# CHANGES IN PERMEABILITY DURING FLOW OF WATER THROUGH GRANITE SUBJECTED TO A TEMPERATURE GRADIENT

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The useful lifetime of a geothermal reservoir as an energy source can depend strongly on the technique used to extract heat. In both naturally occurring geothermal fields and artificial geothermal reservoirs, such as the Los Alamos hot dry rock experiment, continuous extraction of heat requires maintenance of a channel of permeable material to and away from the heat source. Since such a system must be recharged to maintain production over a useful period of time, water must be heated and thus transported through rock in the presence of large temperature gradients.

We have designed experiments to study permeability changes in rock due to fluid flow along a temperature gradient to further understanding of how heat production in geothermal reservoirs may depend on these effects. Cylindrical samples of Westerly Granite, 8.9 cm long, 7.6 cm in diameter, and containing a 0.56 cm diameter borehole, were used. A resistance heater was placed in the borehole as a heat source, giving a radially symmetric temperature gradient. Confining pressure and pore pressure were applied to the sample; a pore pressure gradient was applied to induce radial flow either toward or away from the borehole. Although permeability may not have remained homogeneous during the experiments, an apparent permeability, averaged over the whole sample, was calculated from Darcy's Law by measuring the pore fluid flow rate.

Figure 1 shows the results of two experiments with samples of Westerly Granite; experimental conditions are given in Table I.

Table I

| | | Experiment I | Experiment II |
|---|---|---|---|
| Confining Pressure (bars) | | 300 | 600 |
| Pore Pressure | -borehole (bars) | 105 | 200 |
| | -jacket (bars) | 100 | 205 |
| Temperature | -borehole (°C) | 310 | 358 |
| | -jacket (°C) | 115 | 145 |

In both experiments the permeability decreased,, In experiment I, pore fluid flowed away from the hot borehole; the decrease in permeability may have been caused by deposition of dissolved minerals because of a decrease in solubility with lowered temperature. In experiment 11, pore fluid flowed toward the borehole. In this experiment, the decrease in permeability may likewise have been due to deposition of dissolved minerals. At pressures below 300 bars the solubility of silica as a function of temperature goes through a maximum between 320° and 340°C. If the pore fluid is saturated at this temperature, it must deposit silica on heating as it moves toward the borehole, thus decreasing the permeability. Permeability may also have been decreased in both experiments I and II by alteration of minerals in place, resulting in clogging of pores. Further experiments are being conducted to determine the relative importance of these two effects.

These results suggest that under the proper conditions, fluid flowing through rock along a temperature gradient can result in decreased permeability. Although this effect is undesirable in geothermal applications, it may be of use in the disposal of nuclear waste materials. In this case, transportation of nucleides away from the hot disposal site by ground water may be inhibited by decreases in the permeability. The experiments reported here were designed to show that permeability can be decreased by fluid flow. We are currently conducting experiments to study the conditions under which permeability can be increased by fluid flow. When this problem is thoroughly understood, it should be possible to design geothermal heat extraction systems so as to take advantage of these effect:; and thereby improve energy production.

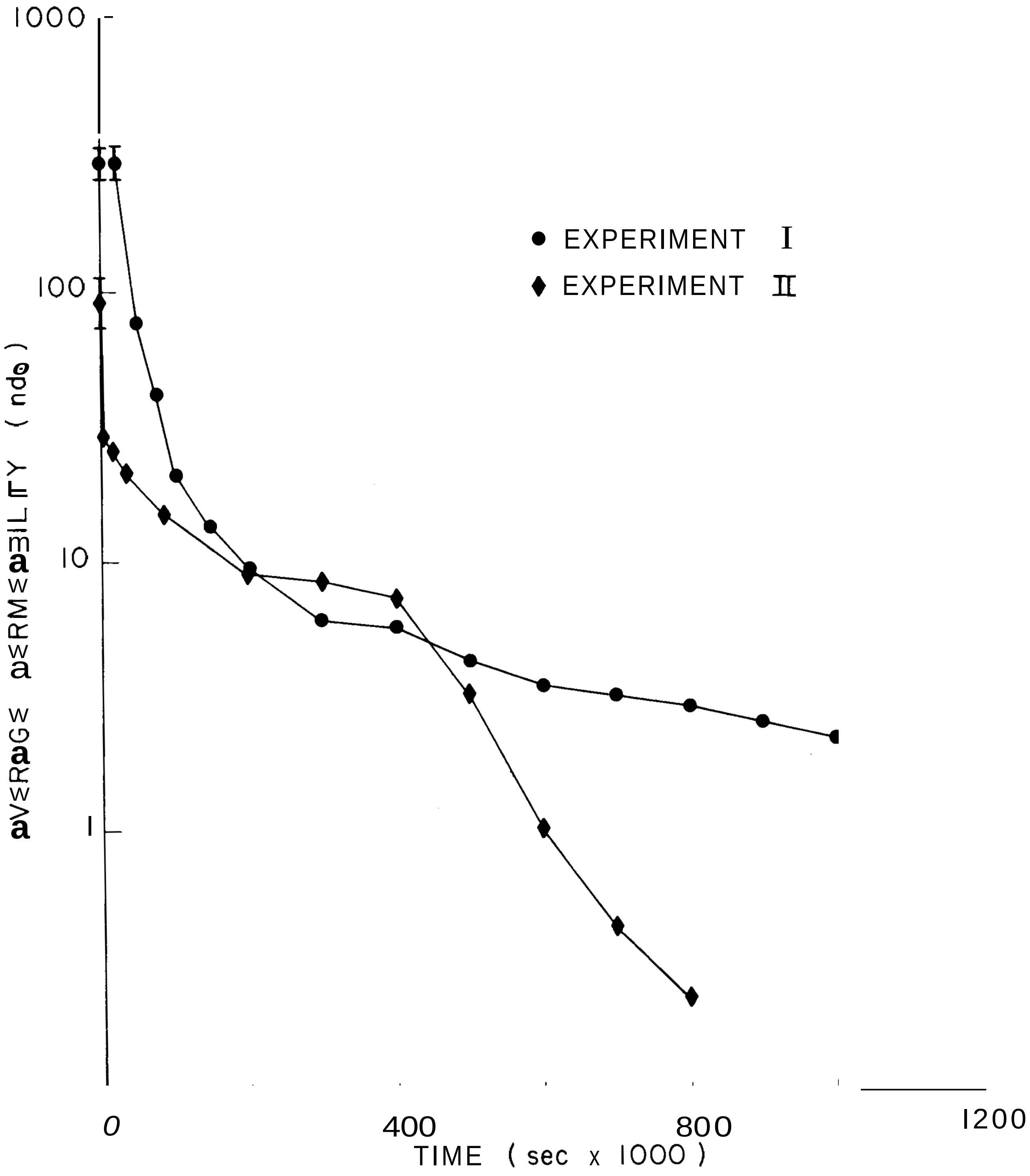


FIG. 1. **Plot of average permeability vs time €or two samples of Westerly Granite. In Experiment I, water cooled as it flowed away from the borehole. In Experiment 11, water flowed toward the borehole, increasing in temperature. In both experiments, permeability decreased with time.**