Electrical conductivity of carbonate in subducted slab

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Carbon is recycled, mainly as carbonates, by means of a subduction process into the deep Earth. The extent of the deep mantle cycle that largely depends on the preservation of carbonates during subduction is so far unknown. Previous experimental studies demonstrate that Mg- and Ca-bearing carbonates should be stable in mantle conditions. Therefore, it is important to investigate the physical properties of carbonate minerals for an understanding of the behavior of carbon in the deep mantle. Recent advances in geophysical observations have allowed mapping of the electrical conductivity of the Earth’s mantle interior. Electrical conductivity measurements on carbonates at high pressures and high temperatures can help the estimation of the distribution of carbon in the deep mantle.

The starting material were synthetic carbonates, magnesite ($MgCO_3$), aragonite ($CaCO_3$) and dolomite ($(Mg,Ca)CO_3$). In this study, a conventional multi-anvil high-pressure apparatus was used [1]. The cell assembly was kept at 383 K in an oven, and was removed just before the compression experiments began. The experiments were performed at pressures up to 6 GPa and temperatures up to 1000 K. Alumina was used as an insulator between the electrical resistivity measurement lines and the heater lines. The resistivity of alumina used in this study was sufficiently higher than that of the sample at high pressures and high temperatures. The complex impedance was measured with a Solartron 1260 Impedance/Gain-Phase Analyzer with a 1296 Dielectric Interface over a frequency range of 0.05 Hz to 1 MHz. The impedance data of the samples were acquired at temperatures in the range of 500 to 1000 K at each 50 K interval. The measured conductivity was fitted to an Arrhenius equation to calculate the activation enthalpy, energy, and volume.

The activation enthalpies of dolomite and magnesite decrease as pressure increases. In contrast, that of aragonite increases as pressure increases. It is known that the activation volume is related to the electrical conduction mechanism. In the case when extrinsic ionic conduction is the dominant mechanism of the electric conductivity, it is expected that the activation volume would have a positive value. Therefore, the ionic conduction mechanism would be dominant in aragonite [2]. In contrast, the negative activation volume would be expected for minerals with a hopping conduction mechanism. Thus, magnesite and dolomite exhibit hopping conduction at high pressures and high temperatures.

The electrical conductivities of magnesite [1] and dolomite [3] were of the same order of magnitude as that of olivine. Therefore, it is difficult to identify the Mg-dominated rock bodies in the upper mantle from the perspective of electrical conductivity. In contrast, the electrical conductivity of aragonite [3] was one to two orders of magnitude higher than that of olivine. When the Ca-dominated carbonate rocks, such as marine sediments, in the subducted slabs are dragged into the deep mantle, the electrical conductivity of the aragonite-dominated rock bodies is higher than that of the surrounding rocks in the upper mantle. It is known that the electrical conductivity of wet rock, which contains a hydroxyl ion component in its minerals and/or a fluid phase, is higher than that of dry mineral. The calcium carbonates could contribute to the higher electrical conductivity in the same way as the water effect.

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[3] Ono & Mibe (2015) Influence of pressure and temperature on the electrical conductivity of dolomite, Phys. Chem. Minerals, 42, 773-779.

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