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The potential for acid stimulation of a deep geothermal reservoir: an experimental investigation

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The Soultz-sous-Forêts geothermal plant (Alsace, France) is being considered for acid stimulation under the auspices of the European DESTRESS project. In order to explore the influence of acid stimulation on the physical properties of the reservoir rock, samples were subjected to a range of thermal and chemical treatments. Sample material comprised variably-altered leucocratic granites containing muscovite and biotite, an analogue for the deep reservoir material at Soultz-sous-Forêts. Samples were divided into three suites for experimentation: a fine-grained leucocratic 2-mica granite (G2M-A): a slightly hydrothermally altered granite containing additional secondary minerals such as apatite (G2M-B): and an unaltered granite identical to G2M-A, but containing abundant macroscopic fractures (G2M-F).

Batch reaction tests were performed whereby sample suites were immersed in acid solutions for varying periods of time. Mass, porosity, and permeability were measured prior to immersion. Periodically, samples were removed and re-characterised in order to monitor the evolution of these physical properties. Additionally, some samples underwent thermal stressing in a furnace.

Naturally fractured samples (G2M-F) are markedly more permeable (10^{-16} m^2) than their non-fractured counterparts, highlighting that fractures provide the most important fluid pathways within the granitic basement. Further, the altered granite (G2M-B) is more permeable than the unaltered (G2M-A), with permeabilities on the order of 10^{-18} and $<10^{-21}$ m^2, respectively. The initial permeability of G2M-A is extremely low. However, by heating samples to incrementally higher temperatures, we observe an onset of measurable permeability between 200 and 300 ˚C, coinciding with an uptick in porosity formation (from <0.3% to 1.6%), presumably due to thermal microcracking. By thermally stressing samples to 600 ˚C and higher, permeability was increased by over 5 orders of magnitude (up to 10^{-16} m^2). Immersion in 0.2 N HCl for 1008 hours yielded an increase in permeability of intact G2M-A samples from $<10^{-21}$ m^2 to $>10^{-18}$ m^2. Under the same conditions, G2M-B samples increased in permeability by a factor of approximately 1.5 over the same timeframe. Permeability of G2M-B samples was only increased by a factor of 2 by increasing the acid concentration by an order of magnitude (2.0 N HCl).

Acid stimulation was found to be an inefficient means of increasing permeability following high-temperature thermal stressing (600 or 700 ˚C). In such cases, permeability had already been increased significantly (from $<10^{-21}$ m^2 to $>10^{-16}$ m^2) due to the introduction of new microcracks. Mineral dissolution by HCl was not sufficient to increase permeability beyond this value. Similarly, the naturally fractured granites (suite G2M-F) exhibited little or no increase in permeability following acid treatment, presumably due to their high pre-stimulation permeabilities. Based on our results, acid stimulation techniques could prove effective for locally increasing reservoir transmissivity. However, as fluid flow at depth is certainly dominated by pre-existing fractures, introduced acid agents may be rapidly leached from the system, thus not allowing the time required for significant dissolution of the low-permeability basement rock. Retarding agents may serve to improve the potential for dissolution to occur, by increasing the residence time of acids introduced to the system.