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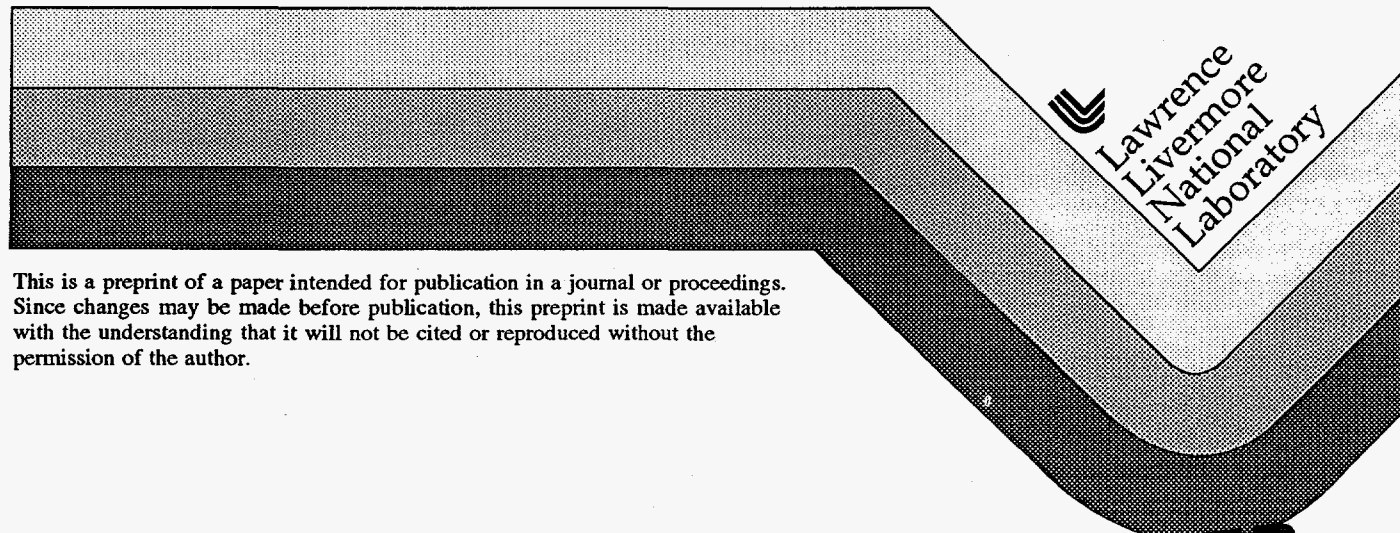
Electrical Properties of SB-15D Rocks at Reservoir Conditions

J. Roberts
B.P. Bonner
A. Duba

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Electrical Properties of SB-15D Rocks at Reservoir Conditions

Jeffery J. Roberts, Brian P. Bonner, and Al Duba

Introduction

The electrical properties of reservoir rocks are important for many reasons including the establishment of a database for interpretation of borehole data and surface EM measurements and for the information that can be obtained regarding the physical and transport properties of the rock/water system. We have measured the electrical properties of several samples of geysers core at pressures up to 100 bars (confining pressure) and temperatures between 20 and 150°C. Two types of measurements have been made, those with separate pore pressure control and those without pore pressure control.

Experimental

Samples of preserved core from SB-15D Run 12, 919 feet, were prepared by machining right cylinders approximately 1.5 cm high and 2.5 cm diameter. Porosity was determined by drying the samples, weighing, then evacuating the samples and backfilling with water under pressure. When a steady weight was obtained it was assumed the samples were saturated (after saturating for more than 10 days). The porosity was determined by subtracting the dry density from the wet density. Porosity varied between 1 and 6.5% with a mean of 3.7% for twelve samples. Prior to electrical conductivity measurements, samples were saturated in a brine solution consisting of distilled water with 1.87 g NaCl/liter. The conductivity of the solution is 3.74 mS/cm.

Samples were jacketed in viton with Hastalloy endcaps backed by a perforated Pt foil electrode. For measurements without separate pore pressure control, the endcaps contained a chamber that acted as a reservoir for water exiting the sample upon pressurization. Three or four samples were simultaneously placed inside the externally-heated pressure vessel which used isopar fluid as the pressurization medium. Electrical leads exited the vessel through conical seals in the vessel closure. An HP 4274A LCR meter was used to measure the resistance and capacitance of the samples between 100 and 2000 Hz. All data were collected and stored via computer including pressure and temperature measurements.

The main differences in the experimental set-up for the control of pore pressure are that only one sample was examined at a time and a Si-based oil was used as the confining pressure medium. A system of valves, screw presses, and gauges were used so that pore-pressure could be controlled and monitored on either end of the sample.

Results and Discussion

Pore pressure not explicitly controlled.

Measurements began on samples at room temperature ($\sim 21^\circ\text{C}$) and ~ 3 bars pressure. The resistivity values for three samples ranged between 70 and 120 Ωm . Increasing pressure had only a small effect in the electrical resistivity for measurements made at 20°C . An increase in pressure up to ~ 90 bars increased the resistivity only slightly, by ~ 0.05 log units. Increasing temperature had a large effect on the electrical resistivity of all samples. At a pressure of ~ 10 bars, increasing temperature from 20 to 145°C resulted in a decrease in the electrical resistivity of nearly an order of magnitude, from ~ 100 to 15 Ωm .

Lowering the pressure when the samples were at temperatures of $\sim 145^\circ\text{C}$ produced some interesting effects. Although the pore pressure was not controlled explicitly, lowering the confining pressure lowered the pore pressure enough so that the steam field was entered. At 145°C the electrical conductivity drops by about 2 orders of magnitude between 4 and 6 bars confining pressure (Fig. 1).

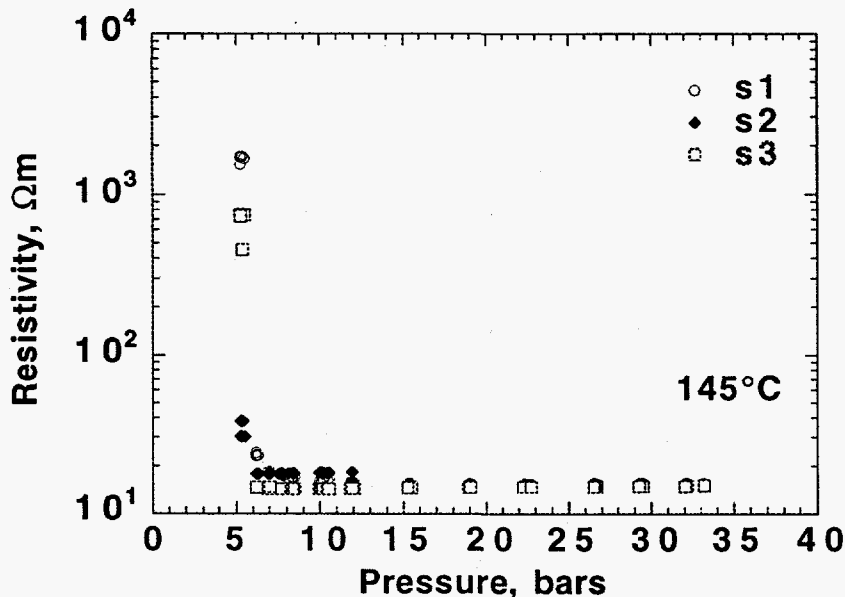


Figure 1. Resistivity of three SB-15D samples at 145°C as a function of confining pressure.

Pore pressure controlled experiments.

One experiment was successfully run controlling the pore pressure separate from that of confining pressure. The total length of the experiment was about three months. The porosity of this particular sample was 3.4% and would be described as an argillite or

metashale rather than a metagraywacke. Despite creating differential pressures in excess of 15 bars, there was never observable flow through the sample, even in the steam stability field, for periods up to several days. Previous experiments that we have performed on other rocks using a similar set-up indicate that the permeability of the sample is below 500 nD (10^{-21} m^2), and could be orders of magnitude less. Figure 2 shows the resistivity of the sample as a function of temperature at a confining pressure of ~40 bars. Pore pressure was controlled during this experiment. One end of the sample was held to a pore pressure below 1 bar, which allowed boiling to occur at sufficiently high temperature. As seen in the plot, the resistivity at 20°C is near 600 Ωm , and reaches a minimum of 100 Ωm between 100 and 110°C. At higher temperatures the resistivity again increases, due to the formation of steam. At 145°C the resistivity is the nearly same as at 20°C. An important point is that in the absence of a system where fracture properties dominate the electrical properties, care must be taken with the inversion and interpretation of field data since within a narrow resistivity range a transition from liquid-dominated to steam-dominated conditions exists.

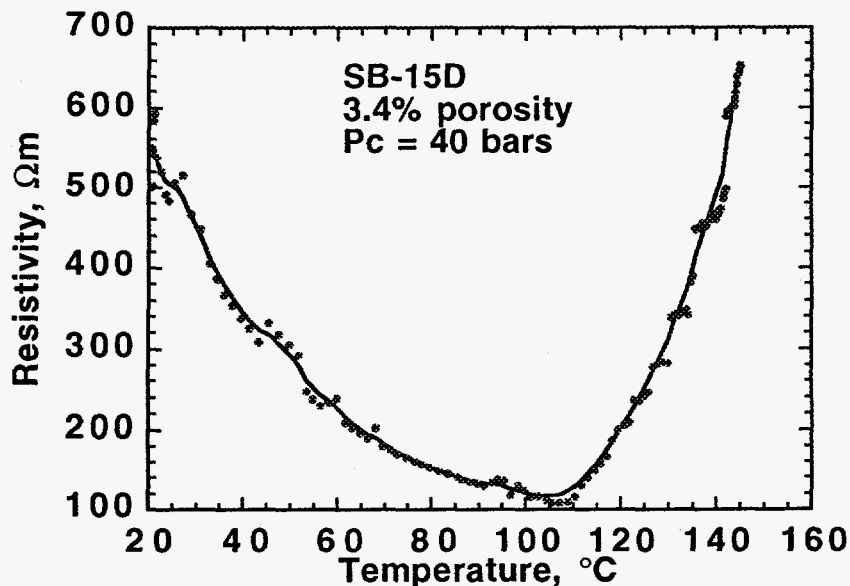


Figure 2. Resistivity of one SB-15D sample as a function of temperature at a confining pressure of 40 bars. Pore pressure was explicitly controlled to ~15 and less than one bar on either end of the sample. This permitted boiling to occur on the low pressure end of the sample.

Figure 3 is a plot of the resistivity as a function of pore pressure at 147°C and a confining pressure of 50.5 bars. The 'downstream' or low side pore pressure was varied

while the pore pressure on the other side of the sample was held to ~15.3 bars. Only the downstream pressure was varied because of the low permeability of the sample. This plot shows an interesting trend of increasing resistivity with decreasing pore pressure. At about 1.5 bars there is a change in slope. Further investigation is needed, but this change in slope is probably caused by the first boiling to occur in the largest, most accessible pores. One idea is that boiling occurs over a range of temperature because of the different surface tension, or suction potential that exists in pores of smaller radii. This accounts for the slope of the segment at lower pressure. This result is in basic agreement with the experiment performed without explicit pore pressure control, in that decreasing the pressure (pore pressure) causes a large increase in resistivity at high temperature and confining pressure.

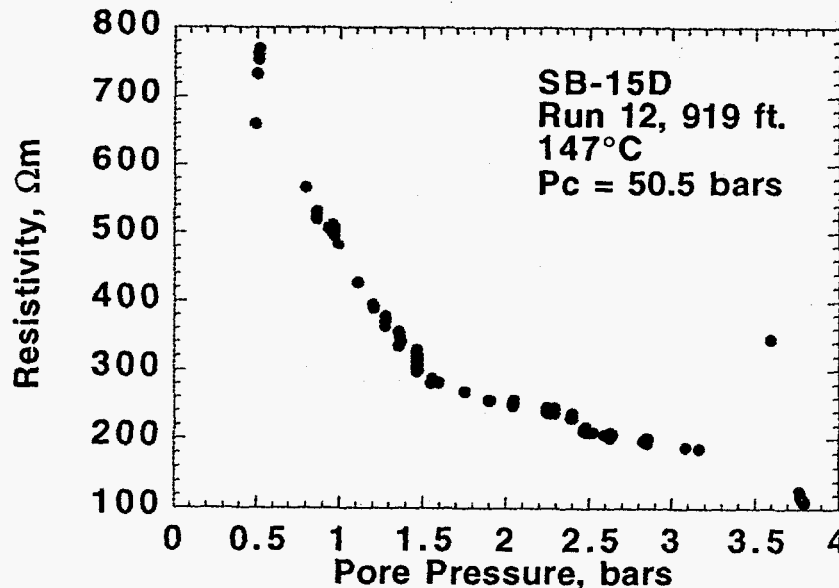


Figure 3. Resistivity as a function of pore pressure for a sample from SB-15D, Run 12, 919 ft. Confining pressure was held to ~50.5 bars and temperature was 147°C. The pore pressure on one end of the sample was held to 15 bars while the low pressure end was varied.

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