Siting Criteria for Heat Extraction from Hot Dry Rock; Application to Switzerland

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Abstract — For selecting possible hot dry rock extraction sites for geothermal energy applications, the following criteria have been considered: (i) depth to the crystalline basement, (ii) temperatures at depth, (iii) pattern of regional stress field and (iv) natural permeability (= degree of fracturing) of basement rocks. A contour map of the basement topography is presented. From outcrops at the northern border of Switzerland (crystalline rocks of the Black Forest massif, mainly granites and gneisses of Hercynian age) the basement dips gently toward the SE under the Mesozoic and Tertiary sediments of the Molasse Basin and reaches its maximum depth (7 km) underneath the front of the Alps. Some 30 km further SE the basement rocks appear at the surface (Aar- and Gotthard-massif, Penninic units), where they are deformed and fractured to a great extent. Temperature-depth profiles have been obtained by model calculations. Locally increased heat production (in granite batholiths) at the base of the Molasse Basin, combined with the blanketing effect of the overlying sediments, could raise the temperatures to 150–170°C at a depth of 5 km. According to earthquake fault-plane solutions (P-axes) the regional stress field in the area of the Swiss Alps and in its northern Foreland is characterized by the maximum horizontal compression oriented N(150 ± 20)°E in the upper crust. In situ stress determinations (overcoring experiments) show that considerable excess horizontal compressive stress is present in the Alpine crust (up to 200 bar). The deep Alpine tunnels exhibited considerable fracturing of crystalline rocks at depths greater than 1–2 km. Information about the degree of fracturing has also been obtained by refraction profiles. The velocity-depth functions show lower than normal velocities in the uppermost 1.5 km, indicating that the rocks there are fractured. A 30–40 km wide region, running along the axis of the Molasse Basin (which coincides with the majority of the population and most of the industry of Switzerland) would provide the best hot dry rock sites.

Key words: Geothermal energy; Hot dry rock; Crystalline basement; Temperature-depth profiles; Stress field; Fracturing; Radioactive heat generation; Switzerland.

Introduction

In exploiting the earth’s internal geothermal energy, man has historically utilized water naturally occuring at depth, either as steam or hot water, as the transfer medium to transport the energy to the surface; both high and low enthalpy resources have been so developed. Use of that mechanism has restricted the principal developments


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to those limited regions of the crust characterized not only by a large geothermal anomaly, but also by the presence of permeable rocks containing groundwater circulating in sufficient volumes to permit significant heat extraction and recovery.

Such geothermal systems are rather rare in nature and their potential is limited. On the other hand, in most continental areas geothermal heat is present in great quantities at depths which are accessible with today’s drilling technology, even when geothermal fluids are absent due to the low natural permeability of the deep strata. From such ‘hot dry rock’ (HDR) resources heat could be extracted by establishing artificial fluid circulation. One possible circulation system is now under development at the field test stage in New Mexico, USA and is known as the ‘Los Alamos Concept’. It requires drilling of two holes into hot crystalline rock, connecting them at depth through a large hydraulic fracture, and then circulating pressurized water through this closed system to recover heat from the rock.

While at present a multi-disciplinary team at the Los Alamos Scientific Laboratory (LASL) is thoroughly investigating the technical and economical as well as the environmental aspects of this new technology (Blair et al., 1976), methods for the location and evaluation of HDR reservoirs still need to be developed (West and Shankland, 1977). In this study we aim at the formulation of criteria for selecting possible HDR heat extraction sites3) in a given geologic environment (Switzerland) with respect to technical and economical feasibility.

**Siting criteria**

In general terms, rock masses at or above 150°C and with low natural bulk permeability to fluid flow (≤ 1 μdarcy) can be considered as HDR resources. As far as rock types are concerned, basement crystalline rocks such as granites and gneisses, and also volcanics can be regarded as possible candidates. The presence of these rock types at accessible depths, possibly below a few km of sediment, is one of the prerequisites for a successful HDR site.

Since drill holes play a decisive role in most of the possible HDR systems and since drilling costs increase nearly exponentially with depth in crystalline rocks (Garinish, 1976) the economy of HDR heat extraction at a given site will strongly depend on the local geotherm (=temperature versus depth curve) and so the variation of temperature with depth represents an additional consideration.

The state of stress within the earth’s crust at the depths in question is of particular interest in all HDR operations. In the case of the LASL technique which applies hydraulic fracturing as the method for creating heat exchange surfaces the knowledge of the stress field orientation is essential. The orientation of a hydraulic fracture will

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3) As an HDR ‘site’ we refer, in accordance with the recommended definition of the U.S. Hot Dry Rock Assessment Panel (1977), to an area on the earth’s surface under which an HDR resource prospect may be found.