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	Project Information	Project Number : 22H04932 Keywords : CO ₂ fixation, mantle, water-rock interaction, subduction zone Project Period (FY) : 2022-2026

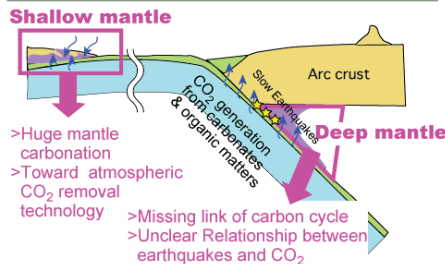
Purpose and Background of the Research

● Outline of the Research

The global carbon cycle has a significant impact on the Earth's surface environment and the state of plate boundaries. Mantle is a rock that can absorb CO₂ like a sponge. However, except near the surface, the nature of CO₂ fixation (carbonation) of mantle is not well understood. We conceived this study to elucidate the reactions between CO₂ fluids and rocks at the surface and at depth, and their chemical and mechanical effects on plate boundaries. In this study, carbonation and serpentinization of mantle bodies within the subduction zones will be clarified through geological surveys, and through laboratory experiments on mantle carbonation at conditions near the surface and beneath island arcs (Fig. 1). We will clarify the essential mechanism of CO₂ fixation in mantle rocks related to fracturing and mass transport, and propose a CO₂ cycle model linking the CO₂ fluid-rock interaction, fault behavior, and earthquakes at plate boundaries.

Essential questions

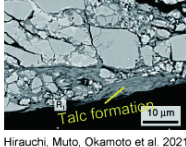
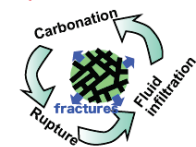
1. By what mechanism is carbon at the Earth's surface fixed in mantle rocks?
2. How does CO₂ fluid affect reactions, material cycles and seismic activities at subducting plate boundaries?



Hypothesis 1
Reaction-fracturing-mass transfer feedback promotes CO₂ fixation?

Hypothesis 2
Reaction between CO₂-H₂O fluids and the mantle cause to slow earthquakes at plate boundary?

Expansion vs. Contraction



Hirauchi, Muto, Okamoto et al. 2021

Figure 1. Image of the whole project.

Purpose of this study

To determine the mechanisms of CO₂ generation and CO₂ storage in the mantle at subduction zones and their dynamical effects on plate boundaries.

Research Contents

<p>Deep mantle</p> <p>[1] Geological surveys of mantle bodies from subduction zone origin (Sanbagawa belt etc) • Origin of CO₂ fluids • Extent and distribution of carbonation • reaction-fracturing structures</p>	<p>Shallow mantle</p> <p>Mantle bodies carbonated at near the surfaces (Oman ophiolite etc)</p> <p>[3] Reaction -fluid flow Exp • Fracturing and permeability change due to volume expanding reactions • Porosity generation and volume contraction due to elemental leaching • Link above mechanisms to CO₂ fixation</p>
<p>[2] In-situ Reaction -deformation Exp • Reaction & mass transfer at deep mantle-crust boundary • CO₂ fixation mechanism • Relationship between changes in fault-slip behavior due to CO₂</p>	<p>[4] Geochemical modeling of subduction zone fluids Prediction of fluid composition along the subduction zone by state-of-the-art solution chemistry and its impact on CO₂ reaction processes</p>

Comparison (between 1 and 3) / Integration (between 2 and 4)

A new Earth material science that links material cycles from the surface to the depths and dynamic processes at subducting plate boundaries, based on fluid chemistry

Ripple effects
Effective CCS technologies inspired by natural process

● The paradox of CO₂ fixation in rocks

A continuous fluid supply is essential for the mantle carbonation. However, as CO₂ absorption causes the rock volume expansion, clogging of the flow paths and inhibits a supply of CO₂. There are two possible ways to overcome this problem in nature; first is fracturing rock by the volume expansion; second is volume contraction accompanied by removal of elements. We will elucidate this paradox through multiple approaches: natural, experimental, and modeling.

● Fluid - rock reactions and fault processes within subduction-zone plate boundaries

We focus on the characteristic chemical reactions via CO₂ fluids at the mantle-crustal boundary within subduction zones, and tests whether the reaction products slow fault slip at plate boundaries (associated with slow earthquakes).

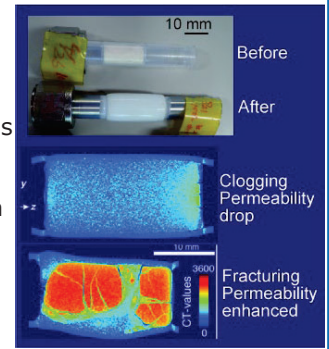


Figure 2. Clogging vs. fracturing during hydration of MgO (Uno, Okamoto et al. 2022)

Expected Research Achievements

● The state of mantle carbonation in subduction zones

State of carbonation in mantle wedge in subduction-zones are still unknown. We investigate the Sanbagawa metamorphic Belt, where numerous mantle wedge-derived bodies occur, to assess the degree of carbonation progression and to investigate the origin of CO₂ fluids, based on mass transport and stable C-O isotopes analyses (Fig. 3).

● Mechanism of CO₂ fixation in the mantle with crack and porosity formation

We will construct a new apparatus for reaction-fluid flow hydrothermal experiments with monitoring the volume change during the reactions. We will conduct systematic runs by changing the initial fluid (pH, ions, complexes) and the rocks to investigate the control factors on CO₂ fixation associated with fracturing and porosity formation (Fig. 4).

● Influence of CO₂ fluid-rock reactions on fault slip behavior

Reaction-deformation experiments will be conducted at mantle wedge conditions. First, a crustal-mantle boundary is set up to reveal the reactions under hydrostatic conditions. Then, deformation experiments with differential stress are conducted to know how the reactions involving H₂O-CO₂ fluid affect the slip behavior of the plate boundary fault.

● Integration based on the geochemical modeling of subduction zone fluids

We will calculate the fluid compositions from surface to deep subduction zones, and build fluid-rock interaction model that integrates lab experiments and natural observations, and links material circulation and behaviors of subduction zone faults.

● Toward CO₂ fixation Technology inspired by nature

Based on the carbonation mechanism in natural mantle bodies, we will search an effective CO₂ fixation technology that is controlled by the fluid composition.



Figure 3. Sheared carbonated mantle rocks

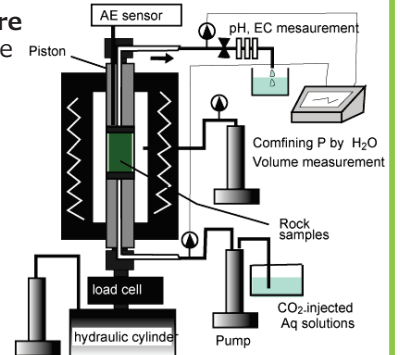


Figure 4. Apparatus of new reaction fluid flow exps.