RESISTIVITY OF BRINE SATURATED ROCK SAMPLES AT ELEVATED TEMPERATURES

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Electrical resistivities of rock samples saturated with NaCl solution have been measured at 1 KHz and under 31 MPa hydrostatic pressures and at temperatures up to 350°C. The samples included Berea sandstone, Boise sandstone, cores from the Cerro Prieto geothermal field, Mexico, and Hawaiian basalt.

The measurements were aimed at studying the effect of mineralogy and thermal alteration of rock on the contribution of surface electrical conduction to the overall conductivity. The mineralogical composition of the samples were determined by X-ray diffraction analysis.

The details of the experimental setup have been reported elsewhere and will not be repeated here.[1] Since the overall behavior of saturated rock samples is influenced by the saturating fluid, data from a previous study[2] on the electrical resistivity of brines as a function of temperature are included here.

All samples indicated a typical behavior as shown in Figure 1. In general, the resistivity of the samples decrease sharply between 25°C to 200°C. The rate of decrease slows down considerably beyond this temperature and then a slight increase in resistivity is noticeable above 300°C.

The general behavior of the saturated rock samples shown above is very similar to the behavior of the saturating fluid as shown in Figure 2. In addition to the brine, however, there are other factors controlling the temperature dependence of rock. These include formation resistivity factor, surface conductance, mineralogy, etc.

As shown in Figure 3, formation resistivity factor decreases with temperature up to 150°C-175°C and then stabilizes at higher temperature. The rate of decrease is a function of surface conduction of the rock sample. The observed decrease in formation resistivity factor is explained by the effect of temperature on the conductance of the ionic double layer. The specific surface conductance of constant charge density surfaces changes only if the average mobility of ions changes with temperature.

Experiments with Berea sandstone samples indicate that the relative contribution of surface conductance to the overall conductivity is dependent upon the solution concentration. This is evident from the comparison of Figure 4 and Figure 5.

As shown in Figure 6 the relative formation resistivity factor of samples with surface conductance vary with temperature. The samples with a high content of clay minerals show a higher decrease in the relative formation resistivity factor. Increasing the solution concentration affects this considerably. For example, the Cerro Prieto sample No. 5 shows a 16% decrease in formation resistivity factor at about 150°C when the pore fluid concentration is 0.5 wt%. The change is reduced to 10% when the pore fluid concentration is 3 wt%.

For a sample of Berea sandstone ignited up to 550°C for four hours, a plot of solution resistivity versus sample resistivity is shown in Figure 7. All data points up to a temperature of 175°C fall on a straight line and deviate from it at higher temperatures. As shown in Figure 8, the formation resistivity factor appears to be constant and independent of temperature up to 175°C and then increases with temperature. Although the pore fluid concentration is 0.5 wt%, no appreciable surface conductance is observed. This is explained by the thermal alteration of the cation exchange capacity of clay materials because of ignition. This is in agreement with the data presented by Kern, et al.[3] but is in contradiction with those of Sanyal.[4]

The observed increase in formation resistivity factor at temperatures higher than 175°C may be attributed to physical changes in pore construction because of thermal expansion. Based on the work published by Maxwell and Verral[5] and Maxwell[6] some degree of reduction in the porosity with temperature is expected. The magnitude of such reduction is, however, not enough to support the hypothesis that the reduction of porosity is fully responsible for the observed increase in formation resistivity factor.

The other contributing factor is the porosity exponent. The composite effect of both the porosity reduction and an increase in porosity exponent is a more reasonable explanation of the observed behavior of the formation resistivity factor.

From the experiment on the ignited Berea sample and another Berea sample unexposed to high temperature, we were able to compute the effect of surface conduction on formation resistivity factor and as a function of temperature, Fig. 9. In general, above a temperature of 150°C, the structural change in the rock may offset the true effect of surface conduction on the formation resistivity factor.

References

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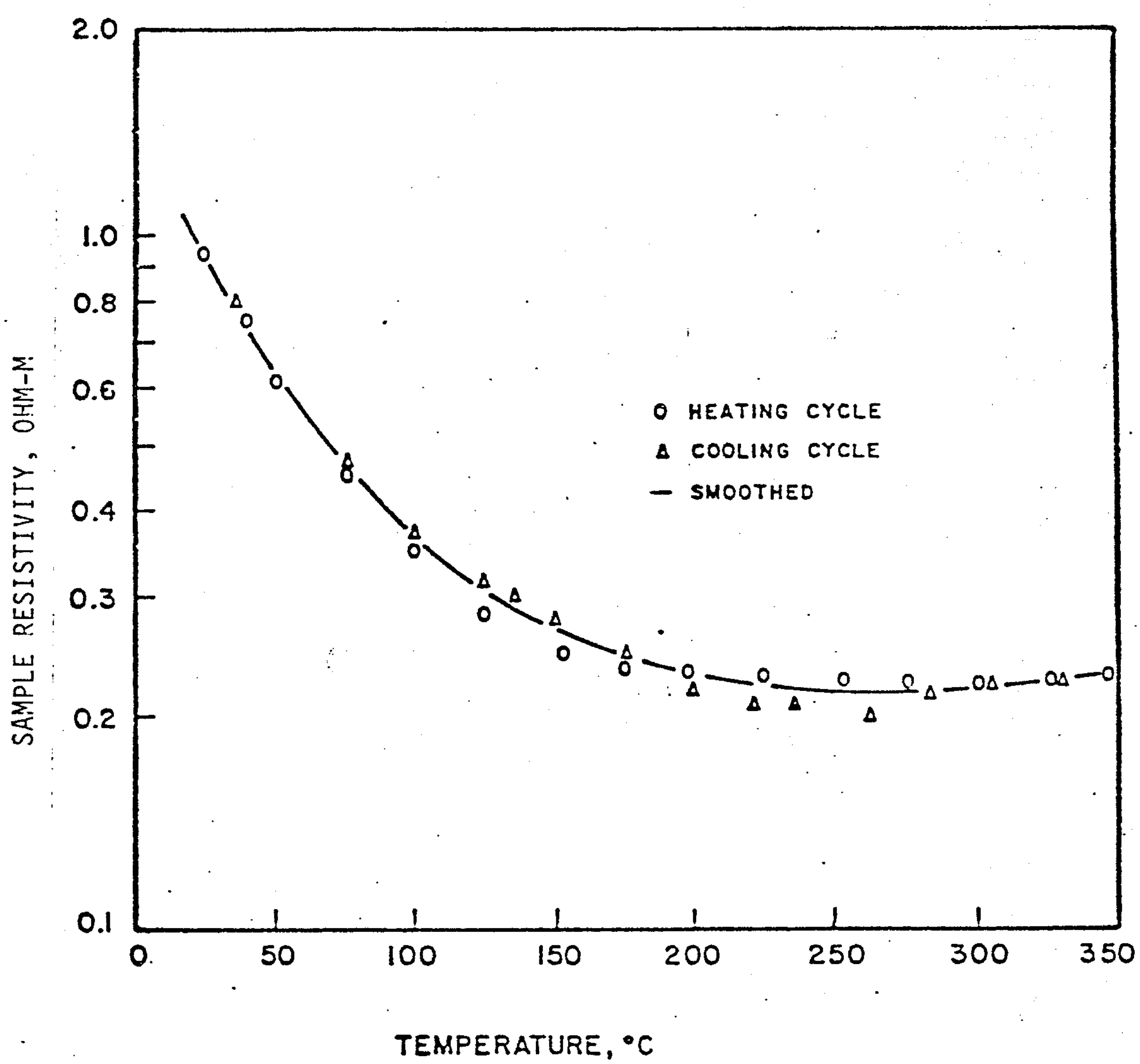

Fig. 1- Typical Resistivity Behavior
With Temperature

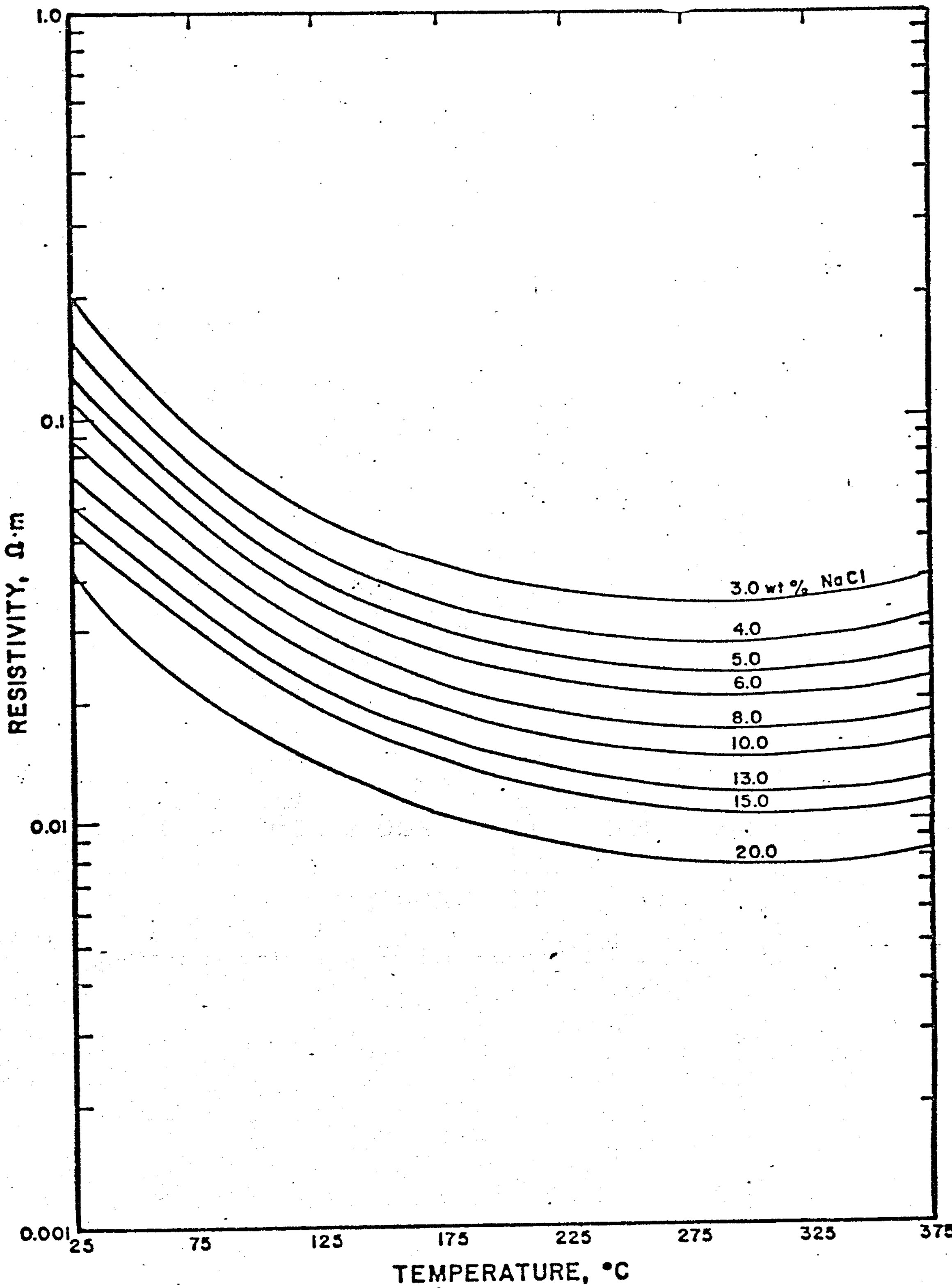

Fig. 2- Resistivity of NaCl Solution
as a Function of Temperature
(Ref. 2)

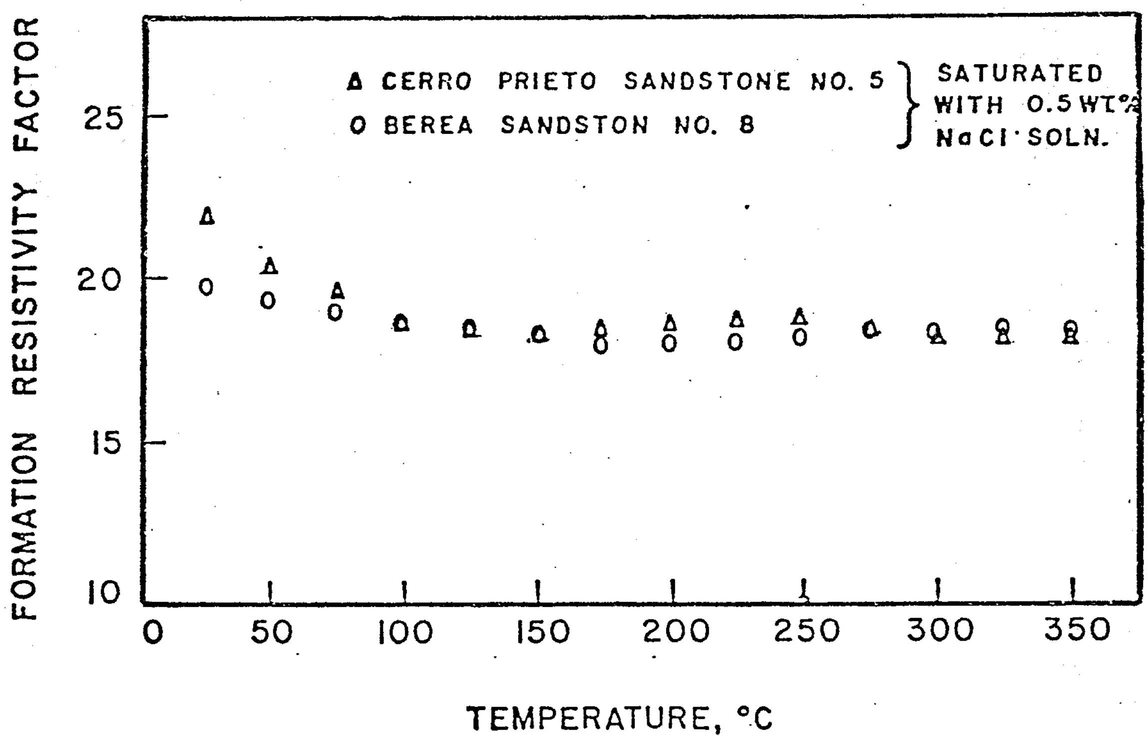

Fig.3-Effect of Temperature on Formation Resistivity Factor.

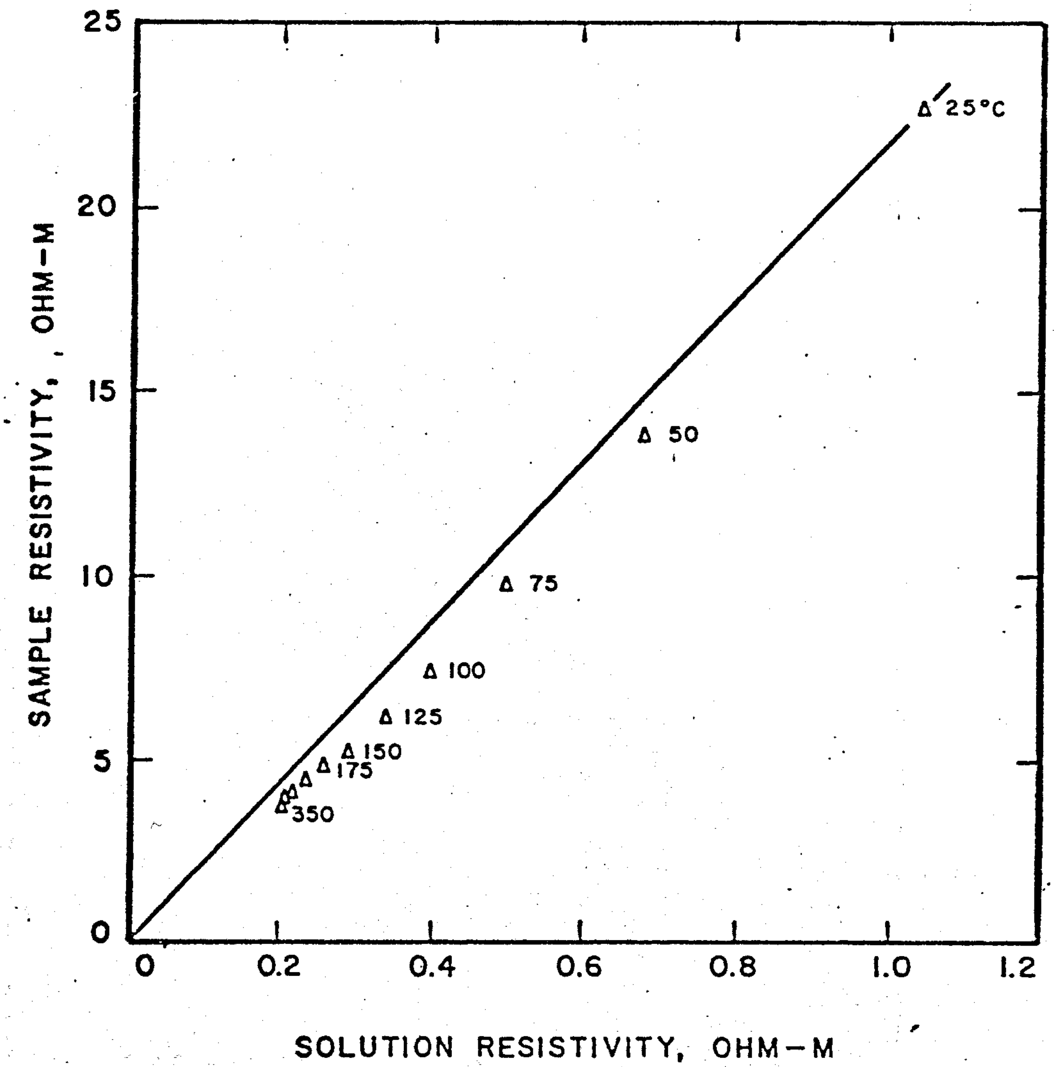

Fig. 4- Behavior of Berea Core Resistivity With Temperature at Low Brine Concentration.

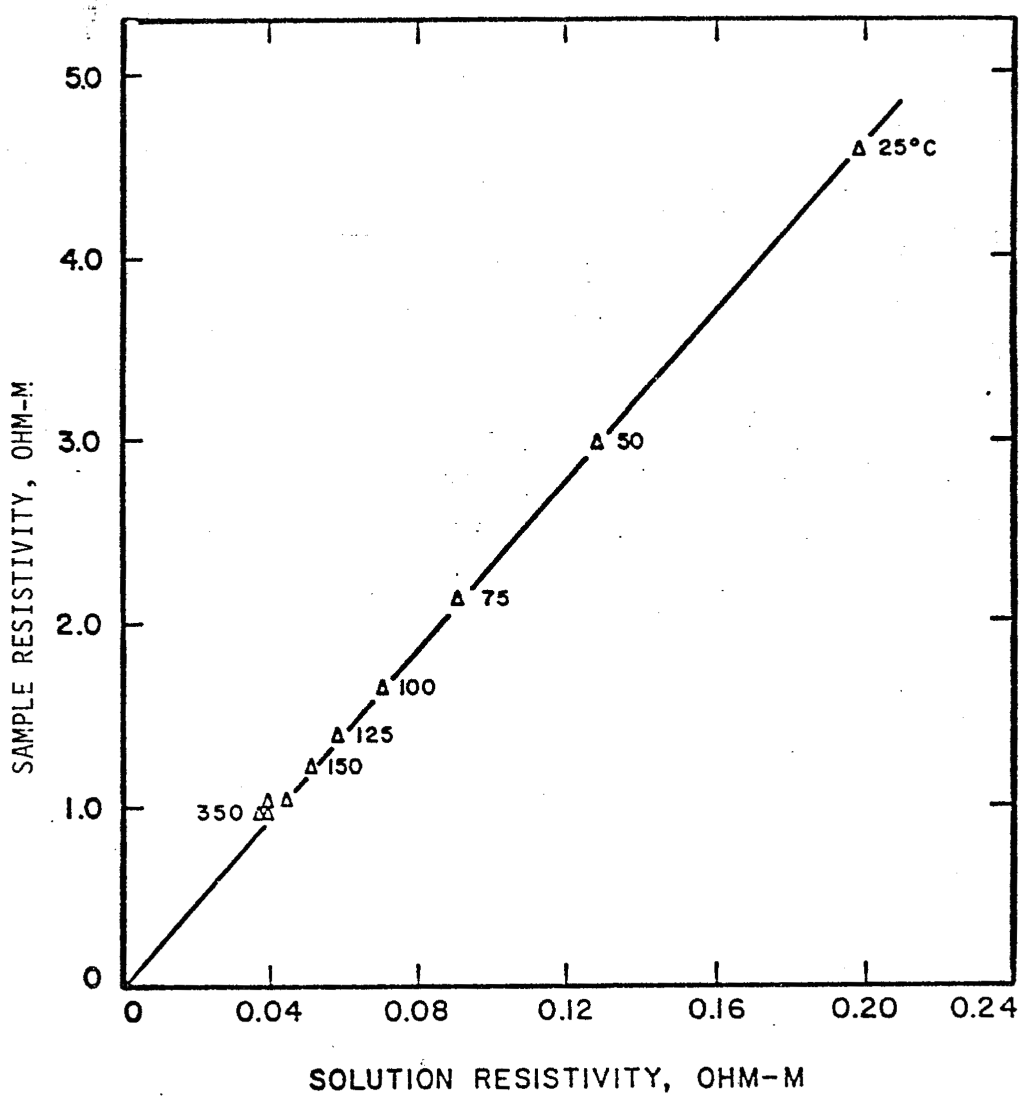

Fig. 5- Behavior of Berea Core Resistivity with Temperature at High Brine Concentration.

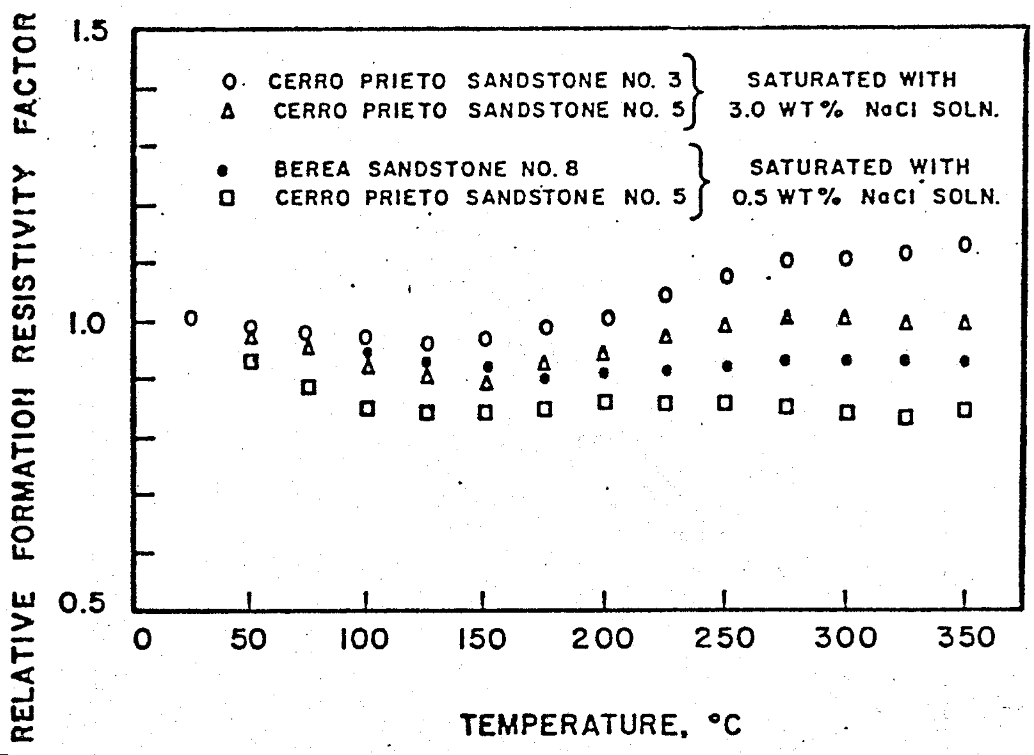

FIG. 6: EFFECT OF TEMPERATURE ON RELATIVE FORMATION RESISTIVITY FACTOR

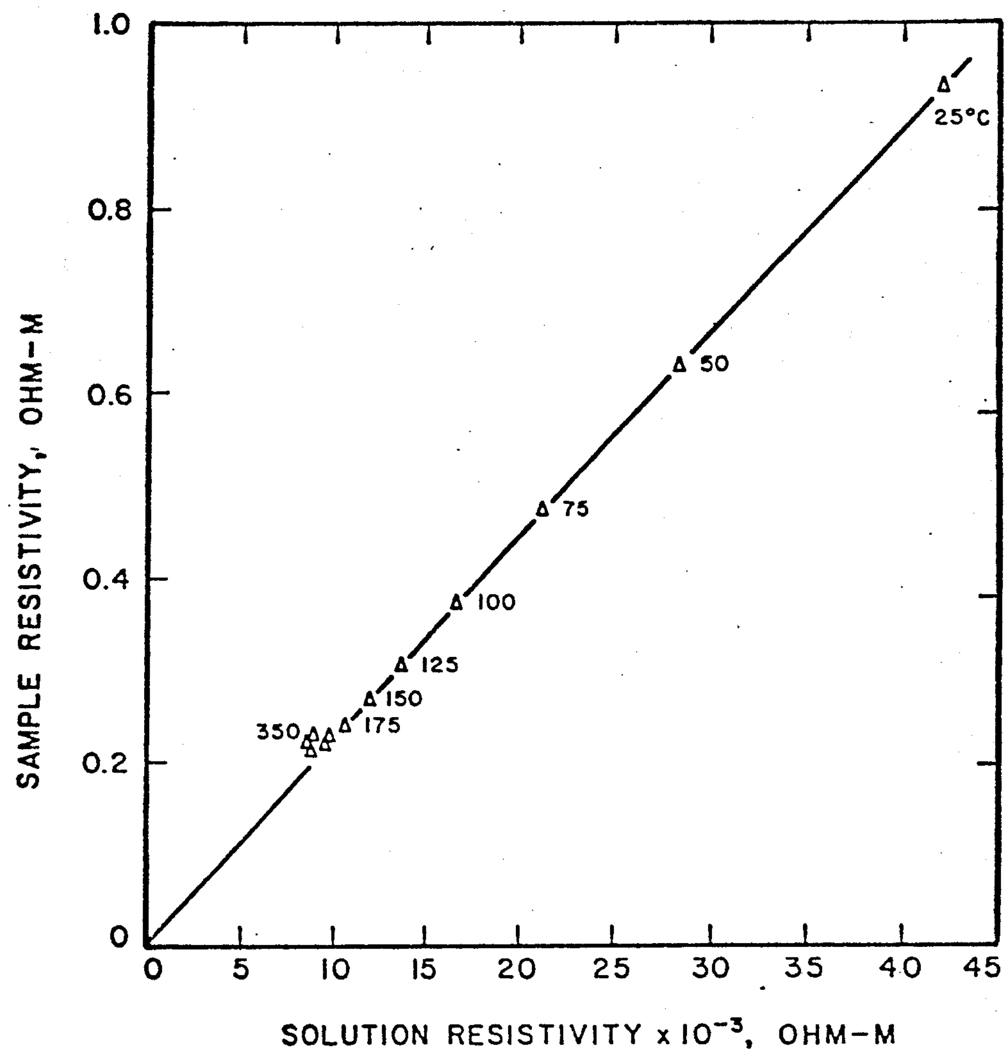

FIG. 7: SAMPLE RESISTIVITY VERSUS SOLUTION RESISTIVITY FOR THE IGNITED BEREA CORE

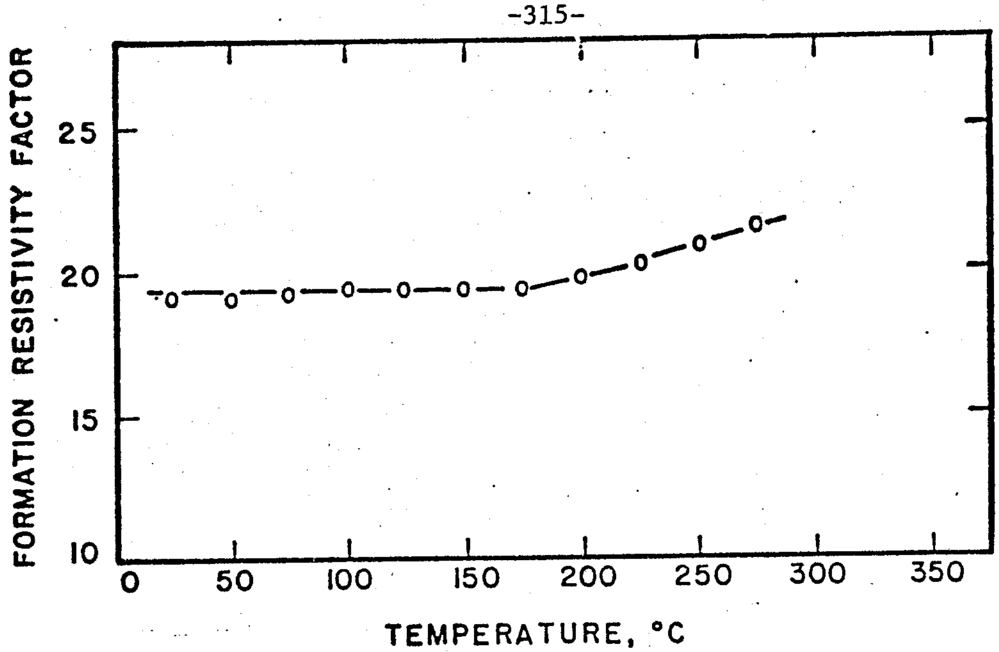

Fig. 8- Formation Resistivity Factor vs. Temperature for the Ignited Core.

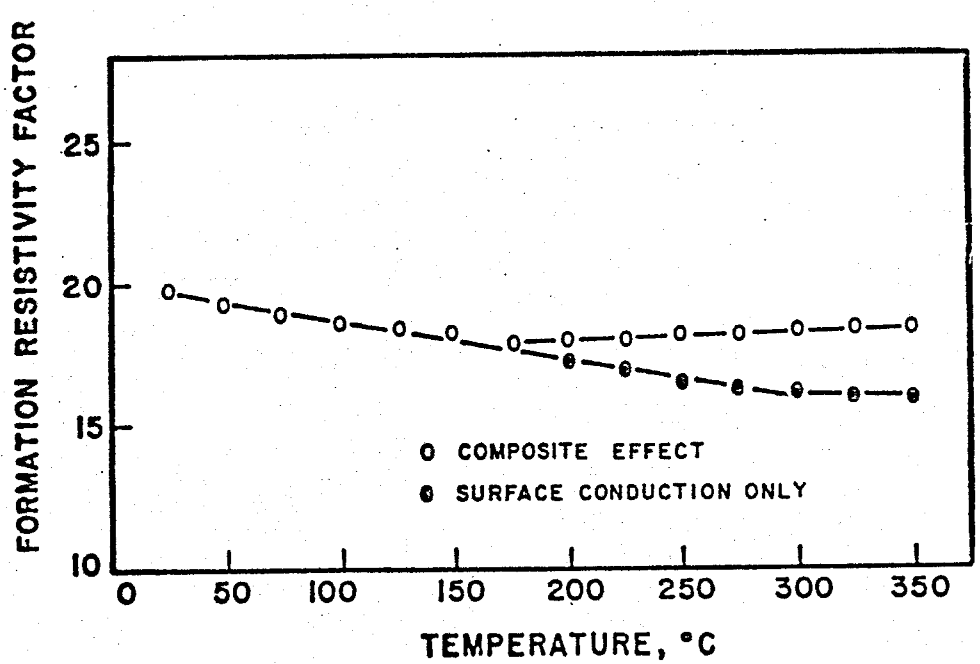

Fig. 9- Effect of Surface Conduction on Formation Resistivity Factor.