Geophysical Research Abstracts
Vol. 19, EGU2017-19489-1, 2017
EGU General Assembly 2017

Use of neutron radiography and tomography to identify fracture network connectivity in low permeability carbonates

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For low permeability rocks, open fractures have the potential to provide a dominant flow pathway, but determining effective connectivity, and associated single or multi-phase flow characteristics within an intact sample, is not simple. Flow tests can provide bulk values for any one sample, but general predictability requires considerably more information. X-ray tomography (XRT) has been used to identify fracture patterns and apertures in 3D. Here, in addition to XRT of experimentally-fractured low-permeability laminites, neutron beam radiography and tomography have been used to image flow via sensitivity to protons. To our knowledge this is the first identification of fluid front movement through fracture arrays using neutron tomography.

Specifically, samples of a very fine-grained laminite, a layered carbonate rock deposited in a lake bed environment, with a "grain" size of approximately 5μm, were deformed experimentally under conditions representing 1 to 2 km burial depth, creating a series of shear- and extension- fractures that XRT indicated were at least partly open (Fig 1).

But only destructive assessment (e.g. SEM) could verify this, destroying the ability to test flow capabilities in the process. Neutron tomography, using deuterated and then distilled water (which have slightly different densities and significantly different Neutron absorption) are 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, following by distilled water that mainly flows in the fractures (Fig. 2). Radiography and tomography identify a complex but rational pattern of initial water movement into the matrix laminae that suggests that in 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 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 across the sample and also moving into most laminae. Front progression is slowed in the central part of the sample where some stylolitisation is provisionally interpreted, and where the fracture network appears less well developed. Once that central part is entered, filling is rapid, suggesting a stacked low permeability then higher permeability 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 is introduced, it follows a similar path but the already saturated rock responds differently, supporting the expectation that multi-phase behaviour will be complex. But note that the two forms of water have a strong tendency to not mix.

In this study, because the sample is intact, we make predictions of the geological characteristics from the flow behaviour, in contrast to the more typical arrangement of predicting flow from observed geological characteristics. However, in common with XRT studies and unlike the destructive analyses, we can subsequently test our geological inferences.