

Parameterization of melting phase relations in CO₂-H₂O-silicate system toward understanding carbon cycle

*Masaki Ohno¹, Hikaru Iwamori^{1,2}

1. Tokyo Institute of Technology, 2. Japan Agency for Marine-Earth Science and Technology

Carbon dioxide in the atmosphere acts as a greenhouse gas together with H₂O vapor, and its increase by artificial degassing during the past decades has attracted societal and scientific attention. Through the Earth's history over the past several giga years, the atmospheric CO₂ partial pressure drastically decreased, during which partitioning of CO₂ between the surface environment and the Earth's interior has controlled the budget. Behavior of CO₂ in subduction zones is important for the partitioning as subduction zones are the site where the surface materials enter the mantle. Fluid and magma play crucial roles in material cycling, including CO₂, in subduction zones. Therefore, how CO₂ is transported by and interacts with the processes of hydration-dehydration and melting is key to understanding the carbon cycle in the Earth system (Dasgupta & Hirschmann, 2010, EPSL; Kelemen & Manning, 2015, PNAS). For this sake, phase relations in the wide and continuous compositional space of CO₂-H₂O-silicate system and their quantitative description are necessary, which, however, are not available at present. In this study, we compile the relevant phase relations based on the previous experiments, and attempt to establish their quantitative parameterization, ultimately aiming at revealing the carbon cycle and its evolution in the Earth's system.

Material cycling and melting in subduction zones have been discussed long, in which volatile components are critical. For, volatile components decrease solidus temperatures of mantle rocks. Carbon exists mostly as CO₂ in the shallow part above ~300 km depth of subduction zones. Both H₂O and CO₂ are released from slabs, and affect melting. The effect of H₂O on melting has been parameterized in the previous studies (e.g., Iwamori, 1998, EPSL). Utilizing the parameterized phase relation, numerical simulation of mantle-fluid flow, melting and elemental transport in subduction zones has been performed (e.g., Ikemoto & Iwamori, 2014, EPS). On the other hand, the effect on melting has not been parameterized for CO₂, and even more so for the combination of CO₂-H₂O. In this study, on the basis of previous experimental studies, the phase relations within the range of CO₂=0-5 wt.%, H₂O=0-1 wt.%, pressure=0-12 GPa, temperature=0-2000 degree C are parameterized.

Below 2.2 GPa CO₂ constitutes a gas-fluid phase, and does not dissolve much to melt or solid phase, which minimize its effect on melting (e.g., several degree C at most). Above 2.2 GPa, solidus temperature of mantle peridotite decreases by ~200 degree C, due to occurrence of carbonate minerals (ex., magnesite) and carbonatite melt. Carbonate and carbonatite melt are incompatible with silicates mainly consisting of the peridotite. Because of this nature when melting occurs, carbonatite melt appears at once on the solidus temperature, whereas silicate melt is produced on higher temperature than solidus temperature.

In the system involving both CO₂ and H₂O, the role of volatiles is complicated. Below 2.2 GPa, CO₂ is mixed with H₂O in the gas-fluid phase and prevents H₂O from decreasing solidus temperature by suppressing the activity of H₂O. In this case, the solidus temperature of peridotite is higher than that only with H₂O. On the other hand, above 2.2 GPa, both CO₂ and H₂O increase their solubilities into the melt and solid phases, affecting significantly the phase relations, including peridotite melting. As a result, melting occurs at lower temperatures: under the presence of the two components, the lowest solidus temperature is ~850 degree C at pressure=~3 GPa. This new parameterization enables us to perform quantitative evaluation and numerical simulation concerning the carbon cycling in the upper mantle, including subduction zones.

Keywords: material cycling, subduction zone, dehydration-hydration, carbon dioxide, Earth history, solidus