

Pore Morphometrics and Thermal Evolution of Organic-Matter Microporosity, Colorado Group, Western Canada Sedimentary Basin*

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Abstract

The physics of flow in conventional oil and gas reservoirs is reasonably well understood, however, the nature of flow in carbonaceous mudstone reservoirs is unclear due to highly heterogeneous micropore structure. A quantitative model relating micropore morphometrics and matrix permeability, as yet undeveloped, is required to infer the contribution of microporosity to economic flow rates.

Carbonaceous mudstones of the Upper Cretaceous Colorado Group of the Western Canada Sedimentary Basin (WCSB) span a wide spectrum of thermal maturity levels. This affords an opportunity to combine regional scale of investigation with quantitative micropore morphometrics of related carbonaceous mudstones with variable burial and thermal histories. The first phase of this effort requires cataloguing of dominant modes of intrinsic microporosity (Schieber, 2010) and relating these to process dynamics in the depositional and burial domains.

Phyllosilicate framework (PF) and organic matter (OM) pores are the dominant microporosity modes observed in the correlative equivalents of the Second White Specks, Belle Fourche and Fish Scales Formations of the lower Colorado Group in a gamut of samples spanning the foredeep, forebulge and backbulge segments of the WCSB foreland basin. The PF fabric suggests advective transport of mud floccules or fecal pellets as a dominant mechanism for formation of intrinsic PF microporosity. Abundant OM microporosity development in thermally immature organic matter may be indicative of non-catagenic pathways to porosity development and preservation in carbonaceous mudstones.

Introduction

The broad areal extent of the WCSB and the availability of samples throughout the basin provide an excellent framework for studying organic matter micropore morphometrics in relation with thermal maturity. The Cretaceous Colorado Group (Albian to Santonian) is located within the Western Canada foreland basin and consists of a predominantly marine succession that tapers eastward from the Rocky Mountains to the Manitoba Escarpment.

Nanometre- to micrometre-scale phyllosilicate framework (PF) pores, organic-matter (OM) pores are intrinsic fabric elements common to most carbonaceous mudstone reservoirs (Schieber, 2010). PF-pores are elongate, or triangular matrix intercrystalline pores between clay platelets, cement crystals and larger detrital particles. OM-pores are vesicular intraparticle pores developed within organic matter. In addition, localized occurrences of pyrite-framboid intercrystalline pores may have significant storage potential (Loucks et al., 2009).

Method

Samples were collected from full-diameter cores of the lower Colorado Group (the Second White Specks, Belle Fourche and Fish Scales Formations and their correlative equivalents) in the Energy Resources and Conservation Board (ERCB) Core Research Centre in Calgary, and the Saskatchewan Subsurface Geological Laboratory in Regina. A subset of these samples was selected based on stratigraphic position and Rock-Eval characteristics, in coordination with ongoing regional Colorado Group petroleum system research at Western University. Imaging and pore characterization of the samples has been conducted using the LEO (Zeiss) 1540XB focused ion beam and secondary electron microscopy (FIB/SEM) system in Western University's Nanofabrication Facility. EDX elemental mapping and spot chemical analyses have been conducted in conjunction with the imaging work in order to determine detrital matrix and authigenic phase mineralogy. The resulting digital image files are used in subsequent quantitative petrographic image analysis to generate sets of scaled morphometric variables for microporosity characterization.

Observation and Discussion

PF pores and OM pores are the dominant pore types in the lower Colorado Group. Characteristic elongate and triangular openings (Schieber, 2010) are common in PF pores ([Figure 1](#)). The PF pores commonly exhibit clay platelets that bend around silt grains and pierce into other platelets due to compaction, which Schieber has suggested implies a detrital origin ([Figure 1](#)). The 'edge to face' structure described by Schieber (2010) may be indicative of clay floccule fabrics. In addition to detrital clays, authigenic clays locally develop within large PF pores. As shown in [Figure 2A and 2B](#), significant authigenic clay growth occurs along quartz grain boundaries and PF pores between clay platelets. PF pores are abundant in Upper Colorado Group carbonaceous mudstones and are preserved in both thermally mature and immature samples.

OM pores are developed within disseminated organic matter particles and usually have a round aspect. Pore sizes range from several nanometres to hundred nanometres. [Figure 3](#) illustrates the local variability in OM porosity development, which is typical of samples studied to date. In this figure, OM porosity development is quite advanced in the OM particle in the centre bottom of the image (labeled "B"), but much less developed in the large OM particle ("A") located immediately above. The explanation for this heterogeneous OM porosity development is still unresolved, but may be due to different kerogen composition in the two respective organic macerals. Previous studies suggested that OM micropores preferentially develop in bacterially degraded organic matter (e.g. bituminite) rather than degradation-resistant organic matter (e.g. alginite, inertinite) (Loucks et al., 2009; Schieber, 2010). In-situ characterization of organic matter type would be required to resolve the apparent discrepancy in OM porosity development in adjacent macerals, but this is beyond the scope of the current research.

OM pores are thought to develop because of kerogen degradation during catagenesis, and are considered as evidence of thermal maturity of the carbonaceous mudstone (Curtis et al., 2010). However, the Colorado Group samples analyzed thus far appear to exhibit exceptions to this

hypothesis. Samples from cores with Rock-Eval Tmax values indicative of mature catagenic kerogen degradation (i.e.: Tmax in excess of 450°C) contain common occurrences of non-porous OM particles. In contrast, some thermally immature samples (i.e.: Tmax less than 420°C) have common occurrences of advanced OM porosity development. Consequently, thermal maturity alone appears to be a poor predictor of OM porosity development in Colorado Group carbonaceous mudstones. It is possible that absence of OM pores in thermally mature samples reflects preferential preservation of refractory (inert) organic matter following complete degradation of reactive organic matter, but this conclusion is not supported by the Rock Eval S2 data. Alternatively, remobilization of bitumen during catagenesis may result in infilling of previously formed OM micropores, which would be difficult to detect in the SEM images. The presence of well-developed OM pores in thermally immature samples is more problematic, suggesting that non-thermal pathways, possibly of an early diagenetic or syndepositional biogenic nature, may produce intrinsic OM microporosity that is unrelated to burial / thermal history.

Conclusions

Phyllosilicate framework porosity and organic matter porosity exhibit diverse forms and modes of formation in the Colorado Group, and are distributed in a manner that is not readily related to thermal maturity or burial history. This contributes to a high level of reservoir heterogeneity that presents significant challenges for flow characterization. Future research should attempt to address depositional and burial domain processes that govern the dominant modes of intrinsic porosity formation and preservation within a basin evolution context in order to improve predictive capability.

Acknowledgement

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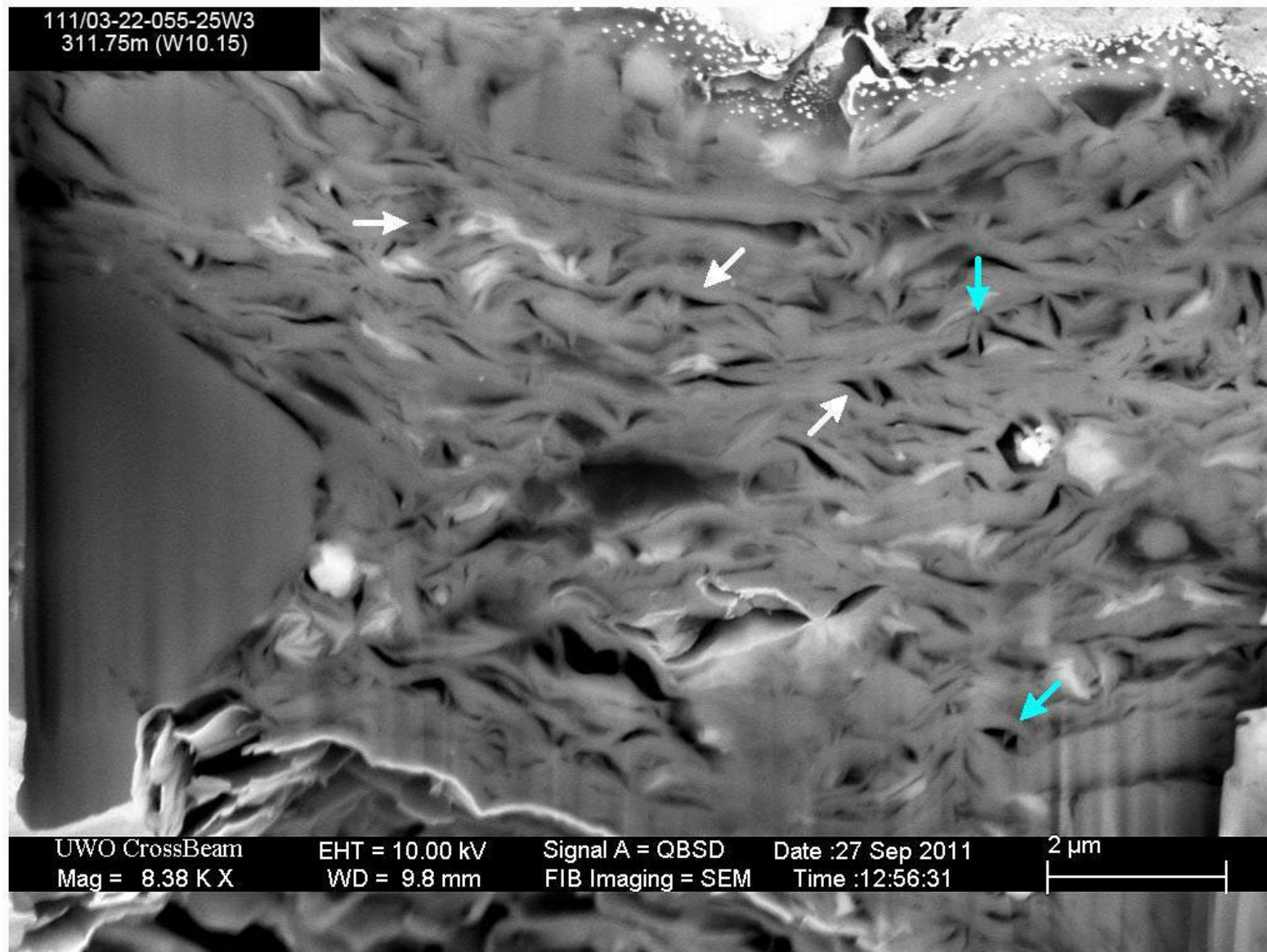


Figure 1. Backscatter electron (BSE) image illustrates profuse PF pore development in a Second White Specks Formation sample from 111/03-22-055-25W3 (311.75 mKB). Large PF pores appear to occur along grain boundaries and small PF pores dispersed within the fabric defined by clay platelets showing preferred orientation. White arrows indicate triangular opening; blue arrows indicate clay platelet piercing into another platelet because of compaction.

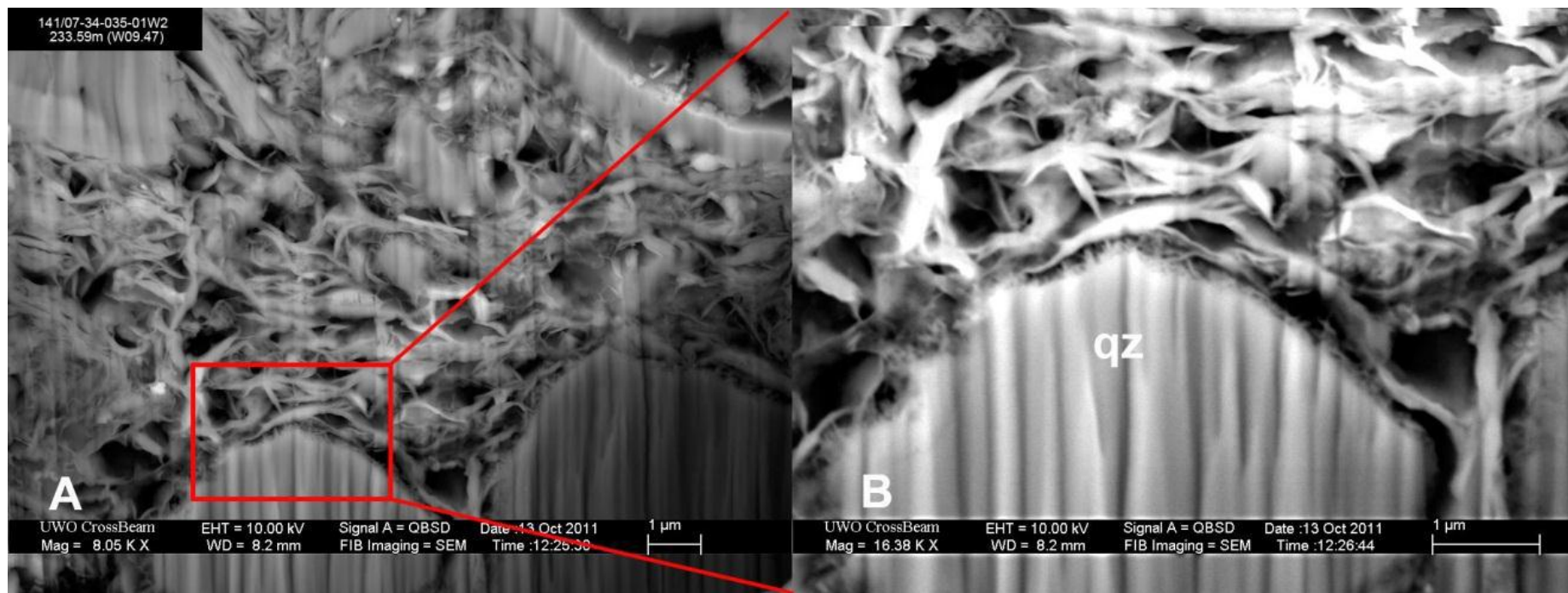


Figure 2. (A) BSE image from 141/07-34-035-01W2 (233.59 mKB) illustrating authigenic clay growth within PF pores and along quartz boundaries. (B) Enlarged view of the area outlined in red in (A).

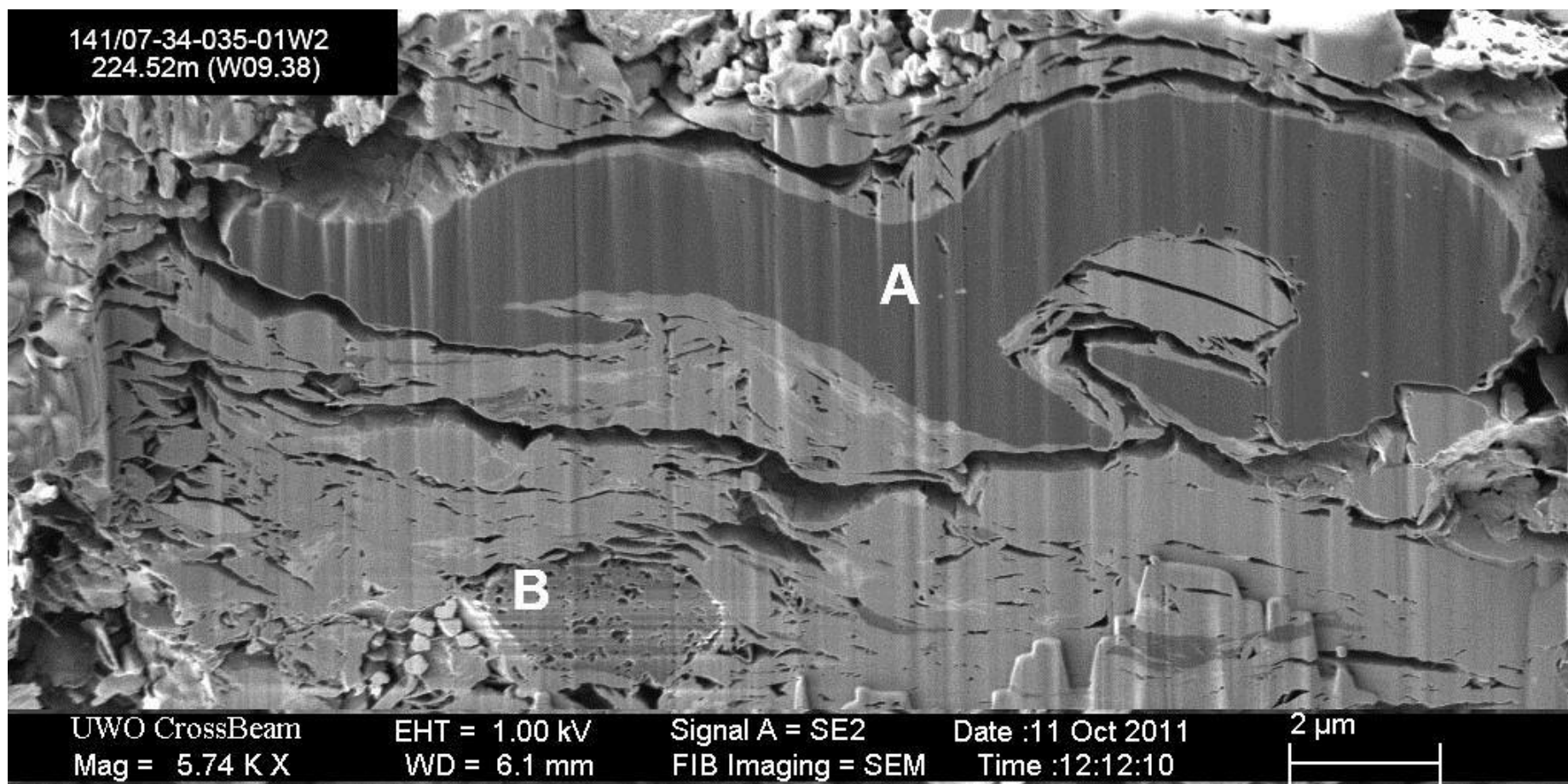


Figure 3. SEM image from 141/07-34-035-01W2 (224.52 mKB) illustrates heterogeneity of OM porosity development. Notice that OM porosity development in kerogen maceral "A" is limited to isolated micropores, whereas kerogen maceral "B" exhibits denser development of larger micro- to meso-pores. The small particles sizes present targeting challenges for in-situ characterization of kerogen components (i.e.: by FTIR or ToF-SIMS), but this remains a goal for future research.