PROVING THE VIABILITY OF THE GEOTHERMAL RESOURCE

Gary W. Crosby
Phillips Petroleum Co.

A comparison is often made between geothermal resource companies and utility companies in which the resource company is cast in the role of engaging in high-risk venturing, and the utility company in the role of making more conservative investments. There is some basis in fact for making this contrast, and for obvious reasons. Nevertheless, utility representatives would no doubt seize on any opportunity to remind us that they are acquainted with risk taking and that no one guarantees their financial success. On the other hand, applying capital to prove the existence of a natural resource that is deeply buried will always be fraught with grave risks. We in exploration learn to accept it and formulate rules designed to win in spite of it. But we are never comfortable with it, and the first point to be made is that the resource operator makes every effort to reduce risks.

We do this by applying state-of-the-art and cost-effective exploration methods, drilling techniques, and reservoir assessment methods. We also apply statistical models and attempt to predict the future in economic analyses. These methods have been reviewed in previous sessions of this conference.

The investment prior to coming on stream with a field and plant is comparable for the resource and utility companies, in the order of $25,000,000 each for a 55 MW plant. To this cost the resource company must add the earlier exploration costs of those unsuccessful prospects that had to be evaluated on the way to that one prospect that is destined for commercial development.

A second point to be made, then, is that it is just as much in the operator's own self-interest to be assured of the viability of the resource before proceeding with field development, as it is for the utility to be assured prior to proceeding with plant construction.

Manifestly, a marriage of the fuel supplier and the utility must be consummated to produce kilowatts. The courtship should begin as soon as the resource company has a discovery that has commercial possibilities. The wedding may take place at the time both are convinced that the resource is durable enough to amortize their respective facilities. Like any marriage, it only works when both win. Negotiating for anything less spells failure, and that is my third point.

Point number four is - - - - the sooner the better. The resource company is in a somewhat delicate position in that it is investing in the resource years before the utility comes on board. We spend today's dollars, which are seriously eroded by interest and inflation by the time cash flow starts. The longer it takes to come on stream, therefore, the more costly the fuel, if the project goes at all. A negotiated steam price must reflect these sunk costs that rise in time with the leaven of inflation and the time value of money. Both of us, along with the consumer, are interested in a lower, competitive, product price.

The greatest single source of delays stems from governmental regulation. Geothermal fields in the Philippines, for example, are going on stream in four to five years, whereas in this country seven to eight years or longer separates first exploration surveys and first kilowatt produced. Ideally, the resource and utility companies should combine forces at an early stage to streamline a program to grapple with the excessive body of regulations and the multiple agencies and to assure that there are no delays in addition to the legal and institutional barriers.

But because of these inevitable delays economics demands that sunk costs, that is, costs incurred in proving the resource in the ground, be kept to a minimum until the latest possible moment. This means that the geothermal operator will drill only enough holes and perform only those reservoir tests adequate for demonstrating the quantity and quality of the resource to his own satisfaction and to inspire the confidence of the utility. The final holes and surface facilities are made ready while the plant is under construction. A fifth point, then, is let us decide what kind of information and how much of it is necessary for a clear demonstration. That's why we are here.

Nothing said so far purports to be profound. These simple axioms are part of economic reality. And the whole point is, we can cope better together. The resource company is ready, indeed eager, to furnish what information you need and to make the utility a party to the demonstration when an interest in participating in development of the new resource is shown.

PROVING THE RESOURCE

The viability of the geothermal resource, measured in terms of quantity, quality, recoverability, longevity, and economic constraints, is a prime consideration from the time first exploration activities are planned and continues through deep exploratory drilling and reservoir testing. The exploration program is designed to generate information bearing not only on the existence or nonexistence of subsurface heat but also on the nature of permeability and porosity, the dominant phase, temperature, and chemical aspects of reservoir water, depth and areal extent of the reservoir, and recharge characteristics. Preliminary economics are run out on the basis of these findings before the second and third phases, exploratory drilling and reservoir testing, are entered.

Exploration Program

Phillips Petroleum Company's geothermal exploration program is based on three core surveys; namely, water chemistry, magnetotellurics, and heat flow. All prospects that continue to show promise are investigated by these three methods. Any additional tools that might be run on a given prospect are ad hoc surveys designed to answer specific questions for that prospect.

Water Chemistry. Water is sampled, where available, from springs, wells, and perennial streams in an extensive region surrounding a locality where surface indicators, recent volcanics, and hot springs, for example, suggest the possible existence of a reservoir. Unstable compounds and the physical properties of the water that are apt to change under the new P-T conditions at the surface are measured in the field. Samples are then brought to the laboratory for additional analyses (3). Altogether some eighteen different measurements and analyses are carried out on a routine basis, and other analyses are undertaken as the local situation dictates.

The appropriate compounds are plotted in Piper diagrams to determine the chemical populations extant in the region. Each sample location is then plotted on a map with a symbol designating the population to which it belongs. This distribution is interpreted in terms of possible origin of its chemistry, with particular emphasis placed on man's activities in the basin and known subsurface geology, as well as anomalous shallow crustal heat. Maps are also prepared showing distribution of concentrations of certain marker compounds or elements. These interpretations are made with the aid of a map of the piezometric surface in the basin.

Various combinations of compounds, ratios of compounds, and physical properties are graphed against each other to study mixing of waters originating as distinct family types, among other things. Various statistical tests are carried out on the combinations. Finally, geothermometers are calculated (5) and interpreted, often applying subjective judgment prompted by the above findings. Thus, information on focus of a possible heat source within the basin, the dominant phase of the water, lithologic aspects of the reservoir, and temperatures are revealed in the water chemistry.

Magnetotellurics. The magnetotelluric (MT) method determines electrical conductivity distribution in the subsurface from surface measurements of natural transient electric and magnetic fields. The time variations of the earth's electric and magnetic fields at a site are recorded simultaneously over a wide range of frequencies, commonly .001 to 8 Hz, on digital tape. Later, in the office, the variations are analyzed with the aid of a computer to obtain apparent resistivities as a function of frequency contained within the wavelength spectrum.

Electric field measurements are made by determining meter differences of potential between two mutually perpendicular sets of electrodes a few hundred feet apart. The electrodes are small lead plates buried to a depth of about one foot. Magnetic field measurements are accomplished with three mutually perpendicular induction coils, approximately three feet long and four inches in diameter. These are commonly buried just below the surface so that wind shaking the coils will not generate magnetic "noise."

Interpretation consists of matching the computed plots of apparent resistivity against frequency to curves calculated for simplified models. The MT method depends on the penetration of electromagnetic energy into the shallow subsurface. Depth control is a natural consequence of the greater penetration of the lower frequencies.

Conductivity increases with increasing temperature of reservoir water, salinity, and shaliness. Thus, not all conductive regions in the subsurface express the presence of heat. Anomalies must be interpreted with caution, applying what is known about the subsurface. As a general rule, however, salinity increases with temperature. Moreover, if thick shale sections and/or evaporites occur in the regional stratigraphy, the geologist is apt to be aware of it.

Ideally, then, the areal extent of the geothermal reservoir and its approximate depth and thickness are reflected in the MT field. In some cases, information on a deep seated heat source is revealed in the MT data.

Heat Flow. Shallow holes, averaging 91 m deep (300 ft), are drilled on the prospect for the purpose of making temperature measurements. Normal crustal gradients in the western United States are approximately .66°C/30 m (1.5°F/100 ft). We look for something in excess of this value by five to ten times, or more. Initially, ten holes, more or less, are drilled, but as a thermal anomaly develops, additional holes are drilled to define it adequately. This requires that temperatures be measured and gradients determined concurrent with drilling, except for a small lag time to allow rebound from the temperature disturbance caused by drilling. If hydrologic or other problems are suspected, a 600 meter-deep (2000 ft) observation hole may be drilled.

Temperature gradients are plotted and contoured to show the extent of the anomaly. Where viable geothermal reservoirs exist, it is common for hot reservoir water to leak into shallow aquifer(s) and spread laterally. Thus, shallow gradient holes bottoming above the hot aquifer may have anomalously high gradients, yet be offset from the reservoir. It is important, therefore, to check correlation between gradients and the magnetotelluric conductivity anomalies to arrive at the best estimate of the reservoir size and to determine the most probable cause of the MT anomaly.

Thermal conductivity measurements are not routinely undertaken by Phillips. Where the refinement that accrues from heat flow determinations, as opposed to gradients alone, answers critical questions, these measurements are made by either the needle probe or the divided bar apparatus.

Additional Surveys. Other surveys that may be undertaken, including gravity, magnetics, active and passive seismics, soil gas surveys, isotopic studies, petrologic investigations, and other types of electrical surveys, may provide information on gross stucture of the geothermal occurrence, distribution of igneous rocks, active tectonics, convective systems, fracture systems, hydrology, alteration, phase relations, and geologic ages.

Ideally, the progressive assimilation of new data narrows the field of working hypotheses and allows them to converge on the best geologic interpretation (1). If this model includes a geothermal reservoir with commercial parameters, a drill site is selected, and a recommendation is made to test the model by deep drilling.

Exploratory Drilling

Deep drilling, 1220-3050 m (4000 - 10,000 ft), is undertaken with oil field-type drilling rigs and drilling procedures (4), modified slightly to accommodate anticipated high temperatures. Drilling is a continuous problem solving exercise, and no two holes are drilled the same way. Commonly, a conductor pipe, surface pipe, and a production string are successively run and cemented in the borehole as drilling proceeds. The blowout prevention stack is installed on each string in turn. Below the production string, terminating at depths in the order of 457-1372 m (1500 - 4500 ft), the hole is, more often than not, completed open hole.

During drilling, the mud returns are continuously monitored for temperatures and gases, including CO_2, H_2S, and combustibles. Filtrate resistivities are measured, chemical analyses are carried out for elements that have distinct affinities with geothermal reservoirs, a lithologic log is kept current with drilling, and drill rates are logged. The complete drilling history includes a record of lost circulation and all measurable fluid loss or gain. At projected depth, a suite of electric and temperature logs are run. From time series measurements, equilibrium temperature, which will be attained after rebound from the drilling disturbance, is calculated.

Thus, having generated a large mass of information during the drilling operation, the presence of a reservoir and the quality of the resource is indicated. A short flow test is carried out with the rig in place to characterize the production from the reservoir encountered through the prepared borehole. With favorable data from all these sources, one or more confirmation hole is drilled.

Reservoir Testing

With several holes drilled into the reservoir, an interference test is initiated in which one well, commonly, is flowed, while instruments in the others monitor pressure drawdown during flow and buildup after the well is shut in (2). These time series data reveal the transient wave that moves through the reservoir from the disturbance at the production well. Computational and graphical methods have been worked out whereby reasonably close estimates can be made from these data for permeability-thickness product of the reservoir, distance (and sometimes direction) to boundaries, reservoir volume, recharge, and well productivity. Phillips has used a variety of pressure measuring devices; the Hewlett-Packard quartz pressure transducer, however, is judged to provide the greatest accuracy at approximately ± 1379 Pa (± 0.2 psi) resolution.

While these transient data are being obtained, a variety of information is gathered at the flowing well. Wellhead flowing pressures and temperatures are logged, flow rates versus back pressure and through various orifices are determined, mass flow and steam fraction are measured, steam quality is determined by calorimetric methods, and fluids are sampled and analyzed to determine detailed chemistry and types and amount of noncondensable gases.

Phillips has used two systems to obtain flow data; namely, a steam-water separator with measuring devices in each line and a lip-critical apparatus that permits measurements of mass flow. The method utilizing the separator is standard; however, we have tested both systems connected in series to check comparability. The results are within ten percent of each other with mass flows up to 126 kg/s (10^6 lb/hr). This favorable comparison justifies the use of the simpler lip-critical apparatus in testing exploratory wells, and Phillips has fabricated a single-unit, skid mounted, integrated test module that can be trucked to any well site.

The exploratory, drilling conclusions flow test programs thus provide reliable data on which reservoir size, longevity, production characteristics, and steam quality can be estimated. This data base permits sophisticated economic analyses to be carried out by both the geothermal resource company and the utility. The data are adequate to estimate the life of the field and establish both design criteria for the plant that will utilize the steam and optimum well spacing, which dictates the layout of plant and gathering facilities.

REFERENCES

1. Jim Combs. "Geophysical Techniques in Exploration." In Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources, pp. lxxxi - lxxxvi, 1975.

2. N. D. Dench. "Well Measurements." In Geothermal Energy, pp. 85-96. Paris: UNESCO, 1973.

3. A. J. Ellis and J. A. Ritchie. "Methods of Collection and Analysis of Geothermal Fluids." In *Reports of the Department of Science, Industry, and Research*, Government of New Zealand. No. 2039, 1961.

4. International Association of Drilling Contractors. *A Primer of Oilwell Drilling*. Austin: University of Texas, Petroleum Extension Service, 1970.

5. A. H. Truesdell. "Geochemical Techniques in Exploration." In *Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources*, pp. liii-lxxxix, 1975.