Journal of Asian Earth Sciences 127 (2016) 47–62

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Full length Article

Joint development and tectonic stress field evolution in the southeastern Mesozoic Ordos Basin, west part of North China

Lin Jiang [a,*], Zhen Qiu [b], Qingchen Wang [c], Yusen Guo [a], Chaofan Wu [a], Zhijie Wu [a], Zhenhua Xue [c]

[a] College of Resource and Engineering, Longyan University, Longyan, Fujian 364012, China
[b] PetroChina Research Institute of Petroleum Exploration and Development, Beijing 100083, China
[c] State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

ARTICLE INFO

Article history:
Received 1 March 2016
Received in revised form 14 June 2016
Accepted 21 June 2016
Available online 22 June 2016

Keywords:
Joint
Stress field
Mesozoic strata
Ordos Basin

ABSTRACT

Major joint sets trending E-W (J_1), ENE-WSW (J_2), NE-SW (J_3), N-S (J_4), NNW-SSE (J_5), NNE-SSW (J_6), NW-SE (J_7), and WNW-ESE (J_8) respectively are recognized in Mesozoic strata within the southeast of Ordos Basin. Among them, the J_1, J_2 and J_3 joint sets are systematic joints, while the other five joint sets (J_4, J_5, J_6, J_7, J_8) are nonsystematic joints. There are three groups of orthogonal joint systems (i.e. J_1 and J_4 sets, J_2 and J_5 sets, and J_6 and J_8 sets) and two groups of conjugate shear fractures (ENE-WSW and NNE-SSW, ENE-WSW and ESE-WNW) in the study area. Joint spacing analysis indicates that: (1) layer thickness has an effect on the joint spacing, but the correlation of joint spacing and layer thickness is low; (2) joint density of systematic joints is greater than nonsystematic joints, and the joint density of a thin layer is also greater than that of a thick layer; and (3) the joints of Mesozoic strata in the basin are the result of tectonic events affected by multiple stress fields. All these joints in the Mesozoic strata are formed in the two main tectonic events since Late Mesozoic times. One is the westward subduction of the Pacific Plate beneath the Eurasia Plate, which formed the approximately E-W-trending compressive stress field in the China continent. The trends of the J_1 joint set (E-W) and the bisector of conjugate shear fractures composed of ENE-WSW and ESE-WNW fractures are all parallel to the trend of maximum compressive stress (E-W). The other stress field is related to the collision of the Indian and Eurasian Plates, which formed the NE-SW-trending compressive stress field in the China continent. The trends of the J_3 joint set and bisector of conjugate shear fractures composed of ENE-WSW and NNE-SSW fractures are all parallel to the trend of maximum compressive stress (NE-SW). Finally, we conclude that the J_1 and J_4 sets are formed in the E-W-trending compressive stress field, and the J_2, J_3, J_5, J_6, J_7 and J_8 sets are formed in the NE-SW-trending stress field.

1. Introduction

Rock joints occur either by rupture in shear or rupture in tension. Pollard and Aydin (1988) point out that rupture in tension leads to the propagation of joints. Therefore, we know that joints are opening-mode fractures formed as a consequence of the deformation of brittle rock masses in the Earth's crust (Pollard and Aydin, 1988; Mandl, 2005). At the depth in basins where stress is compressive, when the pore fluid pressure exceeds the minimum principal compressive stress, tension occurs and prompts joint formation, so the joints are natural hydraulic fractures (Engelder, 1982; Mandl, 2005; Engelder et al., 2009; Gale et al., 2007, 2014). Joints are frequently systematic and may be pervasive over large regions (Hodgson, 1961). Therefore, joints often have a greater effect on hydrocarbon reservoirs than faults.

The Ordos Basin is large Mesozoic intracontinental basin that is superimposed upon the North China Paleozoic cratonic platform. Since Mesozoic times, the Ordos Basin has experienced multiphase tectonic events (Xu et al., 2006; Zhang et al., 2007, 2011), and formed a series of natural fractures (i.e. joints). Chinese researchers (Zhang, 1996; Wang et al., 2010; Jiang et al., 2013, 2015) have performed research about natural fractures (joints). There are many reservoirs with low porosity and permeability in the Ordos Basin: these natural fractures have a great effect on petroleum reservoirs (Zeng and Li, 2009). Therefore, studying the joint patterns, formation mechanism, distribution characteristics, and elucidating the relationship between the joint system and migration of hydrocarbons, are necessary.

Meanwhile we know that joints are sensitive to the regional stress orientation (Hancock, 1985; Pollard and Aydin, 1988), and

* Corresponding author.
E-mail address: ly_university@163.com (L. Jiang).

http://dx.doi.org/10.1016/j.jseaes.2016.06.017
1367-9120/

they are good indicator of stress orientation. So analysis the relationship between the joints and the stress field is helpful to understand the formation of the joints. Although the entire Ordos Basin has evolved into an intracontinental basin during Late Triassic times, the basin is still affected by adjacent regional tectonic events, such as the closure of the Mongol-Okhotsk ocean (Zorin, 1999), the convergence between the Pacific Plate and the Eurasian Plate, and the convergence between the Lhasa Block and the Eurasian continent (Dong et al., 2008; Zhang et al., 2011). However, the influence of remote effects on the joint formation has not yet been understood clearly. In the following section, we will discussion the tectonic evolution history of the Ordos Basin and adjacent region in Section 2.2. But because the main study object of this paper is the joint in Mesozoic strata, we will focus our discussion on the relationship between joint formation and the Mesozoic-Cenozoic tectonic evolution in Section 5.

The aims of this paper are to: (1) describe the joint characteristic patterns in Mesozoic strata, such as joint orientations and joint spacing, (2) describe the interaction between joint sets, (3) find the effects of bed thickness and stress field, and (4) interpret the relationship between the joints and stress field. Moreover, because most joints in the study area are vertical, we discuss horizontal stress. This is because the minimum compressive principal stress occurs approximately in the horizontal plane, with the orientations of the joints being controlled by the maximum (σ_H) and minimum (σ_h) horizontal stress. The minimum compressive stress is important in joint formation and propagation.

2. Geologic setting

2.1. Location and stratigraphy

The Ordos Basin is located in the western part of the North China Block; it is a large intracontinental composite basin, which was developed based on Paleozoic shallow marine sediments and Mesozoic continental deposits. The Basin's eastern boundary lies in the Luliang Orogenic Belt, west of the Helan-Liupan Orogenic Belt; the northern boundary is the Yinshan-Yanshan Orogenic Belt; and the basin is separated from the Qinling Orogenic Belt by the Weihe graben in the south (Fig. 1). The basin, in which faults and folds were not developed, is a gentle monocline where the dip angle is less than 1° from east to west (He, 2003).

According to the analysis of sedimentary records and lithofacies paleogeographic evolution history, the Ordos Basin experienced multiphase evolutionary stages from Paleozoic sedimentary marine facies, Mesozoic sedimentary continental facies, to Cenozoic basin peripheral fault-depression activities. In the basin, outcropping strata from east to west, in turn, are Cenozoic, Mesozoic, and Paleozoic sedimentary strata. Among them, the Paleozoic marine facies and the Mesozoic continental facies are petroliferous. The Mesozoic sedimentary rocks provide the source of continental hydrocarbon and the reservoir of low-permeability sandstones. The source rock is mainly shale (or mudstone) of the Yanchang Formation, whose cumulative thickness is about 60–140 m (He, 2003).

In the basin, the Mesozoic strata are very complete, mainly fluvial-lacustrine sedimentary facies; the lithology is mainly sandstone or mudstone, locally conglomerate. According to the sedimentary records and lost strata, Mesozoic strata were divided into four structural sequences (Fig. 2): (1) The Triassic, which is in a conformity contact relationship with the underlying Late Paleozoic sediments; the tectonic setting is consistent with Late Paleozoic time; and the sedimentary environment is mainly stable platform and inland facies (J.B. Chen et al., 1997; S.T. Chen et al., 1997). The Yanchang Formation contains shale (or mudstone), which is the main source rock. (2) The Jurassic, which has a parallel unconformity contact with underlying Late Triassic strata; the tectonic setting is more stable than that of the Late Triassic. The sediment is mainly fluvial-delta depositional facies (Li et al., 1995). (3) The Upper Jurassic-Fenfanghe Formation, which is coarse clastic alluvial fan facies, reflecting basin-periphery strong tectonic activity and molasse formation caused by uplift. The contact with the underlying Anding Formation is a parallel unconformity (Lu et al., 1989). (4) The Cretaceous; only Lower Cretaceous strata in the study area, which covers the underlying Fenfanghe Formation by an angular unconformity (Lu et al., 1989). The Early Cretaceous strata are mainly red colored; the sedimentary environment may be inferred as ancient desert facies or droughty lacustrine facies.

2.2. Regional stress fields in the Ordos Basin

The tectonic evolution of the Ordos Basin was closely associated with that of the North China Block (NCB). NCB experienced five major tectono-sedimentary periods (Yang, 2002): (1) Meso to Neoproterozoic intracontinental rifting and aulacogen development along the western margin of the cratonic block; (2) Early Paleozoic (Cambrian to Middle Ordovician) shallow platform facies deposition and subsequent uplift and erosion during Late Ordovician to Early Carboniferous times; (3) Late Paleozoic (Middle Carboniferous to Middle Triassic) marine to continental transition facies deposition; (4) Mesozoic (Late Triassic to Early Cretaceous) fluvial-lacustrine facies deposition; and (5) Cenozoic uplift and graben system formation around the Ordos Block.

During Late Permian times, the collision between North China Block and Siberia Plate led to the closure of the Paleo-Asian Ocean (Li, 2006; Eizenhöfer et al., 2014; D. Li et al., 2015), which is along the Solonker Suture Zone (i.e. northern margin of North China Block). Associated with the Triassic collisional amalgamation between the North and South China along the Qinling-Dabie-Sulu orogenic belt (Enkin et al., 1992; Meng and Zhang, 2000), the Ordos Basin became a large intracontinental basin. Since Middle-Late Jurassic times, tectonic differentiation in the Ordos Basin took place, from the eastern part of NCB, and gradually formed the current morphotectonic pattern (J.B. Chen et al., 1997; S.T. Chen et al., 1997).

During Late Triassic times, the Qinling Ocean was closed along the south boundary of the Qinling Microcontinent (Hacker et al., 2004), which is located at the southern margin of the Ordos Basin: this is caused by the convergence between the South China Block (SCB) and NCB (Wan and Zhu, 2002; C.Y. Liu et al., 2006; Wang et al., 2006; Dong et al., 2008; Ritts et al., 2009; Hou et al., 2010). Meanwhile, the lack of Late Triassic to Early Jurassic strata in the southwest margin of the basin shows that the southwest margin of the basin is affected by NE-SW-trending remote compressive stress, which is related to the Qiangtang Block's convergence towards the Qaidam massif, and the formation of the Songpan-Ganzi fold belt (M. Liu et al., 2006; Dong et al., 2008; Ritts et al., 2009). However, in the northwest margin of Ordos Basin, there is a sedimentary record of Triassic intraplate extension in the Helan Mountains and the Zhouzi Mountains (Ritts et al., 2004). Therefore, there is not a uniform stress field in the entire basin during Late Triassic times.

Since Jurassic times, the Ordos Basin and the adjacent region have experienced a complicated tectonic evolution, and the Jurassic Period is also a transitional phase of tectonic regime in the North China Block, also for East Asia as a whole (Ren et al., 2002; Dong et al., 2008; Liu et al., 2008; Hou et al., 2010; Zhang et al., 2011). The understanding of the regional stress field of the Ordos Basin during this period is still in dispute. Some Chinese geologists have interpreted that the North China Block was under a WNW-ESE-trending compressive stress field during Jurassic times, which was caused by the westward subduction of the Pacific Plate