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MECHANICAL AND TRANSPORT PROPERTIES OF ROCKS AT HIGH TEMPERATURES AND PRESSURES

TASK II.

FRACTURE PERMEABILITY OF CRYSTALLINE ROCKS AS A FUNCTION OF TEMPERATURE, PRESSURE, AND HYDROTHERMAL ALTERATION

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TASK II

Fracture Permeability of Crystalline Rocks as a Function of Temperature, Pressure and Hydrothermal Alteration

Introduction

We are not submitting at this time a renewal proposal, instead we are in the process of requesting a no-cost extension, with the intent of submitting a renewal proposal at a later date (ca. 3/83). The delay results primarily because the elevated-temperature, corrosive fluid permeability system is just now nearing completion. Shakedown testing should begin this month (November), after which we will undertake the permeability experiments we proposed for this year's effort. The emphasis of these first experiments is on assessing the effects of dissolution and pressure solution upon the fracture permeability of a quartzite. The effects of secondary mineral formation will be studied at a later date. It is on the basis of an operational permeability system and results of the first phase of permeability experiments that we will make our renewal request.

During the design and construction phase of the system, we have concentrated on several other complementary subtasks: (1) experimental study of the evolution of surfaces undergoing dissolution, with specific emphasis on the changes of surface roughness and asperity shape; and (2) an exploratory experiment to assess whether measureable pressure solution could occur in the time constraints typical of our proposed permeability experiments. Below we briefly describe the permeability system and some

specifics of the dissolution experiments. The final technical report will present a more thorough report of our results.

Permeability System

Approval from DOE for expenditure of hold-over monies came in early July with construction and acquisition of components commencing immediately. Most basically, the permeability system consists of an upstream servo-controlled syringe-type pump that can be operated to generate either a constant flow rate or constant differential pore fluid pressure across the sample. Under constant flow rate control, the system is designed to achieve flow rates as low as 1 to 10 ml/day at fluid pressures to 20 MPa and temperatures to 300°C. Back pressure is regulated by a second, downstream, servo-controlled syringe-type pump. All wetted parts (tubing, valves, specimen pistons) at elevated temperature are made of a highly corrosion resistant Ni alloy (Hastelloy C-276). The sample, jacketed in either teflon or gold (depending upon temperature), is hydrostatically loaded (up to 100 MPa) in an externally heated, high pressure Aminco hydrothermal reaction vessel modified to allow through flow of the pore fluid. The pressure drop across the sample is measured using a highly sensitive differential pressure transducer. Integral to the system is a microprocessor for data acquisition and servo-control of the pumping rates of the up- and downstream pumps. The system also has an in-line reaction vessel so that in the future we can investigate permeability changes resulting from fluid that has reacted with other rock materials prior to entering the sample.

The system is designed to measure permeability in either of two modes: (1) continuous, constant flow for high to medium permeabilities,

or (2) pressure pulse decay for the lower permeabilities (microdarcy to nanodarcy range).

This system is being built in conjunction with CGS, Inc., a small research-oriented firm, which also has underwritten part of the cost.

Dissolution Experiments

Using a closed-system, hydrothermal reaction vessel, we are studying the evolution of surfaces undergoing dissolution, in an effort to obtain a physical picture of the process and identification of important parameters. As stated earlier, we are interested particularly in the changes in surface roughness and asperity geometry as a consequence of dissolution. This is important to our permeability experiment because the surface roughness and asperity geometries of contacting fracture surfaces affect significantly the mechanical compliance and effective hydraulic aperture of the fracture. These studies should allow us to better interpret the results of permeability experiments and provide the foundation for development of a theoretical model of permeability incorporating dissolution effects.

The experiments consist of reacting small discs (6mm diameter) of Sioux quartzite in sealed gold capsules containing either distilled water or 0.1 to 4N aqueous solution of Na_2CO_3. The Na_2CO_3 provides a buttered high pH solution that increases the solubility of quartz; solubility is proportional to the Na_2CO_3 concentration, hence we are able to obtain differing amounts of dissolution by varying the initial concentration. Typically, experiments are conducted at 200°C and 20 MPa fluid pressure. Run times are 2 to 3 days, which is sufficient for saturation of the fluid with respect to quartz. Scanning electron

microscopy is the principal method of documenting changes of surface features with increasing amounts of dissolution. We have used two markedly different starting surface textures: flat polished surfaces and tensile fracture surfaces.

The results to date are interesting and allow us to better appreciate the important parameters. These experiments clearly indicate the manner of preparation of fracture surfaces to be used in the fracture permeability experiments may have a dramatic influence on the results obtained and may as a consequence limit the application of such laboratory data to naturally formed fractures in the field. Although not surprising, our experiments indicate the flaws and fractures play a very important role in the evolution of surface topography during dissolution. Crystallographic effects are secondary and primarily affect the geometry details of a specific dissolution feature evolving from a crack or flaw. Surface roughness can go through a dramatic evolution as most clearly demonstrated by the changes observed in the flat polished surfaces. These surfaces changed from an optically flat surface to one with a roughness of the order of the grain size (0.5 to 1 mm). Grain boundaries, pre-existing intragranular microcracks and cavities, and grinding and polishing induced flaws were principal loci of dissolution. The later features, which in general are extremely small, played an important role in the early stages. The former features dominated after the initial stage. It is easy to appreciate that the affect of preparation induced flaws on more coarsely ground or saw-cut surfaces would be even more dramatic. As a consequence, observed chemically induced changes of permeability with ground or sawcut surfaces may strongly reflect this effect and not be representative of a "natural"

surface. This is pointed out here, because most previous experimental fracture permeability studies investigating the effects of stress have used sawcut or ground surfaces.

The dissolution experiments provide insight into what may happen to that part of a fracture surface not in contact with asperities of the opposite surface. At regions of contact the situation is expected to differ. Transfer of material from the contact surface will depend more strongly on diffusional transport because of very low rates of fluid flow in this area. Furthermore, a pressure solution mechanism should occur. Experimental studies of the kinetics of pressure solution are limited but theory provides some estimates. The biggest uncertainty in the models is the appropriate value of the surface diffusivity coefficient. Depending upon the diffusion film thickness this coefficient can vary by 2 or 3 orders of magnitude.

Taking an empirical approach we performed an exploratory experiment designed to determine whether observable pressure solution would occur under loading conditions similar to and times typical of the proposed permeability experiments. A monolayer of subrounded to rounded quartz sand grains (ca. 100 m diameter) was sandwiched between ends of two, polished, optically flat, cylinders of Sioux quartzite. The sample, saturated with distilled water, was sustained under a triaxial load at 300°C for 4 days. Confining pressure, pore fluid pressure and axial load were adjusted to obtain a 10 to 15 MPa effective normal stress across the layer. During the experiment, loading column length and acoustic emissions were maintained continuous; the latter was intended to allow adjustment of axial load to as high as possible without extensive fracture of the sand grains. Upon completion of the experiment, it was

planned to examine with SEM the sand grains and the quartzite surfaces for evidence that pressure solution had occurred. Unfortunately, we lost confining pressure during the fourth day and a large number of grains were crushed. SEM studies, (still underway) are not definitive but several features suggest pressure solution may have occurred. Nevertheless, the effect was not dramatic; the extremely small shortening (ca. 5×10^{-3} mm) of the loading column further underlines this observation. These experiments suggest measureable pressure solution of load bearing asperities may not occur during the time of permeability experiments. We have not been able to repeat the experiment because the apparatus used is dedicated full time to other DOE contract research.