Marine and Petroleum Geology 43 (2013) 464–477

Contents lists available at SciVerse ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Biogenically enhanced reservoir properties in the Medicine Hat gas field, Alberta, Canada

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A R T I C L E I N F O

Article history:
Received 21 September 2011
Received in revised form
7 October 2012
Accepted 7 December 2012
Available online 22 December 2012

Keywords:
Bioturbation
Porosity
Permeability
Reservoir quality
Micro-CT
Spot-minipermeametry
Medicine Hat gas field
Ichnology

A B S T R A C T

Spot-minipermeametry and micro-CT analytical techniques were employed to evaluate the effect(s) of bioturbation on porosity and permeability distributions in reservoir facies of the highly prolific Medicine Hat gas field of Alberta, Canada. This study focuses on five cm-scale samples that occur at different stratigraphic positions and intersect discrete bioturbated horizons within the Medicine Hat Member. Spot-minipermeability results demonstrate that permeability in bioturbated sandstones is up to two orders of magnitude greater than those of the muddy matrix, thus corresponding to a dual-porosity fluid flow system. Graphing bioturbation intensity versus measured permeability indicates that burrows are well connected horizontally and provide flow conduits. Micro-CT models reveal that burrowed sandstones are isolated and planiform in character; rare interpenetrations from vertically oriented trace fossils serve to interconnect these hydraulically isolated strata. Results show that bioturbated sandstones possess reservoir properties comparable to those associated with laminated sandstones, yielding an anisotropic porous medium. Understanding the impact of trace fossils on porosity–permeability distributions in the Medicine Hat gas field can be used to identify potential reservoir from previously interpreted non-reservoir rock, and, ultimately, improve reserve estimations.

1. Introduction

Bioturbating organisms have been shown to alter both the textural and fabric attributes of sediments and create macropores in the shallow marine and vadose zones, thereby enhancing porosity and permeability (Meadows and Tait, 1989; Perret et al., 1999; Pierret et al., 2002; Bastardie et al., 2003). More recently, the effects of bioturbation on permeability in the rock record has also been explored (Gingras et al., 1999; Gingras et al., 2004; Pemberton and Gingras, 2005; Gingras et al., 2007; Cunningham et al., 2009; Tonkin et al., 2010; Lemiski et al., 2011; La Croix et al., 2012). Together, these studies demonstrate that the effective permeability of a stratum can be markedly enhanced by the presence of discrete, tubular, coarser-grain filled burrows in an otherwise finer-grained and less permeable matrix. Perhaps most importantly from a reservoir-development standpoint, is that the bulk permeability of burrowed horizons can be predicted (e.g., Gingras et al., 1999).

To investigate the effects of bioturbation on porosity distribution in the rock record, the textural attributes of *Macaronichnus*-burrowed sandstone were visualized in three dimensions, using magnetic resonance imaging (MRI) paired with the petrographic techniques elucidated by Gingras et al. (2002b). Based upon the distribution of mineral grains and porosity, they surmised that the burrowed zones represented a dual-porosity flow media (discussed below). A similar flow media was documented in Gingras et al. (2002a) from carbonate rocks of the Palliser Formation in the Alberta Foothills.

Two mechanisms have been proposed for biogenic permeability enhancement: 1) burrow-mediated modification of the primary

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http://dx.doi.org/10.1016/j.marpetgeo.2012.12.002

depositional fabric; and 2) diagenetic alteration of the sedimentary matrix *via* recrystallization (Pemberton and Gingras, 2005). Furthermore, two types of fluid flow networks can result from biogenically altered media; *dual-porosity* and *dual-permeability* networks. Dual-porosity systems are characterized by burrow-associated permeability that is within two orders of magnitude relative to the permeability of the surrounding matrix. A dual-permeability system results when the permeability contrast between burrow fills and the matrix is greater than two orders of magnitude. Such systems produce highly contrasting, well-defined permeability fields (Gingras et al., 2007).

Tonkin et al. (2010) and Lemiski et al. (2011) constitute the most recent examinations of the role of trace fossils in the analysis of reservoir facies in the Jean D'Arc basin of Atlantic Canada and the Alderson Member of southwest Saskatchewan, respectively. These previous investigations provide the framework for the present study focused on the effects of bioturbation on porosity and permeability.

Herein, spot-minipermeametry and micro-CT analyses of sporadically bioturbated intervals are used to assess the impact of sand-filled trace fossils on porosity and permeability development and connectivity in intervals that were previously interpreted as marginal reservoirs, or non-reservoir rocks (i.e., siltstones and mudstones with thin sandstone laminae and beds) in the Medicine Hat gas field of Alberta, Canada. Characterization of burrow-associated permeability may help to improve development strategies applied in this gas field by delineating secondary reservoir targets that have previously been bypassed, and potentially increasing reserve estimates from these reservoirs. Moreover the results provide valuable insight into the management of other pervasively bioturbated gas-bearing intervals (e.g., Colorado Group; Milk River and Lea Park formations) in the Western Canada Sedimentary Basin, and elsewhere.

2. Study area

The Medicine Hat gas field is located from Townships 8–22 (49.6111°N–50.9068°N), and Ranges 1–9 (110.0000°W–111.1334°W) west of the fourth meridian, spanning an area of more than 6000 km^2 (Fig. 1). The Medicine Hat field is one of the largest gas fields in Canada. Estimations of gas-in-place within the Medicine Hat Member reservoirs range from 4 to 6 trillion cubic feet (1.13×10^{11}–1.70×10^{11} m^3; O'Connell, 2003). At the time of this study, approximately 16 000 wells penetrated portions of the Medicine Hat Member. Approximately 156 of these wells are cored, and the remainder possess markedly varying vintages of wireline log data.

3. Geologic setting

The Santonian Medicine Hat Member is part of the Upper Cretaceous Niobrara Formation, lying above the Verger Member and overlain by the First White Specks Member (Fig. 2). The Medicine Hat Member broadly correlates with the Marshybank, Dowling, and Thistle members of the Wapiabi Formation in the southern Alberta Foothills, and records the westward extension of

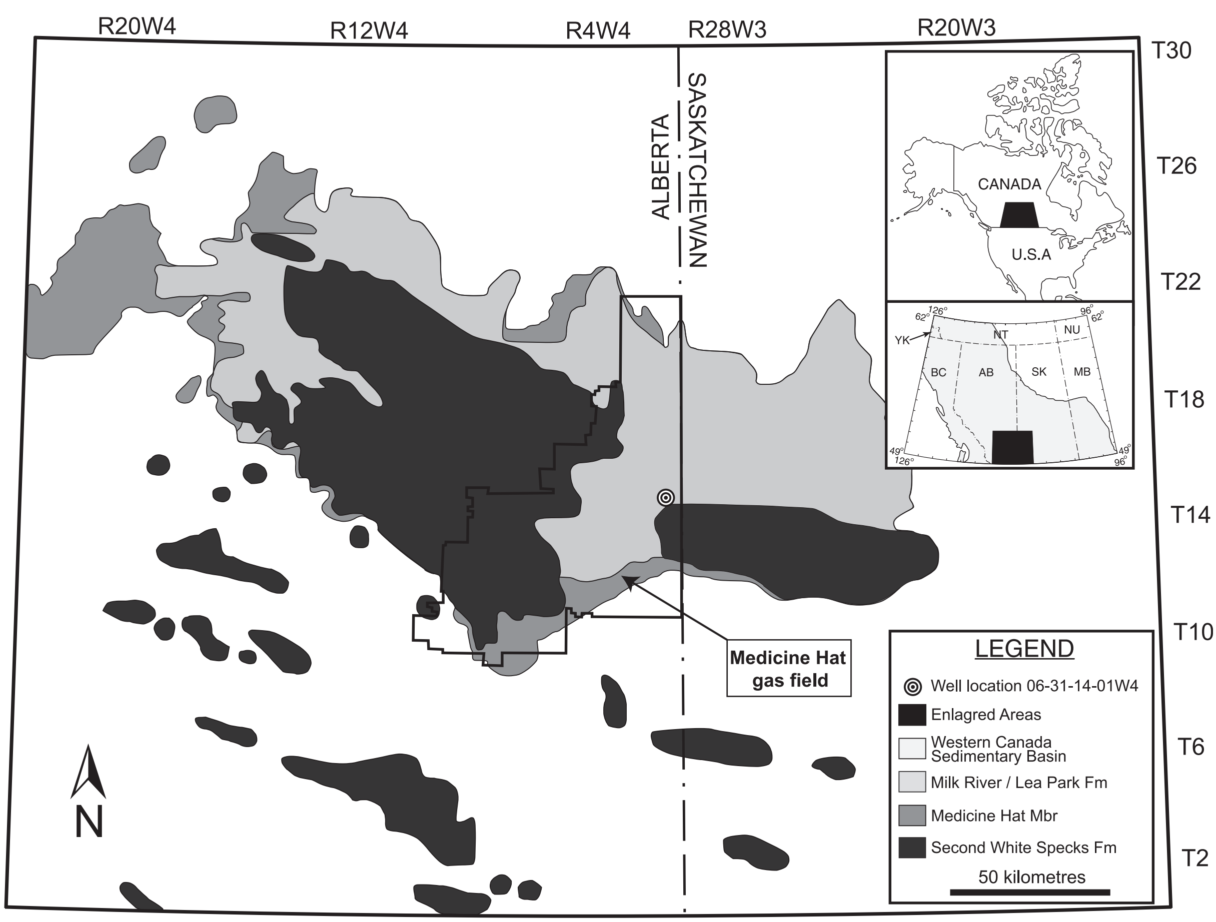

Figure 1. Distribution of Upper Cretaceous gas fields in southeast Alberta and southwest Saskatchewan. The combined reserves of the Milk River/Lea Park Formation, Medicine Hat Member (Niobrara Formation), and Second White Specks Formation constitute some of the largest gas accumulations discovered in Canada. The Medicine Hat gas field (study area) is highlighted. The well 06-31-14-01W4 indicated on the map contains the cored interval examined in this study (modified from O'Connell, 2003).