Proceedings World Geothermal Congress 2026, Calgary, Canada, June 8—11, 2026

# Enhanced hydraulic fracturing of volcanic rocks at elevated temperatures using a biobased reactive fluid system

Nagi Obata[1]*, Eko Pramudyo[1], Fuyuki Kaneko[2], Abubaker Mohamed[3], and Noriaki Watanabe[1]
[1]TOHOKU UNIVERSITY, [2]INPEX CORPORATION , [3]INPEX JAPAN, LTD.
*obata.nagi.r6@dc.tohoku.ac.jp

## 1. INTRODUCTION

### 1.1. Geothermal Energy, Natural Gas, and Blue Hydrogen/Ammonia

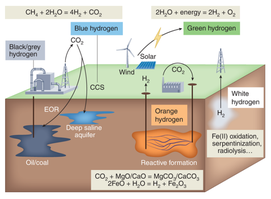
Geothermal energy and natural gas, both of which offer relatively stable supply and low carbon intensity, are crucial for energy security and decarbonization. When natural gas is used as a feedstock for blue hydrogen and blue ammonia, the associated $CO_2$ emissions can be captured and stored underground. Expanding the utilization of geothermal and natural gas resources in reservoirs composed of volcanic rocks is therefore highly desirable. To achieve this, research and development of technologies that enhance well productivity in volcanic rock reservoirs, which are typically fractured systems, are essential.

### 1.2. Hydraulic Fracturing of Volcanic Rock Reservoirs

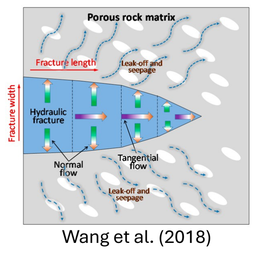
In the Nagaoka gas field, hydraulic fracturing has often faced difficulties with proppant injection (Kidogawa et al., 2025). Studies on geothermal reservoirs show that volcanic rocks with relatively high porosity and permeability, such as tuff, tend to form fractures that do not open or propagate well (Takuma et al., 2024). This is mainly due to severe leak-off of low-viscosity water at high temperatures, which reduces fracture pressure and promotes matrix expansion. Similar difficulties are also expected in volcanic rock gas reservoirs, where high porosity and permeability may hinder fracture opening and propagation.

### 1.3. Objectives

Through hydraulic fracturing experiments on rhyolitic lava and hyaloclastite from the Minami-Nagaoka gas field, we examine why stimulation has often been ineffective and propose fracturing methods suitable for volcanic rock reservoirs.

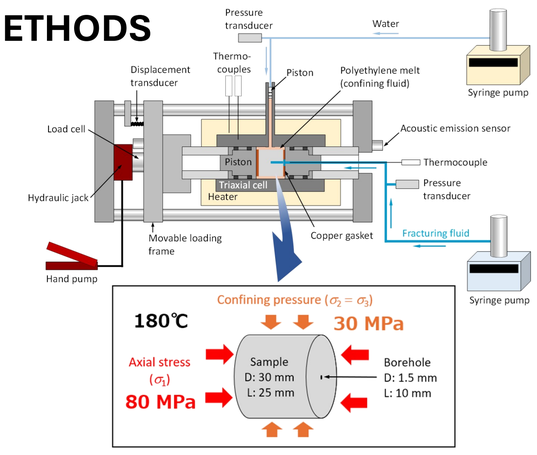



Osselin et al. (2022)




Wang et al. (2018)

## 2. METHODS



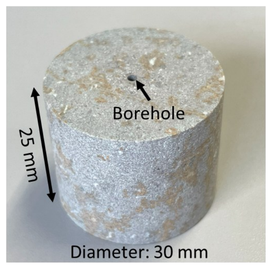

The fracturing fluid was first injected at 10 MPa and maintained for 20 minutes, after which injection was continued at a rate of 1 mL/min.

## 3. HYDRAULIC FRACTURING CHARACTERISTICS

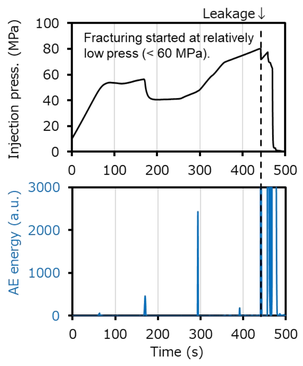
**Frac. Fluid: Water (2 wt% NaCl )**

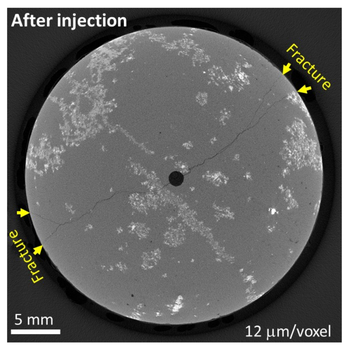
### 3.1. Reservoir Rock with Relatively Low Porosity and Permeability

**Lava (Low Poro. & Perm.)**




Porosity: 5%
Permeability: $2 \times 10^{-18}$ m$^2$

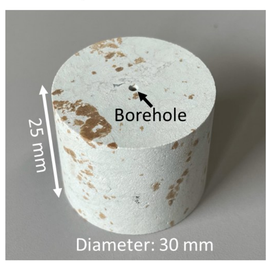


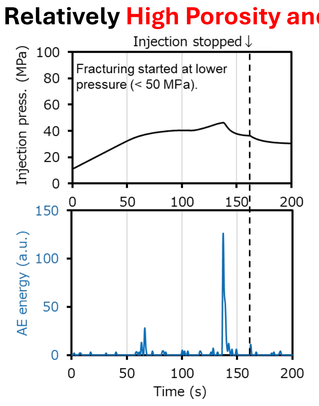

Theoretical fracture initiation requires ≥60 MPa, but actual pressures were lower. Fractures opened and propagated, yet fluid penetration was not negligible even in low-porosity, low-permeability rocks. In highly porous hyaloclastite, stronger leak-off may prevent fracture opening and propagation.

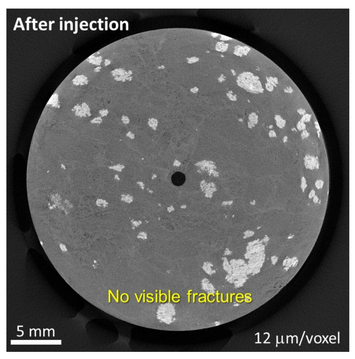
### 3.2. Reservoir Rock with Relatively High Porosity and Permeability

**Hyaloclastite**



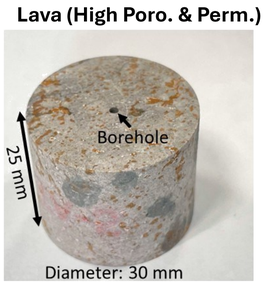

Porosity: 15%
Permeability: $6 \times 10^{-18}$ m$^2$



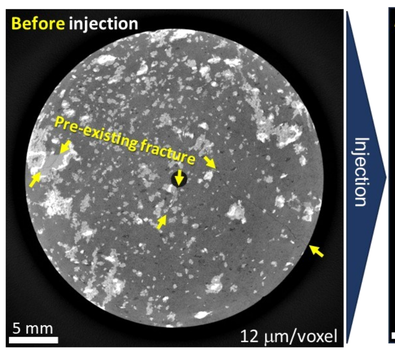



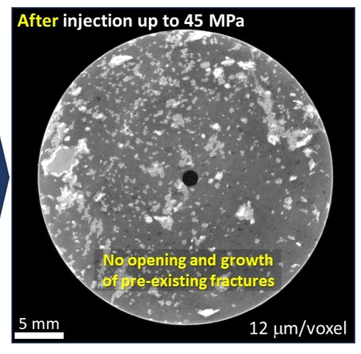

In highly porous and permeable hyaloclastite, fractures with apertures large enough to be visualized by XCT were not formed. Similarly, in rhyolitic lava with relatively high porosity and permeability, fracture opening and propagation may also fail to occur.

**Lava (High Poro. & Perm.)**




Porosity: 8%,
Permeability: $2 \times 10^{-17}$ m$^2$



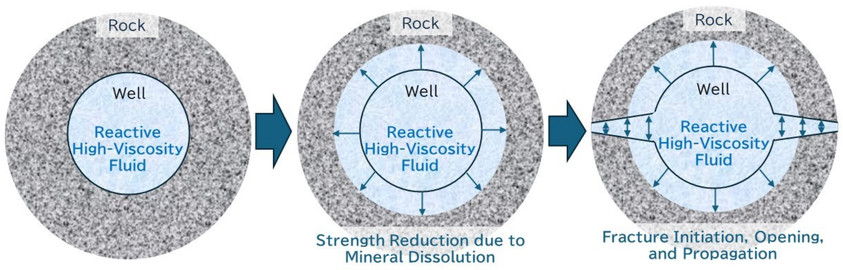

Injection

Fracture opening and propagation did not occur in rhyolitic lava with relatively high porosity and permeability. High-viscosity fracturing fluids are recommended for volcanic reservoirs to facilitate fracture development.

## 4. FRACTURING WITH REACTIVE HIGH-VISCOSITY FLUID

### 4.1. New Approach Employing Mineral-Dissolving High-Viscosity Fluids

Reactive high-viscosity fluids, consisting of a mineral-dissolving agent and a thickener, are first injected into the well at constant pressure for a short time to weaken the near-wellbore rock. The fluids are then pressurized to initiate fracturing. The mineral-dissolving agent can be, for example, a chelating agent, while the thickener can be a polysaccharide. In this study, biobased and biodegradable materials were employed.



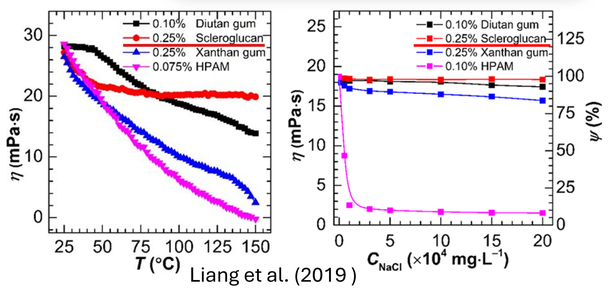

### 4.2. Mineral-Dissolving Agent: GLDA-$Na_4$ (L-Glutamic Acid N,N-Diacetic Acid Tetrasodium Salt)

GLDA-$Na_4$ (L-Glutamic Acid N,N-Diacetic Acid Tetrasodium Salt) is a plant-based, biodegradable chelating agent that is already widely used in various industries. It can also be applied to improve permeability in oil and gas reservoirs, geothermal systems, and $CO_2$ storage formations. By binding to metal ions in minerals, it forms water-soluble complexes, thereby promoting mineral dissolution and suppressing secondary precipitation. GLDA-$Na_4$ is effective over a wide pH range and can be used at high temperatures up to 200 °C.




### 4.3. Thickener: Scleroglucan (SCLG)

Scleroglucan (SCLG) is a polysaccharide produced by microorganisms such as *Sclerotium rolfsii*. It dissolves in water to form highly viscous solutions or gels and is widely used in cosmetics, food, and pharmaceuticals. SCLG shows high stability against temperature, pH, and salinity (Liang et al., 2019, *ACS Omega*; *Handbook of Hydrocolloids*, ed. Phillips & Williams).

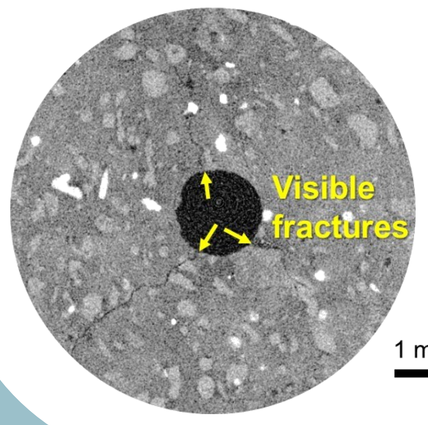



Liang et al. (2019 )

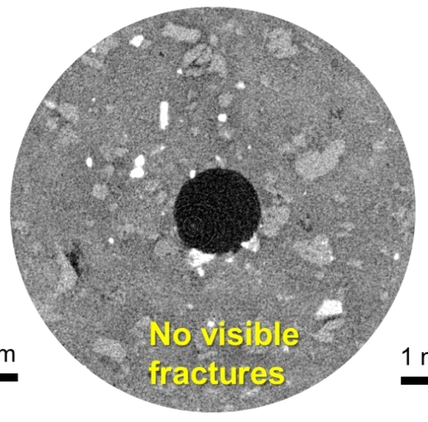
### 4.4. Verification of Effectiveness Using Tuff

**Andesitic Tuff (Poro.: 23-24%, Perm.: 1 x $10^{-17}$ - 1x $10^{-16}$ m$^2$)**

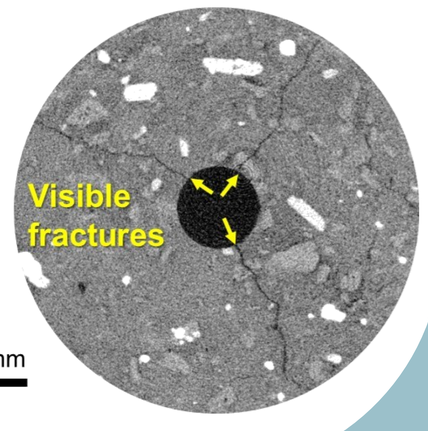
**Water + 10 wt% GLDA + 0.25 wt% SCLG, pH 2**
**(Major Frac. Initiation: 51-58 MPa)**




**Water**
**(Major Frac. Initiation: 51-58 MPa)**




**Water + 0.25 wt% SCLG**
**(Major Frac. Initiation: 66 MPa)**

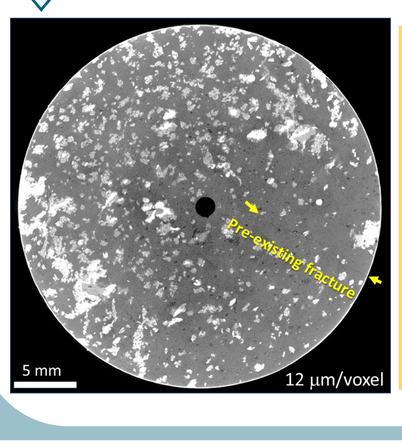



**XCT Scan of the Borehole Region after Fracturing (12 µm/voxel)**

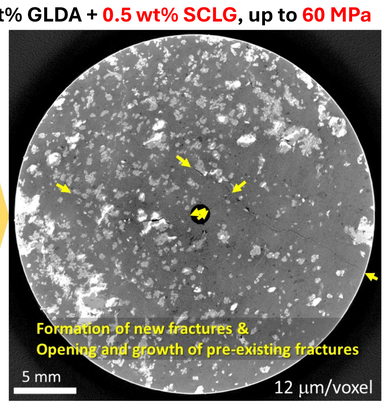
Reuse

## 5. APPLICATION OF REACTIVE HIGH-VISCOSITY FLUID FRACTURING TO RESERVOIR ROCKS

**pH 2, 10 wt% GLDA + 0.5 wt% SCLG, up to 60 MPa**

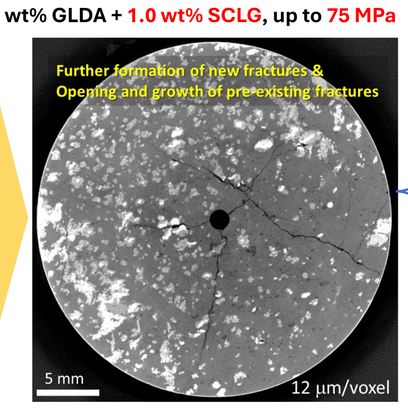



Reactive High-Viscosity Fluid Injection




**pH 2, 10 wt% GLDA + 1.0 wt% SCLG, up to 75 MPa**

Higher-Viscosity Fluid Injection

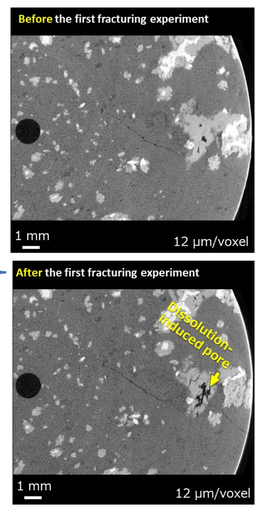



← Reactive high-viscosity fluid created new fractures and enhanced the opening and propagation of existing ones, unlike in Section 3.2 experiment.

← At similar pressures (up to 80 MPa) as in Section 3.1 experiment on low-porosity lava, reactive high-viscosity fluid generated more fractures with larger apertures.

Additional pore formation was observed, confirming the mineral -dissolution effect of the reactive high-viscosity fluid.→ → → →

**Reactive High-Viscosity Fluid Fracturing Proven Effective.**




## CONCLUSION

Fluid leak-off hinders volcanic reservoir fracturing. Our biobased reactive high-viscosity fluid enables fracture growth via mineral dissolution and viscosity, without raising initiation pressures.

**Acknowledgements <AcknowStyle>**

This work was supported by JSPS KAKENHI Grant Numbers JP22H04932, JP22H02015, JP23K23283, JP23H01903, JP23K26596 JP24K01412, JP21K18200.

**REFERENCES < HEADING STYLE>**

Kidogawa et al.: Tackling breakdown and proppant placement issues in a high-temperature volcanic reservoir: Lessons learned through multistage fracturing in the Minami-Nagaoka gas field, Japan, *SPE Journal*, **30**, (2025), 1219–1236.
Liang et al.: Comparative study on enhancing oil recovery under high temperature and high salinity: Polysaccharides versus synthetic polymer, *ACS Omega*, **4**, (2019), 10620–10628.
Osselin et al.: Orange hydrogen is the new green, *Nature Geoscience*, **15**, (2022), 765–769.
Takuma et al.: $CO_2$ fracturing of volcanic rocks under geothermal conditions: Characteristics and process, *Geothermics*, **120**, (2024), article number 103007.
Wang et al.: Numerical simulation of hydraulic fracture propagation in coal seams with discontinuous natural fracture networks, *Processes*, **6**, (2018), article number 113.
Wang et al.: $CO_2$ capture, geological storage, and mineralization using biobased biodegradable chelating agents and seawater, *Science Advances*, **10**, (2024), article number eadq0515.