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Cenozoic pulsed compression of Da'an-Dedu Fault Zone in Songliao Basin (NE China) and its implications for earthquake potential: Evidence from seismic data

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ABSTRACT

The Da'an-Dedu Fault Zone (DDFZ) is a major tectonic feature cutting through the Songliao Basin from south to north in NE China. Pulsed compression deformation of DDFZ during the Cenozoic implies a complex geodynamic process, and the latest stage of which occurred in the Quaternary directly influences the present seismicity of the interior basin. Although most of the evidence for Quaternary deformation about the Songliao Basin in the past decades was concentrated in marginal faults, all five earthquake swarms with magnitudes over 5.0 along the buried DDFZ with no surface expression during the past 30 years suggest it is a main seismogenic structure with seismic potential, which should deserve more attention of geologists. However, limited by the coverage of the Quaternary sedimentary and absence of strong historic and instrumental earthquakes records ($M > 7$), the geometric pattern, Quaternary activity and seismic potential of the DDFZ remain poorly understood. Thus, unlike previous geophysical studies focused on crust/mantle velocity structure across the fault and the aim of exploring possible mineral resources in the basin, in this study we have integrated a variety of the latest seismic data and drilling holes from petroleum explorations and shallow-depth seismic reflection profiles, to recognize the Cenozoic pulsed compression deformation of the DDFZ, and to discuss its implication for earthquake potential. The results show that at least four stages of compression deformation have occurred along the DDFZ in the Cenozoic: ~65 Ma, ~23 Ma, ~5.3 Ma, and ~1.8 Ma, respectively, although the geodynamic process behind which still in dispute. The results also imply that the tectonic style of the DDFZ fits well with the occurrence of modern seismic swarms. Moderate earthquake potential ($M \leq 7.0$) is suggested along the DDFZ.

1. Introduction

Most of the evidence for Quaternary deformation along the Songliao Basin in NE China is concentrated in its marginal faults (Chen et al., 2010; Huang et al., 1996; Hsiao et al., 2004; Li et al., 2010; Li et al., 2013; Liu et al., 2007, 2010; Wang et al., 2006; Min et al., 2011, 2013; Zhang et al., 2003a, 2003b; Zhu et al., 2015) (Fig. 1b). Nevertheless, the interior of the basin, which has been less studied, also shows evidence of Quaternary deformation. Particularly, the neotectonic activity inside the basin appears to be concentrated along a 400 km long belt, called Daan-Dedu Fault Zone (DDFZ), which extends through the basin from south to north to form what has been interpreted as a Mesozoic to Quaternary, first order fault zone at the interior of the basin (Yu et al., 2015a, 2015b). More than five earthquake swarms with magnitudes over 5.0 that occurred along the DDFZ during the past 30 years suggest it is a seismogenic structure with seismic potential. However, the geometric pattern, kinematics and seismic potential of it have previously been unknown due to the sedimentary coverage and limited working conditions.

Songliao Basin, well known as one of the biggest rift basins in the world, consists of complete and continuous Cretaceous terrestrial sediments with a maximum thickness of ~8000 m and Cenozoic sediments with a maximum thickness of only ~700 m which discovered by abundant petroleum drillings and seismic profiles (Song et al., 2014; Yu et al., 2015b). The obvious steer's head geometry in a cross-section is related to lithospheric stretching during thermal subsidence in the late Cretaceous (Song et al., 2014; White and McKenzie, 1988).

Geographically (Fig. 1), the basin is surrounded by the Great

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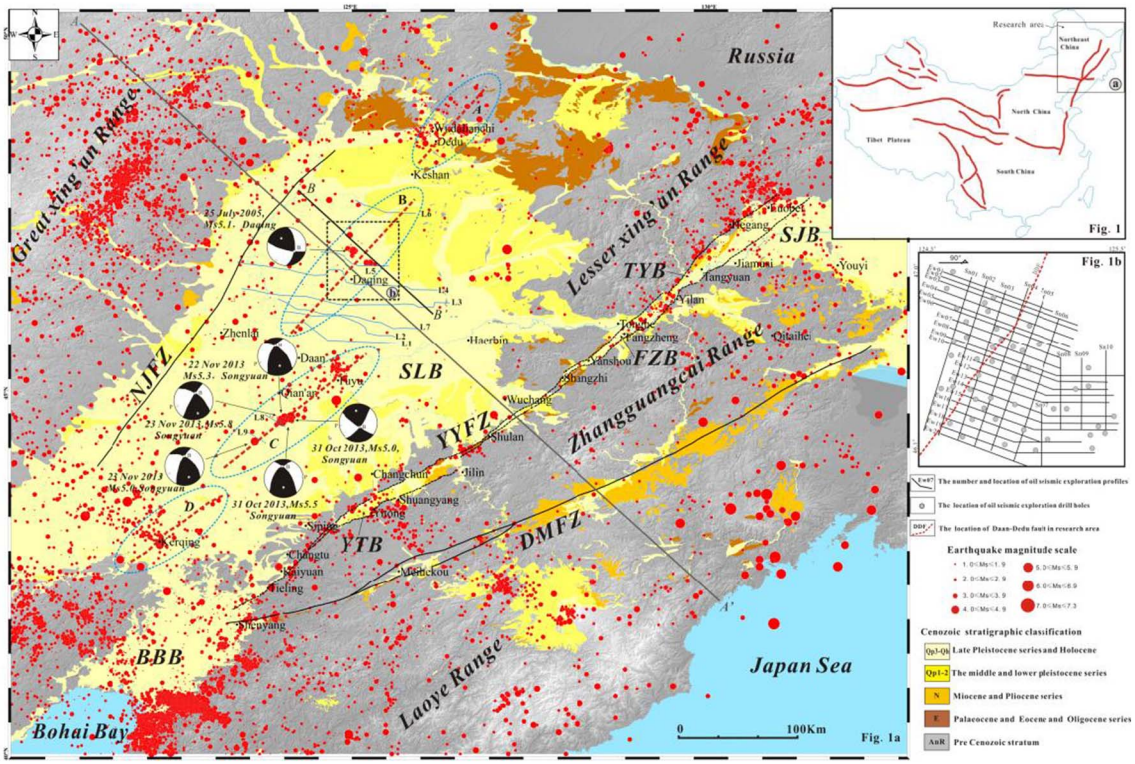

Fig. 1. Active tectonic map of the Songliao Basin in NE China. Panel a represents the scope of our research area. Panel b represents the scope of seismic lines the drill holes. The location of topographic profile A-A′ traversed NE China from west to east is represented by straight gray line (A-A′), and the geological cross section B-B′ crossing the DDFZ is marked in dark gray line (B-B′). Abbreviations are NenJiang Fault Zone (NJFZ), Yilan-Yitong Fault Zone (YYFZ), Dunhua-Mishan Fault Zone (DMFZ), Songliao Basin (SLB), Bohai Bay Bain (BBB), YiTong Basin (YTB), FangZheng Basin (FZB), TangYuan Basin (TYB) and SanJiang Basin (SJB). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

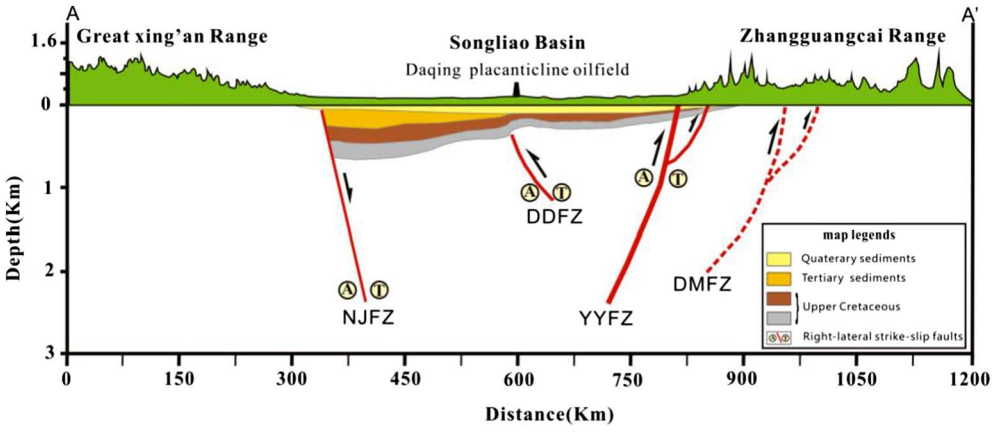

Fig. 2. (Top) Topographic profile AA′ traversed NE China from west to east. (Bottom) Sketch map of main faults formed in Songliao Basin and adjacent areas.

Xing'an Range to the west, the Lesser Xing'an Range to the north, the Zhangguangcai Range to the east (Song et al., 2014; Wu et al., 2014), and the Bohai Bay to the south (Yu et al., 2015b). The super giant Daqing oilfield, located at the middle of the basin, was discovered in 1959, and has already produced > 2.1 billion tons of oil so far (Song et al., 2014).

Tectonically (Fig. 1), the basin is bounded to the east by the Yilan-Yitong Fault Zone (YYFZ) and Dunhua-Mishan Fault Zone (DMFZ), both of which are considered as the main branch faults of the northern section of the Tan-Lu Fault Zone (TLFZ). Seismic activity along the TLFZ is well revealed by obvious late Quaternary deformation (Chen et al., 2010; Huang et al., 1996; Li et al., 2010; Wang et al., 2006; Min et al., 2011, 2013; Zhu et al., 2015) as well as by frequent and violent earthquakes (Hsiao et al., 2004; Li et al., 2013; Liu et al., 2007, 2010; Zhang et al., 2003a, 2003b). More than 10 catastrophic earthquakes have been recorded around TLFZ since the 15th century, including the 1668 Tancheng earthquake (M ~8.5) as well as 70 BCE Zhucheng earthquake (M ~7.0) in the Shandong part, 1969 Bohai Bay earthquake (M ~7.4) in the Bohai part, 1975 Haicheng earthquake (M = 7.3) in the northern part, and other strong events (Allen et al., 1997; Hsiao et al., 2004; Li et al., 2013; Liu et al., 2007, 2010; Yin et al., 2015; Zhu et al., 2015). Studies of Paleo-earthquakes and shallow seismic profiles also revealed the strong activity of TLFZ in late Quaternary (Huang et al., 2014; Liu et al., 2015; Yin et al., 2015; Zhu et al., 2015). Recently, Min et al. (2011, 2013) revealed that the Holocene tectonic activity in Tonghe in Heilongjiang province as a section of the YYFZ displaced a sedimentary layer that is approximately 1730 ± 30 a BP and formed 70-km-long surface fault scarp with a height varying from > 1 m to < 2 m, and in Shulan in Jilin province as a part of the YYFZ revealed a ^{14}C displacement date of 4410 ± 30 a BP. Yu et al.