ANALYSIS OF GEOTHERMAL WELL LOGS*

by

Subir K. Sanyal
Stanford University
Stanford, CA 94305

INTRODUCTION

In the petroleum industry, well logging is a well-developed discipline that has matured over a fifty-year period. Compared to this, geothermal well logging is a very new field of activity.

The current practice is to use the same logging equipment and the same log interpretation techniques for geothermal wells as had been used for petroleum wells. However, this approach has proven either inadequate or ineffective in most geothermal areas. The problems here are of two types: (1) those associated with logging equipment and operation, and (2) those connected with log interpretation techniques. Temperatures encountered in geothermal wells are normally higher (greater than 175°C or 350°F) than those in petroleum wells. In many geothermal wells, some of the standard well logs cannot be run due to the well temperatures being higher than the maximum temperature for which those logging tools are designed. Lack of financial incentive has so far discouraged large investments by logging service companies in developing new logging instrumentation or interpretation techniques for geothermal wells. U.S. Department of Energy (formerly U.S. ERDA) has established a new geothermal logging hardware development program at the Sandia Laboratories in New Mexico. The U.S. Geological Survey also has a similar program of hardware development for geothermal logging. These programs have progressed well and there is a strong hope that most of the hardware-related problems of logging geothermal wells will be resolved over the next few years. Sanyal and Meidav (1977) have discussed the differences in the objectives of well logging in the geothermal reservoirs from those in the petroleum reservoirs, and their implications on the state-of-the-art of geothermal well logging. These authors have also discussed the problems associated with the logging operation, log quality problems and log interpretation problems in the geothermal industry. This paper focuses on the log interpretation aspects only.

PROBLEMS IN ANALYSIS OF GEOTHERMAL LOGS

The existing techniques of interpretation of well logs in the geothermal industry are inadequate or ineffective in many wells. Some of the reasons are as follows:

*Summary of the paper presented at the Third Annual Stanford Geothermal Program Workshop on Geothermal Reservoir Engineering, Dec. 14-16, 1977.

(1) For an accurate formation evaluation, one needs a "suite" of well logs. Because of the temperature limitation of logging equipment, a complete suite of logs is not available from many geothermal wells.

(2) In many geothermal wells, logs are run faster than usual to avoid undue thermal strain on the equipment. This reduces the quality of the log, making interpretation less accurate. This rush sometimes causes operational problems.

(3) Many concepts and formulas used in well log interpretation have been developed over the last four decades from laboratory study of rock and fluid samples at ambient conditions. It is now known that many petrophysical properties of reservoir rocks are altered, reversibly or irreversibly, at elevated temperatures and pressures (for example, refer to Sanyal, et al., 1972; Sanyal, et al., 1974). However, sufficient experimental data are lacking. Thus, the usual approach to geothermal well log interpretation may be fraught with inaccuracies.

(4) Well logging experience in the petroleum industry has been confined to sedimentary formations, while geothermal wells may encounter any rock type (sedimentary, igneous, or metamorphic) often subjected to hydrothermal alteration. Also, lithology in a geothermal reservoir can vary drastically from layer to layer or from well to well, thus complicating log interpretation. The responses of the logging tools to such unfamiliar lithologies are not well known; calibration data for such cases are lacking. Since logging tools were originally designed for sedimentary formations, using them in igneous and metamorphic rocks tend to give poorer quality logs.

(5) The estimation of the location, orientation, and aperture of fractures is very important in planning production from many geothermal wells. Naturally fractured petroleum reservoirs are less common, hence the technology of estimating fracture location, orientation, and aperture is not well developed in the petroleum industry. Also, unlike most petroleum reservoirs, large scale natural fractures or faults may be the primary flow conduits in geothermal reservoirs. Current logging technology is inadequate to delineate such large scale fractures.

(6) Permeability is a most important property for both petroleum and geothermal reservoirs. No widely used well log exists that can measure in-situ permeability of a reservoir. In the petroleum industry, permeability is either measured from core samples of rocks taken from the well or estimated from well test data. For detailed formation evaluation, permeability is estimated from log-derived porosity values by using a suitable empirical correlation, which is developed for each petroleum

field from core analysis data. Sufficient data are not yet available to develop such empirical correlations for most geothermal fields. Moreover, presence of fractures in a geothermal reservoir can drastically increase the permeability around a well bore, while small core samples may not reflect the existence of such in-situ fractures. In any case, coring of hard, igneous and metamorphic formations is more expensive than coring of sedimentary formations. Hence, cores are usually not taken in geothermal wells.

(7) Accurate measurements of formation temperature are not critical for most petroleum wells. Hence, techniques for estimating the equilibrium temperature profile of the formation from measured temperature profiles are not well known.

(8) The composition of the formation water is a critical parameter in the geothermal industry, while in the petroleum industry it is usually not. Hence, the techniques for prediction of formation water quality from well logs are not sophisticated.

(9) Perhaps the most important log-derived parameter in the petroleum industry is the hydrocarbon saturation in the reservoir. A major part of the research and development in well log interpretation techniques has historically been devoted to detecting and estimating hydrocarbon saturation. In geothermal wells there is no hydrocarbon saturation, hence, many of the classical developments are not useful to the geothermal log analyst.

(10) Only a limited number of geothermal fields has been developed to date. A large enough data base, and consequently, useful empirical correlations of rock and fluid properties, do not exist in the geothermal industry.

(11) A geothermal reservoir is usually more complicated in geometry and flow behavior than its petroleum counterpart. For this reason, it is desirable and often imperative to correlate the well log data with surface geophysical and geochemical measurements. This aspect has not been as important in the petroleum industry.

Besides the above-mentioned problems, geothermal well logs display a myriad of log quality problems, many of which are also found in the petroleum industry and most can be rectified. This presentation includes a number of examples of these problems and their solutions, where possible.

CONCLUSIONS

Analysis of geothermal well logs is fraught with problems. However, with proper care, experience and a synergistic approach one may obtain an effective analysis of geothermal logs. However, this is not assured. There is an urgent need for further research to improve the state-of-the art of geothermal well log analysis.

REFERENCES

Baker, L. E., Campbell, A. B., and Hughen, R. L., 1975a. "Well-Logging Technology and Geothermal Applications," Sandia Laboratories, Energy Report SAND 75-0275, May 1975

Baker, L. E., Campbell, A. B., and Hughen, R. L., 1975b. "Geothermal Well Logging: Air Assessment of the Art," The Log Analyst, Vol. XVI, No.6, November-December, 1975, p.21

Sanyal, S K., Marsden, S. S., Jr., and Ramey, H. J., Jr. 1974. "Effect of Temperature on Electrical Resistivity of Porous Media," Trans. Thirteenth Annual Loggging Symp. of Soc. Prof. Well Log Analysts, Tulsa, Oklahoma, May 1972

Sanyal S. K., S. S., Marsden, Jr., H. J. Ramey, Jr., 1974."Effect of Temperature on Petrophysical Properties of Reservoir Rocks," Paper #SPE 4898 presented at the 49th Annual Fall Meeting of the Society of Petroleum Engineers, Houston, Texas, October 1974.

Sanyal, S. K., and Meidav,H. T., 1976. "Well Logging in the Geothermal Industry," Paper presented at the 17th Annual Logging Symp. of the SPWLA, Denver, Colorado, June 1976.

Sanyal, S. K., and Meidav, H. T., 1977. "Important Considerations in Geothermal Well Log Analysis," SPE paper No. 6535, presented at the 47th Annual California Regional Meeting of the SPE of AIME, Bakersfield California, April 13-15, 1977