



Natural Analogue Study for Geological Sequestration of CO₂ at the Matsushiro Earthquake Fault Zone, Japan: CO₂ Seepage Mechanism

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Introduction

Studies of natural analogues are very useful for identifying key mechanisms and processes relevant to long-term stability and seepage mechanisms associated with CO₂ geological sequestration. Recent science reports on the safety of CO₂ geologic sequestration, identifies faults and their dynamic behavior as the major potential paths and cause of CO₂ seepage, respectively. Because the dynamics and long-term behavior of faults are difficult to characterize by laboratory tests, studies of natural analogues provide valuable knowledge about potential fault behavior during deep injection of CO₂.

In mid-1965, a swarm of earthquakes began in the Matsushiro area of Nagano city, Central Japan. The most active period lasted until 1967, followed by a five-year period of lower activity until 1970. During the earthquake swarm, a large volume of CO₂-saturated water discharged at the ground surface through surface ruptures in the epicenter region. The earthquake swarm was well observed and documented, and many scientists investigated the mechanism behind the tremors.

The Matsushiro earthquake swarm is a promising natural analogue to study the interaction of CO₂ bearing fluid flow and solid deformations. Thus, we have initiated a joint project using state-of-the-art coupled processes modelling and CO₂ flux measurement. In this paper, we briefly describe the Matsushiro earthquake swarm, one hypothesis of the mechanisms (leading to/causing) the swarm, and our research plan to investigate and try to verify such a hypothesis.

This study is carried with a grant of the Ministry of Economy, Trade and Industry of Japan. This paper describes the whole project and the scope of the geomechanical modelling. The scope of geochemical study is described by Todaka et al. [2006a, submitted] in GHGT-8.

Matsushiro earthquake swarm

During the five-year term of the swarm, between 1965 to 1970, approximately 60,000 earthquakes were felt while an additional ten times, i.e. about 600,000, unfelt tremors were recorded [JMA, 1968]. The total energy released was M6.4, and the energy of the maximum single earthquake was M5.4. During the swarm, ten million tons of CO₂ bearing water discharged at the surface through newly created surface ruptures.

The distribution of the surface ruptures and horizontal displacements of the ground surface showed movements along a left lateral, NW-SE oriented, strike slip fault, which is centered near the swarm epicenter. Also, up to 90 cm of uplift was measured. One probable cause of the swarm is water intrusion from great depth and associated dilatancy reactivated the fault system (Nur 1974, Kisslinger, 1975). Nakamura [1971] defined this mechanism as “water eruption”. Shimizu [1971] reported about CO₂ dissolved in the water.

We hypothesize that the water intrusion was the main cause of the earthquake swarm, and chemical and mechanical interactions of CO₂ with the formations played key roles controlling the eruption of water and CO₂ at the surface. Hence, we are studying how CO₂ migration depends on the dynamic behaviour within the deep formations. Specifically, we are studying how the dynamic fault behavior affects the trapping mechanisms for CO₂, and how potential breaches of cap formations along faults and the overlying fault system may control CO₂ up-flow. A schematic view of the assumed CO₂ path is shown in **Figure 1**.

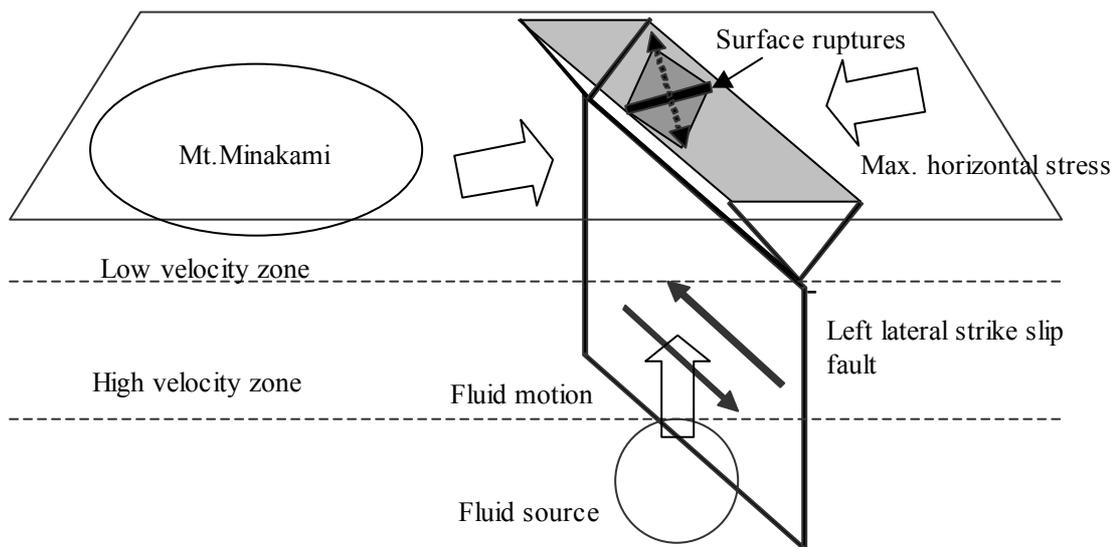


Figure 1. Schematic of the assumption of fluid intrusion and fault motion of Matsushiro earthquake swarm.

Investigation methodology

To investigate and try to verify the hypothesized mechanism for CO₂ release, and to investigate at what conditions such phenomena could occur at a CO₂ injection site, we plan to 1) synthesize existing data for the Matsushiro site, 2) conduct new CO₂ flux measurements at

the site, and 3) perform state-of-the-art coupled processes modelling, including both geomechanics and geochemistry. New soil gas and CO₂ flux measurements will be conducted in the area to identify the present path and magnitude of the CO₂ flow. Geochemical modeling with the TOUGH-REACT reactive transport simulator Xu et al. [2004] is used to analyze fluid flow, including phase transition of CO₂ and chemical reaction of carbonic acid and rocks. The coupled CO₂ fluid flow and mechanical processes, including fault motion and associated permeability changes, are modelled using the TOUGH-FLAC coupled reservoir-geomechanical simulator [Rutqvist et al., 2002]. The study structure is shown in **Figure 2**.

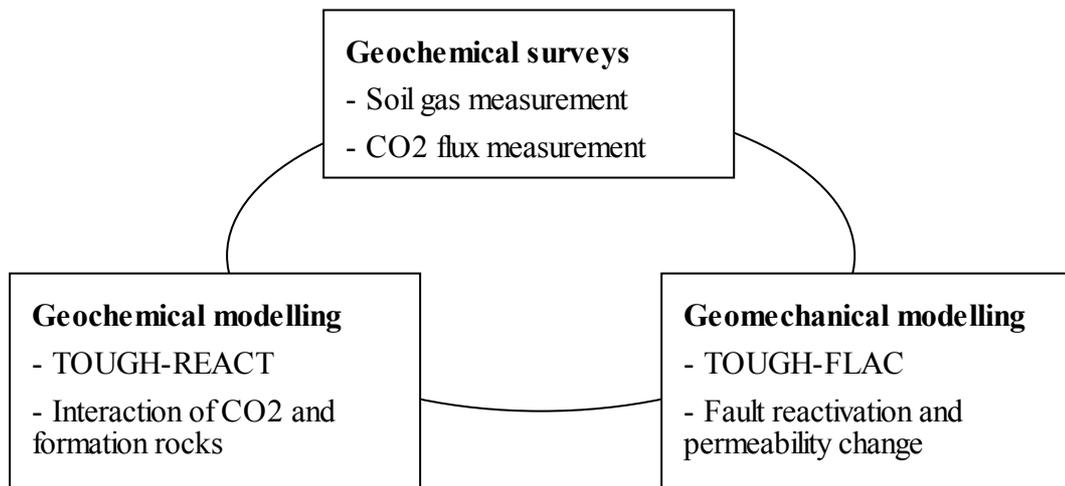


Figure 2. Plan for the natural analogue study of the Matsushiro site.

Conclusions

The Matsushiro site has been identified as a promising natural analogue for studies of fault - fluid interaction related to CO₂ injection, including both mechanical and chemical interactions. The combination of geochemical surveys, geochemical and geomechanical modelling, as well as comparison with other natural analogue sites are expected to add knowledge about the fluid seepage through a faulted rock system. Also, simulation models employed here will be tools for assessing the risk of CO₂ seepage and designing CO₂ storage facilities. The outcomes of the study will be valuable for establishing risk assessment and management guidelines for CO₂ seepage through faults.

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