-off**

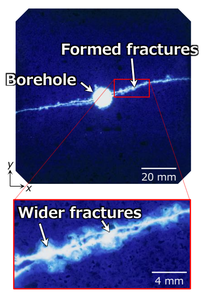
Sample
Andesitic tuff (porous rock)

Reactive fluid injected through borehole



Experimental system
True triaxial stress

Fractures created



CO_2 reactive fracturing creates fractures and chemically roughens their surfaces, forming wider flow paths that can remain open under stress.

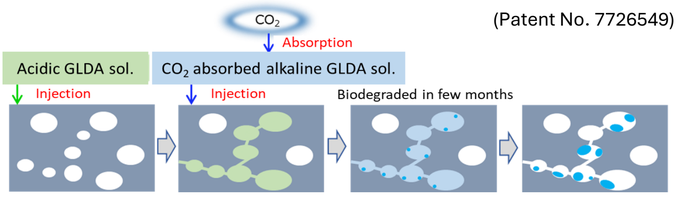
Enhanced CO_2 geological storage and mineralization using biodegradable chelating agents

Geological carbon storage (CCS) has emerged as a promising technology for permanent CO_2 storage. However, many target reservoirs exhibit insufficient pore connectivity, permeability, and mineral reactivity.

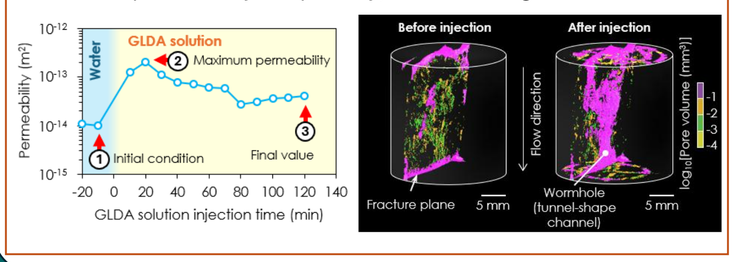
To enable efficient and safe CO_2 storage, we developed a novel method for enhancing CO_2 geological storage and mineralization using biobased and biodegradable chelating agent.

Enhanced CO_2 geological storage and mineralization

(Patent No. 7726549)



Application of this technology to basalt and peridotite significantly increased permeability and porosity, demonstrating its effectiveness.

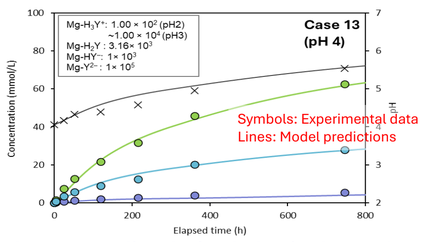


Modeling of enhanced mineral dissolution

To evaluate the spatial and temporal impacts of the method and determine optimal operating conditions, numerical modelling are underway.

Development of a Numerical Simulator

Chemical equilibrium considering complex formation + Reaction kinetics driven by the degree of disequilibrium

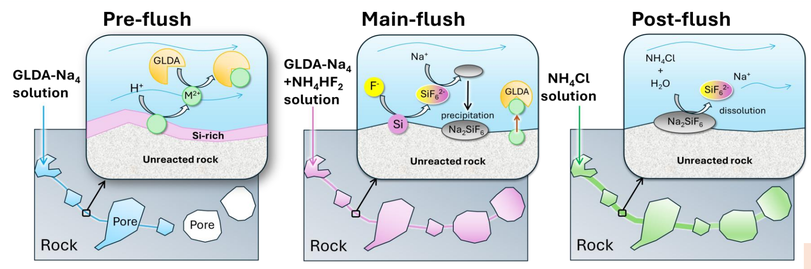


Long-term dissolution behavior beyond experimental timescales can be predicted.

Green chelating agent–HF synergy for near-wellbore stimulation in geological CO_2 storage

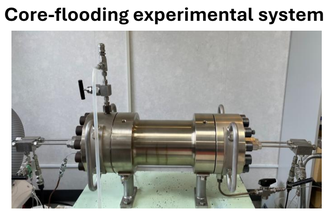
Efficient CO_2 injection requires high near-wellbore permeability. However, chelating agents alone are not effective at promoting Si release from feldspars and clay minerals, limiting permeability enhancement.

To overcome this limitation, we developed a novel three-shot reservoir stimulation method combining GLDA solution, GLDA–HF solution, and brine flushing . 「Patent Application No. 2025-069581」

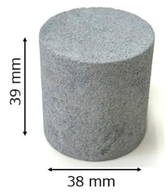


The effectiveness of the method was demonstrated using sandstone and sandy siltstone from CO_2 storage formations.

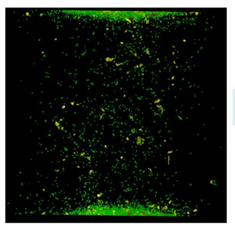
Core-flooding experimental system



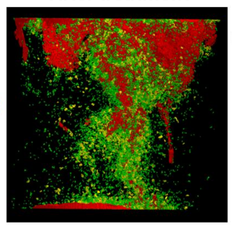
Sandy siltstone



Before treatment



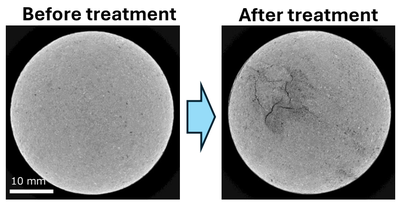
After treatment



Pore volume (mm³)
10^8
10^7
10^6
10^5

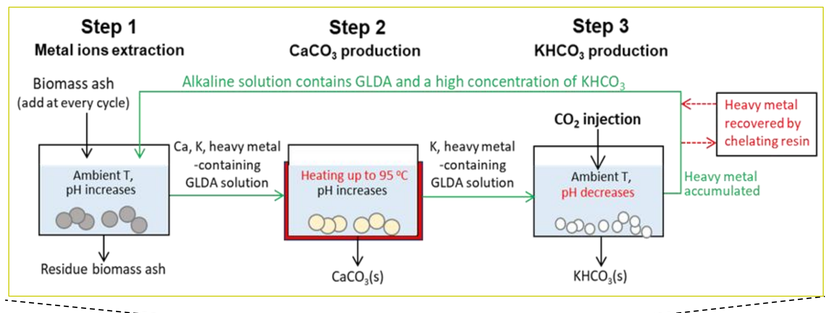
Sustained mineral dissolution created fluid flow pathways and enhanced permeability within a short time.

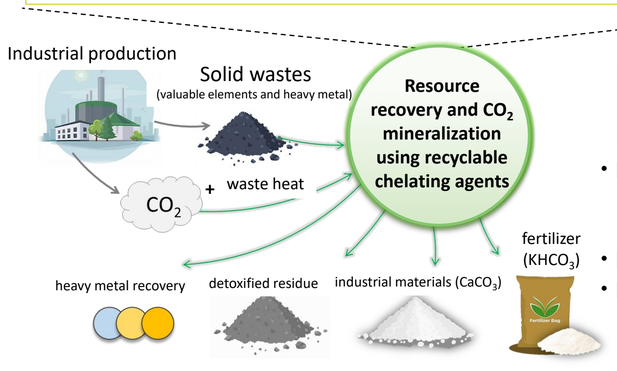
Before treatment **After treatment**



Brine permeability increased 9-fold

Metal resources recovery and CO_2 mineralization using industrial solid wastes





Recyclable chelating agents assisted-CO_2 mineralization process

- **Low cost**：industrial waste utilization, chelating agent is recyclable, use low to moderate T and ambient P
- **High returns**：valuable products (e.g., $CaCO_3$, $KHCO_3$)
- **Environmentally friendly**：few wastewater generation biobased, biodegradable chelating agent utilization

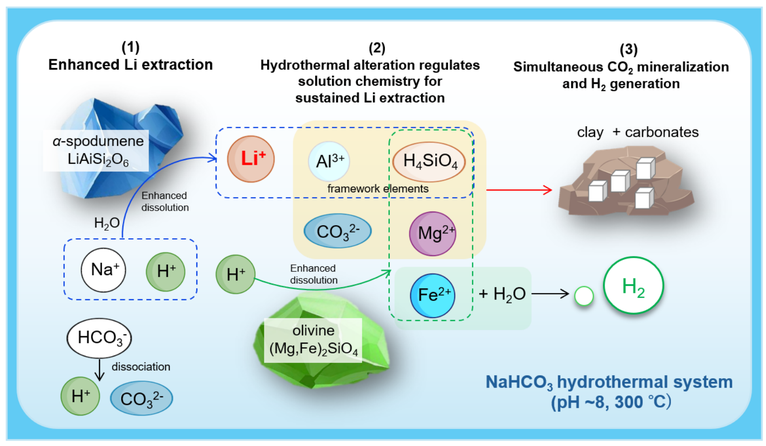
Sustained lithium extraction from α-spodumene with CO_2 storage and H_2 generation

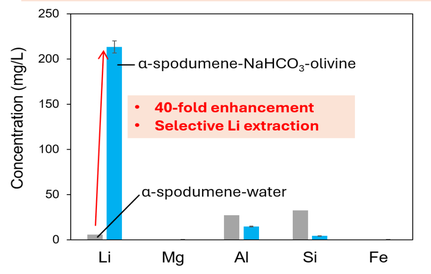
Rising lithium demand highlights the need for sustainable extraction technologies, as conventional hard-rock Li recovery relies on high-temperature roasting and entails substantial environmental impacts.

Simultaneous selective Li recovery, CO_2 mineralization, and H_2 generation under mild conditions (<300°C).

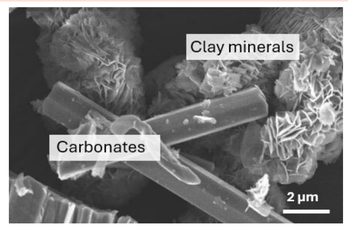
Our Novel Technology

Li extraction via hydrothermal CO_2–water–rock reactions:
No roasting required • CO_2 storage • H_2 production





Impurity immobilization through secondary mineral formation



This process establishes a new reaction-engineering framework for the simultaneous generation of resource, environmental, and energy value.