Journal of Natural Gas Science and Engineering 24 (2015) 185–196

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

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

Fractal analysis of tight gas sandstones using high-pressure mercury intrusion techniques

Jin Lai, Guiwen Wang*

State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing 102249, China

ARTICLE INFO

Article history:
Received 29 December 2014
Received in revised form
9 March 2015
Accepted 20 March 2015
Available online 25 March 2015

Keywords:
Tight gas sandstones
Pore structure
Fractal dimension
High-pressure mercury intrusion
r_{apex}

ABSTRACT

Pore structure is one of important factors affecting the properties of sedimentary rocks, however, it is difficult to describe microscopic parameters of the pore structure such as pore geometry, pore-size distribution, and pore space topology. Fractal theory is an effective and available method to quantify the complex and irregular pore structure of rocks. Routine rock properties measurements and high-pressure mercury intrusion tests (HPMI) were performed on a suite of the Bashijiqike tight gas sandstone samples to delineate the pore network characteristics of these reservoir rocks. Thin section epi-fluorescence and scanning electron microscopy (SEM) analyses were used to gain insight into pore geometry and pore size distribution of these sandstones.

The results show that the pore system of the sandstones mainly consists of intergranular macropores and intragranular micropores. The HPMI analysis shows that these reservoir rocks have complex, heterogeneous microscopic pore structure. There are clear inflection points on the fractal curves of log (SHg) versus log(Pc), i.e., the fractal curves break into two segments at the capillary pressures corresponding to the apex of the Pittman's hyperbola (plot of the ratio of mercury saturation over capillary pressure against mercury saturation). Fractal dimensions were calculated using the slope of straight part of each curves. Small pores ($<r_{apex}$) tend to have fractal dimension (*Df*) values less than 2.5, while large pores ($>r_{apex}$) were more likely to have *Df* values larger than 3.0. *Df* for small pores is strongly correlated with r_{50} and r_{35}, while for large pores, no obvious relationship exists between *Df* and the pore structure parameters. *Df* for small pores could be used to evaluate the microscopic pore structures and heterogeneities of reservoir rocks. Over-simplification of cylinder shape of pore space, the high working pressure and well developed micro-fractures result in the high *Df* values (>3.0) for large pores ($>r_{apex}$).

1. Introduction

Tight gas sandstone reservoirs in China are suggested to be reservoirs with porosity less than 10%, in situ permeability less than 1 mD, pore throat diameter less than 1 μm and gas saturation less than 60% (Zou et al., 2012). These sandstones are all characteristic by typically poor reservoir quality and showing strong heterogeneities (Higgs et al., 2007; Zou et al., 2012; Lai et al., 2015). Pore structure is one of the important factors affecting the properties of rocks, and processes of fluid transport through underground reservoirs are closely related with the microscopic pore structure (Tsakiroglou and Payatakes, 2000). However, the complexity and irregularity of pore structure make it difficult to quantitatively characterize pore structure by Euclidean geometry and other traditional experimental methods (Wang et al., 2012). Since the concept of fractal was firstly proposed by Mandelbrot (1977), fractal geometry has been successfully used to characterize the spatial heterogeneities of different patterns over a wide range of pore spaces in sedimentary rocks (Xie et al., 2010). Fractal theory is an effective method for investigating pore structure of rocks, which builds a bridge between micro-morphology (pore size and shape, pore size distribution, pore connectivity) and macro performance (porosity, permeability) (Hu et al., 2012). Many scholars have developed the fractal theory to study the fractal characteristics of pore structure in rocks (Li, 2010a; Wang et al., 2012; Giri et al., 2012; Anovitz et al., 2013). They confirmed that the pore distribution in rocks is statistically self-similar, i.e., identically independent of the scale of magnification (Wang et al., 2012), such fractal objects are characterized by the fractal dimension *Df* (Kulesza and Bramowicz,

* Corresponding author. China University of Petroleum-Beijing, 18 Fuxue Road, Changping District, Beijing 102249, China.
E-mail addresses: sisylaijin@163.com (J. Lai), wanggw@cup.edu.cn (G. Wang).

http://dx.doi.org/10.1016/j.jngse.2015.03.027
1875-5100/

2014). Fractal dimensions have been extensively used in quantifying the complexity of pore structure and physical properties of rocks (Wang et al., 2012).

High pressure Mercury intrusion techniques are widely used for the determination of total pore volumes and pore size distributions for reservoirs rocks (Nooruddin et al., 2014). Fractal dimensions calculated from capillary pressure curves are frequently used to evaluate the microscopic heterogeneities of reservoir rocks (Li, 2010a). The major goals of this work are to investigate the fractal characteristics of tight gas sandstones from the Bashijiqike sandstones in Kelasu thrust belt, Kuqa depression in the Tarim Basin of West China (Fig. 1; Zhao et al., 2005). The fractal dimension was calculated from capillary pressure curves, and then the relationships between pore structure parameters and fractal dimensions were analyzed. Thin section and epifluorescence analyses were used to reveal the pore systems of the Bashijiqike tight gas sandstones. Further the fractal characteristics are correlated with the pore throat radius corresponding to the apex (r_{apex}) by Pittman (1992). In addition, how r_{apex} affect the fractal dimensions is investigated, then the internal relationships between pore size distribution and fractal dimensions were also discussed in this work. The sandstones have complex, heterogeneous microscopic pore structures. The log(SHg) − log(Pc) plots have clear inflection points at certain capillary pressures. Small pores and large pores have different fractal dimension values. Small pores tend to have fractal dimension (*Df*) values less than 2.5, while larger pores were more likely to have *Df* values larger than 3.0. Fractal dimension is mainly associated with micropores. At last, the reasons why the small pores and large pores have different fractal dimensions are also discussed in this paper. The fractal analysis results are of great importance for quantitatively characterizing the pore structure and heterogeneity of tight gas sandstones, and for industry engineering systems such as petroleum exploration and hydraulic engineering.

2. Materials and methods

2.1. Methodology

Previous studies on sedimentary rocks confirmed that the pore system has a fractal nature (Giri et al., 2012). Several methods have been proposed to calculate fractal dimension of pore structure on the basis of SEM, SANS, thin-sections, and mercury intrusions. However, only the mercury intrusion technique was considered in this study. There have been mainly three models to derive fractal dimensions from capillary pressure curves (Li, 2010a). Fractals are virtual, self-similar geometrical objects that appear identically independent of the scale of magnification (Kulesza and Bramowicz, 2014). Self-affinity with a dimension is an important feature of a fractal object in nature, and this feature can be represented

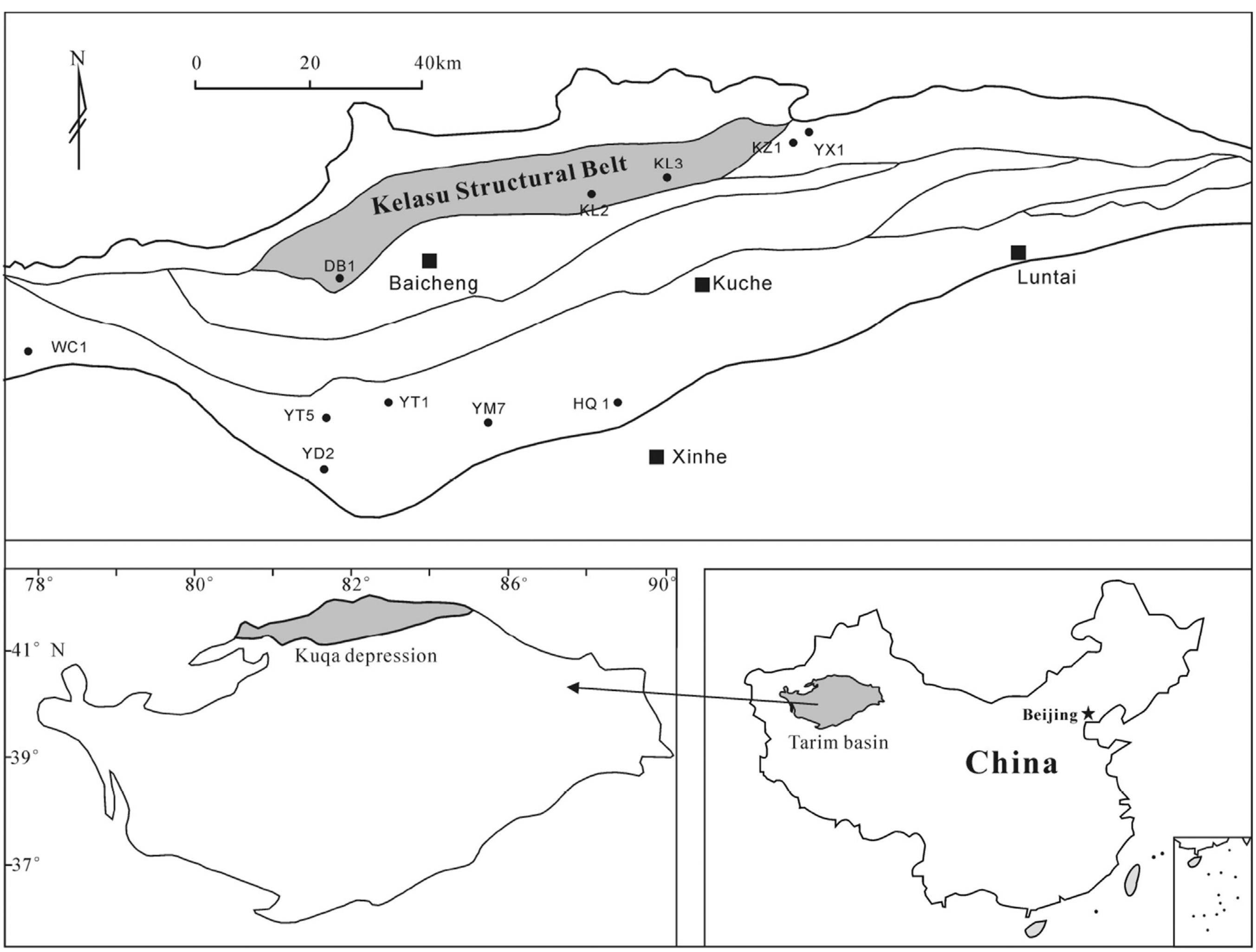

Fig. 1. Map showing the location of the study area (Kelasu structural belt in Kuqa Depression of the Tarim Basin) (modified after Zhao et al., 2005).