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Substratum transverse faults in Kuqa Foreland Basin, northwest China and their significance in petroleum geology

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ABSTRACT

The importance of transverse faults in basin evolution and petroleum geology has been often emphasized. However, the transverse faults in the Kuqa Foreland Basin, the most important gas producing area in China, have rarely been studied. Interpreted seismic sections and earthquake focal mechanism solutions, as well as other geological and geophysical data, allow us to identify a few widely-spaced, approximately NS trending, transverse strike-slip faults separating major structural units, and to clarify the geometry and kinematics of these transverse faults hidden below thrust faults. In the Kuqa Foreland Basin, two major structural domains can be distinguished. Transverse faults in the northern Kuqa Foreland Basin are mainly NNE trending sinistral, indicating clockwise-rotation of fault-bounded blocks. In contrast, the predominant NW trending dextral faults in the southern Kuqa Foreland Basin imply counterclockwise-rotation of fault-bounded blocks. We propose a tectonic model in which crustal blocks are bounded by strike-slip faults in a zone of simple shear rotation about vertical axis. The strike-slip faulting and thrust faulting in the Kuqa Foreland Basin suggest that some of the convergence between South Tianshan and Tarim blocks may have been accommodated not only by obvious crustal shortening and thickening along thrust faults, but also by rotation and possible lateral movement of the crust along transverse faults. Controlled by the remote collision of Indian block with Eurasian block since the Miocene, these reactivated substratum faults, which may inherit from Paleozoic deformation, control various elements relevant to gas accumulation in the Kuqa Foreland Basin which should expect to be paid more attention in the future. These elements include maturity of Tertiary and Jurassic source rocks, a difference in the regional cap of Kumugelimu salt beds from east to west, reservoir bed properties, gas migration channels, and traps formation. In addition, the strike-slip faulting of the transverse faults may affect deformation of the sedimentary cover, including making the western Qiulitag structural belt to form an arcuated structure curved to the SSW.

1. Introduction

Transverse faults, approximately perpendicular to or oblique to major structural belt with a high angle, have attracted much attention in hydrocarbon exploration because of their complex characteristics and control on oil and gas accumulations in many basins worldwide. The Canadian Rockies (Price, 2001; Bégin and Spratt, 2002), the Zagros Basin (McQuillan, 1991; Baker et al., 1993; Hessami et al., 2001; Sepehr and Cosgrove, 2004, 2005; Yassaghi, 2006; Shabani-Sefiddashti and Yassaghi, 2011; Nadimi and Konon, 2012), the South American Andes arc foreland tectonic zone (Sillitoe, 1974; Bourgois et al., 1982; Jacques, 2002; Kuhn, 2002), the Dead Sea rift (Ben-Avraham and Ten Brink, 1989; Ben-Avraham et al., 1990; Ginzburg et al., 2006), and the Evia island (Palyvos et al., 2006), all have significant transverse faults controlling hydrocarbon accumulations and production. Around the world, most of basins, including cratonic basins, synrift basins, and foreland basins, have been affected by transverse faults.

Petroliferous basins with transverse faults in China also exist (e.g., the Junggar Basin, the Ordos Basin, the Bohai Bay Basin, and the Kuqa Foreland Basin) (He et al., 2004, 2009; Li and Wang, 2006; Zhao et al., 2006, 2009; Tang et al., 2010). Among these, the Kuqa Foreland Basin is an important petroliferous basin with the largest gas production in China. Based on gravity anomalies, Li and Wang (2006) proposed the existence of substratum faults, segmenting thrust faults. Through field observation, remote sensing interpretation, and physical simulation, some researchers (He et al., 2009; Tang et al., 2010) suggested the significance of

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approximately NS trending structural weakness anomaly in geological history, especially the Kalayuergun Fault (KYF) in the western Kuqa Foreland Basin, which may have caused a variety of deformation styles and hydrocarbon accumulation conditions on the eastern and western sides. However, there is obvious absence of systematic research on the transverse faults in the Kuqa Foreland Basin, and there are also few substantive discussions on the role and significance of basin-mountain coupling, as well as a lack of clear understanding of the relationship of transverse faults with petroleum geology. In order to answer these questions, based on interpreted seismic sections and earthquake focal mechanism solutions, as well as other geological and geophysical data, we identified and calibrated a few widely-spaced approximately NS trending transverse strike-slip faults separating major structural units, including KYF, Muzate Fault (MF), Kapushaliang Fault (KSF), and Kuqa Fault (KF), and clarified the geometry and kinematics of these transverse faults. Apart from KYF, these transverse faults have rarely been reported. The model proposed in this paper not only interprets the kinematic mechanism of transverse faults, but also provides a new idea of basin-mountain coupling, as well as clarifies the control of transverse faults on petroleum geology in the Kuqa Foreland Basin.

2. Geological setting

2.1. Structural characteristics

The Kuqa Foreland Basin, located on the northern margin of the Tarim block, is a transitional site between South Tianshan block and Tarim block. It is bounded by the Tianshan block in north, by the Tabei Uplift in south, while by the Wushi Sag in the west and by the Yangxia Sag in the east (Jia et al., 1998). The surface of the Kuqa Foreland Basin is dominated by mountains and deserts. The exploration area is approximately 2.8×10^4 km^2 with the length of approximately 500 km from west to east and the width of approximately 30–70 km. A series of south-vergent thrust and fold beds in the Kuqa Foreland Basin developed from north to south can be divided into the northern monocline structural belt, the Kelasu structural belt, the Yiqikelike structural belt, the Wushi Sag, the Baichen Sag, the Yangxia Sag, the Qiulitag fold structure, and the front uplift belt (Fig. 1). Vertically, influenced by the Paleogene and Neogene gypsum-salt beds, Li et al. (2012) suggested that tectonic deformation of the Qiulitag fold structure was thin-skinned, and deformation of the subsalt strata accumulated mainly in the hinterland. The deformation above the salt strata are mainly fault-propagation folds and detachment folds, while the structural style can be described as a wedge of southerly vergent thrust sheets (Hubert-Ferrari et al., 2007; Wang et al., 2011).

Although there are many different viewpoints on the tectonic evolution of the Kuqa Foreland Basin (Jia et al., 1998; Yin et al., 1998; Zeng et al., 2004; Chen et al., 2005; Wang et al., 2011, 2014), it has been proposed that the Kuqa foreland developed from Late Permian to Quaternary is a peripheral foreland basin or a collisional successor foreland basin. Jia et al. (1998) suggested that the Kuqa Foreland Basin contains a late Permian–Triassic foreland phase, a Jurassic-Paleocene extensional phase and a Neogene rejuvenated foreland phase. Zeng et al. (2004) proposed that the Kuqa Foreland Basin was a wedge-shaped foreland basin at the foot of the Tianshan mountain in the Triassic, when transverse faults might have already existed (He et al., 2009). In the Jurassic, the Kuqa Foreland Basin underwent a limited weak extension (Zeng et al., 2004). Since the Cenozoic, the Kuqa Foreland Basin has been experienced continuous deformation (Yin et al., 1998; Zeng et al., 2004; Wang et al., 2011). Based on absence of Miocene–Pleistocene marine sediments, Yin et al. (1998) assumed that the activities of the Kuqa Foreland Basin dated back from 24 to 21 Ma. Restoration of balanced cross section suggests that shortening began locally at approximately 26–25 Ma, studies of growth strata and landscape folding indicate accelerating shortening in late Miocene/early Pliocene and in early Pleistocene (Hubert-Ferrari et al., 2007; Wang et al., 2011; Li et al., 2012), and displaying active-tectonic geomorphology indicate continued fold growth (Hubert-Ferrari et al., 2007). Zeng et al. (2004) thought that the timing of tectonic activities occurred since the Miocene in the northern belt and in the Pleistocene in the southern front uplift zone, when transverse faults came to deform again (He et al., 2009).

2.2. Stratigraphy and petroleum geology

Based on field outcrops and drilling cores, Mesozoic–Cenozoic continental clastic rocks, mostly sandstone, shales, of ten thousand meters thick developed above the Triassic to the Quaternary (Fig. 2). There are three reservoir bed-seal assemblages, namely in the Jurassic, Paleogene, and Neogene. According to recent

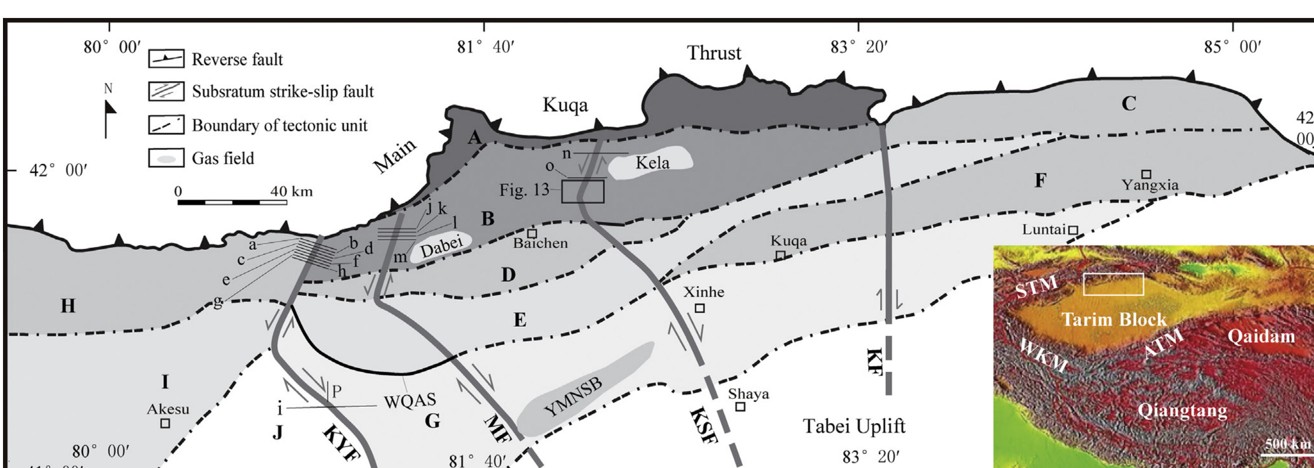

Fig. 1. Map showing the location of the Kuqa Foreland Basin within the Tarim block. (A) Northern monocline tectonic zone. (B) Kelasu tectonic zone. (C) Yiqikelike tectonic zone. (D) Baichen Sag. (E) Qiulitag tectonic zone. (F) Yangxia Sag. (G) Front uplift belt. (H). Wushi Sag. (I) Wensu Salient. STM: South Tianshan Mountains; WKM: Western Kunlun Mountains; ATM: Altum Mountains; KYF: Kalayuergun Fault; MF: Muzate Fault; KSF: Kapushaliang Fault; KF: Kuqa Fault; WQAS: Western Qiulitag Arc Structure; YMNSB: Yinmai No. 7 Structure Belt.