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Development of A Preliminary Reference Rock Model for Physical Properties of Fluid-bearing Rocks

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Backgrounds: Recent advances in seismic tomography and magneto-telluric (MT) imaging have increased the potential for mapping the distribution of geological fluids (i.e., aqueous fluids and silicate melts) in the Earth's crust and uppermost mantle, since seismic velocity is sensitive to the fluid fraction, while electrical conductivity is strongly dependent on the connectivity of conductive fluid phases. To interpret the observed physical properties into the nature of the fluid, their correlation with the microstructure of fluid-bearing rocks is essential.

Sources of uncertainty: The seismic wave velocities are dependent on temperature and lithology, i.e., the phase and solid-solution compositions of the major minerals composing the rocks, besides on the fluid fraction. Especially in the middle and lower continental crusts, there is often considerable uncertainty regarding the lithology and temperature. Therefore, when the lithological and thermal structures are not well constrained, the uncertainties of the estimation of fluid distribution becomes large. On the other hand, the electrical conductivity is less dependent on the mineral compositions and phases, compared to the large contrast between those of silicate minerals and fluid phases. Although experimental data of electrical conductivity of minerals and fluids at elevated pressure and temperature are still insufficient, MT observations provide important constrains on the fluid distribution in the crust and mantle.

Scale resolutions of the geophysical imaging and length scale of geological heterogeneity: The observed seismic velocity is an average value typically in a km scale. Space resolution of the MT imaging is a few to tens of km, dependent on the depth. Given the high electrical conductivity in the middle to lower crusts of active convergent margins, interconnection of the fluid phases should be established in these km scales.

Role of heterogeneity: Since the dihedral angles between aqueous fluids and minerals in crustal conditions are generally larger than 60 degree, large fluid fraction is required for the fluid interconnection. The saline components in the fluids decrease the dihedral angle, but carbon dioxide increases, counteracting with each other. The veins and cracks can increase the fluid connectivity locally and anisotropically, but their individual length scale is much smaller than the imaging resolution. There are several other mechanisms to produce small scale heterogeneity or fabrics of the fluid distribution, but they may not responsible for the pervasive fluid interconnection in a km scale. Therefore, grain-scale fluid interconnection is still the first hypothesis to be tested. The relation between the volume fraction and connectivity of the pore fluids should be quantitatively understood for major crustal rocks.

The PROM project: In this context, we have reviewed and compiled the data of seismic velocities, electrical conductivities, and dihedral angles and other microstructural factors that determine the grain-scale fluid distribution for the rocks of crust and uppermost mantle. Although lack of the physical property data at elevated pressure and temperatures does not allow us to develop a comprehensive data base, a possible data set composed of some major rock types and their physical properties as a function of fluid fraction can be presented as a preliminary reference model for the crustal rocks.

Keywords: physical property of rocks, pore fluid, microstructure