Investigation of Pore Structure within the Weyburn Oilfield using Synchrotron Microtomography

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Synchrotron X-ray Computed Microtomography (CMT) is a powerful imaging technique that utilizes coherent and brilliant synchrotron light to produce high-resolution, three-dimensional images based on differences in X-ray attenuation within a sample. CMT provides a unique and novel approach for extracting physically realistic images of reservoir quality rocks, non-destructively with micron-scale (50µm-0.1µm) resolution. Tomographic images of rocks collected at this scale permit identification, visualization and quantification of minerals and pore structure (i.e. volume, shape, connectivity and throat radii) that can be used to obtain and understand petrophysical properties such as permeability, capillary pressure and formation factor (Kayser et al., 2006). CMT analysis can be done on small (cm-mm) sections of core, such as side-wall cores and damaged, fragile and unconsolidated samples, which has implications for using CMT methods to study future conventional and unconventional (i.e. coal bed methane (CBM), tight gas and shale gas) reservoirs (Arns et al., 2005).

In this study, CMT analyses have been carried out on Mississippian limestone and dolostone samples obtained from the Weyburn Reservoir, site of EnCana Corporation's CO_2-miscible Enhanced Oil Recovery (EOR) project. Sections of carbonate core collected prior to CO_2 injection have been imaged with synchrotron CMT at a spatial resolution of 7 to 10µm. Total porosity information obtained from CMT on the carbonate cores show variable pore volume distributions ranging from $10um^3$ to $4mm^3$ on sample volumes ranging from $213mm^3$ to $306mm^3$ which correspond favorably with empirical results from gas permeability measurements (Figure 1). Mercury porosimetry is being performed on these same carbonate cores to resolve the submicron porosity existing below the CMT image resolution and, for mercury capillary pore volumes ≥10µm, to provide a direct comparison with pore volumes extracted from CMT data. Calculation of theoretical permeabilities will be attempted using the Kozeny-Carmen and Katz-Thompson relationships with porosity information obtained from both CMT and mercury porosimetry data. These theoretical permeabilities will then be compared with conventional laboratory based gas and liquid permeability measurements on identical sections of carbonate core to elucidate the validity of these relationships in carbonate lithologies and potential application of CMT as a new formation evaluation tool.

Additionally, the sensitivity of CMT to density related differences within the carbonate cores permits the identification of minerals. Using transmitted light microscopy, electron probe micro-analysis (EPMA) and backscattered electron images, compositional information (Figure 2a) can be obtained and integrated with differences in X-ray attenuation from CMT to delineate the relationship between mineral phase and X-ray attenuation (LAC) (Figure 2b). From this, minerals having an X-ray attenuation difference of approximately 4.5% can easily be resolved within the CMT data (Figure 3). However, CMTs dependence on density contrasts within a sample minimizes visualization of different sedimentological and ichnological textures occurring in the same mineral phase (Figure 2a).

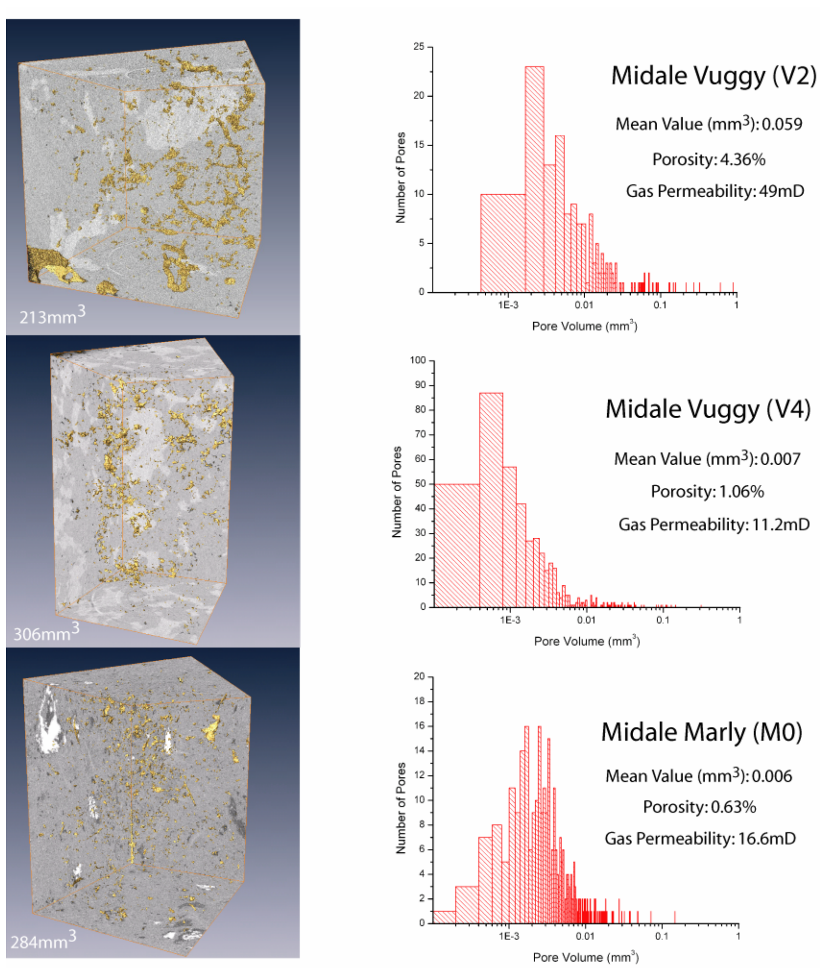

Figure 1. Rendered CMT images of porosity in the Midale Vuggy and Marly units (left) and corresponding CMT pore volume distribution (right). Gas permeability values (Klinkenberg corrected) have been performed conventionally.

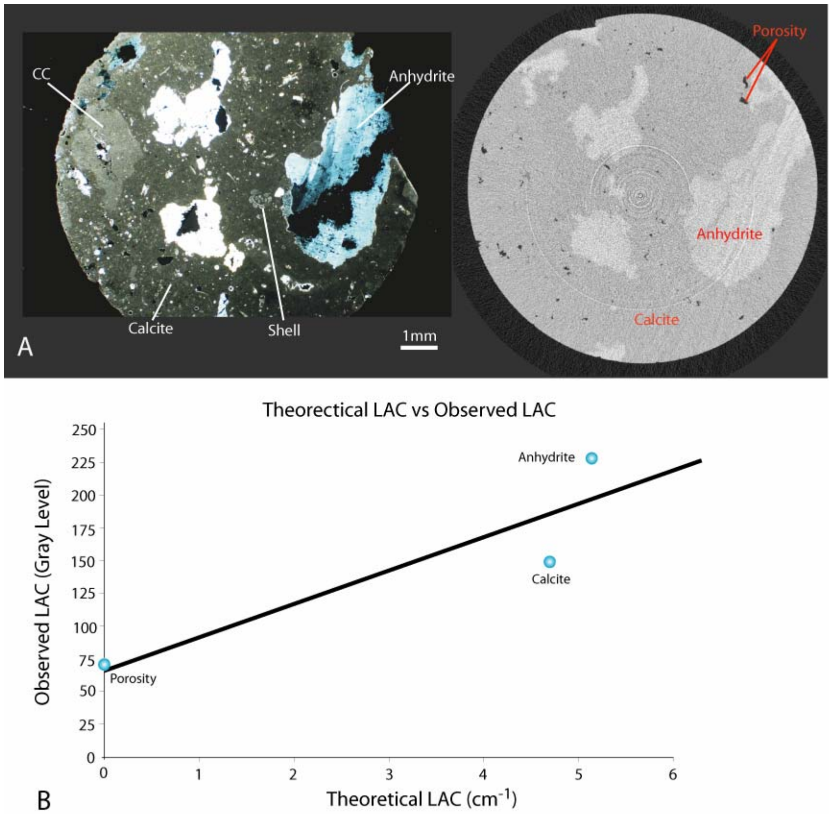

Figure 2. (A) Comparison between a thin-section of the Midale Vuggy observed under cross-polarized light (left) and its corresponding CMT image (right). Note enhanced porosity in the thin-section can be attributed to 'plucking' that occurred during the preparation process. Additionally, the coarser calcite (CC) located on the right side of photomicrograph and the endothyrid foraminifera test (shell) located at the center of the photomicrograph do not appear in the CMT image. This can be attributed to both the coarser calcite and endothyrid test being composed of similar density calcite to that of the matrix. (B) Preliminary calibration curve correlating mineralogy from observed gray-level values in a CMT image with calculated theoretical linear attenuation coefficients (LAC).

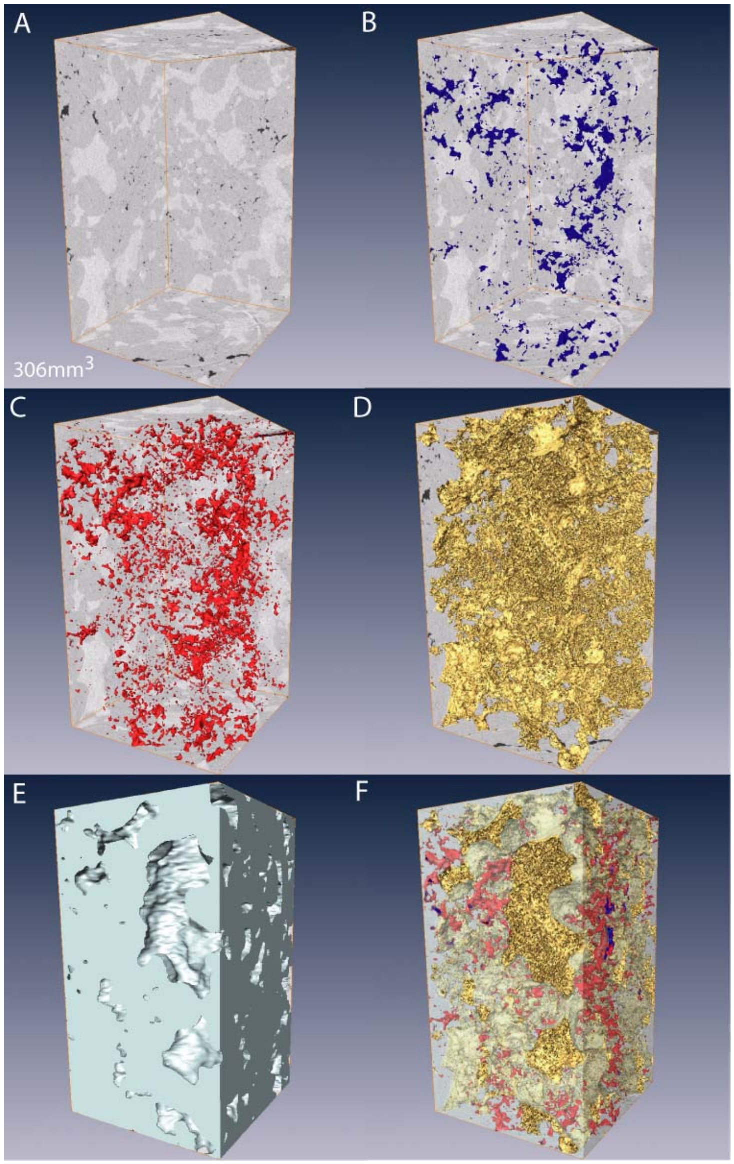

Figure 3. Sequence of CMT images of the Midale Vuggy (V4) segmented according to the present mineral phases verified by EPMA. Image A shows the total sample volume (306mm^3), light gray and gray regions are the rock volume and black areas are porosity. Image B displays the 3-D distribution of porosity (blue). Red surfaces in image C depict the 3-D distribution of dolomite. Image D displays the 3-D extent of the light gray (highest density) mineral phase, anhydrite (gold). In image E, the metallic silver represents calcite which is gray in the CMT slices. Image F shows all mineral phases (calcite is transparent gray) and porosity plotted together.

References

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