Journal of Petroleum Science and Engineering 138 (2016) 31–49

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Analysis of developmental characteristics and dominant factors of fractures in Lower Cambrian marine shale reservoirs: A case study of Niutitang formation in Cen'gong block, southern China

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ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form
11 October 2015
Accepted 7 December 2015
Available online 8 December 2015

Keywords:
Shale
Fracture
High maturity
Niutitang formation
Lower Cambrian
Southern China

ABSTRACT

Fractures are important to shale gas reservoirs because they can increase the storage spaces and seepage pathways. In addition, natural fracture systems are important to hydraulic-fracture stimulation to form fracture networks. Currently, China has achieved a breakthrough of the Lower Silurian Longmaxi formation in Sichuan basin and its surrounding areas. Compared with the Longmaxi shale, the Lower Cambrian Niutitang shale has greater TOC content, depositional thickness and wider distribution areas; thus, it is another significant stratum for China's shale gas. This paper discusses the characteristics and dominant factors of fractures and their relationship to the gas content in the Niutitang shale based on several types of data: observations and descriptions of fracture systems in outcrops, drilling cores, casting thin sections and field-emission scanning electron microscopy (FE-SEM); detailed fracture characteristics and parameters; and analyzes and tests of corresponding fracture segment samples. The results indicate that the Niutitang shale has similar brittle mineral and TOC content as Barnett shale, except that it has a higher maturity (equivalent Ro > 2.2%). Multiple types of fractures are abundant and have suffered multi-stage activation and modification; these are mainly structural fractures due to the late diagenetic stage and multi-stage tectonic movements in southern China. The primary types of micro-fractures are interlayer, inter-particle and intra-particle fractures. The fractures with scratches have abundant pores in mylonitic minerals, and unsealed fractures (inter-particle, intra-particle fractures, and cleavages) and pores (inter-particle, intra-particle and dissolved) in the cement of the fractures and have improved the effectiveness of sealed fractures. The development of fractures is controlled by structural factors, mineral composition, TOC, reservoir heterogeneity, lithology and rock mechanical properties, and the structural factor is the uppermost. Within the same tectonic setting, the content of the brittle minerals, brittleness (rock mechanical properties), and heterogeneity are positively correlated with the fracture density. When the TOC is less than 6.5 wt%, the fracture density, porosity and brittleness display positive correlations with TOC; however, when the TOC is greater than 6.5 wt%, the positive correlations become negative. The high quartz content (rigid particles), which is usually accompanied with high TOC, favors the development and preservation of micro-pores and fractures. Fractures have played important roles in seepage pathways, storage spaces, and interconnections of isolated micro-pores, which leads to positive correlations between the fracture density, total and desorbed gas content. Knowledge regarding this area will guide the exploration and development of shale gas and is helpful in optimizing the intervals of drilling and fracturing stimulation.

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http://dx.doi.org/10.1016/j.petrol.2015.12.004
0920-4105/

1. Introduction

The success of the “Shale gas revolution” in North America has drawn considerable attention around the world to shale as a commercial hydrocarbon reservoir (Curtis, 2002; Montgomery et al., 2005; Jarvie et al., 2007; Pollastro et al., 2007). Many countries have undertaken studies and experimental work of shale gas evaluation, exploration and development. Geological evaluation of shale gas and predictions of favorable areas have achieved considerable understanding in various sedimentary basins and shale distribution areas in China (Nie et al., 2009; Zou et al., 2010; Ding et al., 2011a, 2013a; Guo, 2013a; Jiu et al., 2013a; Nie et al., 2013; Tian et al., 2013, 2015). Recently, the commercial development of the Jiaoshiba shale gas field of Lower Silurian Longmaxi formation in Chongqing indicates that southern China is an important strategic area for China's shale gas. Compared with North America, Paleozoic marine organic-rich shales in southern China have the characteristics of multiple strata, old formation age, high

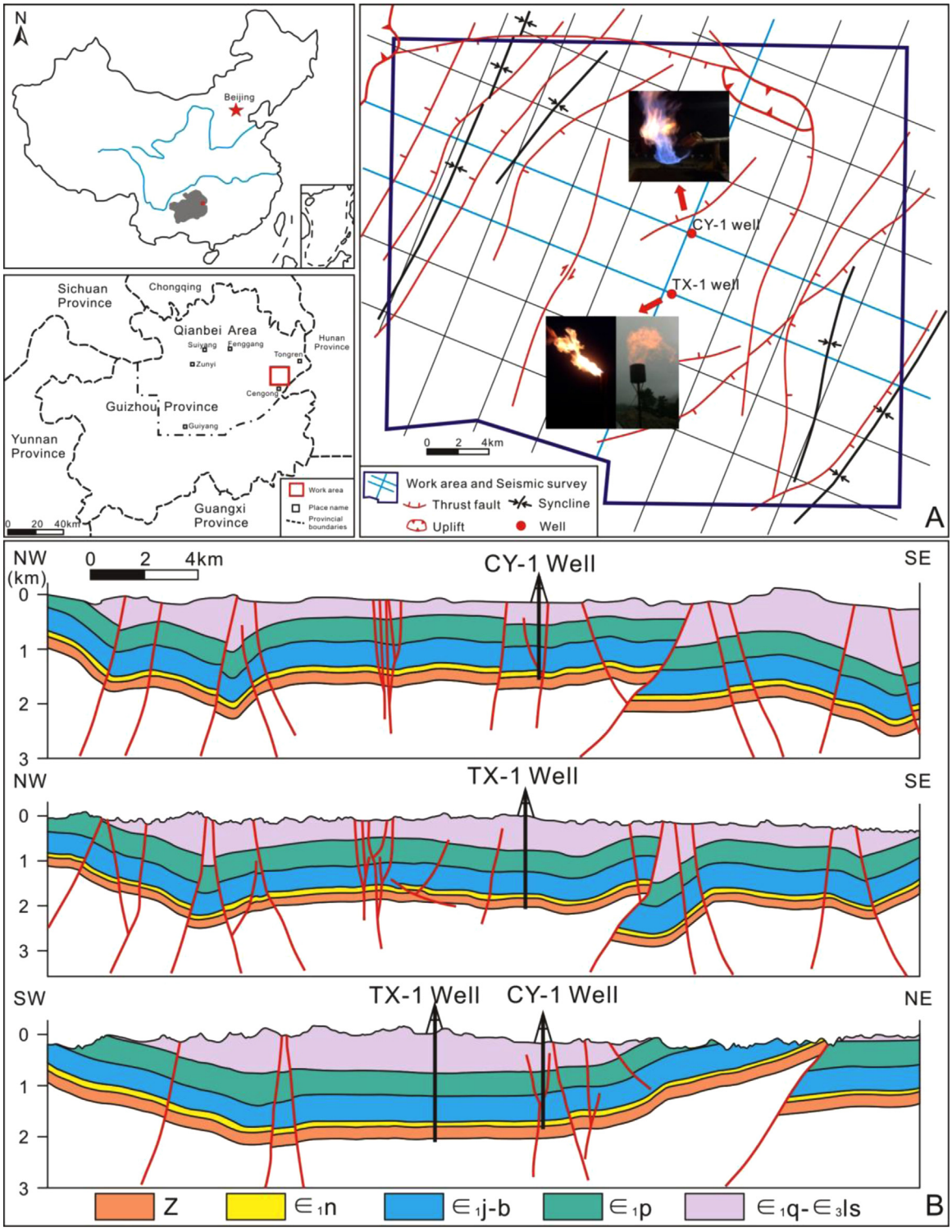

Fig. 1. (A) Location of the study area; the map shows the structural features; and (B) the seismic cross-section of the CY-1 well and TX-1 well with the location shown in (A).