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Solid bitumen as a determinant of reservoir quality in an unconventional tight gas siltstone play

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ABSTRACT

In this study of the Triassic Montney tight gas siltstone play in the Western Canadian Sedimentary Basin petrophysical measurements of drill-core samples (porosity, pore throat size, water saturation and grain size) are integrated with Rock-Eval TOC data, organic petrography observations and SEM imaging to show that reservoir quality in the gas window is strongly influenced by the pervasive presence of pore-occluding solid bitumen (and pyrobitumen at higher thermal maturity). The solid bitumen formed as a pore-filling liquid oil phase that was diagenetically and thermally degraded with further burial and increase in temperature. The proportion of solid bitumen filling the intergranular paleopore network can be expressed as bitumen saturation, and this attribute is found to be the dominant control on pore throat size and absolute permeability. The samples with low bitumen saturation and large pore throat radius (>0.01 μm) have water saturations that generally increase as pore throat size diminishes, a relationship consistent with capillary theory for conventional water wet conditions. The samples with high bitumen saturation and small pore throat radius (<0.01 μm), on the other hand, have abnormally low water saturation, a condition inconsistent with capillary theory for conventional water wet rocks. The coincidence of small pore throat size, low water saturation and high bitumen saturation is attributed to the presence of well-connected nanopores within the devolatilized, solid bitumen and the hydrophobic nature of the bitumen. Siltstones in economic portions of the Montney tight gas fairway have porosity mostly in the range of 3 to 7%. The results of this study show that reservoir quality in this economically key porosity range is influenced more strongly by bitumen saturation than by conventional determinants of porosity and permeability such as grain size, sorting, clay content and cementation. The concept of pore-occluding solid bitumen as an important negative control of reservoir quality elucidated here for Montney siltstones likely has application to the technical and economic evaluation of other tight gas plays particularly those in indirect basin-centered gas accumulations.

1. Introduction

The significance of thermally degraded solid bitumen in the evaluation of unconventional tight gas and shale gas plays has become increasingly recognized in recent years (Bernard et al., 2012, 2013; Cardott et al., 2014; Fishman et al., 2014; Hackley, 2012; Haeri-Ardakani et al., 2015; Isinguzo et al., 2014; Mastalerz et al., 2013). The solid bitumen in many of these shales and tight lithologies conforms to the concept of migrabitumen (Jacob, 1989), i.e. solid bitumen derived from a previous hydrocarbon liquid phase which migrated any distance from a fraction of a millimeter to several kilometers. Recent organic petrography and pyrolysis studies (Chalmers and Bustin, 2012; Freeman, 2012; Sanei et al., 2015 submitted accompanying paper) show that solid bitumen in a world-class unconventional tight gas play, the Triassic Montney Formation of the Western Canadian Sedimentary Basin (National Energy Board, 2013), was originally introduced as a liquid oil phase which substantially filled the pore network of this regionally extensive marine siltstone succession. In this paper we use petrophysical measurements of porosity, pore throat size, water saturation and grain size together with Rock-Eval TOC data, organic petrography observations and SEM imaging to show that solid bitumen is a major determinant of reservoir quality in this indirect basin-centered gas system (sensu Law, 2002).

2. Geologic setting

The Early Triassic Montney Formation is up to 320 m (1050 ft) thick and forms part of an enormous tight gas fairway located immediately to the northeast of the Cordilleran deformation belt in the Western

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Canadian Sedimentary Basin of Alberta and British Columbia (Kuppe et al., 2012; National Energy Board, 2013; Wood, 2013). The formation is composed overwhelmingly of siltstone and was deposited predominantly in lower shoreface to offshore environments (Davies et al., 1997; Edwards et al., 1994; Wood, 2013). Turbidite depositional environments have also been reported for parts of the Lower Montney section (Davies et al., 1997). The Montney tight gas fairway passed into the thermogenic gas window prior to the time of maximum burial approximately 50 to 60 Ma (Ness, 2001), and forms an indirect basin-centered gas accumulation (Law, 2002), i.e. a regionally pervasive, unconventional gas system in which migrated and trapped oil was thermally cracked to gas. Present-day total organic carbon, typically in the range from 0.25 to 4.0 wt.%, is virtually all in the form of solid migrabitumen (Chalmers and Bustin, 2012; Freeman, 2012; Sanei et al., 2015 Submitted accompanying paper) which occurs as a pervasive intergranular network (Figs. 1 and 2). The solid bitumen is a previous oil phase that partially filled the paleopore network of Montney siltstones during hydrocarbon charging. With further burial and increase in temperature the oil phase cracked in-situ to solid bitumen and light hydrocarbon fluids.

3. Methods of study

3.1. Analytical methods

Samples for this study were collected from 17 wells in Alberta and British Columbia with cored intervals in the Montney Formation. Complete sets of porosity, mercury injection capillary pressure and total organic carbon (TOC) measurements were acquired for 123 samples from these cores at depths ranging from 2099 to 4038 m. Routine porosity measurements were made on one-inch-diameter plugs at ambient conditions by use of the Boyle's Law method (API RP40) with helium as the gaseous medium. The samples were cleaned with toluene and methanol and then oven-dried at 100 °C for a period of 24 h prior to porosity measurement. Mercury injection capillary pressure tests were conducted following established methods (Purcell, 1949) and pore throat size distributions were generated by use of the Washburn (1921) equation. TOC contents were measured by means of standard Rock-Eval 6 analysis (Lafargue et al., 1998).

Water saturations were determined by the toluene distillation method (Dean and Stark, 1920) for 322 full-diameter core samples from 10 of the wells, but only a subset (n = 82) with accompanying TOC and mercury injection capillary pressure measurements are shown here. The whole cores, ranging in diameter from 65 mm (2.56 in.) to 100 mm (3.94 in.), were cut in oil-based drilling mud with aluminum sleeve coring equipment. The aluminum-sleeved cores were cut into sections (typically 1.5 m or 4.92 ft long) in the field and immediately capped to preserve fluid saturations. This method of water saturation determination has been found to give consistent results in the Montney tight gas fairway (Wood, 2013).

Organic petrography observations and measurements were made on 93 samples from the Montney tight gas fairway, under white and fluorescent reflected light using a Zeiss Axioimager II microscope coupled with Diskus-Fossil imaging and photometry software. Sample pellets were made with a cold-setting epoxy–resin mixture and then ground and polished in preparation for microscopy. Vitrinite-

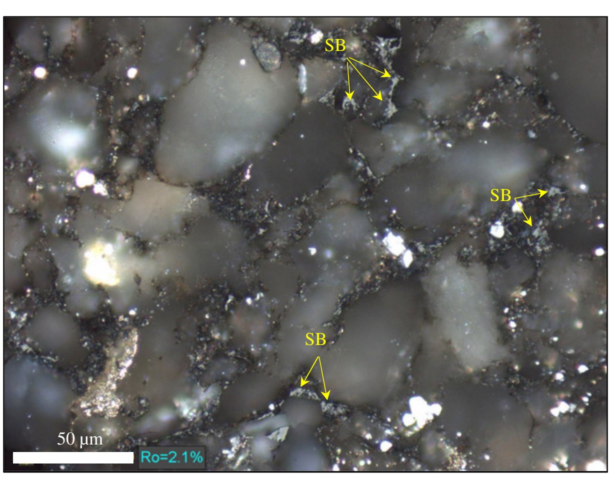

Fig. 1. Photomicrograph (oil immersion, white incident light, 50× objective) of a typical coarse-grained siltstone from the dry gas window of the Montney Formation showing pervasive paleo-pore filling, solid bitumen (SB).

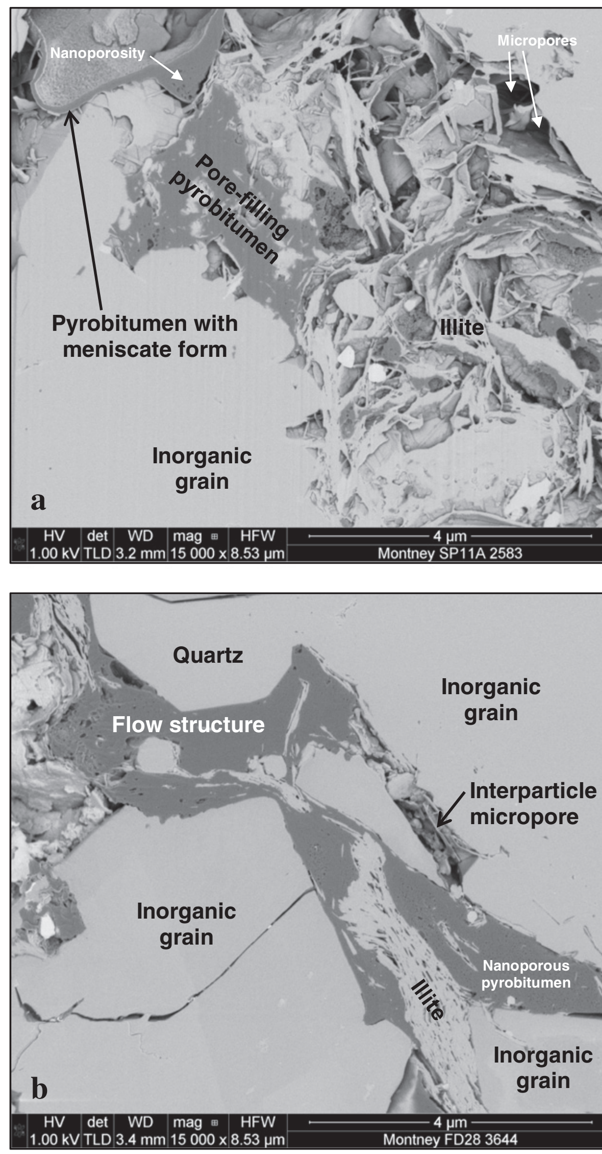

Fig. 2. FIB/SEM images showing paleo-porosity partially filled with solid bitumen and illite platelets. (a) Remnant interparticle porosity preserved as micropores (upper right). Solid bitumen with meniscate form (upper left) is indicative of previous liquid oil phase. Meniscate solid bitumen maceral contains nanoporosity. (b) Flow structure within solid bitumen (upper left) is indicative of previous liquid oil phase. Solid bitumen in lower right contains pervasive nanoporosity. Interparticle micropore preserved where tight packing of silt grains prevented intrusion of oil/bitumen (center right).