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# ACOUSTIC AND ELECTRICAL PROPERTIES OF MEXICAN GEOTHERMAL ROCK SAMPLES

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## Introduction

The interpretation of geophysical well logs requires established relationships between the petrophysical properties of typical reservoir rocks. Laboratory and borehole log studies [Archie, 1947; Wyllie et al., 1956; Geertsma, 1961; King, 1966; Carothers, 19681 indicate a strong dependence of acoustic velocities and electrical resistivity on the porosity and state of fluid saturation of porous rocks. Effects of temperature, state of stress and pore texture have also been demonstrated to be significant.

In this study, acoustic compressional and shear–wave velocities have been measured on a suite of ten sandstone samples obtained from wells in the Cerro Prieto geothermal field and on two rock samples from other Mexican geothermal fields. The samples were tested in both their dry and fully brine–saturated states at uniaxial stresses to 15 MPa. Electrical resistivities and associated phase angles have been measured on the same core samples as a function of frequency in the range 10 Hz to $10^5$ Hz under drained conditions at hydrostatic confining stresses to 10 MPa. The electrical properties were measured on samples tested in their fully saturated state, using brines of two different concentrations.

A comprehensive summary of the existing information on laboratory–measured petrophysical properties of sandstones from the Cerro Prieto geothermal field has been presented by Contreras et al. (1984). The summary includes sections on bulk density, porosity, fluid permeability, bulk and pore compressibility, thermal expansion and conductivity, acoustic velocities, and electrical resistivity.

The methods used in this study for specimen preparation and saturation with brine have been discussed by King (1983, 1984). The first-pulse arrival technique for measuring the acoustic velocities under different states of stress has been described by King (1970, 1983). The two–electrode technique used in this study for determining the electrical properties as a function of frequency under different states of stress has been described by King (1977), and by Pandit and King (1979). The sample porosities were calculated from the test specimen dimensions, weights dry and fully brine–saturated, and the brine density.

## Results and Discussion

Compressional and shear-wave velocities were both observed to increase with an increase in axial stress, with the velocity increases more pronounced when the samples were dry. Although saturating the samples with brine resulted in higher compressional-wave velocities, the shear-wave Jelocities in most cases remained close in value to those measured dry. Typical results for two of the samples tested have been reported by Contreras et al. (1984).

A relationship of the form $1/V_p = A + B\phi$, between compressional wave velocity ($V_p$) and porosity ($\phi$) for saturated sandsdone rocks, with A and B constants, is prediqted both by the empirical time–average equation proposed by Wyllie et al (1956) and by one developed theoretically by Geertsma (1961)- Figure 1 shows reciprocal Vp, measured with specimens fully brine–saturated at an axial stress of 10 MPa, as a function of $\phi$. A relationship of the form given above fits the data well, with the intercept A yielding $V_p = 5500$ m/s for the solid rock matrix material, as expected for quartz.

Electrical resistivities for the brine-saturated specimens first showed a small decrease as the frequency was increased; the resistivities then decreased asymptotically to constant values at frequencies above 200 Hz. Contreras et al. (1984) have reported the results for two of the samples tested; these are typical of the remainder. Measured phase angles were always less than 5°, except those for frequencies less than 200 Hz. The low frequency behavior observed for resistivity and phase angles is probably due to electrode polarization effects; these have been discussed by Pandit and King (1979). Small increases in resistivity were observed over the whole range of frequencies for an increase in hydrostatic stress, as shown by Contreras et al. (1984) for two of the samples. Formation factors (F) calculated from the resistivities measured with the specimens saturated with brines of two different concentrations showed a small increase with an ipcrease in brine concentration. This behavior is probably due to the lesser importance of the effect of mineral surface conductivity as the brine saturant resistivity decreased.

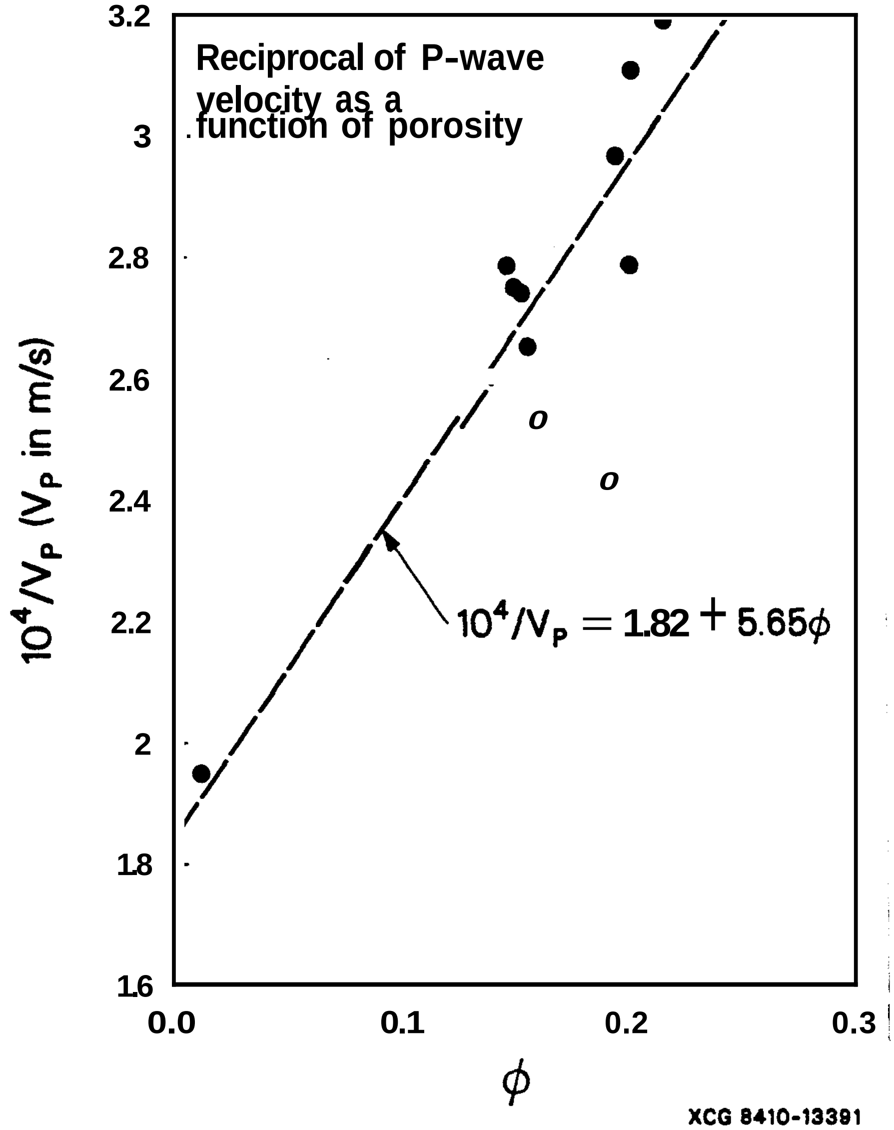


Figure 1. Reciprocal of compressional wave velocity as a function of porosity.

An empirical relationship of the form F • 1/42, relating the formation factor and porosity for porous rocks, has been proposed by Archie (1947) and discussed by Keller and Frischnecht (1966). This relationship has been demonstrated to hold for a wide range of rock types, including those of low porosity [Brace et al., 1965; Gonten and Whiting, 19671. Figure 2 shows reciprocal $F^{1/2}$, with specimens fully saturated with brine of resistivity 0.1146 Ωm and under a hydrostatic stress of 10 MPa, as a function of $\phi$. Archie's relationship is seen to be valid for the suite of samples tested.

Wyllie et al. (1958) have demonstrated experimentally that, for sandstones of different porosities, compressional wave velocities measured under uniaxial stress conditions are very close in magnitude to those measured on the same specimen under similar hydrostatic stress conditions. Figure 3 shows reciprocal $V_P$, with specimens brine saturated under an axial stress of 10 MPa, plotted as a function of reciprocal $F^{1/2}$, with specimens brine-saturated under a hydrostatic stress of 10 MPa. The correlation between the two parameters is good.

## Conclusions

It is concluded that the compressional-wave velocity and electrical resistivity of brine-saturated porous rock samples from the Mexican geothermal fields correlate well with

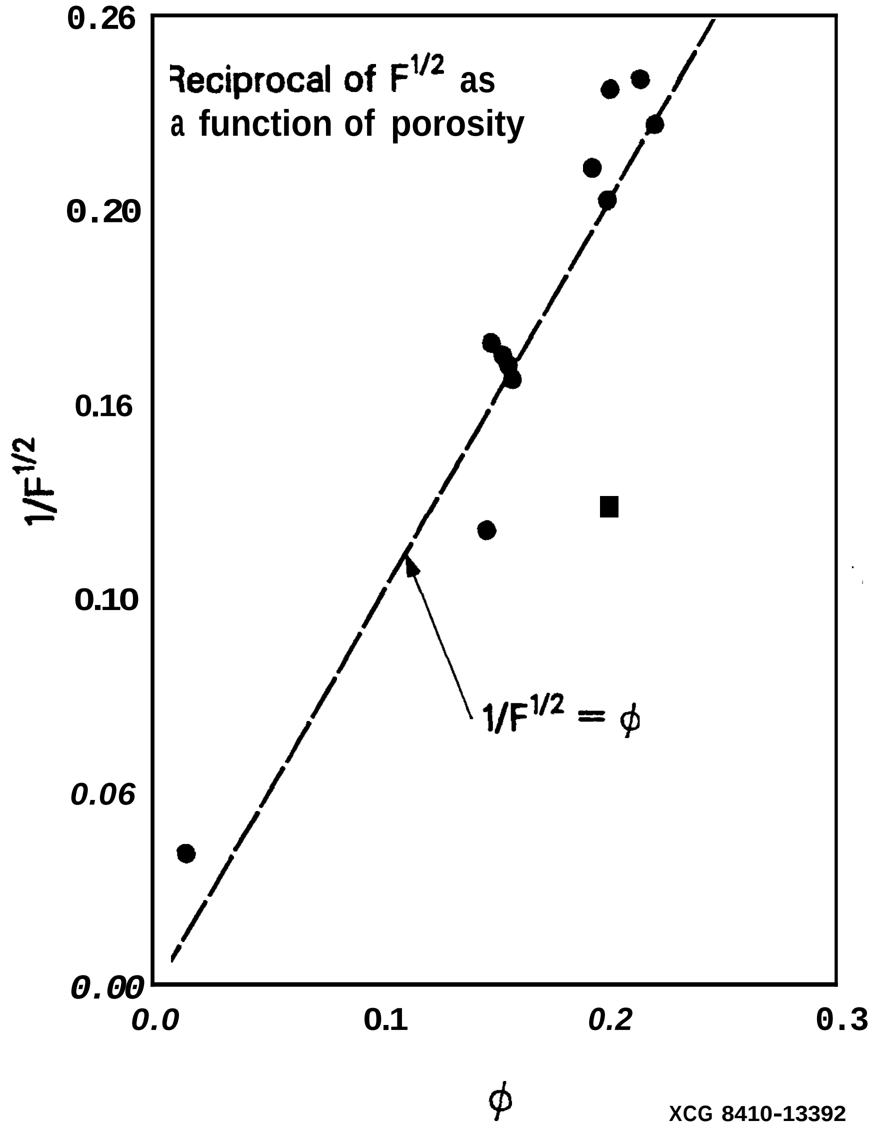


Figure *2.* Reciprocal of $F^{1/2}$ as a function of porosity.

their porosities. Provided the brine-saturated samples are subjected to the same state of stress, the compressional-vave velocity and electrical resistivity are well correlated.

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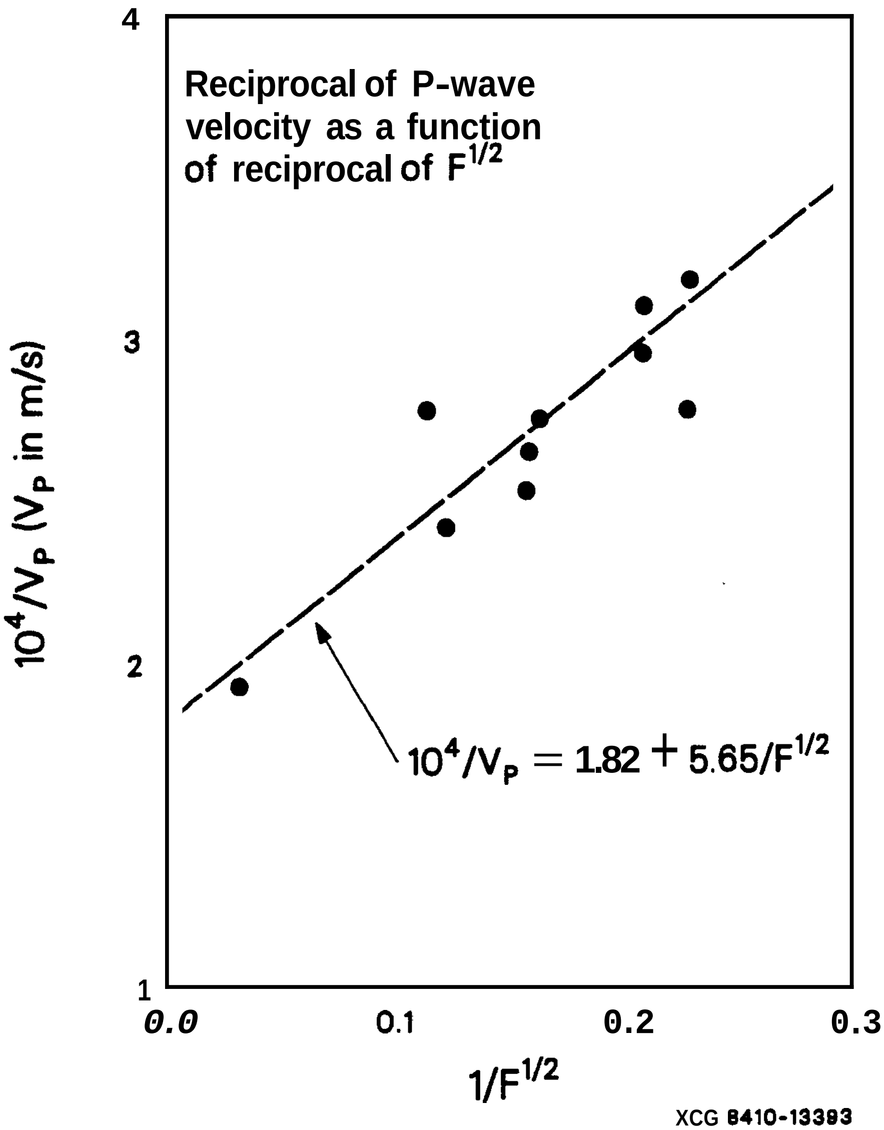


Figure 3. Reciprocal of compressional wave velocity as a function of reciprocal of $F^{1/2}$.

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