SEDIMENT-FILLED FRACTURES IN TRIASSIC SANDSTONES - PATHWAYS OR BARRIERS TO CONTAMINANT MIGRATION?

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INTRODUCTION

Observations of sediments infilling fractures in Triassic Sandstones, an important aquifer in the United Kingdom may explain sand production in some water supply boreholes in the UK and why the aquifer transmissivity increases with time, which would occur if sediments were being washed from the fractures. The fracture infills are variable from sands to complex interlaminated sand, silt and clay. It is clear that, depending on the fill material, fractures may form either pathways or barriers to contaminant migration, questioning current concepts for flow in fractured sandstones, and throwing doubt on our ability to predict or remediate contaminant migration in this nationally important aquifer.

Mineralogical differences between the fracture fill material and the host sandstone may also affect sorption and precipitation reactions, which, if not considered, may significantly alter the prediction of contaminant migration through either the fracture fill or host sandstone matrix. At present, there is little knowledge of the extent of fracture fills, how they form, whether they occur above and below the water table and whether in vertical joints or bedding plane fractures. There are few measurements of their hydraulic properties to be able to assess their hydrogeological significance and how they should be represented in contaminant transport models. For instance, if the fill has a similar permeability to the rock matrix, a porous medium model may suffice. If the fractures are filled with clay with lower permeability, or if preferential flow along fractures exists, a different modelling approach involving a porous medium with planar barriers may be required.

It is hoped the improved representation of fractures in solute or NAPL migration models will lead to better assessment of contaminant migration and risk, focused remediation techniques, and more precise evaluation and management of groundwater resources.

This ongoing study aims to understand the nature and geological controls on how fracture fills develop and to improve the representation of fractures in solute or NAPL migration models. The first stage in this is to establish the distribution and occurrence of these features at outcrop, to establish formation mechanisms and provide data such as textural information and permeability measurements that will contribute to a better understanding of their influence on hydrogeology. This will lead to a better assessment of contaminant migration and risk, more focused remediation techniques, and more precise evaluation and management of groundwater resources. A key problem is that sediment infills may not be preserved at outcrop and may also be destroyed during standard borehole sampling procedures. This requires a careful approach to sampling, both at outcrop and in the borehole.

THEORY OF FORMATION

The origin of sediment-filled fractures is potentially complex. There are two issues that must be considered separately: the origin of the fracture infill and the origin of the parent fracture. These two aspects may or may not be interrelated. In some cases, the process forming the fractures may also produce the sediment infill and they are therefore are coeval. However, in other cases, the sediment infills pre-existing fractures. In this situation, the formation of the parent fracture is unrelated to, and may be much older than, the process introducing the sediment fill. Each of these scenarios will have different influences on the distribution and significance of sediment-filled fractures. Fractures, fissures or joints filled with true sedimentary detritus are often referred to as *clastic dykes* (Newsom, 1903).

Clastic dykes are common features in many sandstone formations. Five generic types of clastic dyke can be defined on the basis of their genesis and mode of emplacement (Hayashi, 1966): (*i*) *Intrusive clastic dykes* formed when clastic materials are forced upwards into fissures during igneous activity; (*ii*) *Injection clastic dykes* formed by the injection of *liquefied* sediments under overpressured conditions from below, or by lithostatic pressure from above; (*iii*) *Squeezed-in clastic dykes* formed when *unconsolidated* or semi-*consolidated plastic strata* are squeezed under stress, and flow plastically into fissures in adjacent rocks; *(iv) Infilling clastic dykes* formed by the accumulation of clastic detritus under the influence of gravity. The latter process might be expected to occur subaerially or subaqueously at shallow levels during the early burial history of the sandstone (Lowe, 1975). We consider that *Intrusive clastic dykes* (*i*) are unlikely to be important in the Permo-Triassic sandstones in the United Kingdom. However, processes (*ii*) to (*iv*) are considered to be potentially important mechanisms for the formation of sediment-filled fractures in the Sherwood Sandstone Group.

Dykes associated with glacial processes Since extensive glaciation during the Quaternary has greatly influenced the present-day topography of the UK, we have considered how glacial processes and environments may have influenced pre-exiting fracture networks. Clastic dykes are common in glaciated areas in tills and soft sediments (e.g. Dreimanis, 1992). Ice and sand wedges are types of clastic dyke formed by infilling of open fissures in permafrost terrain (process (*iv*) above). Open fractures form in material subject to sliding or slumping. Clastic dykes also develop in soft or water-saturated sediments through unstable density loading (process (*iii*) above). Clastic dykes have been formed beneath glaciers from downward injection of material, usually diamicton or sand into underlying tills, sands or gravels (process (*ii*) above).

The porosity in many fractures is not necessarily controlled by, or the result of, structural or tectonic phenomena. In many fractures, the porosity results from the dissolution of older mineral fills. Also much of the fill in a normal fracture is likely to be from the detritus remaining after removal of the soluble cements. Detailed studies from Sellafield in west Cumbria (Milodowski *et al*., 1995 and references therein), clearly demonstrated that much of the present fracture porosity in the Sellafield area, in both near surface sandstones and deeper basement rocks, is secondary in origin, and results from the dissolution of carbonate and anhydrite vein mineralisation. Many of the fractured veins in the Permo-Triassic sandstones of the Cheshire Basin have similar characteristics (Plant *et al*., 1996). Secondary fracture porosity formation by the dissolution of carbonate and anhydrite vein mineralisation probably exerts a major influence on the development of open fracture porosity in the UK Permo-Triassic sandstones and can extend to over 200 m depth below the present surface. Thus, dissolution of vein mineralisation in the shallow sandstone aquifer environment may be an important process for creating open fissures which can be filled by sediment – either derived by gravitational filling from the overlying soil or strata, or injected from above under subglacial overpressuring.

RECONNAISSANCE SURVEY

A reconnaissance survey of Permo-Triassic sandstone exposures in both glaciated and non-glaciated areas of the UK has been made. The survey had two principal aims: (*i*) to determine the regional extent of sediment-filled fractures and the influence of lithology, exposure and glacial history on that distribution and (*ii*) to identify a site suitable for further detailed research. This survey focussed mainly on quarry exposures plus some underground tunnels and cave excavations (Alderley Edge mine, Nottingham man-made cave system, the man-made Williamson Tunnels in Liverpool). Sediment-filled fractures were observed in some of these exposures and a few examples are highlighted below.

Fractures observed in the Sherwood Sandstone Group in the Wirral area, UK include 'cataclastic' healed, tight fractures, and rare open sediment-filled fractures. Sediment-filled fractures were also observed during two surface and underground surveys near Runcorn by Wealthall *et al*. (*in press*). Cataclastic fractures were common throughout the aeolian facies of the Wilmslow Sandstone Formation. At Runcorn Hill (aeolian Helsby Sst. Fm.) a fracture, up to 3 cm wide, is filled with sand and clay which appeared to be locally derived (i.e. within 20 cm). At Irby Hill Quarry (fluvial Delamere Sst. Mbr., Helsby Sst. Fm.) two sediment-filled fractures, up to 3 cm wide, comprise clay-fill along margins with a silty-sand fill along the centre. The fracture was sub-vertical and up to 4 m long (Figure 1).

Similar sediment-filled fractures, although rare, were observed in the Egremont area, in the East Irish Sea Basin. These areas were extensively glaciated during the Quaternary. However, sediment infills were also observed in Somerset (Capton quarry) which was in a periglacial margin during the Quaternary. This may suggest that glacial processes are not responsible for all sediment infills.

Figure 1: Sediment-filled sub-vertical, fracture, at Irby Hill Quarry, Cheshire

At the Neston Railway Cutting, Wirral, UK (fluvial Chester Pebble Beds Fm.) sediment-filled fractures have a horizontal spacing between 60 and 100 m. These included a fracture (possibly a reactivated cataclasite), up to 10 cm wide, filled by red sandy clay (Figure 2); the margins of this fracture comprise ?silicified cataclasite. The fracture extended approximately 10 m vertically, to the top of the cutting. Also several fractures, filled by micaceous sand, have similar composition to the bedrock.

Figure 2: Sediment -filled fracture at Neston Railway Cutting, Cheshire, UK.

Generally, the reconnaissance survey indicated that sediment-filled fractures are not widespread but occur as isolated features in some locations. Caution should be exercised when interpreting some features where other factors, such as quarrying process, may locally contribute to sediment-infills.

SAMPLING TECHNIQUES

Techniques for sampling sediment-filled fractures at outcrop have been developed. Sediments are impregnated with low-viscosity resins followed by careful excavation or removal using hand-held corers. This technique enables preservation of sediment textures and their relationships to the fracture wallrock for petrographic characterisation. Once returned to the laboratory, samples can be re-impregnated with further resin and then sectioned for petrographic analysis.

RESULTS

Preliminary characterisation of the sediment-infills indicates they are derived from the sandstone wallrock in most cases. However, clay infills are probably derived from adjacent mudstones. The mineral assemblage in the clay-infills, sampled in the Dumfries Basin, Vale of Eden and East Irish Sea Basin, typically comprises quartz, K-feldspar, albite, illite and chlorite. Chlorite was taken to indicate a till component to the infills since chlorite is not present in the interbedded mudstones. The source of the chlorite is more likely from the Southern Uplands and Lake District upland glaciated metamorphic terrains. The small proportion of smectite or chlorite-smectite observed in these infills indicates subsequent alteration of this assemblage. This smectite has not developed in the mudstones and suggests preferential water-flow along the fractures causing localised alteration of the clay-assemblage. The mineral assemblage of the sand-filled fractures is typical of the adjacent sandstones, although subaerial weathering has dissolved more soluble carbonate species.

Texturally, the infill comprises grains oriented sub-parallel to the wallrock. In some cases these form finer and coarser laminations and are often associated with weak iron oxyhydroxide cements. This suggests infills are deposited from intermittent water films running along the wallrock via surface infiltration.

SUMMARY

Sediment-filled fractures have been observed at several locations in near-surface outcrops. However, they are not common or widespread at outcrop and caution should be used when examining fractures in operating quarries, where the quarrying process can lead to local sand deposits within open fractures. The principle mechanism of formation appears, in most cases, to be by transport of sediment along the fracture walls via episodic water flow from surface infiltration. However, limited evidence at one site indicates that a till component may be present in addition to the predominant wallrock component. The sand- and clay-fills are derived from the adjacent wallrock or, in the case of clay fills, nearby mudstones. Smectite and iron oxyhydroxides form as a result of low-temperature subaerial weathering. We have yet to establish if these features occur below the water table. Once a suitable site has been identified, a drilling campaign will aim to sample sediment-fills from below the water table. The texture, mineralogy and permeability of these fills will be determined to establish their potential influence on solute or NAPL migration.

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