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TITLE: WIRELINE WELL LOGGING AN UNDERUTILIZED TECHNIQUE IN RESERVOIR EVALUATION

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WIRELINE WELL LOGGING AN UNDERUTILIZED TECHNIQUE IN RESERVOIR EVALUATION

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ABSTRACT

Wireline well logs have three general uses in geothermal exploration and reservoir evaluation: reservoir parameter analysis, lithologic column determination, and reservoir size resolution.

Reservoir flow testing data are acquired to understand the flow rate, life, and production potential of the geothermal reservoir. These data are a coarse subsurface measurement of the geothermal prospect. Wireline logs acquired from wells in a geothermal prospect are used to define in detail, or estimate the reservoir parameters of temperature, thickness, lateral size, amount of fracture and intergranular pore space, and the quantity and quality of fluid that might be produced. Laboratory measurements can be made on core samples and drill cuttings samples to define the intrinsic behavior of the materials and fluid that compose the geothermal reservoir. Wireline log measurements are needed to correlate and link the reservoir testing and core analysis, reduce the amount of time needed for flow testing, and predict the production life (amount of heat and fluid available) in a geothermal field.

INTRODUCTION

Wireline well logs aid in subsurface geologic correlation between wells in a geothermal prospect. The lithologic column is generally devised by combining studies of the drill cuttings and core description to identify rock units, and then correlating these units between wells. Properly interpreted, well log responses can then produce a reasonable correlation between wells in sedimentary, igneous, and metamorphic rocks (Benoit et al., 1980). In sedimentary environments, as in the Imperial Valley, the wireline logs help to eliminate sample biasing from out of place drill cuttings when constructing a lithologic section (Miller and Elders, 1980).

Data are obtained at geothermal sites to characterize the regional geological and geophysical properties of a geothermal province. These data are also used to define a geothermal prospect and to locate a drilling site to test the potential geothermal reservoir. Correlation of appropriate log date (which contain the vertical control) with surface geology and geophysics (that contain the horizontal control) is routinely done in the oil and gas industry especially with seismic surveys (surface data) and the sonic-density (borehole data) log data (Stone and Evans, 1980). A recent study on combining borehole resistivity data with surface resistivity data (magnetotellurics) has shown how the three dimensional size of a geothermal reservoir can be estimated (Rigby, 1981).

The intrinsic mechanical and chemical behavior of the reservoir materials that compose a geothermal prospect can be inferred by making laboratory measurements on core samples. These measurements then can be related to the regional geological and geophysical aspects of the reservoir with wireline log measurements. An increase in the radius of investigation and a better understanding of a geothermal reservoir can be attained by correlating core analyses with wireline well logs, and both with reservoir testing data and with geophysical surveys .

LOG INTERPRETATION PROGRAM GOALS

The main goal of the Geothermal Log Interpretation Program* (GLIP) is to develop the geothermal well log interpretation technology in the appropriate U.S. commercial sector. This was accomplished by building on the already existing highly developed petroleum and mineral logging interpretation techniques and procedures. Research and development in geothermal reservoir engineering, logging tool improvement and development, and log interpretation is now being pursued by the evolving geothermal industry (see Figure 1). The technical goals of GLIP are to improve the basic techniques and technologies of geothermal log interpretation.

Research areas were selected to aid interpretations:

- Establishment and support of calibration facilities (test pit models from which rock matrix and fracture responses of logging tools can be standardized) and test wells which are representative of the major geothermal reservoir categories.
- Documentation and publication of case histories valuable to geothermal log interpretation.

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- Special, advanced logging runs and, especially the subsequent interpretation technique developments based upon the log data enhancement afforded by these log runs.
- Establishment and support of a geothermal log library that has the capability of furnishing logs in analog and digital format and the supporting data.
- Establish property measurements on cores, well cuttings, and rock samples from many different geothermal reservoirs for log interpretation applications.
- Describe and exhibit logging tool responses to fractures by analytical and/or numerical fracture modeling studies.
- Design and organize a short course on the introduction to geothermal log interpretation.
- Compile and publish a geothermal log interpretation handbook.

PARAMETERS NEEDED FOR RESERVOIR EVALUATION

Critical to reservoir evaluation is the development of techniques for the interpretation of geophysical logs obtained from both exploration and production wells. Certain parameters are essential for evaluation of a particular geothermal resource, and the priority of a parameter determination varies with resource type. A list of the major parameters needed for the development of log measurements, and of interpretation techniques for formation evaluation and production management, are summarized by Mathews, 1980.

GEOTHERMAL LOG INTERPRETATION--STATE-OF-THE-ART

An in-depth study of the state-of-the-art in geothermal well log interpretation has been made that encompasses case histories, technical papers, computerized literature searches, and actual

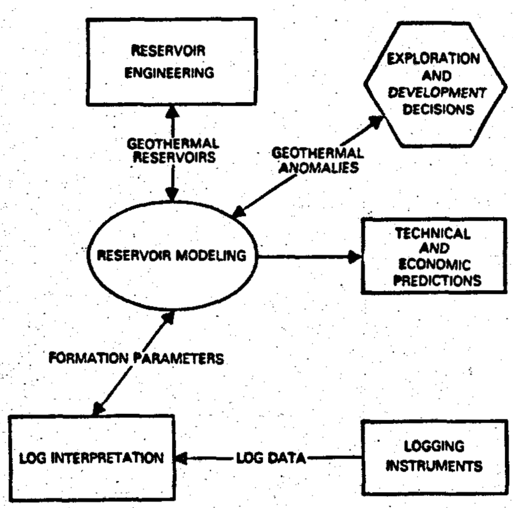

Figure 1. Interelations among reservoir assessment elements.

processing of geothermal logs from wells in New Mexico, Idaho, and California. A classification scheme of geothermal reservoir types has been published which distinguishes fluid phase and temperature, lithology, geologic province, pore geometry, salinity, and fluid chemistry (Sanyal et al., 1980).

CALIBRATION TEST PITS AND WELLS

Since 1978 two calibration wells were made available to industry and others for testing the validity, comparability, and versatility, of interpretation techniques, and to calibrate logging instruments.

The first calibration well, C/T-1 (Mesa 31-1) in the East Mesa Geothermal Field of California penetrates non-marine sediments and has a temperature of 165°C (330°F). The second calibration well, C/T-2 (Phillips 9-1) penetrates igneous and metamorphic lithology in the Roosevelt Geothermal Field of Utah and has a temperature of 220°C (445°F). Both wells have been extensively logged (logs are available), and are described geologically in detail (Miller and Elders, 1980; Glenn et al., 1980).

Three large calibration models were installed at the U.S.G.S. Denver Federal Center in Colorado, to simulate fractured igneous and metamorphic rock environments (Mathews, 1980).

CASE HISTORY STUDIES

Case history reports have been published on the following geothermal fields, which emphasize the use of geothermal well log interpretation techniques in evaluation of geothermal prospects.

East Mesa, California
Cerro Prieto, Mexico
Rift River, Idaho
Surprise Valley, California

Case history reports of these geothermal fields, which will contain production and reservoir comparisons, will be published.

Salton Sea, California
Brawley, California
Heber, California

Emphasis is on the economic characterization of the estimated potential production of these fields or prospects.

ADVANCED LOGGING AND INTERPRETATION

Advanced logging and interpretation projects are those which combine new or special geophysical logging tools and analysis techniques in the exploration, development, and production of geothermal wells. Support is provided for logging runs that: use advanced and/or new probes; might not be normally selected by an operator; or will fill gaps in evaluation and interpretation data.

Phillips Petroleum Company's Desert Peak well, B-23-1 in Nevada was logged by Dresser Atlas in 1979 as an advanced logging and interpretation project. Sethi and Fertl, (1980) describe these logging procedures and the interpretation from them.

The True Formation Temperature Tool (TFTT) measures the temperature of the formation 6 to 18 inches beyond the borehole in either a fluid-filled or empty borehole. The borehole can be either uncased (open) or cased. A project by the IRT Corporation to test this logging tool was completed with Advanced Logging and Interpretation sponsorship.

A borehole model of 32 slabs of granite (2" thick x 4 ft x 4 ft with a 10" borehole in the center) that can be heated to 220°C (445°F) was constructed to test the TFTT. A report (Nuclear Logging and Geothermal Log Interpretation: Formation Temperature Sonde Evaluation, is in preparation) that describes the successful results of this project.

LOG LIBRARY

(This project was canceled by DOE/DGE on April 16, 1979 and ended the effort to establish a comprehensive library of geothermal logs. A partial log library exists at Petroleum Information Corporation and also at the University of Utah Research Institute.)

Providing a suitable log library and data bank of geothermal well logs and associated related information to industry and interested agencies was a major element of the Geothermal Log Interpretation Program. Information in the log library would have been available, on a fee basis, as an aid to users in interpretating geothermal logs, and to have on file case histories of various geothermal reservoirs and fields. Information that might have become available is:

1. Available digitized logs, and analog logs.
2. Type, availability, and location of cores and samples in the core/sample depositories.
3. Core and sample property data information.
4. Available well data such as location, drilling information, core and sample data, fluid analysis, temperature and pressure, drill stem and production test data, geologic interpretation, unprocessed probe output, calibration information, and performance data on probe and logging systems.
5. Case histories.
6. Description of interpretation techniques, technical reports, and associated computer software for analyzing logs and data in the log library.

CORE PROPERTY MEASUREMENTS AND LOG INTERPRETATION APPLICATIONS

(This project was canceled by DOE/DGE on May 6, 1980. A modest effort on a literature search and compliation of rock properties is continuing.)

Core analysis is important in determining reservoir rock characteristics, but it is only one of the many methods used for the determination of the potential of a geothermal well. The geophysical logs, the well tests, the production records, and geological analysis are all needed for well completion design and development. For many reasons, any particular item may fail to give positive results, but it is doubtful that all will fail in the same well.

Core analysis, is important tool in well completions, and reservoir characterization, by special specific tests, such as connate water, relatively permeability, and acid solubility, among others, aids greatly in predicting the future of a geothermal prospect.

A report by Mathews et al., (1980) tabulates the locations holding geothermal core and well cuttings, and lists the kind of property measurements needed from these samples.

To make optimum use of cores, well cuttings, and rock samples from geothermal wells it is necessary to make various geophysical, petrographic, geochemical, petrological, nuclear, and structural analyses of cores and samples (measurements listed in Rigby and Riardon, (1979) and in Mathews et al., 1980).

FRACTURE MODELING STUDIES

(This project has been initiated but will not be finished at the end of this fiscal year, September 30, 1981.)

A majority of geothermal reservoirs are dominated by fracture permeability. Therefore, calculations of theoretical log responses to fractures intersecting the borehole, by both analytical and numerical techniques, will aid in reservoir evaluations. A tabulation of such characteristic fracture signatures for a suite of logs would be used in identifying and quantitatively defining the properties of such features.

A catalog of log responses to various fracture apertures orientations, and their location in a wellbore would be useful. Obviously, the orientation and aperture of the fracture/fault, and therefore the response of certain logging tools, is helpful in evaluating the yield of geothermal reservoirs.

GRC TECHNICAL TRAINING COURSE NO. 7

(This course was given for the first time, with partial support from GLIP, in Reno Nevada on April 22 and 23, 1981.)

It was designed as an introduction to geothermal log interpretation. It reviewed the purposes of wireline well logging, and attempted to explain the interpretation procedure of identifying zones of potential production.

Mud logging data, core analysis and geological descriptions were correlated with logs to show how a more detailed estimation of the geology and the reservoir can be attained. The use of wireline log data in complementing the interpretations from surface geophysical data was described, and the utility of correlating borehole and surface data with well flow tests was discussed as a means of obtaining the best estimate of the three-dimensional configuration of a geothermal reservoir.

GEOTHERMAL LOG INTERPRETATION HANDBOOK

(The SPWLA (Society of Professional Well Log Analysts), with Walter Fertl as the editor, has started this project.)

Compiling the results of all of the above-described goals into a suitable format is appropriate so that geothermal log interpretors can readily use these findings in interpreting geothermal well logs. A practical handbook to aid log interpretors in analyzing geophysical well logs acquired from geothermal wells is a logical conclusion to these efforts.

RESEARCH NEEDS

Items that are needed for further development of geothermal log interpretation and reservoir analysis are:

- o More accurate measurement of formation temperature.
- o Better efforts in core acquistion and analysis.
- o Careful describing of logging responses related to fractures.
- o Completion of log interpretation handbook.

This background information, when completed, will aid in interpretation and evaluation of geothermal log interpretation and accelerate the development of the nation's valuable geothermal resource potential.

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REFERENCES

Benoit, W. R., Sethi, D. K., Fertl, W. H., and Mathews, M., "Geothermal Well Log Analysis at Desert Peak, Nevada," SPWLA 21st Annual Logging Symposium, Paper AA, July, 1980.

Fertl, W. H., editor, "Geothermal Log Interpretation Handbook," Society of Professional Well Log Analysts Technical Report (in progress), 1983.

Glenn, W. E., Hulen, J. B., and Nielson, D. L., "A Comprehensive Study of LASL Well C/T-2 (Phillips 9-1) Roosevelt Hot Springs KGRA, Utah with Applications to Geothermal Well Logging," Los Alamos National Laboratory report LA-8686-MS, February, 1981.

Mathews, M., "Calibration Models for Fractured Igneous Rock Environments," GRC Transactions, vol. 4, pp. 81-85, September, 1980.

Mathews, M., Gambill, D. T., and Rowley, J. C., "Compilation of Cores and Cuttings from US Government-Sponsored Geothermal Wells," Los Alamos Scientific Laboratory report LA-8253-MS, July, 1980.

Miller, K. R., and Elders, W. A., "Geology, Hydrothermal, Petrology, Stable Isotope Geochemistry, and Fluid Inclusion Geothermometry of LASL Geothermal Test Well C/T-1 (Mesa 31-1) East Mesa, Imperial Valley, California, USA," Los Alamos Scientific Laboratory report LA-8515-MS, September, 1980.

Rigby, F. A., and Riardon, P., "Benefit/Cost Analysis for Research in Geothermal Log Interpretation," Los Alamos Scientific Laboratory report LA-7922-MS, July, 1979.

Rigby, F. A., "Applications of Geothermal Well Log Data for Evaluation of Reservoir Potential," Los Alamos National Laboratory report LA-8778-MS, March, 1981.

Ross, E. W., Vagelatos, N., Dickerson, J. M., and Nguyen, V., "Nuclear Logging and Geothermal Log Interpretation: Formation Temperature Sonde Evaluation," Los Alamos National Laboratory report (in progress), 1981.

Sanyal, S. K., Wells, L. E., and Bickham, R. E., "Geothermal Well Log Interpretation-State-of-the-Art," Los Alamos Scientific Laboratory report LA-8211-MS, January, 1980.

Sethi, D. K., and Fertl, W. H., "Geophysical Well Logging Operations and Log Analysis in Geothermal Well Desert Peak No. B-23-1," Los Alamos Scientific Laboratory report LA-8254-MS, March, 1980.

Stone, D. G. and Evans, H. B., "Extrapolating Logs Run In Exploration or Development Wells Using Seismic Data," SPWLA 21st Annual Logging Symposium, Paper KK, July, 1980.