Seebeck coefficient measurement of olivine by dual heating system and its application to the redox kinetics of the subducted slabs

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Subduction plays an important role in the plate tectonics of the Earth and is closely related to many activities such as water transport, volcanism and mantle convection. In addition, the subducted slabs can also influence the redox state of the Earth's interior because the descending slabs are always colder and more oxidized compared with the surrounding mantle. Since thermal boundary layer is likely to develop around the cold slab, the heat conduction could produce the electrical potential gradient by the Seebeck effect. The Seebeck coefficient is a parameter to define the type of the dominant charge carrier inside the materials under thermal gradient. Positive value of seebeck coefficient means the charge carriers have positive valence such as electron holes (small polarons) and protons. When the value is negative, electrons or metal vacancy are potential charge carriers.

To determine the Seebeck coefficient under high pressure, we established the cell design with dual heating systems on the 6-axis apparatus. Two disk TiB_2 heaters were placed in the octahedral cell to make two insulated heating systems. Temperature differences were produced on the two sides of the sample by dual heaters and the temperatures were measured by separated thermocouples on each side of the sample. In addition, the electromotive force (voltage difference) of the sample was measured by high resolution multimeter. Therefore, we could easily obtain the seebeck coefficient from the formula, $S= \Delta V/\Delta T$. To check the reliability of the method, we use two types of P-type silicon single crystals with different boron doping concentrations as the test materials. The results are quite consistent with previous experimental and calculation results obtained at ambient pressure.

In order to better understand the redox kinetics of the subduction zones, olivine, the dominant phase in the upper mantle, is the most important mineral to control the redox condition. We measured the Seebeck coefficient of olivine under high pressure. The Seebeck coefficient of the sintered Fo_{90} aggregates was measured at 5 GPa. The Seebeck coefficient is positive and decreases with increasing temperature. The positive to negative transition of the charge carrier occurred at around 1100-1200℃. Thus, we can assume that the temperature of the overlying mantle at about 150 km is above 1350℃, and then olivine would behave as N-type semiconductors. In contrast, olivine in the cold slab behaves as P-type semiconductor, suggesting that the cold slab will be oxidized itself by the Seebeck effect.

Keywords: Seebeck coefficient, redox kinetics, subducted slab, thermal boundary layer, charge carrier, olivine