Compound-specific isotope analysis and other tools to evaluate intrinsic remediation of TCE in a bedrock aquifer

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Background/objectives

Two trichloroethylene (TCE) plumes have been mapped at this site— one in glacial outwash sand (referred to as the “Top of Rock” aquifer or “TOR”) and another in an underlying bedrock aquifer (referred to as the “Liston Creek Interface” or “LCI”; Figure 1). The LCI aquifer is a prominent and widespread bedding plane parting surface. The LCI and the TOR are separated by approximately 40 feet of limestone bedrock (Kokomo Limestone). The TOR plume flows to the south while the LCI plume flows to the northeast (Figure 1). The source of each plume appears to originate in roughly the same location. The TOR plume consists of approximately 75% TCE and 25% cis-1,2-dichloroethylene (cDCE) while the underlying LCI bedrock plume consists of approximately 25% TCE and 75% cDCE, which suggests that there is reductive dechlorination occurring as groundwater migrates from the TOR through the organic-rich Kokomo Limestone and into the LCI. In the LCI aquifer however, there is no generation of vinyl chloride, suggesting that reductive dechlorination was not complete conversion to ethene. Dissolved gas analysis for ethene confirmed its presence in every bedrock monitoring well within the footprint of the chlorinated volatile organic compound (CVOC) plume, despite the absence of vinyl chloride. This caused the project team to evaluate alternate degradation pathways using compound specific isotope analysis (CSIA), environmental molecular diagnostics, and other tools. Results indicate a number of synergistic aerobic and anaerobic reactions (reductive dechlorination, aerobic cometabolism, and aerobic direct metabolism [oxidation]) are occurring in LCI and TOR groundwater.

Approach

All of the analysis presented herein was developed from sampling the existing monitoring network. The glacial outwash (TOR) and bedrock (LCI) wells were sampled for CVOCs, redox-sensitive geochemical parameters, total organic carbon, dissolved gases (ethene, ethane, methane, acetylene), CSIA (carbon and chlorine) and a phylogenetic microarray that identifies 150 microorganisms that are known to degrade environmental contaminants. This analysis is part of Pace Analytical’s Remediation Panel analysis package.

Results

Figure 3a. Dual Isotope Plot

Figure 3b. δ13COC/δ37Cl Isotope Balance

Table 1: Redox conditions

<table>
<thead>
<tr>
<th>Activity</th>
<th>MONITORING WELL ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete reductive dechlorination to cDCE, vinyl chloride, and ethene</td>
<td>18 19 26 25 20 24</td>
</tr>
<tr>
<td>Partial reductive dechlorination</td>
<td></td>
</tr>
<tr>
<td>Aerobic cometabolism of TCE and cDCE</td>
<td></td>
</tr>
<tr>
<td>Aerobic direct metabolism of vinyl chloride</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Microbial activity summary for bedrock wells

Note: Dissolved concentrations are presented in milligrams per liter in Table 1.

Discussion

• Similar to most sites, groundwater sampling data indicates the monitoring wells are in communication with multiple geochanical niches. Taken together, the data suggests that reduced groundwater, high in cDCE with some vinyl chloride and methane infiltrates into the more aerobic LCI.

• The low concentration of vinyl chloride and microarray data suggests that vinyl chloride is rapidly degraded by aerobic direct metabolism (oxidation).

• The presence of low levels of methane in an aerobic aquifer, coupled with the presence of microbes capable of cometabolic degradation suggests aerobic cometabolism is occurring in certain locations within the LCI, which is uncommon. 

• The dual isotope plot indicates an enrichment in 13C and 37Cl consistent with reductive dechlorination (slope=0.2) for the TOR wells but the slope is smaller (0.1) and weaker for the LCI wells.

• Isotope balances of CVOCs indicate higher 13C in LCI wells compared to TOR wells (Figure 3b) and more enrichment in 37Cl, providing direct evidence for complete destruction of CVOCs (i.e. without stalling at vinyl chloride or cis-DCE) in the LCI.

• Taken together, the dataset indicates that synergistic aerobic and anaerobic reactions are occurring at the site.

Figure 4. Example degradation pathway/maps for select wells