Tectonophysics 628 (2014) 206–217

Contents lists available at ScienceDirect

Tectonophysics

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

A 3400-year-long paleoseismologic record of earthquakes on the southern segment of Anninghe fault on the southeastern margin of the Tibetan Plateau

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ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form 10 April 2014
Accepted 27 April 2014
Available online 9 May 2014

Keywords:
The Anninghe fault (ANHF)
Paleoseismology
Trenching
Cascading rupturing behavior

ABSTRACT

The Anninghe fault (ANHF) is an active left-lateral strike-slip fault along the southeastern margin of the Tibetan Plateau. Previous studies suggested the ANHF was divided into two segments, which herein we named the northern and southern segments respectively. Multiple trenches were excavated on the northern segment, revealing well-constrained paleoseismic events by radiocarbon ages. However, until now there is no paleoseismic result on the southern segment, which terminates at the Zemuhe fault (ZMHF) around Xichang where there were multiple historical records of large earthquakes. In this paper, we used high-resolution images for mapping fault traces on the southern segment of the ANHF and found a small depression. Through trenching in the depression, five paleoseismic events are identified and named E1 through E5 from youngest to oldest at 1750 AD-present, 1430–1870 AD, 940–1150 AD, 700–1000 AD, and 1400–500 BC respectively. Comparing with the historical record earthquakes around Xichang, we suggest that the latest event E1 is associated with one of the 1850 AD and 1952 AD events, and event E2 is interpreted as the 1536 AD earthquake; event E4 is possibly associated with the 814 AD earthquake. The average recurrence interval of earthquakes on the southern segment is about 600–800 yr, the interval between E1 and E2 is 416 yr or 314 yr, and 386–596 yr between E2 and E3. The interval between E3 and E4 is shorter at 126–336 yr, but much longer at 1314–2214 yr between E4 and E5. These surface-faulting events on the southern segment of the ANHF appear to be unevenly spaced in time. Furthermore, integrating the paleoseismic sequence of the northern segment of the ANHF, the two segments appear to be ruptured individually or interactively triggered within a narrow time range, or co-ruptured during one paleoseismic event, indicating that the ANHF possibly shows a cascading rupturing behavior.

1. Introduction

The southeastern region of the Tibetan Plateau is one of the most intense areas in Mainland China on crustal deformation with frequent large earthquakes (Deng et al., 2003; Xu et al., 2003; Zhang et al., 2003). Historical records show that just in western Sichuan region, located at the junction of three active tectonic blocks — the Sichuan–Yunnan, Bayan Har, and South China blocks (Fig. 1), there are $M \geq 7$ earthquakes occurring on average every 10 to 15 years in this region (Ran et al., 2008a). Such intense earthquake activity has meant that the western Sichuan region has been of great interest to geoscientists, especially after seismic events like the 2001 M_W7.8 Kunlun earthquake, 2008 M_W7.9 Wenchuan earthquake, and 2010 M_S7.1 Yushu earthquake occurred in rapid succession along the boundaries of these three active tectonic blocks (Fig. 1). Consequently, understanding a long-time-scale large earthquake behavior on the nature of crustal deformation along the southeastern margin of the Tibetan Plateau is important for effectively implementing seismic hazard mitigation strategies in this populated region.

The Anninghe fault (ANHF) is a left-lateral strike-slip fault that connects to the Xianshuihe fault (XSHF) in the north and terminates at the Zemuhe fault (ZMHF) in the south, and all these faults collectively compose a larger, more complex left-lateral fault system located along the eastern and northern boundaries of the Sichuan–Yunnan block in the southeastern area of the Tibetan Plateau (Fig. 1). From the end of early Pleistocene to the early of middle Pleistocene, the Sichuan–Yunnan block has been extruded in a southeastward direction due to deformation of the Tibetan Plateau, resulting from the collision of the Indian and Eurasian plates (Peltzer and Tapponnier, 1988; Tapponnier et al., 1982, 2001). Previous studies suggested that the ANHF was divided into two segments around Mianning (Fig. 2). Pei et al. (1998) first divided the ANHF into two segments around Mianning based on differences of geometrical styles on the two fault segments. Wen (2000a) suggested that surface ruptures produced by the historical record earthquake of

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http://dx.doi.org/10.1016/j.tecto.2014.04.040
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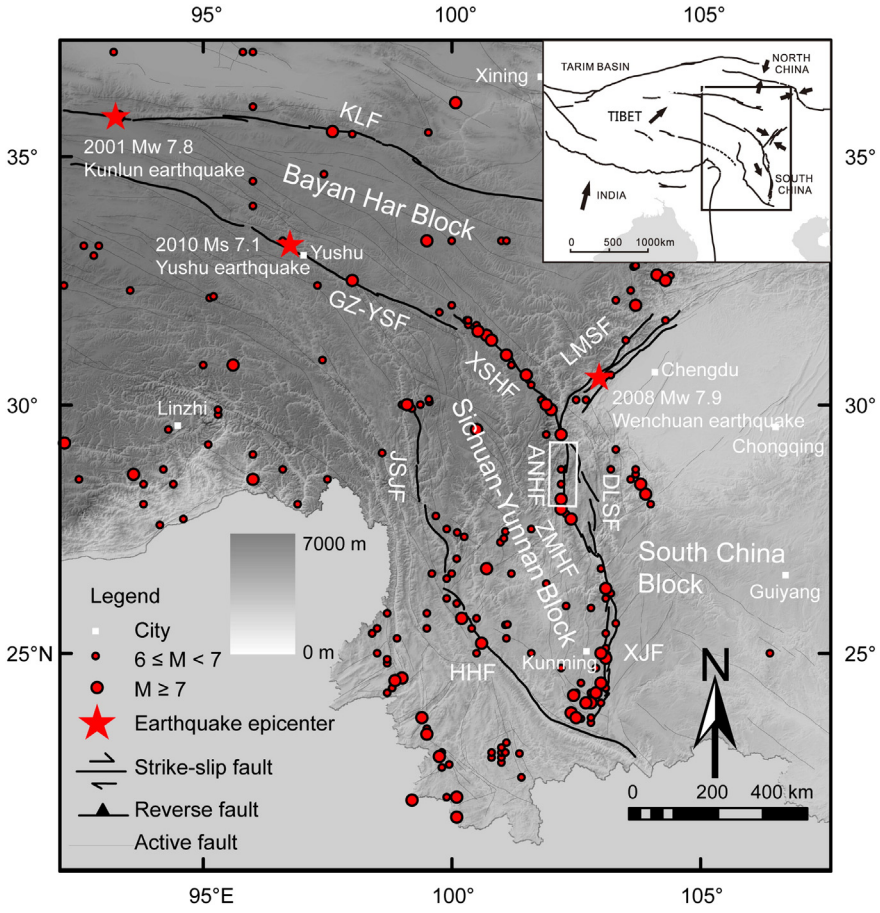

Fig. 1. Tectonic and topographic map of the eastern Tibetan Plateau. The white rectangle shows the study area of the ANHF. Three red stars represent epicenters of the 2001 M_W7.8 Kunlun earthquake, 2008 M_W7.9 Wenchuan earthquake, and 2010 M_S7.1 Yushu earthquake. Red small circles show epicenters of earlier documented (historical and instrumental) earthquakes. White small rectangles denote cities. KLF, Kunlun Fault, GZ–YSF, Ganzi–Yushu Fault, XSHF, Xianshuihe Fault, LMSF, Longmenshan Fault, ANHF, Anninghe Fault, ZMHF, Zemuhe Fault, DLSF, Daliangshan Fault, XJF, Xiaojiang Fault, HHF, Honghe Fault, JSJF, Jinshajiang Fault. The locations of active faults and earthquake epicenters are from a tectonic activity map of China (Deng, 2007).

1536 AD M7$^1/_2$ propagated northward from Xichang and terminated around Mianning, and found that the area around Mianning is an abnormal transition zone of gravitational and magnetic field, and proposed that the ANHF was divided into two segments around Mianning. Herein, we named the two segments from north to south as the northern and southern segment (Fig. 2) and terminate at the ZMHF around Xichang where there were multiple historical records of 814 AD M7, 1536 AD M7$^1/_2$, 1850 AD M7$^1/_2$ and 1952 AD M6$^3/_4$ earthquakes (Department of Earthquake Disaster Prevention, 1995). Presently, there have been several paleoseismic studies on the ZMHF (He and Ren, 2003; Ren et al., 2010; Tian et al., 2008; Wang et al., 2013), specifically, both Ren et al. (2010) and Wang et al. (2013) showed deformation evidence of paleoseismic events that are associated with the historical record 814 AD and 1850 AD earthquakes based on multiple trenching and detailed field investigations. However, whether the surface ruptures produced by these two historical record earthquakes propagated northward to the southern segment of the ANHF or not is still uncertain, and this needs to be resolved when analyzing Holocene faulting behavior of the ANHF. Paleoseismic studies on the ANHF have been mostly conducted on its northern segment (Qian et al., 1990; Ran et al., 2008a; Wen et al., 2000, 2007). Ran et al. (2008a) excavated multiple trenches on the northern segment of the ANHF and measured ages of three recent paleoseismic events (1634–1811 a BP, 1030–1050 a BP and 280–550 a BP) from radiocarbon dating, and then estimated an average of recurrence interval of about 520–660 yr. However, for the southern segment of the ANHF, data on recurrence intervals of paleoseismic events and rupturing behavior are lacking, only Wen et al. (2007) gave some evidence of surface ruptures that were possibly associated with the historical record 1536 AD earthquake based on analysis of geomorphic mapping. Additionally, whether the surface ruptures revealed from trenching on the northern segment of the ANHF propagated southward to the southern segment or not has not been resolved either. Consequently, paleoseismic studies on the southern segment of the ANHF is crucial to explain scientific problems like segmentation of the ANHF, large earthquake behavior and fault interactions between the ANHF and ZMHF, all these above mentioned questions are important to assess risks of large earthquake hazard in the western region of Sichuan and understand crustal deformation along the southeastern margin of the Tibetan Plateau.

Regions from Mianning to Xichang along the southern segment of the ANHF are highly populated (Fig. 2). Due to human activities and intense erosion, it is challenging to find good sites on the fault segment that completely preserve evidence of paleoseismic events and favor for multiple radiocarbon dating. Previous studies including us had attempted to conduct paleoseismic studies along the southern segment of the ANHF but all finally failed due to the challenging environment with fast erosion and widespread modification of the landscape by farming. And now we use high-resolution images (possibly with 1 m resolution from Google Earth) for mapping fault traces of the southern segment of the ANHF and found a small depression located at the