OR/12/023 Discussion

Wragg, J, Rushton, J, Bateman, K, Green, K, Harrison, H, Wagner, D, Milodowski, A E, and West, J M. 2012. Microbial Impacts of CO2 transport in Sherwood Sandstone. *British Geological Survey Internal Report*, OR/12/023.

Whole rock and clay mineralogy

Comparison of XRD analysis of both post-test materials indicates that no significant differences were apparent between the control and biotic residues. However, analysis of clay mineralogy data for the control and biotic residues indicated trace amounts of smectite (estimated <1% of the clay fraction) to be associated with the biotic column. This observation may be the result of the introduction of microbes into the biotic column or as a result of sample heterogeneity (e.g. laminations within the sandstone).

Petrography

Control sample

A pore lining of a film-like phase was observed at the inlet end and within the sample material. This film-like phase was noted to be more common at the inlet end. Some of the characteristics of the film-like phase are consistent with it being a biofilm. These include its general appearance, a tendency to be associated with fines and sensitivity to the electron beam. There are also rare cell-like forms on pore walls that are of the correct size (<2 µm) to be of microbial origin.

These observations are consistent with the sample having been microbially colonised at some point during the experiment.

The fibrous phase noted within some patches of the film could be a constituent of the film or illitic clay. Fibrous illitic clay is a diagenetic constituent of the rock and could have been detached and entrained in the flow of test liquid, then subsequently trapped in the film.

Biotic sample

A pore lining of a film-like phase was observed throughout the post-test biotic sample material, with considerably greater abundance at the inlet end and central plug portions than at the outlet end. Some of the characteristics of the film-like phase are consistent with it being a biofilm. These include its general appearance, a tendency to be associated with fines and sensitivity to the electron beam. There are also widespread cell-like forms associated with some patches of film that are of the correct size (<3 µm) to be microbial.

These observations are consistent with the sample having been microbially colonised. The development of biofilm and evidence of microbial cells is significantly greater than that observed in the control sample.

At some sites where pore walls extend towards the centres of pores, film and associated fines are more abundant. This suggests that colonisation may be favoured at sites exposed to more rapidly moving nutrient-bearing test fluids.

A localised fibrous phase noted associated with some patches of the film is most likely of illitic clay, as at some sites their morphology is well displayed. In some cases these appear to be grain- coating clay constituents that have collapsed in situ, in others the fibres are detached, suggesting they have become mobilised before being trapped by the film. Examples of collapsed illitic fibres identified in the absence of the probable biofilm, show that collapse is not necessarily related to the presence or formation of the film; collapse may have occurred before, during or after the testing.

Grey staining

A deposit of a non-aqueous droplet like phase was observed only on the surface of the material, where the grey stain was observed. No other phases were observed in the area. It is not possible to know for certain if the droplets are responsible for or related to the grey colour. However, no other additional phase was observed in the sample portion analysed. No similar droplets were observed in any other portion of the sample. This material may be oil contamination, from greases used on the pressure fittings of the apparatus, which has been transferred to the core, possibly as a result of a small imperfection or hole in the heat shrunk PTFE sheath which may represent and additional microbial food source.

Microbiological and physical measurements

Changes in physical pressure measurement (injection and confining pressure) were continuously monitored with injection pressure presented in Figure 5 together with microbial numbers for both control and biotic experiments. For the biotic core, Figure 5 shows an initial rapid increase in pressure up to circa. 1000 kPa, showing a distinct difference compared to the control core. After the injection of the CO_2 saline solution, the pressure in the biotic core steadily increases from 120 h (5 days), to ca. 980 h (41 days). Beyond this time, and after the injection of *P. aeruginosa*, the pressure, apart from minor variations, is effectively constant. Figure 5 shows that, for the control experiment, there was no backpressure until 400 h. At this point, an increase in pressure was observed, reaching 400–600 kPa between 550 and 700 h.

The differences in pressure in the biotic and control experiments suggest a difference in flow characteristics and physical properties in the two samples although they were sampled from the same depth in the original core material. Both of the plugs used in this study comprise fine to medium grained sandstones that have finely defined laminar bedding planes. These are shown as fine variations in colour in Plate 5. The thin darker laminations are sediment intervals that have higher detrital clay content. The distribution of these laminations represent a potential source of heterogeneity between samples even when they have been taken from horizontally adjacent sites, as the laminations are inclined. Indeed, the biotic plug sample was noted to have a high concentration of the clay-rich laminations at its inlet end (note the overall darker red colour at the top of Plate 16); this concentration was not observed in the control plug sample.

These results demonstrate that in this short study, the injection of *P. aeruginosa* into the biotic experiment does not appear to impact on the physical transport properties of the Sherwood Sandstone. However, in other work which utilised the same organism and rock type but with no introduction of CO_2 saturated fluid, post-inoculation injection changes were observed. These included short but rapid saw-tooth like changes in the pressure profile (Wragg et al, 2012[1]). These impacts were not observed in the current study which suggests that the CO_2 saturated fluid was reducing the tendency for the microbes to alter permeability.

After CO_2 injection, microbial numbers in the biotic experiment rapidly drop from ~1.16 x 107 ml^{-1} (SE 8.01x105 ml^{-1}) at 354 hours to approximately 105 organism's ml^{-1} at the end of the experiment

(Figure 5). In the control experiment, numbers in the outflow fluids drop from approximately 2.0 x 106 (SE 104 ml^{-1}) to approximately 2.6 x 104 ml^{-1} (SE 3 x 104 ml^{-1}) at the end of the experiment. Thus, an indigenous population is present in the host rock. Other work (Harrison et al, 2011[2]) has shown that such populations can impact on fluid transport in rocks because of the formation of biofilms that then impact on rock transport properties. In this study, such a build-up of pressure does not appear to occur in the biotic experiment where indigenous populations and injected *P. aeruginosa* appear to be impacted by the presence of CO_2. However, a microbial

population still exists in the biotic experiments demonstrating that, despite the extreme environmental conditions generated by the presence of CO_2, microorganisms are able to survive. It is possible that the impacts of these microbes on fluid flow will take longer to observe because a period of acclimatisation may be necessary. Consequently, it is important to carry out longer term experiments in order to determine the significance of microbial activity on transport of CO_2 in host rocks relevant to carbon capture and storage.

The microbial biomass counts for the control experiment highlight the presence of indigenous species in this test system and the presence of acetate in the saline groundwater will have stimulated growth. However, acetate was only added to the saline groundwater to allow for direct comparison with the 'biotic' experiment. Injection of contaminated groundwater could be one explanation for the high microbial count in the 'control' experiment, but microbes were not detected in the starting fluid, suggesting this is not the source of the microbes.

Chemical measurements

Migration of chemical species through and from the host rock core under control and biotic conditions was monitored over the lifetime of the experiments and selected elemental data summarised in Figures 5–15. Figures 5–7 show that the chemistry of the system is relatively constant, i.e. Cl and Na and, when introduced into the system HCO_3. In general the data suggest that the presence of CO_2, rather than the microbes, enhances the release and subsequent migration of elements associated with the host rock in the experiments in this study (Figures 10–15).

References

1. ↑ WRAGG, J, HARRISON, H, WEST, J M, and YOSHIKAWA, H. 2012. Comparison of microbiological influences on the transport properties of intact mudstone and sandstone and its relevance to the geological disposal of radioactive waste. *Mineralogical Magazine* 76, 3251–3259.
2. ↑ HARRISON, H, WAGNER, D, YOSHIKAWA, H, WEST, J M, MILODOWSKI, A E, SASAKI, Y, TURNER, G, LACINSKA, A, HOLYOAKE, S, HARRINGTON, J, NOY, D, COOMBS, P, BATEMAN, K, and AOKI, K. 2011. Microbiological influences on fracture surfaces of intact mudstone and the implications for geological disposal of radioactive waste. *Mineralogical Magazine*, 75, pp.2449–2466. doi:10.1180/minmag.2011.075.4.2449.

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