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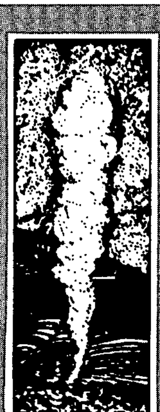

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BENEFIT ANALYSIS FOR GEOTHERMAL LOG INTERPRETATION

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Abstract

Formation evaluation is of great importance in geothermal development because of the high capital costs and the fact that successful exploration will only pay off through a subsequent decision to construct a power plant or other utilization facility. Since much formation data is available from well logging, development of new techniques of log interpretation for application to geothermal wells is called for. An analysis of potential near-term benefits from this program and the types of formation data called for is discussed. Much useful information can be developed by adaptation of techniques used in oil and gas reservoirs, but the different demands of geothermal development from hydrocarbon production also open up new data requirements.

Introduction

Well logging for the petroleum industry first developed in the 1920's and 1930's when there was a sufficient demand for logging services to stimulate industry. Logging techniques have developed slowly over a period of decades. These techniques are sometimes unsuited to the needs of geothermal development, partly because the types of data called for are not identical to the data needs of the petroleum industry, and partly because of the different logging conditions that obtain in geothermal wells. Today, because geothermal development has barely begun, there is only limited demand to stimulate the development of specialized geothermal logging services. However, by developing the knowledge necessary to interpret the characteristics of geothermal reservoirs from log data immediately, the geothermal industry will benefit and development of geothermal resources may be accelerated. The Geothermal Log Interpretation Program at the Los Alamos Scientific Laboratory is charged with the development of log interpretation techniques to address geothermal problems. As part of this effort an assessment was made of potential benefits that might result from application of improved logging data.

Benefit Identification

The analysis focuses on development of hydrothermal resources for electric power generation. This is likely to embrace the bulk of near-term geothermal development. Development of hot dry rock and geopressured resources, and development for geothermal non-electric applications, are not yet sufficiently advanced for a quantitative projection of their logging requirements.

Improvements in the process of geothermal development can come about in three ways. A direct reduction in the costs associated with development will produce a benefit equal to the dollars saved. This benefit may ultimately be realized as a reduction of the cost of power or as increased investment in development elsewhere, which will yield benefits indirectly. A reduction in the risk of development will produce benefits of two types: the cost of development is effectively reduced if losses are cut and development may be accelerated by increased availability of investor capital in response to the reduced risk. Finally, improved data that can aid the process of applying for and obtaining regulatory permits can allow more rapid completion of proposed power plants.

Geothermal development is highly capital intensive. Initial investment involves not only the cost of field development, but also power plant construction. Furthermore, since several production wells are required to supply a power plant, revenue may not be realized until the entire investment is made. Payout on the investment occurs over the 20 to 30 year life of the power plant, which may substantially exceed the life of individual production wells. This renders geothermal development extremely sensitive to initial risk. A large amount of capital is at risk for an extended period, and there is a substantial delay between investment and the commencement of revenues.

Reinjection is another important feature of geothermal development. Reinjection of produced brine will be required in all, or virtually all, geothermal development. The enormous quantities of brine involved make this a major factor, approximately doubling the number of wells required. In addition, the large volumes withdrawn and reinjected raise serious questions regarding the possibility of subsidence or induced seismicity. This may be a significant issue in the permitting process. This places additional value on knowledge of reservoir structure and the mechanical properties of the formation. Permeability and the pattern of flow in the reservoir also become important since reinjection may be needed to maintain productivity.

Log data can be applied to benefit a geothermal development program in a number of ways. Table I summarizes potential beneficial impacts of the development of improved techniques for geothermal logging and interpretation.

Benefit Estimate

A quantitative estimate of possible near-term benefits from research in geothermal logging and interpretation, based on development of hydrothermal areas for electricity generation in the U.S., was prepared for LASL. The estimate was based on a Department of Energy scenario of geothermal development and drilling costs and corrected for inflation and energy costs to 1981 dollars. Details of the scenario and cost/benefit analysis can be found in References 1, 2 and 3. Benefits were grouped into five classes of cost savings plus the benefit of earlier power-on-line. Gross benefits (no allowance for cost of logging and interpretation) in constant 1981 dollars were:

• Improved drilling success	$\$175.8 \times 10^6$
• Reduced exploratory drilling	$\$ 49.5 \times 10^6$
• Reduced flow testing	$\$ 78.4 \times 10^6$
• Reduced drilling costs	$\$175.8 \times 10^6$
• Reduced reinjection requirements	$\$ 80.3 \times 10^6$
• Scenario acceleration	$\$328.6 \times 10^6$

Drilling Success

Wells are sited on the basis of the picture of the reservoir that is built up from geophysical and geological survey data for the area and data from other wells. Obviously, the first well on a site cannot benefit from log data, but later wells may. Interwell correlation is an established tool for revealing reservoir structure. Another application of log data which holds potential value in well siting is the use of the well log to improve or clarify the analysis of other geophysical data. Combination of seismic data with sonic log data has produced good results in the petroleum industry (Ref. 4) and might also be useful in geothermal studies. Rigby and McEuen (Ref. 5) give an example of use of resistivity log data in combination with magnetotelluric data to examine a geothermal reservoir. Development of borehole to surface and borehole to borehole techniques may also offer benefits.

Reduction of Expenditures on Unsuccessful Exploratory Wells

Decisions to abandon drilling in a poor well or to perform cleanups, run a liner, and test a marginal well are difficult and may involve a large fraction of the total well cost. Formation temperature can be an important factor in decisions made during drilling (such as whether to continue to greater depth). Technology that could assist in estimating formation temperature away from the disturbance near the borehole would be useful (Ref. 6). Assessment of permeability is a second important concern in the decision to clean up and test a well. Location and density of fracturing can be valuable information in this context.

Reduced Well Costs

Log data are used in preparing bit and casing plans and in other drilling decisions. It is important to develop an experience base regarding lithologic identification and its relationship to drillability in the igneous and metamorphic lithologies frequently encountered in geothermal wells. Assessing porosity and degree of alteration has been found to be difficult in some areas due to uncertainties in tool response to fracturing and to hydrothermal alteration products. Determination of dominant fracture orientation might also be taken advantage of to control drilling to achieve maximum intersection of fractures. Selection of target depths can be a problem when the geologic goal is not a stratified formation. Logging during drilling to determine temperature, porosity, fractured zones encountered, etc. may be economically desirable in some geothermal areas where well costs are high.

Reduced Flow Testing

Because of the high capital investment involved in the power plant, flow testing may be prolonged, even for wells in established geothermal areas. Large production intervals, uncertainty in locating permeable zones, and heterogeneous formations may make flow test analysis difficult. In dual porosity formations (discreet major fractures together with more disseminated porosity) distinguishing porosity types can be important, as can data on fracture separation. Increased confidence in flow test analysis may allow reduced testing time or an equivalent indirect benefit.

Reduced Reinjection

Requirements for 100 percent reinjection or deep reinjection can represent a significant cost factor. Aside from these, permitting delays may also be encountered due to disputes over the reinjection plan. An effective reinjection plan is also valuable to long-term reservoir performance. Information on the hydrologic regime and *in situ* fluid characteristics, location of major faults and fractures, reservoir boundaries and other structural features, permeability and communication between reinjection and production areas, and mechanical properties of the reservoir rock may be of value in planning and permitting. The ability to monitor for early signs of compaction could also be of value.

Accelerated Power-On-Line

Much greater than any of the five preceding classes of cost reductions is the benefit that may accrue to the nation from time savings which can lead to an earlier start of power plant construction and earlier power-on-line. A key factor in this is the decision by a utility or other investor to commit capital for a power plant, and this will depend on the confidence placed in whatever model or picture of the reservoir there is. Important data will include reservoir temperature and pressure, evidence of resource extent and thickness (to which log-constrained inversion of geophysical data may contribute), hydrologic evidence such as formation fluid salinities, and analysis of reservoir permeability and porosities.

Conclusion

In geothermal development the significant problems of formation analysis and log interpretation contain several shifts in emphasis from conventional practice in the search for fossil fuel resources. Significant national benefits are possible in the form of cost reductions and of more rapid development. The most obvious example is the paramount importance of temperature and temperature gradient. Other factors are introduced by the different reservoir structures, the high cost of drilling in many geothermal areas, and the high capital investment involved in the surface plant.

References

1. MITRE, "Prospects for Improvement in Geothermal Well Technology and Their Expected Benefits," U.S. Department of Energy, HCP/T4014-04, June 1978.

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

3. Rigby, F.A., "Applications of Geothermal Well Log Data for Evaluation of Reservoir Potential," Draft Final Report prepared for Geothermal Log Interpretation Program, Los Alamos Scientific Laboratory Contract No. 4-L69-2142K-1, July 1980.

4. Stone, D.G. and H.B. Evans, "Extrapolating Logs Run in Exploration or Development Wells Using Seismic Data," Society of Professional Well Log Analysts, Twenty-First Annual Logging Symposium, Proceedings, Paper KK, July 8-11, 1980.

5. Rigby, F.A. and R.R. McEuen, "An Example of Resistivity Log Extrapolation with MT Data for a Geothermal Site," S.P.E. of AIME, 55th Annual Conference, Dallas, TX, September 1980.

6. Vagelatos, N., D.K. Steinman and J. John, "Neutron Formation Temperature Guage and Neutron Activation Analysis Brine Flow Meter," U.S. Department of Energy, 1RT-7021-019, March 1978.

Table I. Impact of Improved Interpretation and Application of Logged Data

IMPACT	ACTIVITY	REQUIREMENTS
Improved Drilling Success Rate	Exploration	Better Interaction with Other Exploratory Data, New Logging Techniques
	Development Program	Better Knowledge of the Reservoir
Reduced Drilling Cost	Development Program and Reservoir Modeling	Preplanning Wells, Improved or More Rapid Completion, Better Selection of Total Depth
Reduced Testing Time	Assessment	Reduced Flow Testing of Production Wells Based on Greater Comparability and Relation of Logged Parameters to Production Characteristics
Improved Reinjection Program	Environmental Protection	Justification for Less Than 100% Reinjection, Justification for Shallow Reinjection
	Reservoir Management	Better Control of Reinjection Well Clogging
Smoother Permitting	Environmental Protection	Better Control of Subsidence and Seismicity, Ability to Monitor Reservoir
Reduced Number of Exploratory Wells	Exploration	Achievement of Development Agreements Based on Fewer Wells, Reduced Investment "Up Front"
Accelerated Development	Reservoir Modeling and Assessment	Earlier Utility Committment
Facilitation of Unitization Agreement or Other Regulations Controlling Development	Development Program	Earlier Agreement, More Equitable Allotment of Revenues or Drilling Rights
Plant Design	Plant Operation	Easier or Earlier Determination of Brine Chemistry
Improved Well Performance	Reservoir Management	Application to Selection of Completion and Well Stimulation Techniques
Extended Field Life	Reservoir Management	Reservoir Monitoring, Improved Modeling, and Reinjection Control
Location of New Resources or Resources That Would Otherwise Be Overlooked	Exploration	New Techniques and Interaction with Surface Data