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The Role of Structural Frequency, Style and Weathering on the Fate and Transport of Chlorinated Solvents in Fractured Bedrock

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Background: Structural Frequency Analysis (SFA) of geological structures is a technique commonly deployed on borehole core and in outcrop by the hydrocarbon industry to provide input parameters for models that aim to elucidate geofluid flow through fractured bedrock. A SFA methodology was developed to collect structural data that can be spatially modelled to provide critical information on contaminant fate and transport. Structural logging and the degree of bedrock weathering is undertaken on recovered core, and the results of downhole geophysical tools, thermal sensors and optical televiewers (OTV) can be integrated to enhance the data quantity and quality. Structures are classed by type (including where intersecting structures are observed), and their frequency (per metre) is measured and then spatially modelled in 3D. This produces ‘clouds’ of structural density which may be compared (qualitatively or quantitatively) with contaminant distribution, especially for high-resolution site investigation datasets, leading to fresh insights that improve the conceptual site model. Where structural orientation data exists, such as OTV logs, a standard structural analysis can be related to the regional tectonics, and the fracture sets responsible for contaminant transport can be interpreted.

Case Study 1: The technique was applied as part of a thermal remediation project in Yorkshire, UK, where trichloroethene (TCE) impacts were identified at depths up to 18m in fractured Carboniferous shales. Graphical field sketch logs were utilised to capture structural data in 21 boreholes, with care taken to avoid the inclusion of mechanically-induced fractures. This showed that, at this particular site, there was no coincidence of logged fractures with the distribution of contaminant plumes. Rather, the contaminant plume was seen to be migrating within a finely anastomosing mesh observed in the highly weathered mudstones in the first 10m, with relatively little penetration into structures within the deeper, fresh bedrock. This may be explained by the frequent observation of a weathered clay fill within the structural features in the transition zone between fresh and weathered bedrock.

Case Study 2: The site is located in the south-west of the UK on Devonian meta-pelites and psammites were drilled up to 64m deep in four boreholes. Structural analysis identified the presence of a thrust anticline with fault plane at 57m. Borehole core SFA and OTV data analyses was compared to the detailed the TCE distribution to elucidate two main transport pathways from source areas. The first along 45^{o} bedding plane fractures and the second along 65^{o} slate-cleavage fractures, with both routes further intersected by a minor 20^{o} fracture set. These form a mesh-network with high connectivity, allowing a dissolved phase TCE plume to travel down the hydraulic gradient. These findings have a critical bearing on the planned remedial works demonstrating that contaminant mass is in a fracture network, rather than matrix, therefore the (fracture) porosity is low, dissolved phase mass is low and the reaction to perturbation will be high. Few structures remain open below 40m, placing a lower constraint on the remedial work.

Conclusion: the case studies show contrasting contaminant fate and transport behaviour related to how much weathering had occurred; with SFA useful only in unweathered fractured bedrock. In this case, critical information on the orientation and depths of contaminant-bearing structures can be obtained and used to improve the conceptual site model and develop an effective remedial strategy. In the case of the weathered shale profile, the base of the weathering and the identification of clay-filled fractures was also used to improve the conceptual site model and limit the depth of remedial works, improving cost and environmental efficiency.