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Research paper

Inversion and propagation of the Late Paleozoic Porjianghaizi fault (North Ordos Basin, China): Controls on sedimentation and gas accumulations

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A B S T R A C T

In contrast to typical intracratonic basins, the Ordos Basin comprises marginal deformation belts and complex fault systems. This study uses 3D seismic data tied to sonic and stratigraphic data from exploration wells, to document the geographic extend of the Porjianghaizi fault and its control on sedimentation and gas accumulation in the northern Ordos Basin. Our results show that the geometry of large Porjianghaizi fault is controlled by five small fault segments. The growth history of the Porjianghaizi fault composes four stages: (1) an initiation stage (Late Carboniferous to Early Permian); (2) a reactivation stage during the Late Triassic; (3) an inversion stage during the Middle Jurassic; and (4) an interaction and linkage stage during the Late Jurassic. Detailed studies show that the Porjianghaizi fault had significant control on sedimentation and gas accumulation. During the initiation stage (Late Carboniferous to Early Permian), five fault segments and associated relay ramps controlled the sedimentation in the study area. The relay ramps formed transport pathways in which sediment extended from north basin margin to the basin center. In contrast, sedimentation along the fault was more localized. Based on Shale Gouge Ratios (SGR) and formation water salinity, the fault sealing capacity of the Porjianghaizi fault is characterised by "horizontal segmentation", which means the fault composes laterally sealed areas and laterally connected areas along the fault strike. As a corollary, we propose that gas resources were mainly generated from the south where there are thick source rocks, migrating vertically through interbedded open fractures first, and then laterally through the junction zone of fault (relay ramps). It eventually accumulated in structural traps found in the northern areas. Understanding the evolution of the Porjianghaizi fault is important for predicting the distribution of sedimentary facies in Upper Carboniferous and Lower Permian units. As well as understanding the migration and distribution of gas resources in the north Ordos Basin, these results can further help in hydrocarbon exploration in the north Ordos Basin.

1. Introduction

The Ordos Basin is a typical intracratonic basin with a basin fill gently dipping (< 2°) to the west (e.g., Darby et al., 2001; Darby and Ritts, 2002; Xiao et al., 2005; Zhang et al., 2007; Ritts et al., 2004; Xie and Heller, 2013, Fig. 1). As one of the main petroliferous basins in China (Yang et al., 2005; Hanson et al., 2007), several Ordovician and lower-middle Permian gas fields, including the Changqing, Jinbian, Sulige, and Yulin gas fields, have been discovered in the north and central parts of basin since gas exploration in the Ordos Basin began in the 1980s (Duan et al., 2008; Tang et al., 2012; Zou et al., 2012; Yang et al., 2015a,b; Fig. 1B). Recent exploratory wells in the northern Ordos Basin (i.e., the Hangjinqi area) found significant volumes of gas in upper Paleozoic sandstones (Wang et al., 2011, Figs. 1 and 2). Gas systems in this area are characterised by upper Carboniferous (Taiyuan Formation) and lower Permian (Shanxi Formation) deltaic and swamp coal source rocks, upper Carboniferous to middle Permian fluvial and deltaic sandstone reservoirs, and upper Permian deltaic and fluvial mudstone cap rocks (Zhang et al., 2009; Ji et al., 2013).

Recent studies based on aeromagnetic data, and newly collected 2D seismic lines, suggest that the northern Ordos Basin developed several major fault systems (Yao and Zhang, 2003). Yang et al. (2013) propose a minimum of two phases of fault movement, and that fault systems are composed of multiple, linked fault strands. Sedimentation and gas

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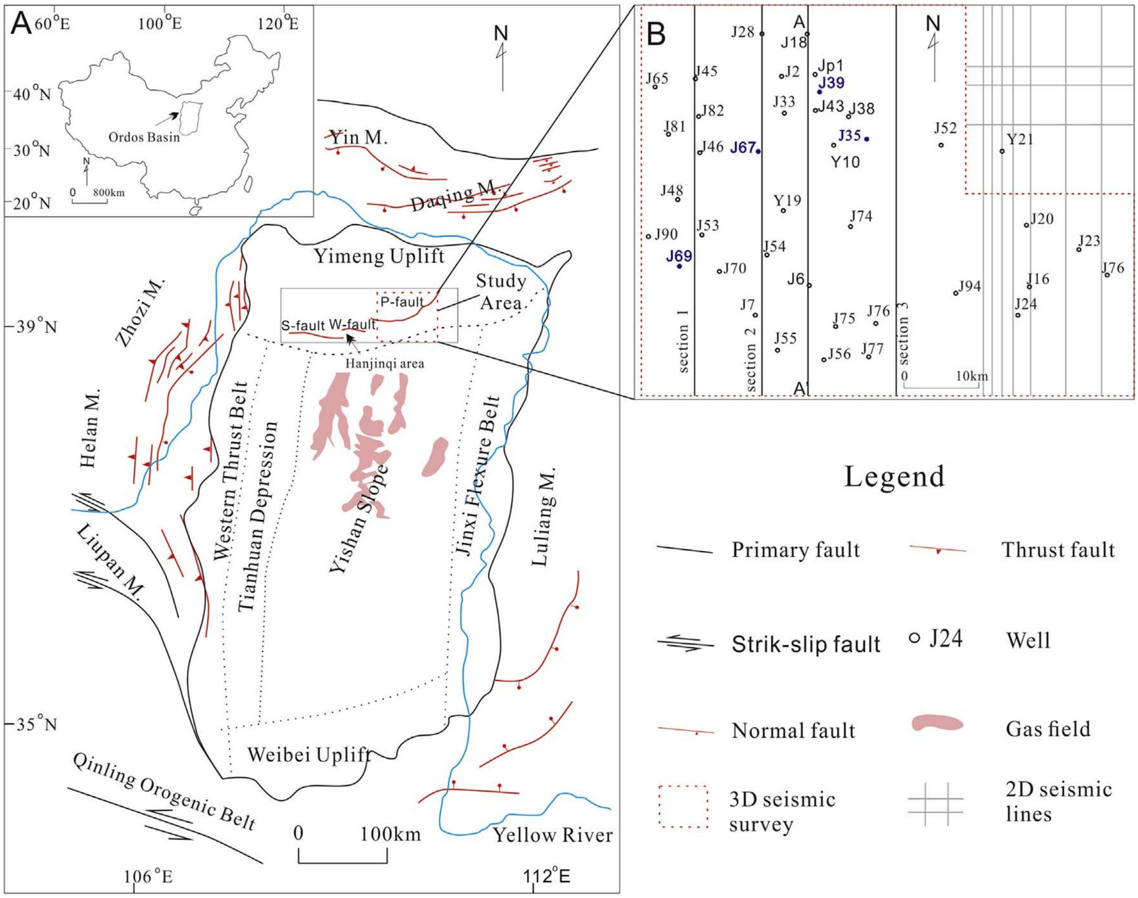

Fig. 1. A: Major tectonic units of the Ordos Basin showing the study area and 3D seismic survey location (modified after Yang et al., 2013). B. 3D seismic survey and 2D seismic sections (grey) and all wells included in this study. Abbreviations: SF: Sanyanjing Fault; WF: Wulanjilinmiao Fault; PF: Porjianghaizi Fault. Section 1 to Section 3 are the locations of seismic profiles used in Fig. 5. Wells in blue color are the location of wells in Fig. 16. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

accumulations show differences across major fault systems from south to north, and along the fault strike from west to east (Jia et al., 1997; Zheng et al., 2006; Zheng and Yan, 2006; Xue et al., 2009). However, the geometries and growth history of major fault systems in the Ordos Basin remain poorly understood.

In this study, sediment core, well-log, and 3D/2D seismic data were used to document fault geometry, growth, and their control on sedimentation and gas accumulation. Our results show that the current Porjianghaizi fault is a single fault, but its development can be subdivided into four stages. Our results are important for gas exploration that predict the distribution of reservoir and source rocks and may apply to other similar intracratonic basins in China.

2. Geological setting

The Ordos Basin is situated in north-central China (Fig. 1). Prior to the Permian, the basin evolved as part of the North China block (Xie and Heller, 2013). By the end of the Paleozoic, the composite Tarim-North China block was sutured to the Mongolian arc terranes and, probably, the Siberian craton to the north (Yin and Nie, 1996; Ritts et al., 2004, Fig. 3). To the south, collision between the South China block and North China block took place progressively from east to west (Yin and Nie, 1996; Webb et al., 1999) and the two blocks did not fully converge until, at least, the Late Triassic (Lin et al., 1985). In the Jurassic, local rifting and tectonic uplift took place on the Ordos Basin's margins (Yang et al., 2005; Xie and Heller, 2013). In the Middle Jurassic and Cenozoic, large scale strike-slip movements and intraplate deformation resulted in tectonic inversion of parts of the Ordos Basin (Zhang et al., 1998; Yang et al., 2005), which eventually separated the Ordos Basin from the North China block. Currently, the Ordos Basin is surrounded by the Lang and Daqing Mountains to the north, the Luliang Mountains to the east, the Qinling Mountain ranges to the south and the Liupan and Helan mountain ranges to the west (Fig. 1). The basin can be further divided into six tectonic units: the Yimeng Uplift, Western Thrust Belt, Tianhuan Depression, Yishan Slope, Jinxi Flexure Belt and the Weibei Uplift (Fig. 1B). The Hangjinqi area is located in the Yimeng Uplift of the northern basin (Fig. 1B).

The Ordos Basin is filled by sedimentary units of Paleozoic to Cenozoic ages (Fig. 2). Its basement is composed of Archean–Proterozoic metamorphic units. In the Hangjinqi area no Cambrian to Devonian strata are present, and the basement is overlain by Late Carboniferous coal-bearing deposits (Yang et al., 2015a,b; Fig. 2). Permian to Triassic strata comprise alluvial fan, deltaic and lacustrine deposits (Zhu et al., 2010; Zou et al., 2010; Yang et al., 2013). Subduction along the eastern margin of Asia in the Early Jurassic caused erosion of Late Triassic deposits and the relative absence of Early