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Measurements of electrical impedance and elastic wave velocity of reservoir rock under fluid-flow test

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The estimation of water saturation under the ground is essential in geothermal fields, particularly for EGS (enhanced geothermal system). To estimate water saturation, recently, electromagnetic exploration using Magnetotelluric (MT) method has been applied in the geothermal fields. However, the relationship between electrical impedance obtained from this method and water saturation in the reservoir rock has not been well known. Our goal is to elucidate this basic relationship by fluid-flow experiments. As our first step to this goal, we developed the technique to measure and analyze the electrical impedance of the cracked rock in the geothermal reservoir. The fluid-flow test has been conducted as following procedures. At first, reservoir rock sample (pyroxene andesite, Makizono lava formation, Japan) was filled with nitrogen gas (P_p = 10 MPa) under 20 MPa of confining pressure. This nitrogen gas imitates the overheated steam in the geothermal fields. Then, brine (1wt.%-KCl, 1.75 S/m) which imitates the artificial recharge to the reservoir was injected to the samples. After flow rate of drainage fluid becomes stable, injection pressure was increased (11, 12, 14, 16, 18 MPa) and decreased (18, 16, 14, 12, 11 MPa) to vary the water saturation in the samples. During the test, water saturation, permeability, electrical impedance (10^{-2}-10^5 Hz of frequency) and elastic wave velocity were measured. As a result of andesite, electrical impedance dramatically decreased from 10^5 to 10^3 Ω and P-wave velocity increased by 2% due to the brine injection. This remarkable change of the electrical impedance could be due to the replacement of pre-filled nitrogen gas to the brine. After the brine injection, electrical impedance decreased with injection pressure (small change of water saturation) by up to 40% while P-wave velocity was almost constant (less than 1%). This decrease of electrical impedance with injection pressure could be related to the flow to the narrow path (microcrack) which cannot be detected by P-wave velocity. After the increasing injection pressure, it was decreased to study the hysteresis of each parameter. In the pressure decreasing process, P-wave velocity was almost constant (less than 1%) while electrical impedance increased with decreasing injection pressure and it was smaller than that in pressure increasing process (up to 27% at 11 MPa of injection pressure). This hysteresis of electrical impedance could be caused by the hysteresis of water saturation. Our experimental results suggest that P-wave velocity can detect the injected water just after the injection while electrical impedance is sensitive to the change of water saturation after the injection.