Wettability-controlled fluid displacements in heterogeneous rock

Arjen Mascini[1], Marijn Boone[2], Veerle Cnudde[1,3] & Tom Bultreys[1]

[1] Ghent University, Department of Geology & Centre for X-Ray Tomography (UGCT), Pore-scale Processes in Geomaterials Research Team (PProGRess), Krijgslaan 281/ S8, 9000 Ghent, Belgium, e-mail: Arjen.Mascini@ugent.be

[2] TESCAN XRE, Bollebergen 2B box 1, 9052 Ghent, Belgium

[3] Utrecht University, Dept. of Earth Sciences, Environmental hydrogeology, Princetonlaan 8a, 3584 Utrecht, The Netherlands

Multiphase fluid flow is a common process in geological systems and has important applications such as aquifer remediation and Carbon Capture and Storage (CSS). Understanding how pore-scale fluid displacements link to the macroscopic descriptions of multiphase flow forms an important gap in our current understanding of this process. At the mesoscale, between the pore and the continuum scale, the distribution of the fluids in the pore network develops into different patterns depending on e.g. flow regime, pore geometry and surface chemistry. Over the years, significant effort has been put into identifying the underlying pore-scale displacement mechanisms [e.g. 1] and classifying these displacement patterns in model porous media based on e.g. the capillary number, viscosity ratio and wettability[2]–[4]. However, subsurface rocks tend to be far more complex in terms of pore structure and wettability than the model materials on which these classifications are based. We hypothesize that pore-scale complexities might induce local variations in the viscous-capillary force balance which could translate in qualitatively new multiphase flow behavior.

To test this hypothesis, we use fast laboratory based X-ray microtomography to image n-decane-brine drainage and imbibition experiments performed on two medium-grained calcareous sandstone samples of the Luxembourg Sandstone Formation (lower Jurassic) at slow flow rates (Ca 10^{-9}). One of these samples was treated using octadecyltrichlorosilane (OTS) to induce an mixed wettability distribution. The experiments were imaged continuously at 60s per 360° rotation using a laboratory based X-ray microtomography scanner optimized for fast image acquisition to generate a time series of images with a reconstructed voxel size of 8µm/vx. We quantify fluid displacements on a pore-by-pore basis to investigate the times scales associated with the fluid displacements. We identify a previously undescribed type of filling event that occurred during water-flooding under mixed-wet conditions, where certain large pores fill at a time scale that is four orders of magnitude slower than the Haines jumps that occur in neighboring pores. This displacement type is responsible for about 20% of the total displacement of the n-decane phase in our sample during water-flooding. The rate-limited behavior of these events can be explained by the fact that under mixed-wet conditions the persistent connectivity of the fluid phases allows the invasion of poorly connected, large pores through low-conductivity pore regions which locally control the flow rates.

[1] R. Lenormand, C. Zarcone, en A. Sarr, ‘Mechanisms of the displacement of one fluid by another in a network of capillary ducts’, *J. Fluid Mech.*, nr. 135, pp. 337–353, feb. 1983.

[2] R. Lenormand, E. Touboul, en C. Zarcone, ‘Numerical models and experiments on immiscible displacements on immiscible displacements in porous media’, *J. Fluid Mech.*, nr. 189, pp. 165–187, jun. 1988.

[3] B. Zhao *e.a.*, ‘Comprehensive comparison of pore-scale models for multiphase flow in porous media’, *Proc. Natl. Acad. Sci.*, vol. 116, nr. 28, pp. 13799–13806, jul. 2019, doi: 10.1073/pnas.1901619116.

[4] R. Holtzman, ‘Effects of Pore-Scale Disorder on Fluid Displacement in Partially-Wettable Porous Media’, *Sci. Rep.*, vol. 6, nr. 1, p. 36221, dec. 2016, doi: 10.1038/srep36221.