ROCK PROPERTIES RELATED TO ASSESSMENT METHODS*

Al Duba
Lawrence Livermore Laboratory

In order to interpret the data obtained from field geophysics measurements as well as well-logging tools that exist or may be developed for geothermal wells, laboratory data under relevant conditions must be available. Since the conditions of the laboratory measurement must closely simulate the reservoir environment, parameters that should be considered independent variables in relevant experiments include, but may not be limited to, rock type, mineralogy, structural state (cementation, fracturing, etc.), temperature, confining pressure, pore pressure, and pore-saturant chemistry. Correct interpretation of field data should provide information on the heat and fluid conductivity and capacity of the reservoir. The ideal situation would be one that provided spatial resolution of these properties in three dimensions.

Laboratory measurement of physical properties at the relevant conditions for a given reservoir should allow interpretation of routine and specialized field measurements. In order for these experiments to be useful, however, samples must be carefully characterized as to pore structure, chemistry, and phase relationships before and after laboratory experiments are performed. Most meaningful physical property measurements need to be supported by petrographic studies, including optical and scanning electron microscopy, chemical characterization by the electron microprobe, and definition of pore structure.

Laboratory measurements of physical properties of rocks under conditions that are relevant to most geothermal reservoirs are either sparse or non-existent at present. The situation for electrical properties typifies the problem. A recent workshop on geothermal exploration concluded, "Most strongly endorsed was a need for comprehensive, high quality, laboratory studies of the electrical properties of rocks under temperatures, pressures, and solution chemistries pertinent to the geothermal environment. Unless we can move off square one in this basic area, the very foundations of electrical methods are in question." (1)

Some data do exist and are useful to gain "first cut" answers to questions concerning permeability, heat capacity, thermal diffusivity, and porosity. A good recent summary of the petroleum literature on these topics, which seeks to apply them to the geothermal problem, is found in (2). However, very few of the results summarized can be applied directly to a particular geothermal system. No complete data set in which pressure, temperature, and pore fluid composition and pressure are varied is available. One has to rely on extrapolation and analogy to get an estimate of the value of a parameter in a geothermal log. And when large expenditures of time and dollars depend on the proper interpretation of such logs, extrapolation and analogy will not suffice. The large reversible decrease in permeability of sandstone to water in the temperature range 21°-150°C (70°-302°F)

*Work performed under the auspices of the U.S. Energy Research & Development Administration under Contract No. W-7405-Eng-48.

which is attributed to "... unsuspected fluid-solid surface attractive forces between water and quartz..." (emphasis mine) exemplifies the problem (3).

Compressional wave velocity (V_p), shear wave velocity (V_s), and compressibility have been measured to about 100 MPa (15,000 psi) and 200°C (392°F) on sandstones and siltstones, some of which were saturated with a KCl brine (4). In addition, they also determined the thermal conductivity at 133°C (271°F) and 3 MPa confining pressure on some of these rocks. Electrical conductivity to 200°C (392°F) and an effective stress of about 7 MPa has been measured on shaly sandstones as a function of brine composition (5).

However, these studies have limited application to geothermal well-log and field survey interpretations. The paramount shortcoming is that the rock types studied have been limited to petroleum reservoir rocks. Igneous and metamorphic rocks have been studied over a much more limited range of pressure-temperature-saturant chemistry (6-9). Another shortcoming is the lack of simultaneous measurement of several physical properties on the same core. Cycling the sample in laboratory experiments produces permanent changes in crack structure, so that sequential information is unreliable for correlating changes in different physical properties when stress or temperature is cycled (10). Such correlations are essential if information on the permeability, porosity, or salinity of a geothermal reservoir is to be inferred from sonic and resistivity logs.

Laboratory data on the variation of the physical properties of reservoir constituents as a function of pressure, temperature, and saturant salinity would be invaluable in the interpretation of field measurements. If such data were available, we would be able to interpret geophysical data in terms of parameters the reservoir engineer needs to know -- the permeability and available porosity of the reservoir. In addition, these data could be useful for designing and interpreting monitoring tools to detect changes in reservoir properties during production. This information would be vital if reservoir stimulation schemes are evolved and employed in geothermal systems.

Specific measurements that need to be performed on typical reservoir rocks as a function of temperature, pressure, pore pressure, structural state of the rock, and pore fluid composition include but should not be limited to:

- ultrasonic velocities
- electrical conductivity
- permeability
- compressibility
- thermal conductivity
- heat capacity
- thermal expansion

Simultaneous measurement of several properties for various durations would be useful.

REFERENCES

1. S. H. Ward and participants (1977). Workshop on Electrical Methods in Geothermal Exploration. Rept. to USGS under contract 14-08-0001-G359 (Jan. 1977).

2. H. J. Ramey, Jr., W. E. Brigham, H. K. Chen, P. G. Atkinson, and N. Arihara. Thermodynamic and Hydrodynamic Properties of Hydrothermal Systems. Stanford University Rept. SGP-TR-6, 1974.

3. M. Aruna, N. Arihara, and H. J. Ramey, Jr. The Effect of Temperature and Stress on the Absolute Permeability of Sandstones and Limestones. American Nuclear Society Topical Meeting, Golden, Colorado (April 1977).

4. W. H. Somerton, A. H. El-Shaarani, and S. M. Mobarak. High Temperature Behavior of Rocks Associated with Geothermal Type Reservoirs. SPE-4897, 44th Annual California Regular Meeting, Society of Petro-chemical Engineers, San Francisco, California (April 1974).

5. M.H. Waxman and E. C. Thomas. Electrical Conductivities in Shaly Sands. I. The Relation Between Hydrocarbon Saturation and Resistivity Index. II. The Temperature Coefficient of Electrical Conductivity, SPE-4094, 47th Annual Fall Meeting, Society of Petroleum Engineers, San Antonio, Texas (Oct. 1972).

6. J. W. Spencer, Jr., and A. M. Nur. "The Effects of Pressure, Temperature, and Pore Water on Velocities in Westerly Granite." Journal of Geophysical Research, Vol. 8, No. 5 (February 1976), pp. 899-904.

7. W. Brace, A. Orange, and T. Madden (1965). "The Effect of Pressure on the Electrical Resistivity of Water-Saturated Crystalline Rocks." Journal of Geophysical Research, Vol. 70, No. 22 (November 15, 1965), pp. 5669-5678.

8. W. F. Brace, J. B. Walsh, and W. T. Frangos. "Permeability of Granite Under High Pressure." Journal of Geophysical Research, Vol. 73, No. 6 (March 15, 1968), pp. 2225-2236.

9. A. Duba, H. C. Heard, and R. N. Schock. "Electrical Conductivity of Olivine at High Pressure and Under Controlled Oxygen Fugacity." Journal of Geophysical Research, Vol. 79, No. 11 (April 10, 1974), pp. 1667-1673.

10. G. Simmons, R. W. Siegfried, and M. Feves. "Differential Strain Analysis: A New Method for Examining Cracks in Rocks." Journal of Geophysical Research, Vol. 79, No. 29 (October 10, 1974), pp. 4383-4385.