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CHARACTERISING FLOW AND ANISOTROPY IN GAS SHALE ROCKS USING MICRO- AND NANO- X-RAY CT IMAGING

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Summary: Unconventional gas reservoirs in shale are a potential abundant energy resource available in many regions worldwide. However, estimations of the amount of exploitable gas stored within the shale remains uncertain, as we continue to try to understand the microstructural flow pathways. Ultra-high resolution X-ray imaging systems are shedding light on interconnected fluid pathways and understanding gas recovery after hydraulic fracturing (fracking).

1. INTRODUCTION

Organic rich, finely laminated mudstones are the source and reservoir of unconventional shale gas which are being explored in gas-mature basins. Gas is exploited by fracking the shale rocks with over-pressured fluids through deep boreholes drilled horizontally through the reservoir. Whilst they are thought to contain significant amounts of natural gas, there remains a limited understanding of how to efficiently exploit this natural resource. Anthropogenic hydro-fractures provide escape routes for the trapped gas through the borehole and the gas is retrieved at surface. The productivity from boreholes has a sharp decline in gas recovery and low rates of gas productivity continue 4 to 6 years after fracking. This suggests an inefficient stimulation during fracking, as large volumes of gas are left behind during economic recoveries. The “decline curve” is possibly thought to record the interconnection of the natural fracture system with the anthropogenic hydro-fractures that exists at depth.

Pores exist at mineral boundaries and within organic matter and may be very small, typically between a few microns and hundreds of nano-meters. X-ray micro- and nano-CT imaging provides a valuable tool to effectively study the three-dimensional distribution and interconnected network of the porous phase that define the flow patterns through the rock at the mineral scale.

2. EXPERIMENTAL METHOD

The experiments were performed at the Electrochemical Innovation Lab (Department of Chemical Engineering, University College London, UK) with a ZEISS Xradia 520 Versa X-ray micro-CT microscope (Carl Zeiss, USA), utilizing a polychromatic micro-focus source (tungsten target) and with a ZEISS Xradia 810 Ultra X-ray nano-CT microscope, utilizing a quasi-monochromatic beam at 5.4 keV (chromium target).

Laminated shale rocks were sampled from boreholes at 3700 meters of depth, provided by the Department of Earth Sciences of UCL, where the rock mechanical properties of the samples are being tested.

The radiographic projections collected were reconstructed using a filtered back projection algorithm (XMReconstructor, Carl Zeiss Inc.) to produce a set of tomographic slices making up a cylindrical volume.

The reconstructed datasets were imported into Avizo (Visualization Sciences Group, FEI Company) where image post-processing, segmentation and image analysis were performed. To facilitate image segmentation, histogram equalization was performed, followed by the application of non-local means (NLM) filtering.

Flux density and tortuosity factors were calculated with the Matlab application *TauFactor* [1]: this software calculates the reduction in diffusive transport caused by convolution in the geometry of heterogeneous media, based on microstructural image data. This effect could be expressed by the tortuosity factor, τ, which is defined in $D_{eff} = D\,\varepsilon/\tau$, where ε is the volume fraction of the conductive phase; D is the intrinsic diffusivity of the conductive phase; and D_{eff} is the effective diffusivity through a porous volume where the second phase is insulating.

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3. RESULTS

Micro-scale X-ray imaging of the samples highlighted the scaly fabric of clay minerals and wavy bedding-parallel alignment of the porous phases that follow the clay morphology (Fig. 1(a)). Four main phases were identified according to grey scale levels: clays; combined pore fraction and organic matter; clastic phase (quartz, calcite and feldspar) and pyrite (Fig. 1(b)). Two main intervals can be recognised, a clay-rich layer at the top of the sample and a clastic-rich layer at the bottom. Flux density analysis for the clay-rich layer show a very complex and tortuous path (Fig. 1(c)) compared to the values obtained for the bottom layer, where the flow is mainly driven by horizontal fractures present in the sample (Fig. 1(d)). Tortuosity factors show a striking difference between the clay-rich layer and the clastic-rich one. This is probably due to the fact that within the upper interval the clay minerals provide an anastomosing fabric for the interconnection of the porous phase, even vertically through the layer. By contrast, in the clastic-rich layer, the lower clay content provides less interconnectivity of the porous phase and vertical fluid flow is not computed through this layer. These new high-resolution images suggest that the alignment of the clay minerals has a governing nanoscale control on permeability and the anisotropy measured in shale rocks.

References

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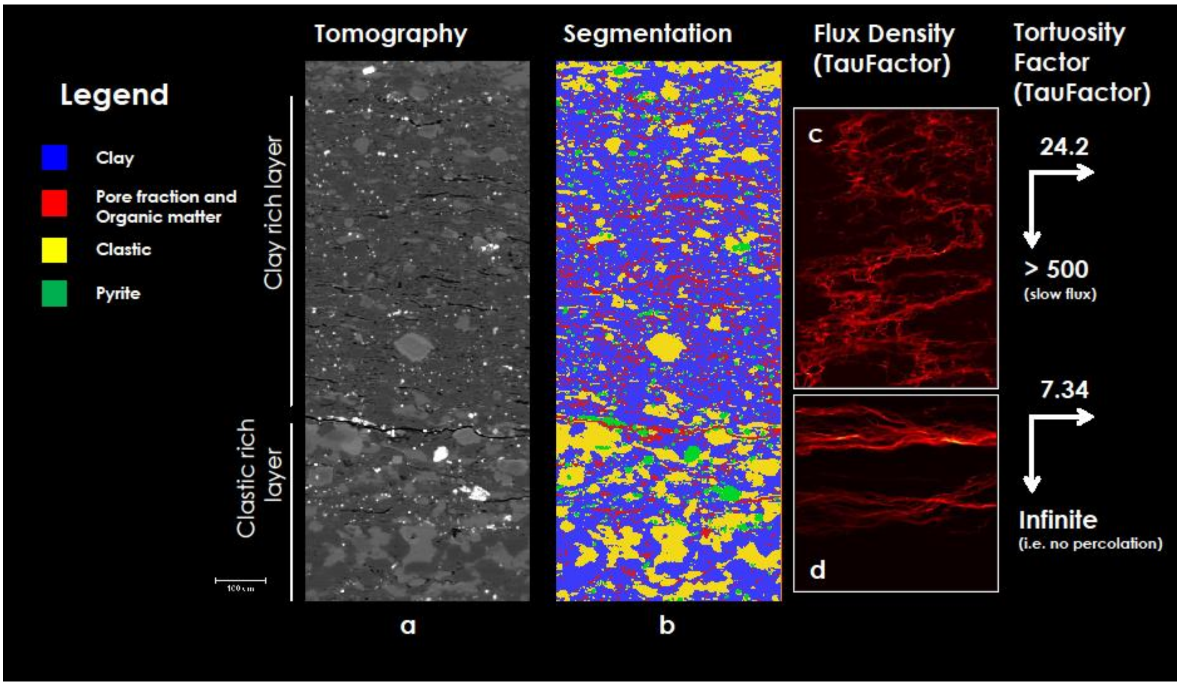

Figure 1: (a) Zeiss Xradia 520 Versa tomograph of a selected subvolume. (b) Segmented volume taking into account four main components of the shale rock: Clay, pores and organic matter, clastic phases (quartz, calcite and feldspar) and iron sulphide (pyrite). (c) Flux density map of the upper part of the sample. (d) Flux density map of the lower part of the investigated sample.