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A comparative study of fabrics and porosity in shaly and sandy facies of Opalinus Clay by BIB-SEM methods

Maartje Houben, Guillaume Desbois, and Janos Urai

Structural geology, Tectonics and Geomechanics, RWTH Aachen University, Lochnerstrasse 4-20, D-52056 Aachen, Germany (m.houben@ged.rwth-aachen.de)

Clay rich formations are known for their low permeability and are considered in several countries as potential host rocks for the deep geological storage of radioactive waste. Favorable host rock properties depend highly on the rocks microstructure. Detailed investigation of the morphology of porosity will help in understanding the sealing capacity, coupled flow, capillary processes and associated deformation. Until now direct investigation of porosity at pore scale remained difficult below 1 μm, but recent development of ion beam milling tools to prepare high quality polished surfaces allows imaging down to the nanometer scale [1]. In this contribution, a Broad-Ion-Beam polisher in combination with SEM-imaging is used to access directly the clay fabric and porosity down to the nm scale on representative elementary areas, in samples from the shaly and sandy facies of Opalinus Clay from the Mont Terri rock laboratory.

Shaly facies of Opalinus Clay constitutes of dark grey silty calcareous shales (70-80%), and diagenetic minerals like carbonates (calcite, siderite, dolomite/ankerite), quartz and pyrite, these are homogeneously distributed within the clay matrix. Pores in the clay matrix can be classified in three types: I – Elongated pores between parallel oriented clay sheets, II – Crescent shaped pores in saddle reefs of folded sheets of clay, III – large elongated pores mainly located along the bedding but also surrounding clasts with rough pore walls and crack tips on both ends. Pores of Type III are interpreted to originate from damage during drilling and/or drying, and thus do not represent the original pore structure (equivalent radius [eqr] between 50 and 200 nm). Pores of Type I and II are mainly oriented parallel to the bedding, 80% of these pores have an eqr below 55 nm and they follow a Log-Log distribution (exponent = 3.4) reflecting self-similarity of pore distribution for pores with an eqr in the 25-400 nm range. Other minerals bearing substantial porosity are siderite and calcite. Pores in siderite are elongated to roughly circular (eqr between 40 and 100 nm) with low wavelength jagged edges and in calcite the pores have smooth angular edges (eqr between 40 and 200 nm). For both siderite and calcite, pores were essentially developed along their edge in contact with clay matrix. The visible porosity inferred from our SEM images (pixel size 12 nm) is about 2.5%.

In contrast, at the same scale, samples from the sandy facies are microstructurally heterogeneous with alternating clay and sand layers and more pore bearing minerals. Other pore bearing minerals identified so far are: siderite, apatite, mica, calcite, quartz, pyrite, K-feldspar and dolomite/ankerite. With regard to fabric and pore morphology, the clay matrix from the Shaly facies and the Sandy facies are similar, although the overall visible porosity is lower (1.7%), furthermore, the sand layers have an even very lower visible porosity of < 1%.

For samples from the shaly facies, when extrapolating the power law distribution to smaller and larger pore values, the calculated porosity (14%-22%) is in good agreement with values given by traditional porosimetry methods measured on sample volumes (centimetre scale) [2], suggesting that the non-visible pores at the SEM resolution follow also the same power law distribution. Pores in fossil and siderite in contact to the clay matrix could maybe act as ‘dead end-pores’ [3], which are assumed to play a role in cation diffusion. Due to a distinct bedding anisotropy in both shaly and sandy facies of Opalinus clay, parameters like permeability are known to depend on the orientation. So far the data presented here may suggest a stronger anisotropy of permeability in the sandy facies, but more research is needed to confirm this.

[1] Loucks, R.G., Reed, R.M., Ruppel, S.C., Jarvie, D.M., 2009, Morphology, genesis and distribution of nanometer-scale pores in siliceous mudstones of the Mississippian Barnett shale, Journal of sedimentary research,

79, 848-861.

[2] Bossart P., Thury, M., 2008, Mont Terri Rock Laboratory. Project, Programme 1996 to 2007 and Results – Rep. Swiss Geol. Surv. 3.

[3] Appelo, C.A.J., Loon, van, L.R., Wersin, P., 2010, Multicomponent diffusion of a suite of tracers (HTO, Cl, Br, I, Na, Sr, Cs) in a single sample of Opalinus Clay, Geochimica et cosmochimica acta, 74, 1201-1219.