Multiple Methods for Discerning Abiotic and Biotic Processes Affecting Trichloroethene Plume Behavior in Fractured Sedimentary Rock

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Background/Objectives. An intensive process-based investigation of degradation processes, both abiotic and biotic, affecting an aged trichloroethene (TCE) plume in sedimentary rock was done using field samples targeting both environs of this dual porosity system: from the low permeability rock matrix between fractures which serves as a contaminant storage reservoir, and from the active groundwater flow system within the fractures. TCE as dense non-aqueous phase liquid (DNAPL) entered the subsurface at an industrial site in Southern California primarily throughout the 1950s and 1960s. The site sits on a regional topographic and is underlain by the Chatsworth Formation, a Late Cretaceous turbidite sandstone with siltstone interbeds. The contaminant mass at the site resides mainly in the rock matrix due to diffusive mass transfer from the fractures. Even though groundwater velocities in the fractures are large, plume fronts are not far from DNAPL source areas due to strong retardation due to diffusion, enhanced by sorption, and degradation processes. The influence of identified degradation processes on the behavior of this long-term plume is illustrated using a discrete fracture matrix (DFM) numerical model informed by high resolution site-derived data.

Approach/Activities. The approach evaluated the occurrence of degradation processes in both the rock matrix and the groundwater within the fractures using multiple methods to discern mechanisms at multiple scales. Historical groundwater monitoring data was reviewed and three methods for sample collection were implemented: i) high resolution volatile organic compound (VOC) characterisation of the rock matrix, ii) depth-discrete in situ groundwater sampling (SNAP Sampler™), and iii) conventional three-volume purge; groundwater samples were analysed for VOCs, dissolved gases, compound specific isotope analysis (CSIA) and hydrochemistry. High resolution measurements of matrix and fracture network parameters informed transport simulations using the two-dimensional model FRACTRAN and three-dimensional model HydroGeoSphere. Both models are capable of simulating advective-dispersive groundwater flow and solute transport with rigorous matrix diffusion and degradation in both the fractures and the rock matrix. HydroGeoSphere has additional capabilities including simultaneous evolution of chain decay.

Results/Lessons Learned. TCE daughter product, cis 1,2-dichloroethene was detected in both groundwater and rock core samples. Minor concentrations of vinyl chloride and ethene detected in conventional wells and SNAP samples, supported by the CSIA results, show microbial reductive dichlorination is a major degradation pathway. Direct evidence in the form of measured acetylene indicate the heterogeneous occurrence of abiotic processes. Consideration of the matrix, its volume of porewater, available surface area, mineralogy, organic carbon content and contaminant residence time suggest that biotic and abiotic processes operating in the matrix are most influential on bulk plume behaviour, as illustrated by DFM transport modeling. Model results show these reactions occurring in the matrix, even at extremely slow rates, are sufficient to contribute substantially to plume front retardation and retreat over many decades.