ORGANIC CONTAMINANT TRANSPORT THROUGH A THIN CLAY AQUIFAR INFLUENCED BY PALAEO-HETEROGENEITIES
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Processes controlling the transport of dissolved-phase organic solutes through clay aquitards that are often assumed to provide protection of underlying aquifers have been investigated. The case-study based research was centred upon a former UK industrial facility contaminated with aromatic hydrocarbons. Dissolved-phase aromatic solutes were known from previous site investigations to have contaminated and in areas penetrated, a discrete clay bed underlying the site. The clay stratum was a 1-2 m thick lacustrine clay of Holocene age at around 6 m below ground surface surrounded above and below by a sandy aquifer. Detailed contaminant depth profiles through the clay were determined from thirteen cores collected from close spatial scales (~0.5 m) and also over larger scales (~10’s m). Two principal types of hydrocarbon invasion profiles were identified; (i) diffusion-based invasion into fairly homogeneous clays and (ii) advection-dominated invasion. The latter has been shown from extensive physiochemical analysis of the clay cores in the laboratory to be primarily through connected “palaeo-root” holes, i.e. root holes produced when the Holocene clay was vegetated at ground level. Root connectivity has been shown at various scales; first, through serial sectioning and secondly at a fine scale in 3-D, via x-ray tomography. High root incidence and connectivity were shown in the advection-dominated cores and were largely absent from the diffusion-based profiles. The hydraulic conductivity of the advection-based cores was ~0.04 m/d, whereas that of
diffusion-based cores was much lower at approximately $3 \times 10^{-5}$ m/d. The sorption characteristics of the clay deposit have been investigated yielding $K_d$ over $2.98 - 6.95$ l/kg and $K_f$ over $2.27 - 6.89 \mu gkg^{-1}/\mu g l^{-1}$ for PCE and $K_d$ over $0.49$ l/kg and $K_f$ over $0.57 \mu gkg^{-1}/\mu g l^{-1}$ for benzene. 2-D (Fractran) and 3-D (bit_map reader + Fat-3D unsat-new) numerical models were used to examine contaminant invasion via diffusion and advection. The modelling confirms that where the clay deposits are homogeneous or contain partially penetrating root holes, slow diffusion dominated invasion will offer significant protection to the lower aquifer with breakthrough times through 1 m of clay at 40 years. Conversely, where the clays contain fully penetrating root holes, advection through the root holes causes much faster contaminant penetration. Discharge from the bottom of the clay stratum will be associated with a significant flux of dissolved-phase contaminant causing contamination of the lower aquifer. The accumulation of mass in the clay stratum is likely to cause prolonged contamination of the adjacent aquifers should the original source concentrations decrease. The study site shows that the absence or presence of micro-scale preferential pathways controls the penetration of contaminants locally through a clay aquitard and the vulnerability to pollution of the underlying aquifer. Similar local controls may be expected to operate at other sites.
Contaminant concentration through rooted area

<table>
<thead>
<tr>
<th>Depth</th>
<th>Sand</th>
<th>Clay</th>
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Contaminant source

Connected root pathways, transporting contamination

Hydraulically active roots penetrate entire clay, rapidly transporting contaminant through stratum

Diffusion of contaminant from root hole into matrix

Organic matter lined root hole

Figure: Conceptual diagram of a root holed clay stratum.