Geothermal resource assessment can be defined as the broadly based estimation of supplies of geothermal energy that might become available for use, given reasonable assumptions about technology, economics, governmental policy, and environmental constraints (Muffler and Christiansen, 1978). This assessment implies not merely the determination of how geothermal energy is distributed in the upper part of the earth's crust but also the evaluation of how much of this energy could be extracted for man's use. Thermal energy in place in the earth's crust (relative to a reference temperature) is the geothermal resource base. The accessible resource base is the thermal energy at depths shallow enough to be tapped by drilling in the foreseeable future (Muffler and Cataldi, 1978). That fraction of the accessible resource base that could be extracted economically and legally at some reasonable future time is the geothermal resource (Muffler, 1973; White and Williams, 1975; Muffler and Cataldi, 1978). This geothermal resource contains both identified and undiscovered components. Finally, the geothermal reserve is identified geothermal energy that can be extracted legally today at a cost competitive with other energy sources. The relationships between these terms can be illustrated on a McKelvey diagram for geothermal resources (figure 1).

In the United States, the U. S. Geological Survey (USGS) is the government agency responsible for assessing mineral and energy resources, including geothermal energy. The goal of the Survey's geothermal assessment is to provide a knowledge of the Nation's geothermal resource in sufficient breadth and detail to allow optimum energy planning, to encourage systematic exploration, and to support appropriate development of geothermal resources by private industry.

The first systematic effort to estimate the geothermal resources of the entire United States was carried out by the USGS in 1975 and published as USGS Circular 726 (White and Williams, 1975). This study evaluated the geothermal resource base to specified depths in several categories: (a) regional conductive environments, (b) igneous-related geothermal systems, (c) hydrothermal convection systems, and (d) geopressed systems. For each category, the USGS study then evaluated the part of the resource base that might be recovered under reasonable technological and economic assumptions.
Figure 1.—McKelvey diagram for geothermal energy showing derivation of the terms resource and reserve (from Muffler and Cataldi, 1978, fig. 3). Scales are arbitrary, and thus the relative sizes of the rectangles have no necessary relation to the relative magnitudes of the categories.
Any resource assessment should be periodically updated in response to changing conditions. For geothermal energy, among these conditions are (a) increased data, resulting from expanded exploration and drilling activity, (b) development of improved and new technologies for exploration, evaluation, extraction, and utilization, (c) rapid evolution of geothermal knowledge, and (d) the increased role of geothermal energy in response to changing economic, social, political, and environmental conditions (in particular, an increasing awareness of the limits to petroleum and natural gas resources, both domestic and international).

Accordingly, the USGS plans to carry out an updated and expanded geothermal resource assessment of the United States by the end of 1978. Aspects to be given increased emphasis include the following:

a. Refinement of areas, thicknesses, and temperatures of high-temperature (>150°C) and intermediate-temperature (90-150°C) hydrothermal convection systems, in part using data acquired and compiled in the course of systematic evaluation of Known Geothermal Resource Areas (Mabey and Isherwood, 1978).

b. Improvement of methodology for estimating the fraction of energy in hydrothermal convection systems or geopressed systems that might be recoverable at the surface.

c. Interpretation of available data on low-temperature (<90°C) geothermal systems, in cooperation with the State Cooperative Direct-Heat Geothermal Program of the Division of Geothermal Energy of the Department of Energy.

d. Utilization of GEOTHERM, the new USGS system of computer-based storage and retrieval of geothermal data (Swanson, 1977).

e. Assessment of geopressed resources not inventoried in 1975 (offshore Tertiary deposits and onshore Mesozoic deposits of the Gulf Coast, and geopressed resources of other sedimentary basins).

f. Refinement of the size and age of young igneous systems and more thorough evaluation of the effects of hydrothermal convection on the cooling of plutons.

g. Evaluation and possible use of the techniques of subjective probability and Monte Carlo aggregation used in recent oil and gas resource assessments of the United States (Miller, et al., 1975).
h. Presentation of data and conclusions on a regional as well as a national basis.

This past year, the USGS has cooperated with the National Electric Agency of Italy (ENEL) in evaluating techniques for geothermal resource assessment, under the sponsorship of the U. S. Energy Research and Development Administration (ERDA), recently absorbed into the new Department of Energy. Recommendations for uniform terminology and methodology were presented at the ENEL-ERDA Larderello Workshop on Geothermal Resource Assessment and Reservoir Engineering (Muffler and Cataldi, 1978) along with a test application to central and southern Tuscany (Cataldi et al., 1978).

These joint studies identified a number of problems in geothermal resource assessment, one of which bears directly on the reservoir engineering community. This is the question of recoverability. In the petroleum and mining industries, one makes a careful distinction between the total amount of a given deposit underground prior to extraction, and that part of the deposit that might be extracted under foreseeable economics and technology. Commonly, the recoverable part is expressed as the total deposit multiplied by a recovery factor.

Extension of the term "recovery factor" to geothermal resources leads one to define geothermal recovery factor as the ratio of extracted thermal energy (measured at the wellhead) to the total thermal energy contained in a given subsurface volume of rock and water (Muffler and Cataldi, 1978). Implicit in this definition is the necessity that recovery take place in an industrial time frame (10 to 100 years) rather than in a geologic time frame (>10^3 years).

Recovery factors for hydrothermal convection systems were discussed in detail by Muffler and Cataldi (1978), and the test of geothermal assessment methodology in central and southern Tuscany (Cataldi et al., 1978) used the following formulations: (1) for systems producing by intergranular vaporization, the formulations of Bodvarsson (1974) and of Nathenson (1975) were modified for a 2.5 bar final pressure limitation (figure 2), and (2) for systems producing by intergranular flow, the analysis of Nathenson (1975) was extended to give a geothermal recovery factor scaled linearly from 50% at an effective porosity of 20% to 0% at an effective porosity of 0 (figure 3).

The first formulation is fairly rigorous, with the major assumption being whether the reservoir initially is filled with water or is vapor-dominated (White et al., 1971). The second formulation, however, is little more than a guess. A better basis for estimating the geothermal recovery factor is needed for geothermal resource assessment,
Figure 2.—Graph showing geothermal resource recovery factor ($R_g$) as a function of reservoir temperature and effective porosity ($\phi$) for reservoirs produced by intergranular vaporization. From Muffler and Cataldi (1978, fig. 7), adapted from Nathenson (1975, fig. 4).

Figure 3.—Graph showing possible variation of geothermal resource recovery factor ($R_g$) as a function of effective porosity ($\phi$) for reservoirs produced by intergranular flow. $R_g$ is taken to be 50% for an ideally permeable reservoir in which total porosity = effective porosity = 20%. From Cataldi et al. (1978, fig. 9).
and I solicit the help of the reservoir engineering community in developing improved ways of estimating geothermal resources from hydrothermal convection systems produced by means of intergranular flow.

Acknowledgments

This contribution draws heavily on manuscripts prepared for the Geothermal Symposium at the IASPEI/IAVCEI Assembly of August 1977 (Muffler and Christiansen, 1978) and the Larderello Workshop on Geothermal Resource Assessment and Reservoir Engineering of September 1977 (Muffler and Cataldi, 1978; Cataldi et al., 1978).

References


