Characterization of Rock Matrix Properties Controlling Contaminant Storage in Fractured Rock Using Novel Geophysical Technologies

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The in situ characterization of physical properties of the rock mass controlling contaminant storage and mass transfer (e.g., rock matrix diffusion / back diffusion) in fractured rock aquifers is inherently challenging. Conventional borehole geophysical logging tools are unable to reliably determine critical transport parameters such as the pore size distribution, the ratio of mobile to immobile porosity and the permeability. The objective of this project is to determine the information content of two emerging single-hole logging technologies, nuclear magnetic resonance (NMR) and complex resistivity (CR) with respect to these critical transport properties. A related objective is to investigate whether the distribution of mass transfer rate coefficients describing rock matrix diffusion can be reliably determined from novel tracer breakthrough tests. These tests involve the simultaneous measurement of the pore fluid conductivity of the mobile phase and the bulk electrical conductivity of the rock mass associated with both the mobile and immobile phase.

We acquired a unique database of physical properties measurements for an extensive inventory of cores extracted from three fractured rock sites (Santa Susanna Field Laboratory [SSFL], California, the former Naval Air Warfare Center [NAWC], New Jersey and Hydrite Chemical Company, Wisconsin). The SSFL and Hydrite sites are primarily sandstone formations whereas NAWC is a mudstone complex. Recorded physical properties include porosity, pore size distribution, permeability, specific surface area and hydraulic tortuosity (determined from electrical formation factor). NMR and CR data were acquired on the cores, with supporting in situ measurements acquired using recent borehole technologies. A first-of-a-kind pressure vessel was constructed to perform novel tracer breakthrough experiments that integrate CR measurements with simultaneous measurements of the specific conductance of the pore fluid.

The experiments found strong relationships between the physical properties of the rock matrix and key parameters extracted from the NMR and CR datasets. NMR relaxation time distributions are well correlated with the pore size distributions from mercury porosimetry and provide a means of determining the mobile and immobile components of the total porosity. Parameters determined from the CR data provide a reliable estimation of permeability to within one order of magnitude. However, the form of the relationships observed for both the NMR and CR datasets vary between sandstone and mudstone formations, indicating that further work is required to incorporate the controls of mineralogy into the geophysical relationships / models to robustly predict the pore geometric properties controlling contaminant transport. Comparison of the NMR and CR laboratory datasets to the borehole datasets highlighted that a current limitation of these emerging geophysical technologies is that the borehole tools lack the resolution obtainable in the laboratory, limiting the resolution of variations in the physical properties along a borehole. The tracer breakthrough experiments exhibit compelling evidence for an electrical signature of rate limited mass transfer in a subset of cores tested from the three sites. Analytical and numerical pore network models of the electrical signature of mass transfer offer a means of estimating the mass transfer coefficients and ratio of mobile to immobile porosity from these breakthrough datasets. Transition of the technology to the field-scale is being implemented through development of a new logging tool that integrates a tracer injection within an isolated section of a hole with simultaneous electrical geophysical and pore fluid conductivity measurements.