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Laboratory bentonite colloid migration experiments to support the Äspö Colloid Project

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ABSTRACT

One of the objectives of the Äspö Colloid Project is to evaluate the potential of bentonite colloids to facilitate radionuclide transport. Since bentonite colloids are not stable in Äspö groundwaters, the field-scale experiments performed at Äspö needed to be limited to using latex colloids. To support the Äspö Colloid Project, laboratory scale colloid migration experiments, using both bentonite and latex colloids, were performed in the Quarried Block (QB) sample, a 1 m × 1 m × 0.7 m block of granite containing a single, well characterized, through-going, sub-horizontal, variable aperture fracture. The main purpose of this laboratory program was to provide additional information that cannot be obtained on the field-scale regarding bentonite versus latex sphere colloid transport, particularly at low flow rates. Tracer tests were performed as dipole experiments within the fracture plane using a borehole pair with a separation distance of 380 mm. Flow rates and ionic strength were varied between tests.

With low ionic strength water, results showed that at high flow velocities typical of forced-gradient field-scale tracer tests (10's cm/h), bentonite colloids and 100 nm latex colloids were mobile and had similar transport behaviour. Differences in transport behaviour between the two colloid types became evident as flow velocity was reduced to centimeter per hour and then millimeter per hour, the latter being more typical of certain natural flow conditions. Bentonite colloid recoveries were reduced by up to a factor of three and eluted colloid sizes were predominately in the smallest particle size range (4–15 nm), particularly at low flow velocities. With high ionic strength, Äspö-type, water, bentonite colloids were not mobile in the QB fracture and could not readily be re-mobilized by subsequent injection of low ionic strength water.

1. Introduction

In recent years, experimental evidence has suggested that radionuclide migration may be facilitated through sorption onto bentonite associated with Deep Geologic Repository (DGR) buffer and backfill materials and subsequent release as bentonite colloids when in contact with groundwater. This is of particular concern to sites with low ionic strength groundwater, for example as found at the Swiss Grimsel Test Site (GTS). This concern has been supported by the observation of significant bentonite colloid transport during high flow rate, force gradient test during the in situ Colloid and Radionuclide Retardation (CRR) experiment at Grimsel (Mori et al., 2003). The Äspö Colloid Project was initiated by SKB to address concerns raised by apparent plutonium colloid migration at the Nevada Test Site (Kersting et al., 1999), and the observed bentonite migration in the CRR experiment. The Project's objectives were: (1) to evaluate colloid stability and mobility, (2) to characterize natural colloid concentrations at Äspö, (3) to evaluate the role of bentonite for generating colloids and (4) to study the potential of colloids to facilitate radionuclide transport (SKB, 2004).

In 2006, the Äspö Colloid Project included in situ colloid migration experiments performed at the Äspö Hard Rock Laboratory (HRL), using boreholes that intersected a fracture and were at a separation distance of 4.68 m (SKB, 2006). The groundwater in the experimental region contained mainly Na, Ca, Mg, Cl and SO_4, with an ionic strength of 0.2 mol/L and a pH of 7.5 (SKB, 2007). Since bentonite colloids are not stable in this type of groundwater, colloid tracers were limited to 50 and 100 nm latex spheres. Carboxylate-modified latex spheres are almost perfectly spherical, resistant to biodegradation and are stable in saline water through a combination of hydrophilic and negatively charged (at pH > 5) surfaces (Becker et al., 1999). The average groundwater velocity used in these experiments was about 0.9 m/h, significantly higher than natural groundwater velocities, which may be closer to 0.0002 m/h (Vilks and Bachinski, 1996).

This paper summarizes a program of laboratory migration experiments using both bentonite and latex colloids to provide

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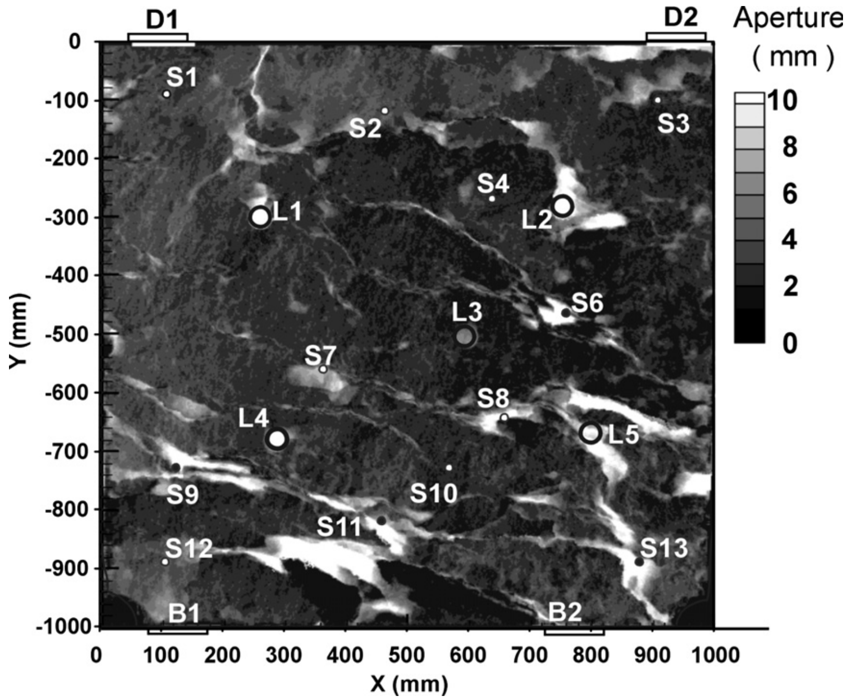

Fig. 1. Borehole and mini-plena locations plotted on digitized aperture distribution model for the Quarried Block fracture.

additional information that cannot be obtained on the field-scale regarding bentonite versus latex sphere colloid transport, particularly with low ionic strength water and low flow rates. The experiments were performed in the Quarried Block (QB) sample, a 1 m × 1 m × 0.7 m block of granite containing a single, well characterized, sub-horizontal, through-going variable aperture fracture (Vilks and Miller, 2006). The experiments were funded by Ontario Power Generation's Deep Geologic Repository Technology Program and performed at Atomic Energy of Canada Limited's Whiteshell Laboratories.

2. Methods

The QB sample was previously excavated at the 240 m level of AECL's Underground Research Laboratory (URL). The outer surfaces of the quarried block sample were coated with a silicone material to prevent loss of moisture from the fracture and from the interconnected pore space in the rock matrix. To support a set of previous transport experiments, the QB sample was first instrumented with position indicators and then opened up to expose the fracture surfaces in order to measure their roughness using an optical digitizing technique based on white light triangulation (Applied Precision, Mississauga, Ontario). Digitizing the re-assembled block provided the necessary reference for developing a fracture aperture distribution model consisting of approximately 1 million points (Fig. 1). The fracture dips from the upper right corner to the lower left corner (Fig. 2). The fracture can be accessed for sampling or tracer injection from the top of the block via 17 test boreholes, which are packed off and terminate at the fracture plane (Fig. 1). Access to the fracture is also possible via four mini-plena located on the vertical faces of the block where the fracture highlights and are labeled as B1, B2, D1 and D2. The main fracture in the QB was the major zone of weakness along which the upper and lower block halves were able to separate. The main fracture is, however, associated with a number of intersecting sub-parallel fractures, which form splays and add to the heterogeneity in the fracture aperture. The fracture volume was estimated at approximately 2.5 L.

All tracer tests were performed in the QB as dipole experiments using borehole L1 as the injection well and L4 as the withdrawal well. The separation distance between L1 and L4 is 380 mm. The ionic medium for tracer tests was either filtered (200 nm) deionized water or synthetic Äspö-type groundwater (total dissolved solids of 6.6 g/L). While residing in the fracture the deionized water

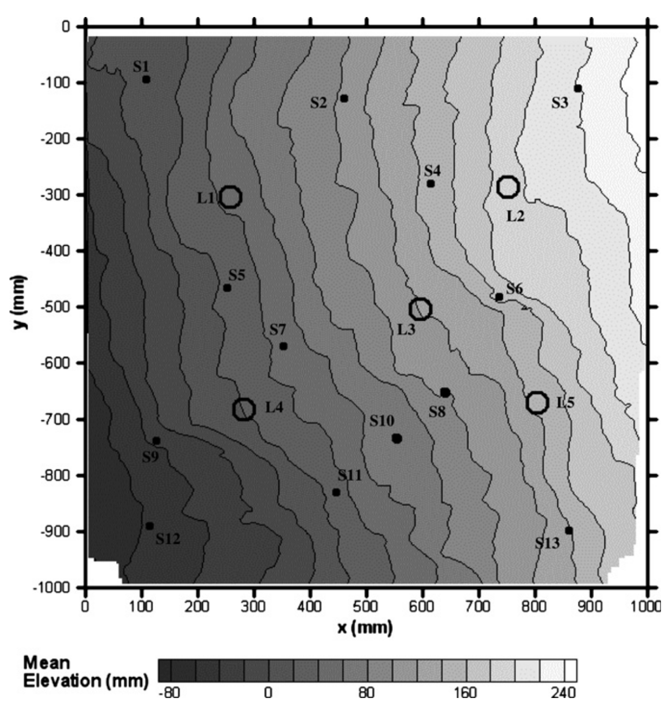

Fig. 2. Mean fracture elevations.