Neutron radiography and tomography used to characterise water flow through a low permeability carbonate altered by an experimentally induced fracture network

H Lewis[1] A Tengattini[2] G Couples[1] E Tudisco[3] EM Charalampidou[1] S Hall[3] M Etxegarai[2] , K Edlmann[4]
[1]Institute of Petroleum Engineering, Heriot-Watt University Edinburgh UK
[2]Laboratoire 3SR, Université Grenoble Alpes, Grenoble, France
[3]Division of Solid Mechanics Lund University Lund Sweden
[4]School of Geosciences, University of Edinburgh, Edinburgh, UK

Keywords: rock, open fracture, flow, tomography

Summary: This work uses neutron radiography and tomography flow tests on experimentally deformed and fractured very fine grained, low permeability carbonate rocks. To our knowledge this is the first identification of fluid front movement through fracture networks using neutron tomography.

1. INTRODUCTION

Fractures are known to play an important role in fluid flow. Existing experimental work on fracture flow is largely focused on single fractures, and does not address complex fracture arrays like those seen in natural situations. Recent x-ray tomographic (XRT) studies by a number of groups have shown the value of this method in identifying the presence and characteristics of a fracture network. But even in special cases when such open fractures have been observed, determining fracture aperture, and particularly the flow pattern in rock pores and fractures under subsurface conditions, is significantly under-informed and needs considerable experimental investigation.

2. EXPERIMENT

This work uses neutron radiography and tomography flow tests on experimentally fractured, very fine grained, low-permeability carbonate rocks, called laminites due to the presence of mm-scale layering. For such low permeability rocks, open fractures that transect the layering have the potential to provide the dominant flow pathway, but determining effective fracture connectivity, and associated single or multi-phase flow characteristics within a sample, is not simple. For the laminites, XRT has already been used to identify the fracture patterns and indicates apertures in 3D unconfined (Zihms et al, 2017). Here, neutron beam radiography and tomography have been used to image flow, particularly the sequential positions of the flow fronts, which includes focused flow in fractures. To our knowledge this is the first identification of fluid front movement through fracture networks using neutron tomography. It requires a rapid acquisition technique that was pioneered (Charalampidou et al, 2017) for shear and compaction band containing porous rock samples.

Specifically, samples of a laminite ("grain" size of approximately 5μm, deposited in a lake bed environment), were deformed experimentally under conditions representing 1 to 2 km burial depth, creating a series of shear and extension fractures (a) that the XRT indicates are at least partly open (b). Destructive assessment (e.g. making thin sections for SEM) could verify this apparent opening, in the process destroying the ability to test the flow capabilities of the sample. Prior to that, Neutron radiography and tomography, using first deuterated and then distilled water (which have slightly different densities and neutron scattering cross sections) are used to track the movement of the two different fluids through the sample. Each fluid is introduced into the sample base, under pressure control, enabling observation of the progression of deuterated water into the air-filled laminite matrix- and fracture space-network, followed by distilled water (c) that has a stronger tendency to occupy the fractures than did the first fluid, the deuterated water.

3. RESULTS

Radiography and tomography identify a complex but rational pattern of initial water movement into the matrix laminations at the sample base that suggests that in an unfractured laminite, the fluid front would progress stepwise from one lamina to the next with a relatively fast filling across an entered lamina and relatively slow progression across the boundary with the overlying lamina. But in the presence of open fractures, when fluid enters the fracture system, it moves up and down along a network of connected fractures, progressing both upwards and across the sample and also moving into most laminae that are connected to the fracture system. Front progression is slowed in the central part of the sample where some calcium carbonate dissolution and marginal residue precipitation is interpreted, and where the fracture network appears less well developed. Once that central part is saturated, filling the rest of the sample is rapid, suggesting a stacked low permeability layer then higher permeability layer arrangement. The upper part of the sample has a smaller number of potentially open fractures and once fluid enters these fractures, the front travels more rapidly to the top of the sample. When the second fluid, distilled water, is introduced, it mainly flows in the fractures and only slowly diffuse and mixes with the deuterated water in the pores.

References

Zihms, S., Miranda, T., Lewis, H. and Hall, S.A., 2017. Comparison of laminite fracture features at different scales. Poster presented at Tectonic Studies Group Annual Meeting, Liverpool, 3-5 January 2017.

Charalampidou, E.M., Tudisco, E., Etxegarai, M., Couples, G., Kardjilov, N., Hall, S., ''Assessment of localised deformation in sandstones via Fast Neutron Tomography'', ICTMS 2017, Lund, Sweden (submitted).

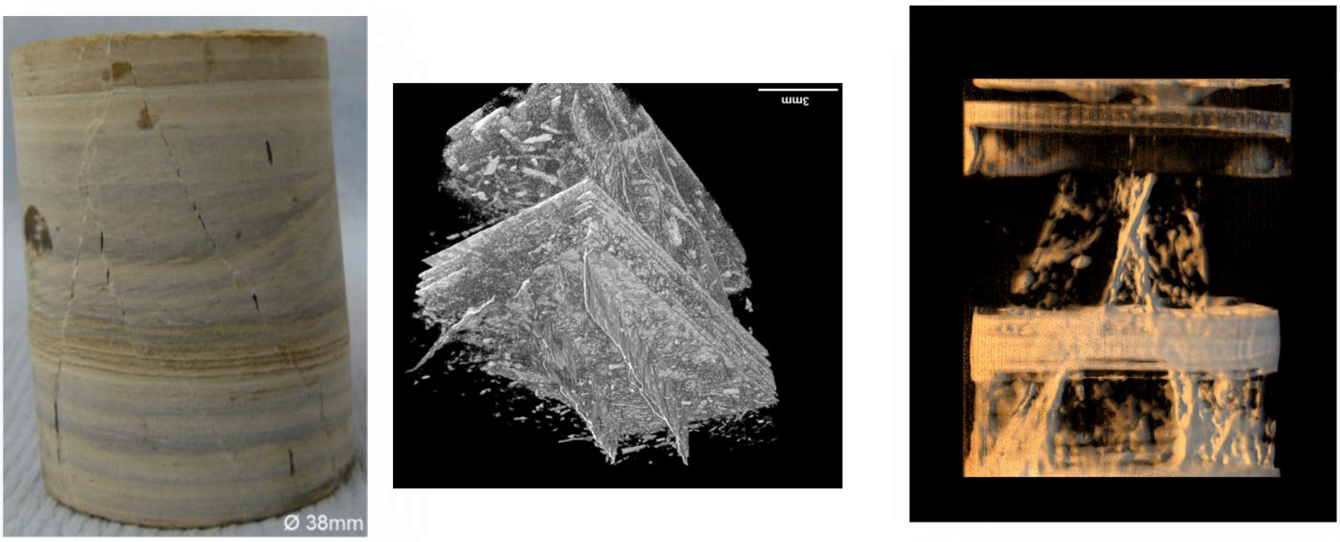

Figure1. *Figure shows (a) deformed laminite cylinder 38mm in diameter with observable and apparently dominantly open vertical and steeply inclined fractures; (b) x-ray tomography of a central section of the deformed laminite cylinder; and (c) neutron tomography of the whole sample when liquid was approaching the top surface.*