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Natural fractures and their influence on shale gas enrichment in Sichuan Basin, China

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ABSTRACT

Natural fractures, which serve as the main flow channels and important storage spaces, have significant effects on the formation, distribution and development of shale gas. We found three types of natural fractures developed in the Paleozoic marine shales of the southeastern Sichuan Basin, including tectonic fractures, diagenetic fractures and abnormal high-pressure-related fractures. Tectonic fractures can be further divided into intraformational open fractures, transformational shear fractures and bed-parallel shear fractures, whereas diagenetic fractures can be divided into bed-parallel lamellated fractures and shrinkage fractures. We determined that the formation of shale fractures is determined by the brittle-mineral content, shale texture, strata attitude, fluid pressure and geological structure. Brittle minerals, e.g., quartz, feldspar and dolomite, are necessary for the formation of shale fractures. Lamellation could change the mechanical property of fractures, which caused the formation of bed-parallel shear fractures. Geological structure is a key factor determining the maturity of shale fractures. The distribution and development of shale gas is barely influenced by shrinkage fractures and abnormal high-pressure-related fractures due to the low transport effectiveness. Intraformational open fractures, transformational shear fractures, bed-parallel shear fractures and lamellation fractures are significant to shale gas. The denser intraformational open fractures and lamellation fractures can enrich the degree of shale gas. We determined that the scale of shear fractures is the key factor influencing gas preservation rather than the density of natural fractures. Transformational shear fractures determine the gas preservation in areas with low dip-angle strata, whereas bed-parallel shear fractures determine the gas preservation in areas with high dip-angle strata.

1. Introduction

Shale gas, which is an important type of unconventional gas resource, is widely distributed in the Paleozoic black marine shale in southern China and the Meso-Cenozoic lacustrine shale in northern China and has broad prospects for exploration and development (Wang et al., 2009b; Yang et al., 2009; Chen et al., 2010; Liu et al., 2010; Zou et al., 2010). Natural fractures can provide the main flow channels and important storage space for shale gas and control the migration, accumulation, and preservation of shale gas in single well production (Hill and Nelson, 2000; Jarvie et al., 2007; Li et al., 2007; John, 2008; Zhang et al., 2008; Chen et al., 2009; Cheng et al., 2009; Wang et al., 2009a; Zhang and Pan, 2009; Dong et al., 2010; Wang et al., 2010; Kassis and Sondergeld, 2010). The characteristics of natural fractures also determine the drilling and completion methods, and have great influences on hydraulic fracturing and development efficiency of shale gas (Gale and Holder, 2010; Weng et al., 2011; Gu et al., 2012; Cho et al., 2013; Gale et al., 2014). Due to the complicated geological conditions in southern China, the distribution of natural fractures in shale gas reservoirs is much more complicated compared with that in sandstones, conglomerates, carbonates and igneous rocks. Therefore, the study of natural fractures is of great significance for the ongoing exploration and drilling design of shale gas.

Increasing the discovery, exploration and development for oil and gas in shale reservoirs has led to an increasing amount of research on natural fractures in recent years (Zeng and Xiao, 1999; Montgomery et al., 2005; Zhou et al., 2006; Gale et al., 2007; Zhao et al., 2007; Engelder et al., 2009; Kajari and Shankar, 2009; Ding et al., 2011, 2013; Zeng et al., 2013). In addition to tectonic fractures, abnormal high-pressure-related fractures formed during the thermal evolution of organic matter are well developed in shales

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(Zeng and Xiao, 1999; Zhou et al., 2006; Zhao et al., 2007; Ding et al., 2011; Kobchenko et al., 2011). However, issues of fracture classification criteria, controlling factors, and genetic effects on the enrichment and production of shale gas have not yet been clarified. The study on such issues is critical to the understanding of shale gas accumulation and enrichment.

Based on the outcrops, core data and fullbore formation microimager logs, we studied the origin types and development characteristics of natural fractures in the Paleozoic marine shales in the southeastern Sichuan Basin. We analyzed the influences of different types of natural fractures on shale gas enrichment. These results serve as a guide for the increasing exploration and development of marine shale gas in southern China.

2. Geological setting

The southeast Sichuan Basin covers southern Chongqing, northern Guizhou and southeastern Sichuan. The southeast Sichuan Basin is composed of S–N and NE–SW trending fold belts and fault zones (Fig. 1). Caledonian movement led to the stratigraphic lacuna of the Devonian and Carboniferous Systems, except from the Neoproterozoic Sinian, Paleozoic and Mesozoic Systems in the study area (Sichuan Oil and Gas Editorial group, 1989) (Fig. 2). Among these sedimentary strata, there are two sets of black marine carbonaceous shales of the Lower Cambrian Qiongzhusi Formation (also called the Niutitang Formation in the northern Guizhou Province) and the Upper Ordovician Wufeng Formation — Lower Silurian Longmaxi Formation in southeastern Sichuan Basin. These shales are widely distributed with great thickness and high pyrite, organic matter and biological fossil content, which are the prior targets for the exploration and development of Paleozoic marine shale gas in southern China (Zhang et al., 2009; Wang et al., 2009b; Dong et al., 2010).

3. Fracture type and characteristics

According to geological characteristics and distribution features of natural fractures in outcrops and cores, natural fractures are divided into three origin types, i.e., tectonic fractures, diagenetic fractures and abnormal high-pressure-related fractures, in the Paleozoic marine shales in southeastern Sichuan Basin. Tectonic fractures include intraformational open fractures, transformational shear fractures and bed-parallel shear fractures, whereas diagenetic fractures include lamellation fractures and shrinkage fractures. Among these types of natural fractures, intraformational open fractures, transformational shear fractures and lamellation fractures are dominantly abundant in the Sichuan Basin.

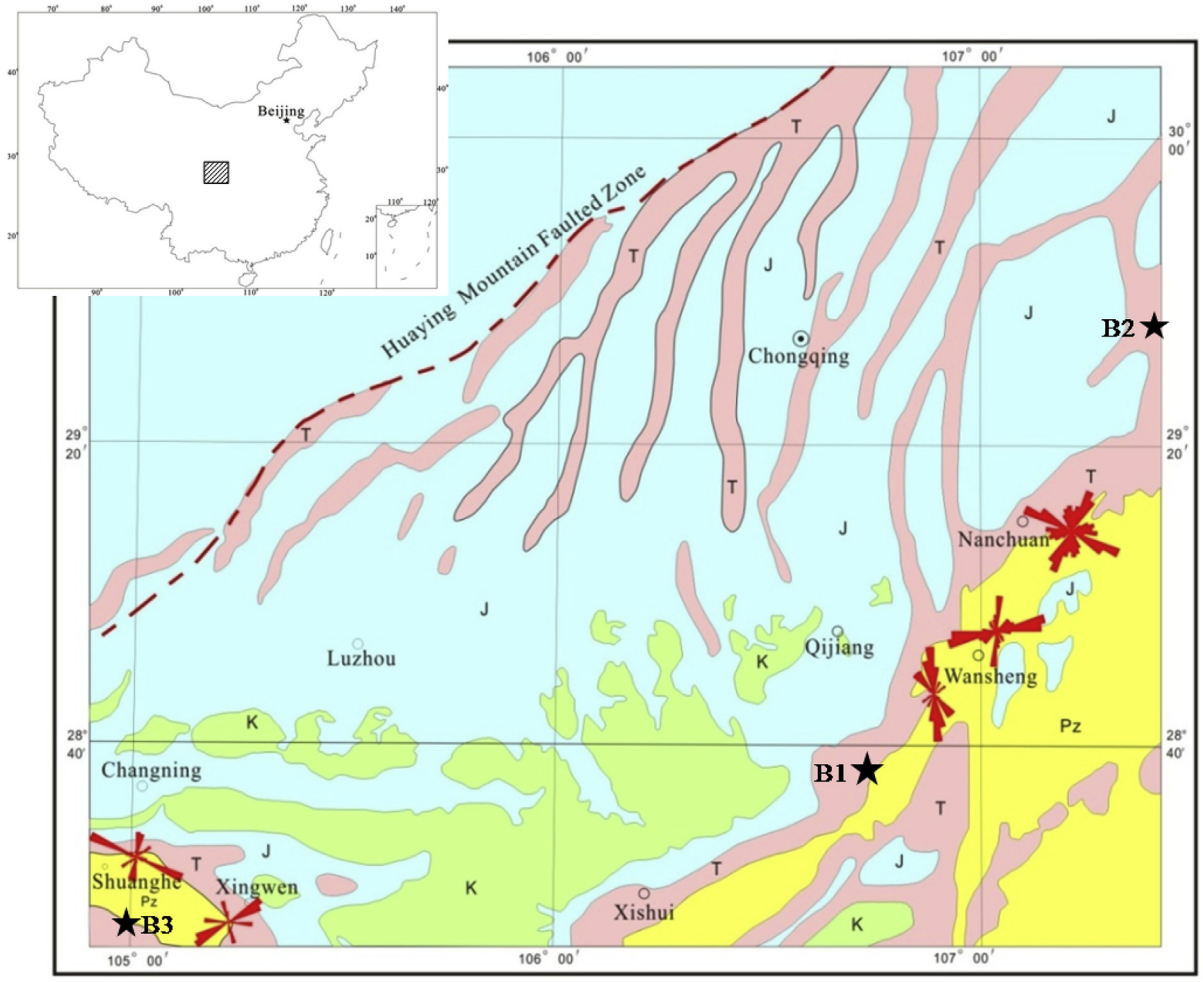

Fig. 1. Geological map of the southeastern Sichuan Basin and the locations of wells, cores and image logs. The rose diagrams indicate the orientations of natural fractures obtained from outcrops of the Paleozoic marine shales.