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New discovery and geological significance of Late Silurian–Carboniferous extensional structures in Tarim Basin

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ABSTRACT

Late Silurian–Carboniferous extensional structures have been discovered after careful interpretation of seismic reflection data in western Manjiaer Sag, Central Tarim Basin in central Asia. The extensional structures comprise numerous small normal faults in nearly N–S strike direction. Groups of normal faults in profile show features suggestive of negative flower structures and small horst-graben structures. Based on growth index calculation, these extensional structures formed in the Late Silurian period, continued activity in the Devonian and Carboniferous and then ceased at the end of Carboniferous. The peak-stage of normal fault activity occurred in Late Silurian. Late Silurian–Carboniferous normal faults also developed in the Tazhong and Tabei areas, which implies that Tarim Basin were under regional extensional tectonic setting during that periods. The extensional structure in southern Tarim resulted from the post-orogeny stress relaxation of the Kunlun Early Paleozoic orogenic belt, and those in northern Tarim resulted from the Paleozoic back-arc rifting which led to the opening of South Tianshan ocean.

1. Introduction

Tarim Basin is a large petroliferous basin in central Asia, with the basin boundaries determined by the distribution of Mesozoic–Cenozoic sedimentary units (Figs. 1 and 2). It has crystalline Precambrian basement and Phanerozoic sedimentary cover strata and is now mainly covered by the Taklamakan desert. It is surrounded with three important mountain chains: South Tianshan on the north, Kunlun on the south and southwest, Altun on the southeast. South Tianshan is the southern branch of Tianshan Mountains, and the major part of the southern Central Asian Orogenic Belt (CAOB) that experienced a complicated Paleozoic accretionary and collisional history (Xiao et al., 2004, 2009; Charvet et al., 2011; Gao et al., 2009; Li et al., 2010a,b). Kunlun is generally believed to be an Early Paleozoic collisional orogenic belt that resulted after closing of proto-Tethys (Pan, 1994; Pan and Wang, 1994; Pan et al., 1996, 2000; Li et al., 2010a,b; Jia et al., 1997; He et al., 2001; Luo and He, 1999; Hao et al., 2003). Xiao et al. (2000, 2003) believed that Kunlun is an Early Paleozoic–early Mesozoic multiple accretionary orogenic belt. Altun is a giant Meso-Cenozoic strike-slip fault belt which superposed on the Paleozoic orogenic belt (Che et al., 2011; Bureau of Geology and Mineral Resources of Xinjiang Uygur Autonomous Region, 1993; Liu et al., 2001; Yin et al., 2002; Li et al., 2008b).

The orogenic belts surrounding this basin underwent intense Cenozoic intracontinental orogeny (Guo et al., 1992; Sobel and Dumitru, 1997; Li et al., 2001, 2008a, 2009), thereby overprinting and rendering unrecognizable older structures. However, Cenozoic structural deformation in the Tarim Basin is relatively weak because of the underlying rigid Precambrian basement (Shao et al., 1996; Yin et al., 1996; Zhou et al., 2001; Xu et al., 2001; Guo et al., 2001; Li et al., 2008c). The older structures are only slightly overprinted, such that older structures are preserved. As a result, valuable information on the orogenic belts can be obtained by analyzing the deformation of the Tarim Basin. Analysis of fault structure forms a crucial part of petroleum geological study and is significant in petroleum exploration and development.

Previous studies on the fault structure of the Tarim Basin focused on Cenozoic thrust structures, observed both around and within the basin. As a consequence of the strong regional compressive tectonism of the Cenozoic, Cenozoic thrust structures were

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observed around the basin, whereas the older structural deformation cannot be identified because of severe destruction (Li et al., 2008a; Yang et al., 2010). Previous fault analyses in the surrounding area of Tarim Basin concentrated on the thrust geometry (Allen and Viocent, 1999; Scharer et al., 2004; Sobel and Dumitru, 1997; Yin et al., 1998; Bullen et al., 2001; Lu et al., 1994; Chen et al., 1998; Jia et al., 1997; Li et al., 2001, 2009, 2010a,b; Sun et al., 2002; Yang et al., 2010; Zheng et al., 2007; Zhang et al., 1996; Tang et al., 2004; Wang et al., 2002, 2009). Within the Tarim Basin, fault studies of thrusts have also been carried out (Zhang et al., 1994; Li et al., 2008a; Zheng et al., 2009; Yang et al., 2007, 2011; Qi et al., 2012).

Few studies have been conducted on extensional structures of the Tarim Basin, and limited studies exist on Jurassic extensional structures (Jia et al., 2001; Chen et al., 2009) and inversion structures in the Yaha (Yanan) Fault Belt and Luntai Fault Belt (Fig. 1) in Tabei Rise (Tang et al., 1999; Wei et al., 2001). We recently studied the normal faults in northern Tarim Basin. We found that the normal faults not only existed in the Yaha (Yanan) and Luntai Fault Belts, but also in other places in northern Tarim Basin. Two episodes of fault activity, which have different causes, were discovered. The older is the normal faulting in Jurassic–Early Cretaceous which is a regional post-orogenic extensional period in the northern margin of Tethys (Jia et al., 2001; Chen et al., 2009; Li et al., 2013a), and the younger is the Late Cretaceous–Neogene normal fault activity, which was caused by block rotation and escape effect under the control of regional tectonic compression which was caused by the long-distance effect of the collisional events at the southern margin of paleo-Eurasian continent (Zhao et al., 2012; Li et al., 2013a). Further work showed that the Late Neogene–Middle Quaternary transtensional fault belts developed around Awati Sag, and these faults are the youngest normal faults ever found in Tarim Basin and may have formed in the same event as the Late Cretaceous–Neogene normal faults in northern Tarim Basin (Qi et al., 2012; Li et al., 2013b).

The Tarim Basin has been considered as the peripheral foreland basin of the Kunlun Early Paleozoic collision orogenic belt and was under regional tectonic compression during the Silurian–Devonian periods (Jia et al., 1997; He et al., 2001; Wei et al., 2002; Zhou et al., 2005; Li et al., 2010a,b). We first discovered the Late Silurian–Carboniferous normal faults while conducting research on fault systems in western Manjiaer Sag in central Tarim Basin. The new discovery benefits from the continued improvement of the quality of seismic data, especially 3D seismic data (see Scheme 1). This paper reports on this new discovery and discusses its geological significance.

Seismic data is the basis of this paper, so we show a concise (seismic) stratigraphic chart of central Tarim Basin to help readers understand this paper (Table 1). Correlations of the seismic reflection surfaces with lithostratigraphic units and chronostratigraphic units in the chart are based on Jia et al. (1992, 2004), Zhang et al. (2004), Wang (1992) and Li et al. (1992).

2. Discovery of Late Silurian–Carboniferous extensional structures

Manjiaer Sag is a large negative tectonic element in Tarim Basin. The degree of oil–gas exploration and geological study in the area is relatively low, and fault analysis has not been done up to now. We carried out a systematic study on fault structures in western Manjiaer Sag in 2012 and 2013, during which we discovered the Late Silurian–Carboniferous extensional structures (Figs. 1 and 3).

The study area is located in the central part of Tarim Basin and covered by Taklamakan Desert. The study was conducted by interpreting seismic data. The Hd5 and Yh2 areas are located in the north, and Shun1 area in the south (Fig. 3).

The quality of Hd5 3D seismic data improved after merging processing in 2012 (Fig. 4), which enabled the detailed interpretation and analysis of fault structure.

In our interpret we used seismic coherence slices to show the fault distribution. This is a technique first proposed by Mike B. et al. in 1995. 3D seismic data are generally binned into a regular grid. By calculating localized waveform similarity in both in-line and cross-line directions, estimates of 3D dimensional seismic coherence are obtained. Small regions of seismic traces cut by a fault surface generally have a different seismic character than the corresponding regions of neighboring traces. This results in a sharp discontinuity in local trace-to-trace coherence. Calculating coherence for each grid point along a time slice results in lineaments

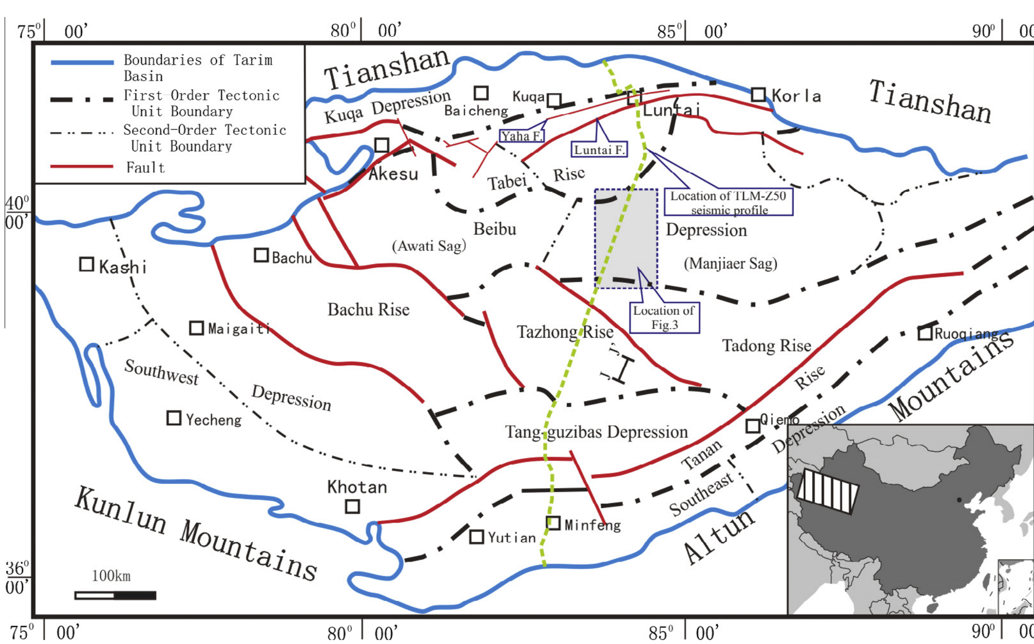

Fig. 1. Tectonic elements of Tarim Basin.