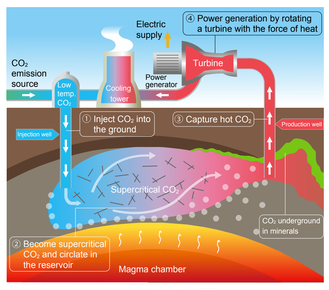
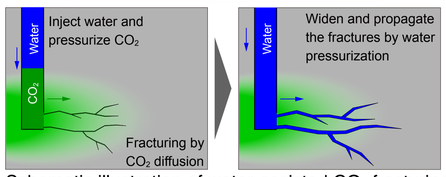
Contribution of Physical and Textural Properties of Volcanic Rock to Slip Characteristics by CO_2 Injection Under Geothermal Environment

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Introduction

CO_2-based Enhanced Geothermal System (EGS)





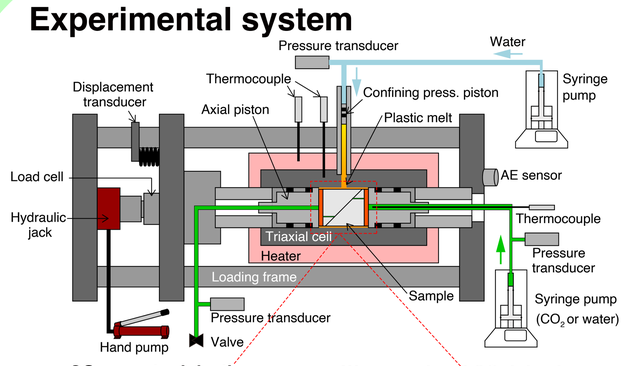
Schematic illustration of water-assisted CO_2 fracturing

- Create artificial geothermal reservoir in the regions with high temperature, but low initial permeability (e.g., volcanic rocks) using CO_2 as a fracturing fluid.
- CO_2 injection produces a more complex fracture network at a lower injection pressure than that of water injection.
- Water-assisted CO_2 fracturing was proposed as a effective permeability enhancement method by Takuma et al. (2024).
- In this method, CO_2 injection induces complex pattern of fractures and subsequent water injection widen and propagate the induced fractures.
- Fluid injection into the subesurface may induce seismicity, such as EGS projects and waste water disposal operations (e.g., Ellsworth et al., 2019; Langenbruch and Zoback, 2016).
- To reduce potential seismic hazards associated with CO_2-based EGS development, an understanding slip characteristics of fractures by CO_2 and water injection is of importance.

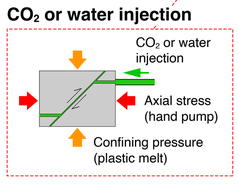
Purpose of this study
Clarify the effect of CO_2 on suppressing shear slip in volcanic rock fractures under geothermal reservoir conditions and its underlying mechanism

Method

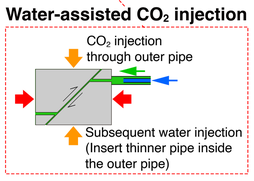
Experimental system



CO_2 or water injection



Water-assisted CO_2 injection



General procedures

1. Set the dry or water-saturated sample in pressure vessel
2. Adjust temperature, confining pressure, and axial stress
3. Fill the sample with CO_2 or water at 8 MPa
4. Inject fluid at 1 ml/min until the pressure reaches 50 MPa.
5. In water-assisted CO_2 injection experiments, switch the injection fluid from CO_2 to water after slip initiation

Sample

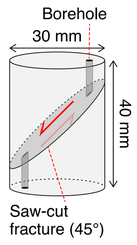
Dry or water-saturated volcanic rocks with saw-cut



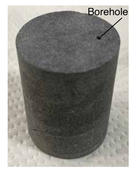
Andesitic lava



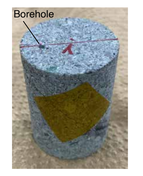
Andesitic tuff



Saw-cut fracture (45°)



Basaltic lava



Dacitic lapilli tuff

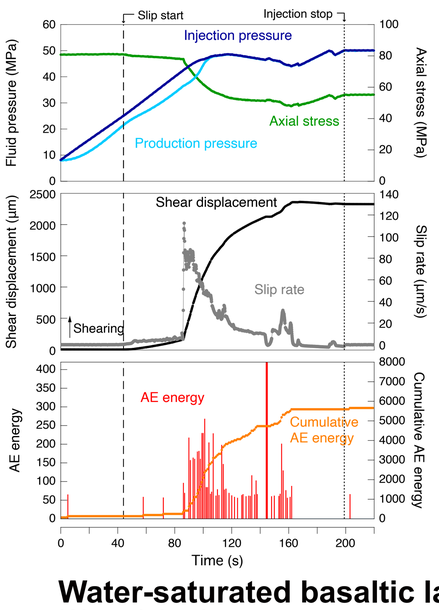
Experimental conditions

- Temperature: 200°C
- Confining pressure: 40 MPa
- Axial stress: 80 MPa
- Initial fluid pressure: 8 MPa
- Target fluid pressure: 50 MPa
- Injection rate: 1 ml/min

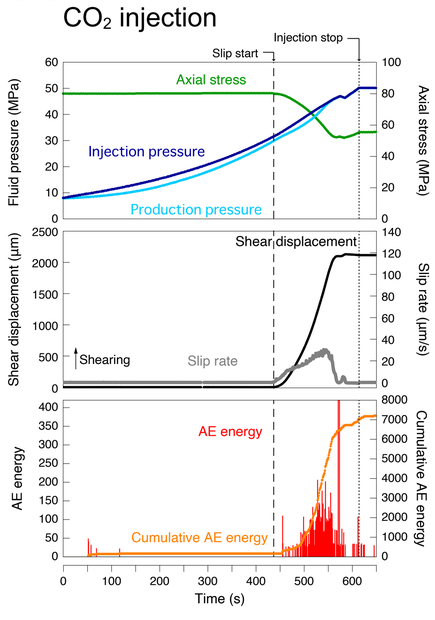
Results

Water-saturated andesitic lava

Water injection



CO_2 injection

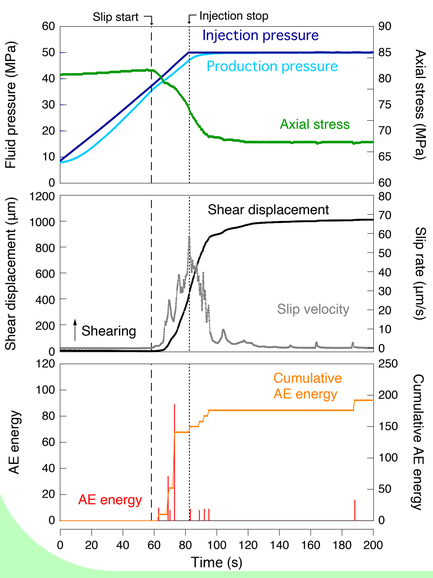


- Fluid pressure required for slip
  CO_2 injection: 31 MPa
  Water injection: 23 MPa
- Maximum slip rate
  CO_2 injection: 30 μm/s
  Water injection: 112 μm/s

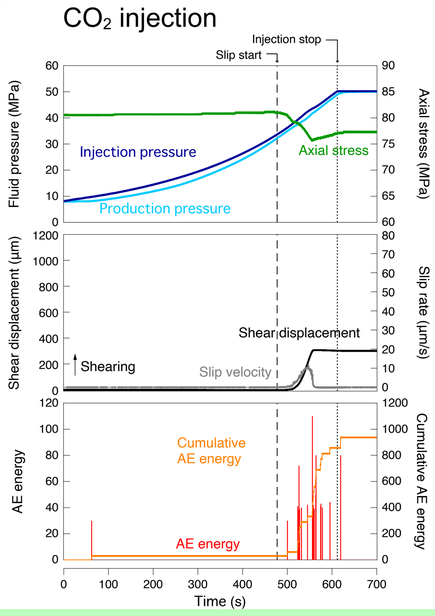
CO_2 injection induces increase in the fluid pressure at the onset of slip and reduction of slip rate.

Water-saturated basaltic lava

Water injection



CO_2 injection

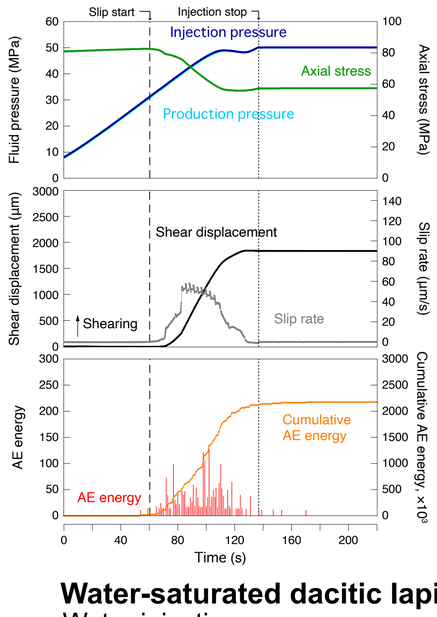


- Fluid pressure required for slip
  CO_2 injection: 33 MPa
  Water injection: 36 MPa
- Maximum slip rate
  CO_2 injection: 11 μm/s
  Water injection: 58 μm/s

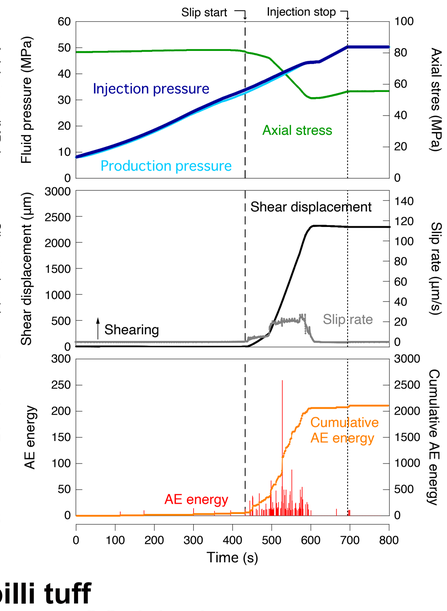
Compared to water injection, the maximum slip rate during CO_2 injection becomes lower.

Water-saturated andesitic tuff

Water injection



CO_2 injection

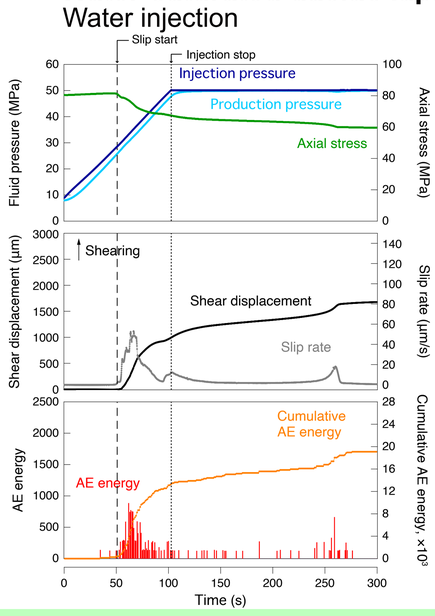


- Fluid pressure required for slip
  CO_2 injection: 33 MPa
  Water injection: 31 MPa
- Maximum slip rate
  CO_2 injection: 27 μm/s
  Water injection: 58 μm/s

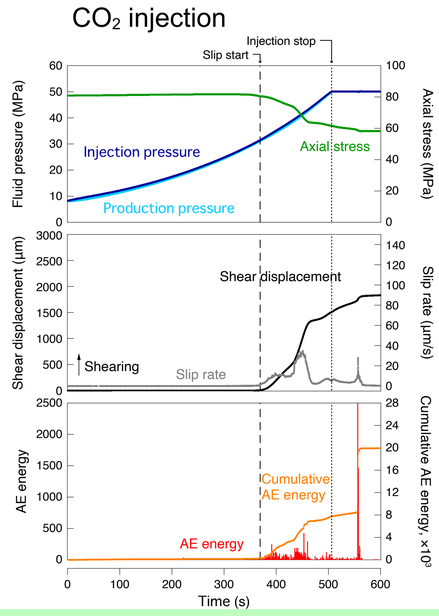
CO_2 injection induces increase in the fluid pressure at the onset of slip and reduction of slip rate.

Water-saturated dacitic lapilli tuff

Water injection



CO_2 injection

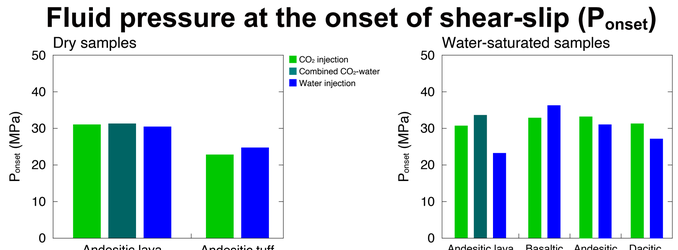


- Fluid pressure required for slip
  CO_2 injection: 31 MPa
  Water injection: 27 MPa
- Maximum slip rate
  CO_2 injection: 35 μm/s
  Water injection: 53 μm/s

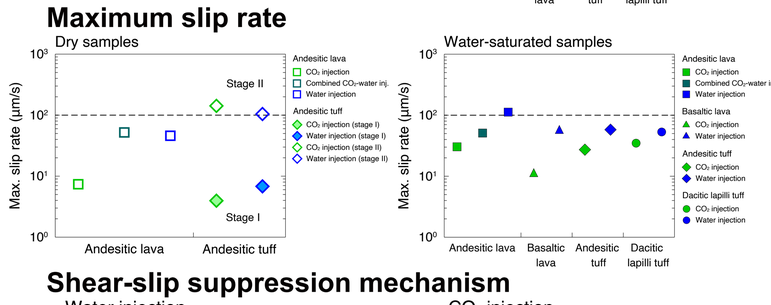
Repeated fluctuations in slip rate due to slip surface heterogeneity were observed.

Discussion

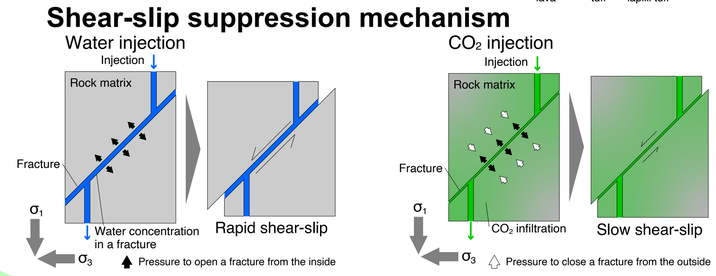
Fluid pressure at the onset of shear-slip (P_{onset})



Maximum slip rate



Shear-slip suppression mechanism



- The pressure at the onset of slip tended to be similar regardless of the injected fluid, or was up to approximately1.3 times larger during CO_2 injection.
- Compared to water injection, the maximum slip rate during CO_2 injection was often significantly reduced.

CO_2 has the effect of making shear-slip less likely to occur and reducing the slip rate.

- Water : concentrate within the fracture
  →higher pressure difference between the fracture interior and exterior
- CO_2 : infiltrate from the fracture into the matrix
  →lower pressure difference

The reduction in pressure difference between the fracture interior and exterior due to CO_2 infiltration from the fracture into matrix suppresses slip.

Conclusions

- CO_2 or/and water injection shear-slip experiments were conducted on various volcanic rocks with saw-cut fracture to investigate the effect of CO_2 on suppressing shear-slip.
- Comparison of the fluid pressures at the onset of shear-slip observed in each experiments revealed that CO_2 injection did not promote shear-slip but rather suppressed its occurrence.
- The maximum slip rate during CO_2 injection often decreased significantly compared to that during water injection.
- The effect of CO_2 on suppressing shear-slip was found to be related to its ease of infiltration from fracture into the rock matrix.

The reduction in pressure difference between the fracture interior and exterior due to CO_2 infiltration into the rock matrix causes increase in the pressure required for shear-slip initiation and reduction in slip rate.

CO_2 injection does not carry higher hazard of induced seismicity in volcanic rocks, as compared to water injection.

Acknowledgements

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