



	Experiment title: Capturing dissolution wormhole growth dynamics in partially saturated porous media	Experiment number: ES-1301
Beamline: ID-19	Date of experiment: from: 22 June 2023 to: 26 June 2023	Date of report: 10.01.2024
Shifts: 12	Local contact(s): Marta Majkut	<i>Received at ESRF:</i>
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Report:

Intricate, finger-like channels, termed wormholes, arise during dissolution of fractured and porous media under certain flow conditions. Their growth is governed by a positive feedback between flow field and chemical reactions at pore surfaces. Most of the studies of wormhole growth have been concentrated on a single-phase scenario, leading to an in-depth understanding of wormhole morphologies and propagation rates. Our team successfully conducted six experiments during the allocated beam time, of which four were two-phase, and two were single phase references. We were able to register the dissolution process with a spatial resolution of 20 microns and a temporal resolution ranging from 2 to 10 minutes, depending on the experiment setup.

To observe a maximum diversity of underlying phenomena, we pre-selected two flow/dissolution regimes: the dominant (fast) wormhole regime and the conical (slower) wormhole regime. The parameters were chosen based on previously performed experiments on same rock type and have been also 4D imaged using standard X-ray tomography, however with significantly lower spatial and temporal resolution.

Samples were placed in a vertically placed Hassler core holder, saturated with water and imaged. Scans were made during 180 deg rotation of the holder, with 1000 images per scan. Each scan covered approximately 10 mm of the sample length. Between 2 and 10 scans per time-frame were gathered, to cover from 20 to 100 mm of sample length. Fast acquisition time is crucial for imaging time dependent structures, especially in liquid-gas systems. High speed capabilities of ID-19 beam-line allowed us to perform single sample scan under 1 minute, which was mainly constrained by physical movement of the sample on the stage.

During experiments we logged amount of fluid pumped through the system, mass of the effluent at room pressure and pressure difference and pressure in nitrogen supply tank. During experiments session we have experienced communication problems (likely due to radiation inside the hatch) with weight-scale and unfortunately significant portion of mass data was corrupted or unregistered. Similar communication issues occurred at pumps interfaces, however we were able to reconnect the system and safely continue the experiments without interruption. We successfully reconstructed most of over 500 scans, using ESRF cluster and finished the process at late December. While most of the scans were successful, we found that sample handling inside the cell was not tight enough and changes of pressure at supply line moved the dissolving core which makes data analysis more difficult as there is no common coordinate system between scans. We already used those information to improve sample fixture for future experiments.

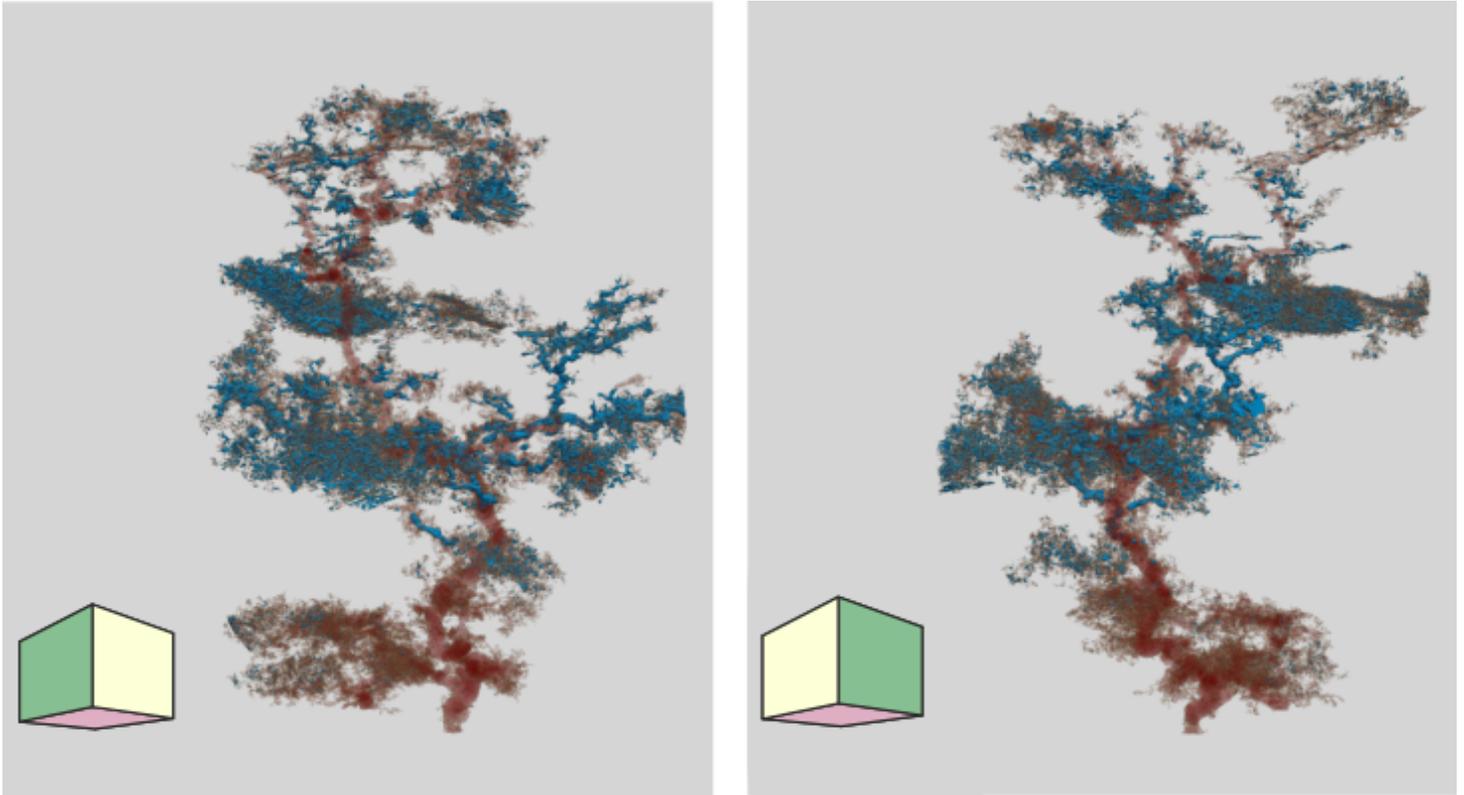


Fig.1: Segmented reconstruction of the wormhole developed inside limestone core. Red: wormhole, blue: trapped nitrogen.

Data analysis have already revealed complex, nonlinear couplings between flow and geometric evolution. Particularly, within a range of physical parameters, we observed the spontaneous creation of dissolution-induced preferential flow channels (fig. 1). Although these channels are also observed in single-flow systems, their dynamics in the two-phase systems differ fundamentally. The presence of these channels dynamically alters phase distribution in a porous matrix, actively redistributing the gas phase. Consequently, the redistribution of gas alters local and global flow characteristics, thereby affecting the dissolution process. Contrast between gas, fluid and rock is significant to observe single bubble trapped in wormhole branches and their travel, along with saturation changes information.

While two-phase flow was primal subject of this proposal, the presence of a secondary phase in the system also opens possibilities for other observations due to enhanced contrast. Two stages of flooding protocol - with nitrogen (black) and acid rendered partially dissolved rock, a ghost zone, visible. Such ghost zones have been already observed using different, multi-stage flooding experiments by Singh et. al. (2018).

In conclusion, we managed to successfully perform six dissolution experiments in 4 days of beam-time. Some of the gathered data is insufficient quality due to sample movement, but it will still be useful to improve design of future experiments.

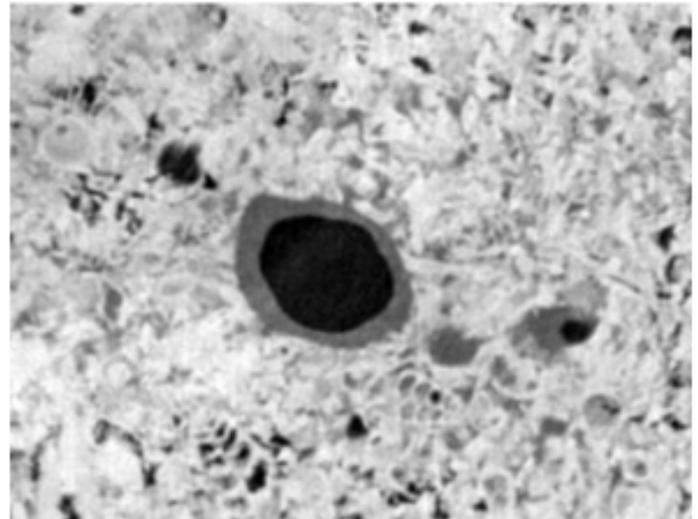


Fig. 2. Injection of nitrogen into acid saturated wormhole showed, partially dissolved zone, that was not visible at water-flooded scans.