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Cenozoic evolution of the Tan–Lu Fault Zone (East China)—Constraints from seismic data

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ABSTRACT

The Tan–Lu Fault Zone (TLFZ) is a continental-scale strike–slip fault zone in the East China that contains rich and significant information about the Mesozoic–Cenozoic evolution of eastern Asia. It experienced a long-term and complex superimposed deformation characterized by Mesozoic sinistral and Cenozoic dextral motions. The fault has a well-documented Mesozoic sinistral displacement history, but its Cenozoic history is poorly known. In this study, based on the observations of the interrelationships of fault kinematics, fault geometry and concomitant sedimentation, the Cenozoic evolution of the TLFZ is constrained by abundant seismic data from oil fields. Numerous bends along the Cenozoic master fault sensitively record changes in the stress field during strike–slip motion. Taking into account the Cenozoic evolution of the Bohai Bay Basin (east China), the evolutionary history of these strike–slip bends is investigated, and the results indicate that dextral motion along the TLFZ began at about 40 Ma. Furthermore, the Cenozoic evolutionary history of the TLFZ is suggested to include an extensional deformation (with a possible weak sinistral shear) from 65 to 40 Ma. From 40 to 0 Ma, dextral motion occurred due to a change in the subduction direction of the Pacific Plate relative to the Eurasian Plate causing the fault to experience dextral shear with a component of extensional deformation. Dextral motion was most intense from 40 to 25 Ma, and then the dextral direction may have suddenly changed from a nearly NE–SW trend to a nearly N–S trend at around 25 Ma. Dextral motion was relatively enhanced again after 12 Ma and was particularly strong after 5 Ma. Episodic and ephemeral thrusting deformation might have occurred during the Quaternary. The cumulative Cenozoic dextral displacement of the TLFZ is far smaller than its Mesozoic sinistral strike–slip displacement (may be no more than 21 km).

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). Since being discovered in 1957, it has been widely discussed due to its significance in many research fields: (1) it is considered that the TLFZ records the evolutionary history of plate interactions in East Asia during Mesozoic and Cenozoic times, therefore its evolutionary history has been used to indicate the regional tectonic evolution (e.g. Xu et al., 1987; Okay and Sengor, 1992; Yin and Nie, 1993; Xu and Zhu, 1994; G. Zhu et al., 2009; Yin, 2010; Li et al., 2012a,b, 2013; Suo et al., 2013); (2) many magmatic rocks evolving from ultrabasic, to basic–felsic and alkaline intruded along the TLFZ, resulting in 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), and therefore it has been investigated as major corridor for magmatism and metallogeny (e.g. Guo et al., 2013); (3) the TLFZ crosses through several sedimentary basins in East China, and obviously controls the hydrocarbon accumulation in these basins, so it also has been studied for the relationship between petroleum and strike–slip deformation (e.g. Allen et al., 1997; Gong et al., 2010; Huang et al., 2012a,b). Despite that, many controversial issues about the evolution of the TLFZ still exist, especially its Cenozoic evolutionary process. Establishing the Cenozoic history of the fault has been hampered by the fact that relatively little Cenozoic strata are preserved in outcrops along the TLFZ, resulting in the absence of systemic records of Cenozoic structural deformation.

The TLFZ experienced obvious sinistral motion during the Mesozoic (Xu et al., 1987; Xu and Zhu, 1994; Gilder et al., 1999; Zhu et al., 2005; G. Zhu et al., 2009; Zhu et al., 2012), whereas it experienced dextral motion during the Cenozoic (Allen et al., 1997; Hsiao et al., 2004; Gong et al., 2010; Huang et al., 2012a,b). Compared with the history of Mesozoic sinistral motion constrained by geochronological data (Yin and Nie, 1993; Zhu et al., 2005; G. Zhu et al., 2009; Zhu et al., 2012), the history of dextral motion during the Cenozoic has not been constrained by any

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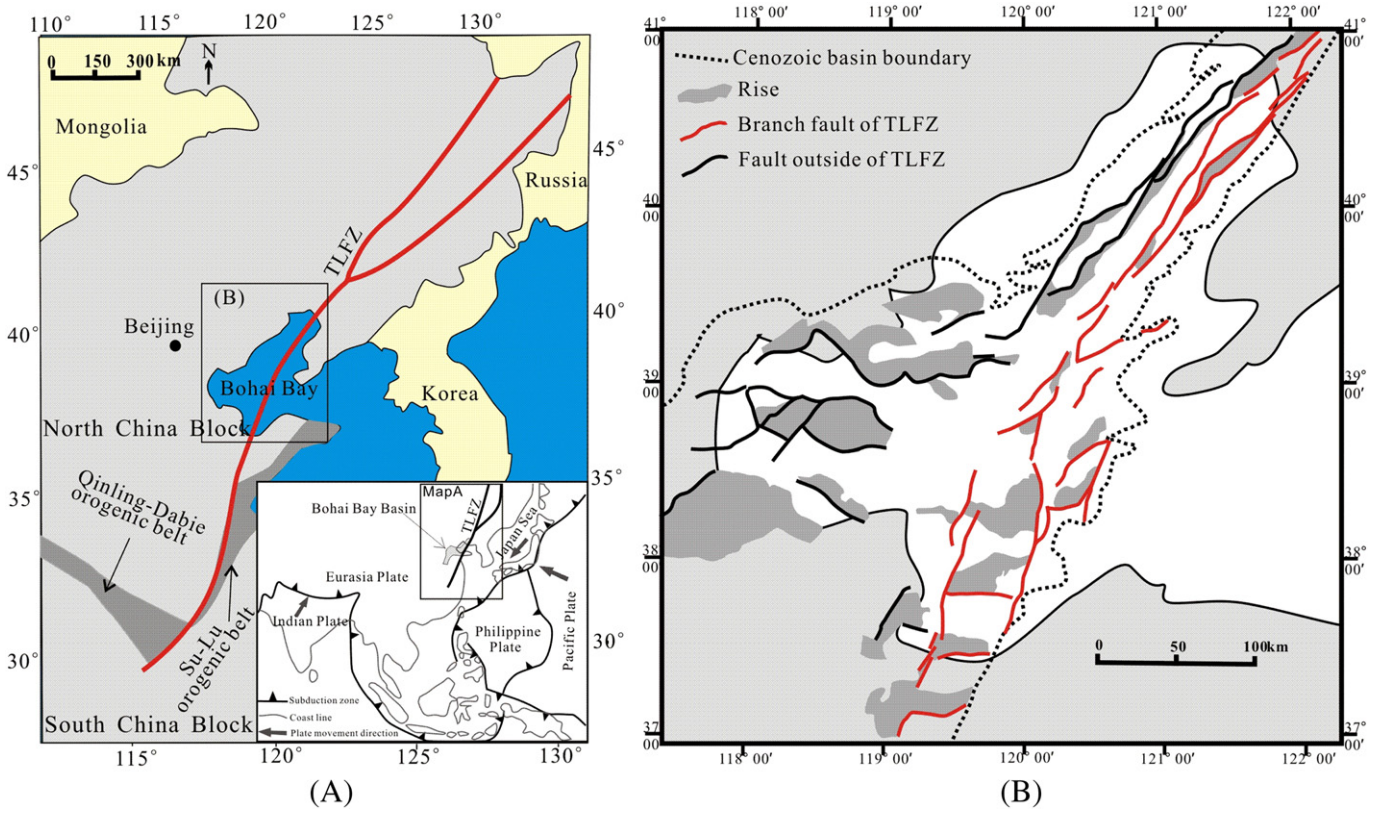

Fig. 1. General geologic maps showing (A) the Tan–Lu Fault Zone in the eastern China and (B) the master faults of the Tan–Lu Fault Zone (red faults) offshore the Bohai Sea. Inset in map A is a highly simplified tectonic sketch map of Asia.

methods and therefore, a significant unresolved question is when did the dextral motion occur. We consider that this unresolved question is the key to understanding the whole Cenozoic evolutionary process of the TLFZ. Thus we take the solution of this question as the main purpose of this study.

Here, we use offshore data from the Bohai Sea to study the Cenozoic history of the fault. This approach has several advantages for deciphering the Cenozoic evolution of the TLFZ: (1) the offshore Bohai Sea is part of a Cenozoic rift basin (i.e., Bohai Bay Basin), and has well-preserved Cenozoic strata. There are abundant exploration data which can reveal the distribution and features of the TLFZ very well (Fig. 1B), including 3D seismic data covering all the areas of the TLFZ and several hundreds of exploration wells; (2) the TLFZ in the study area has not been well-studied, and important information about the evolution of the fault zone present in the seismic data has not previously been discussed. Consequently, this study permits a unique opportunity to investigate the TLFZ development within a sedimentary basin and test structural models for the whole TLFZ against these observations.

2. Methodology and data

Field and experimental investigations of strike–slip fault systems (Mann et al., 1983; McClay and Bonora, 2001; Wakabayashi et al., 2004; Cunningham and Mann, 2007; Mitra and Paul, 2011) reveal that several deformation styles (extensional, contractional, and strike–slip deformations) can synchronously occur along one strike–slip fault zone, resulting from bends in the fault trend. Releasing bends (such as right-steps in right-lateral fault systems) are characterized by extensional deformation and the formation of pull-apart basins, whereas restraining bends (such as left-steps in right-lateral fault systems) are characterized by contractional structures such as thrust faults and flower structures. In other cases, the strike–slip fault may be discontinuous and characterized by step-over fault structures (Crowell, 1974; Ballance and Reading, 1980; Biddle and Christie-Blick, 1985; McClay and Bonora, 2001; Schellart and Nieuwland, 2003; Cunningham and Mann, 2007). Most of these investigations show that these special segments in strike–slip fault zones can sensitively record changes in the stress field. Therefore, documentation of the deformation styles in the TLFZ, especially in these special segments along the fault zone (offset, bend and step-over areas), can be used to determine the history of Cenozoic dextral motion along the fault. Our methodology for constraining the onset time of dextral motion is to analyze these special segments along the fault zone and study their evolutionary history. After determining this onset time of dextral motion, the whole Cenozoic evolutionary history of the TLFZ is assessed.

Abundant seismic data are used to identify the fault bends and constrain their structural evolution in this study. Volume-based geometric attributes (reflectivity time-slice and coherency time-slice) are also used to reveal structural and stratigraphic features. The time constraint is completed by the sedimentary ages of the affected strata in the rift basin. The sedimentary ages were obtained by combining paleontology, paleomagnetism and isotopic dating of volcanic rocks (Liang et al., 1992). The strata, relating sedimentary ages and seismic markers used in this study are listed in Table 1.

3. Results

3.1. Fault bends along the TLFZ in the Bohai Sea

Exploration seismic data reveal that many strike–slip bends are present along the TLFZ, and we identify at least 18 fault bends in this study (Fig. 2A). All of them are developed in Cenozoic strata and show