Tectonophysics 722 (2018) 373–382

Contents lists available at ScienceDirect

Tectonophysics

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

New insights into the distribution and evolution of the Cenozoic Tan-Lu Fault Zone in the Liaohe sub-basin of the Bohai Bay Basin, eastern China

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ARTICLE INFO

Keywords:
Tan-Lu fault zone
Bohai Bay Basin
Strike-slip fault
Tectonic evolution

ABSTRACT

As the largest strike-slip fault system in eastern China, the northeast-trending Tan-Lu Fault Zone (TLFZ) is a significant tectonic element contributing to the Mesozoic-Cenozoic regional geologic evolution of eastern Asia, as well as to the formation of ore deposits and oilfields. Because of the paucity of data, its distribution and evolutionary history in the offshore Liaohe sub-basin of the northern Bohai Bay Basin (BBB) are still poorly understood. Investigations of the strike-slip fault system in the western portion of the offshore Liaohe sub-basin via new seismic data provide us with new insights into the characteristics of the Cenozoic TLFZ. Results of this study show that Cenozoic dextral strike-slip faults occurred near the center of the Liaoxi graben in the offshore Liaohe sub-basin; these strike-slip faults connect with their counterparts to the north, the western part of the onshore Liaohe sub-basin, and have similar characteristics to those in other areas of the BBB in terms of kinematics, evolutionary history, and distribution; consequently, these faults are considered as the western branch of the TLFZ. All strike-slip faults within the Liaoxi graben merge at depth with a central subvertical basement fault induced by the reactivation of a pre-existing strike-slip basement fault, the pre-Cenozoic TLFZ. Data suggest that the TLFZ across the whole Liaohe sub-basin comprises two branches and that the Cenozoic distribution of this system was inherited from the pre-Cenozoic TLFZ. This characteristic distribution might be possessed by the whole TLFZ, thus the new understandings about the distribution and evolutionary model of the TLFZ in this study can be inferred in many research fields along the whole fault zone, such as regional geology, ore deposits, petroleum exploration and earthquake hazard.

1. Introduction

The Tan-Lu Fault Zone (TLFZ), located in the East China, is a NE-trending continental-scale strike-slip fault zone with a length of ca. 2400 km (Fig. 1A). It has been widely discussed due to its important roles in regional and mineral geology of eastern Asia: (1) due to its special location, near the margin of the West Pacific and East Asia continent, its evolutionary process usually has been used to indicate the history of plate interactions in East Asia during Mesozoic and Cenozoic times (e.g. Xu et al., 1987; Okay and Sengor, 1992; Yin and Nie, 1993; Xu and Zhu, 1994; Zhu et al., 2009a; Yin, 2010; Li et al., 2012, 2013a); (2) as a major corridor for magmatism and metallogenic fluids, it controlled the formation of a variety of ore deposits (including diamond, chromium, nickel, copper, iron-bearing magmatic deposits, gold, silver, molybdenum, tungsten, tin, lead, zinc, antimony, mercury, and gemstone-bearing hydrothermal ore deposits) (e.g. Sun et al., 2007; Guo et al., 2013); (3) it also controlled and affected the formation and evolution of several Cenozoic petroliferous basins, including the Cenozoic Bohai Bay Basin (BBB) (Allen et al., 1998; Huang and Liu, 2014) and Yilan-Yitong Basin (Ren et al., 1999; Wang, 2001), and served as the most important factor for hydrocarbon accumulation in these basins (Hsiao et al., 2004; Qi et al., 2008; Wang and Huang, 2013; Huang et al., 2015, 2016); (4) it is associated with a presently active seismic zone from which many historical and recent earthquakes have been recorded (Liu, 1987; Zheng et al., 1988; Fu et al., 2004). Despite this, many controversial issues about the TLFZ still exist, including its detailed geometry and evolution (Wan et al., 2009; Huang et al., 2015, 2016).

As a result of abundant seismic data from an extensive program of hydrocarbon exploration, this fault zone within the BBB, especially within the northern part of the basin (i.e., Liaohe sub-basin), has been widely investigated (Fig. 1b) (Li et al., 2013b; Wang and Huang, 2013; Qi et al., 2013; Yu et al., 2014; Huang et al., 2015). However, because the Liaohe sub-basin of the BBB comprises two parts, offshore and

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https://doi.org/10.1016/j.tecto.2017.11.025
Received 12 October 2016; Received in revised form 10 November 2017; Accepted 18 November 2017
Available online 21 November 2017
0040-1951/

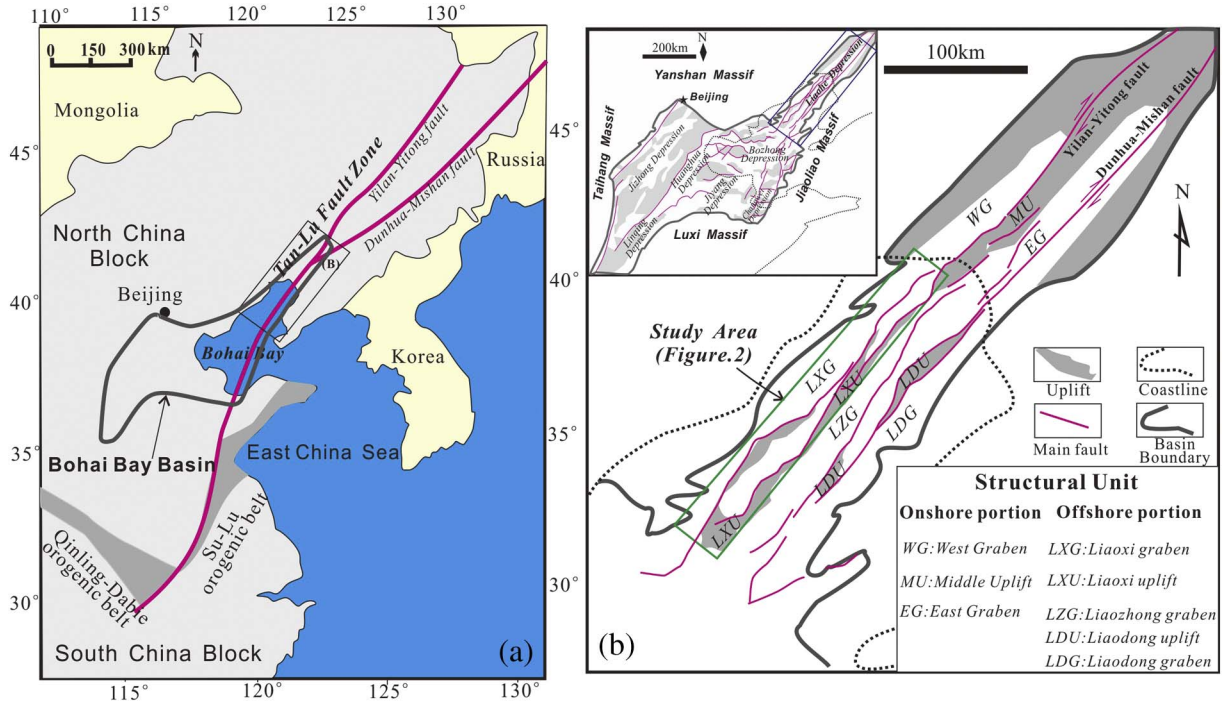

Fig. 1. Locations of the TLFZ and BBB (a), and Cenozoic structural sketch maps of the BBB and Liaohe sub-basin (b). The TLFZ in (a) is based on previous consensus regarding position and extent, while the East and West grabens in the onshore part of the Liaohe sub-basin correspond to the Liaozhong and Liaodong grabens, and the Liaoxi graben in the offshore part of the Liaohe sub-basin, respectively.

onshore, controlled by different oil companies, a unified seismic database is lacking and this has hampered accurate understanding of the distribution of the TLFZ across the whole sub-basin. In the offshore part of the Liaohe sub-basin, it is generally agreed that Cenozoic strike-slip faults typically occurred in the east portion (i.e., Liaozhong and Liaodong grabens), and are considered to be the main sub-faults of the TLFZ (Qi et al., 2008; Wang and Huang, 2013), while no Cenozoic strike-slip faults have so far been identified in the west portion (i.e., Liaoxi graben) (Yu et al., 2014) (Fig. 1). In the onshore part of the Liaohe sub-basin, investigations based on exploration data reveal that Cenozoic strike-slip faults typically occurred in both eastern and western parts (i.e., East and West grabens), considered to be two branches of the TLFZ (Qi et al., 1994, 2013; Tong et al., 2008; Li et al., 2013b; Yu et al., 2015). Previous studies indicated that these two branches of the TLFZ in the onshore part of the Liaohe sub-basin are continuous to the south of the TLFZ; however, the western branch was bent and crossed through the middle uplift, and merged with the eastern branch in the offshore part of the Liaohe sub-basin, distributed into the Liaozhong and Liaodong grabens (Fig. 1) (Qi et al., 2013).

However, new exploration data from the offshore section of the Liaohe sub-basin reveal that some Cenozoic strike-slip faults also occurred within the Liaoxi graben. This new discovery has consequently led to a new understanding of the distribution and evolutionary history of the Cenozoic TLFZ in the BBB, augmenting the comprehensive understanding of the characteristics and evolution of the whole Cenozoic TLFZ. In this paper, we focus on identification and analysis of the strike-slip fault within the Liaoxi graben in the offshore Liaohe sub-basin using new exploration seismic data. The aim of this study is to refine our understanding of the distribution and evolution of the TLFZ in the Liaohe sub-basin.

2. Geological setting

The Cenozoic BBB is one of the most important petroliferous rift basins in eastern China, and contains several hydrocarbon-rich sub-basins. Of these, the Liaohe sub-basin is the northernmost (Fig. 1).

The Liaohe sub-basin consists of two parts, an onshore and offshore section. Of these, the onshore part comprises two half-grabens, west and east, with a middle uplift that creates a basin-and-range structural configuration (Fig. 1) (Qi et al., 1994, 2013). The offshore part of the Liaohe sub-basin consists of three half-grabens, the Liaoxi, Liaozhong, and Liaodong, as well as two uplifts, the Liaoxi and Liaodong, which also lead to a basin-and-range structural configuration (Fig. 1) (Zhou et al., 2009; Xia et al., 2012). As a result, the West graben within the onshore Liaohe sub-basin connects with the Liaoxi graben in the offshore Liaohe sub-basin and the two form a single structural unit. At the same time, the Liaoxi uplift in the offshore Liaohe sub-basin forms the extending portion of the Middle uplift of the onshore Liaohe sub-basin, while the East graben of the onshore Liaohe sub-basin corresponds to three structural sub-units of the offshore Liaohe sub-basin, the Liaozhong and Liaodong grabens as well as the Liaodong uplift (Fig. 1).

As noted above, the TLFZ is a northeast-trending continental-scale strike-slip fault zone that crosses the Liaohe sub-basin. On the basis of recently published geologic maps (Fig. 1a) (e.g.: Hsiao et al., 2004; Li et al., 2012; Xu et al., 2017), it is clear that the TLFZ extends two branch faults to the north of the Liaohe sub-basin, the Yilan-Yitong and Dunhua-Mishan faults, which merge together to the north of the Liaohe sub-basin (Fig. 1a).

It is generally accepted that the TLFZ underwent sinistral movement during the Mesozoic (Gilder, 1999; Xu et al., 1987; Zhu et al., 2005, 2009a), while during the Cenozoic it was reactivated as a dextral strike-slip fault (Allen et al., 1998; Lin et al., 1998; Hsiao et al., 2004; Gong et al., 2010; Huang and Liu, 2014; Huang et al., 2012, 2014) (Fig. 1). Indeed, this fault system remains active, evidenced by present-day earthquakes (Chen and Nabelek, 1988; Hsiao et al., 2004). Our recent studies on the TLFZ within the Bohai Sea, including the eastern part of the offshore Liaohe sub-basin, have elucidated the detailed Cenozoic evolution of the TLFZ and its relationship with basin evolution (Huang and Liu, 2014; Huang et al., 2015). We know that the Cenozoic evolutionary history of the TLFZ began with extensional deformation over 40 million years ago (Ma), followed by dextral shear encompassing a component of extensional deformation from 40 Ma to the present, and