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Geometry and late Pleistocene slip rates of the Liangdang-Jiangluo fault in the western Qinling mountains, NW China

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ABSTRACT

Two groups of faults striking in different direction (NWW-trending and NEE-trending) within the western Qinling mountains play important roles in the tectonic deformation and the transference slip along the east end of the east Kunlun fault. We investigated the fault geometry and kinematics properties in the area. Based on the displacements of landforms and optically stimulated luminescence (OSL) dating techniques, the late Pleistocene slip rates along the Liangdang-Jiangluo fault were determined to be 0.43 ± 0.13 mm/a (thrust) and 0.71 ± 0.18 mm/a (left-lateral strike-slip). We also investigated some other faults, and obtained characteristically low slip rates. These slip rates are consistent with decadal GPS observations. Despite previous studies that point to a systematic decrease in the left-lateral slip rates from >10 mm/a to <2 mm/a along the eastern end of the Kunlun fault, there has been relatively little discussion about the role of the faults, that lie between the east Kunlun and west Qinling faults in accommodating the regional tectonic deformation. From the activity, geometry, and kinematics of the regional faults in the western Qinling Mountains, we concluded that the main driving force that arises from the NE-thrusting and strike slip along the east Kunlun fault dominated the deformation in the area. Our results suggest that the <2 mm/a slip rate at the tip of the east Kunlun fault is absorbed by low slip rate faults, crustal shortening, basin formation and mountain uplift in the western Qinling mountains, and the slip is not transferred to the west Qinling fault or further north.

1. Introduction

The northeastern Tibetan plateau is bounded by several large lateral strike-slip faults such as the Altyn-Tagh fault, the Qilian-Haiyuan faults, the east Kunlun fault and the west Qinling fault. However, the roles of these large strike-slip faults in the tectonic extension and transformation of the northeastern part of the Tibetan plateau have remained a matter of debate (e.g., England and Houseman, 1986; Avouac and Tapponnier, 1993; Meyer et al., 1998; Tapponnier et al., 2001; P. Z. Zhang et al., 2004). Some researchers consider the east-west trending east Kunlun fault and west Qinling fault systems in the western Qinling Mountains to be critical systems that accomplish the northeastward extrusion of the Tibetan plateau (Peltzer et al., 1985; Avouac and Tapponnier, 1993; Duvall and Clark, 2010; Zhang et al., 1995; Kirby and Harkins, 2013). Previous studies on the main boundary faults (the east Kunlun fault and the west Qinling fault) have focused primarily on the slip rates and the onset of deformation over the past several decades (Van der Woerd et al., 1998, 2000, 2002; Jolivet et al., 2003; G. W. Zhang et al., 2004; P. Z. Zhang et al., 2004; Li, 2005; Li et al., 2005; Kirby et al., 2007; Clark et al., 2010; Duvall et al., 2011; Kirby and Harkins, 2013). The distribution of slip rates along faults throughout the western Qinling Mountains has provided opportunities to test the hypotheses regarding whether the strike slip along the Kunlun fault ends, or is transferred to other faults along the margin of the plateau (Harkins et al., 2011; Kirby and Harkins, 2013). This long-standing question has stimulated discussion and debate on the regional tectonics at the end of the east Kunlun fault.

Some researchers believe that slip along the Kunlun fault is transferred to the west Qinling fault (Peltzer et al., 1985; Avouac and Tapponnier, 1993; Duvall and Clark, 2010) or dissipates further to the north of the western Qinling mountains (Duvall and Clark, 2010; Yuan et al., 2011). Another viewpoint is that the lateral slip is absorbed by distributed deformation within the plateau (Kirby et al., 2007; Harkins and Kirby, 2008; Harkins et al., 2010; Kirby and Harkins, 2013). Some other results suggest that the slip at the eastern end of the east Kunlun fault is transferred to the thrusting of the Tazang fault and uplifting of the Min Shan (Chen et al., 1994; Yin and Harrison, 2000; Kirby et al., 2007;

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Harkins et al., 2010; Ren et al., 2013). However, as one of the main boundary strike-slip faults in the northeastern Tibetan plateau (Duvall et al., 2011; Wang et al., 2012), the quantitative slip rate of the west Qinling fault is rarely mentioned. Li (2005) stated that the left-lateral strike-slip rate is 2.94 $\pm$ 0.15 mm/a with a vertical slip rate of 0.29 $\pm$ 0.01 mm/a in the Huangxianggou segment of the west Qinling fault. The decadal GPS measurements along the west Qinling fault show a very low slip rate (Zhang et al., 2003; Duvall et al., 2011; Ge et al., 2015). Based on image interpretation and field investigation, Peltzer et al. (1985) determined that the left-lateral slip rate on the east Qinling fault is ~5 mm/a, which is supported by the result of Zhang et al. (1995).

Previous work has not only investigated the activity and slip rates of the east Kunlun fault (Van der Woerd et al., 1998, 2000, 2002; Kirby et al., 2007; Kirby and Harkins, 2013; Harkins et al., 2011) and the Qinling fault (Peltzer et al., 1985; Zhang et al., 1995; Li, 2005), but also provided a conceptual model to explain of the uplift and extension of the northeastern Tibetan plateau (Van Der Woerd et al., 1998, 2000, 2002; Kirby et al., 2007; Harkins et al.,2011; Duvall et al., 2011; Kirby and Harkins, 2013). However, the geometry and activity of the faults between the mainly left-lateral strike-slip faults (the west Qinling fault and the east Kunlun fault) have received little attention. Several studies have determined slip rates of some faults in the western Qinling mountains (Han et al., 2001; Yuan et al., 2004, 2007; Jia et al., 2012; Liu, 2012; Yu et al., 2012), but in nearly all of the cases, the goal has been focused on the slip rate of a single fault, and the regional tectonic deformation and kinematics have not been discussed. With the goal of examining whether the locus of deformation continues to migrate toward the northeast of the western Qinling mountains, we determined the slip rates of the fault throughout the late Pleistocene by dating displaced alluvial fan surfaces using optically stimulated luminescence (OSL). By combining the herein-presented new data with previous studies on the region and decadal GPS measurements, we discuss the implications on the regional tectonic deformation and kinematics.

2. Regional tectonic setting

Regarding the complex tectonic geometry in the western Qinling mountains, except for the west Qinling fault (WQLF) and the east Kunlun fault (EKLF), there are several faults that have a complex tectonic system, such as the NWW trending of the Lintan-Tanchang fault (LTF), Guanggaishan-Dieshan fault (GDF) and Bailongjiang fault (BLJF) and the NEE trending of the Lixian-Luojiapu fault (LLF), Liangdang-Jiangluo fault (LJF), Kangxian-Lveyang fault (KLF), Hanan-Daoqizi fault (HDF), Wenxian-Kangxian-Lveyang fault (WKLF), and Qingchuan fault (QCF) (Fig. 1) (Deng et al., 2003; Yuan et al., 2004; Zheng et al., 2005, 2007, 2013a). Two groups of faults with different strike directions have the same fault motion properties of a left-lateral strike. Over a period of hundreds of years, several strong earthquakes have occurred in this region (Gu, 1983; LISCSB, 1989). The southern Tianshui M8 earthquake in 1654 is closely related to the Lixian-Luojiapu fault, and has caused a large number of landslides (Han et al., 2001; Yang et al., 2015). The southern Wudu M8 earthquake occurred on the Hanan-Daoqizi fault in 1879, and the surface rupture of the earthquake and landslide sites can still be seen clearly (Hou et al., 2005; Feng et al., 2005). However, several strong earthquakes with more frequent and multiple devastating have occurred in recent years (Zheng et al., 2005, 2007, 2013a; Xu et al., 2014). After the 2008 Wenchuan Ms 8.0 earthquake, scientists have paid more attention to the risk of strong earthquakes in the western Qinling mountains in the north of the Longmenshan fault zone.

The left-lateral Kunlun fault extends roughly E-W for ~1500 km and terminates at its eastern tip near the town of Maqu (Kirby et al., 2007; Harkins et al., 2011; Kirby and Harkins, 2013). The east Kunlun fault plays a key role in absorbing the active deformation of Eurasia (Avouac and Tapponnier, 1993; Van Der Woerd et al., 1998, 2000, 2002; Tapponnier et al., 2001). The time of the initiation of the left-lateral shear along the east Kunlun fault has be inferred as the Miocene (Jolivet et al., 2003). Based on low-temperature thermochronology, Duvall et al. (2013) proposed that the motion along the eastern Kunlun fault may have occurred as early as ~12–8 Ma, with a possible earlier phase of motion from ~30–20 Ma, and ~20–15 Ma along the central fault segment, ~8–5 Ma along the eastern fault segment. To the northeast, the west Qinling fault is oriented parallel to the east Kunlun fault and was previously the western extension of the Qinling fault system. Its western tip terminates south of the Linxia Basin (Fang et al., 2005) (Fig. 1). Low-temperature thermochronology and Ar/Ar-dating results

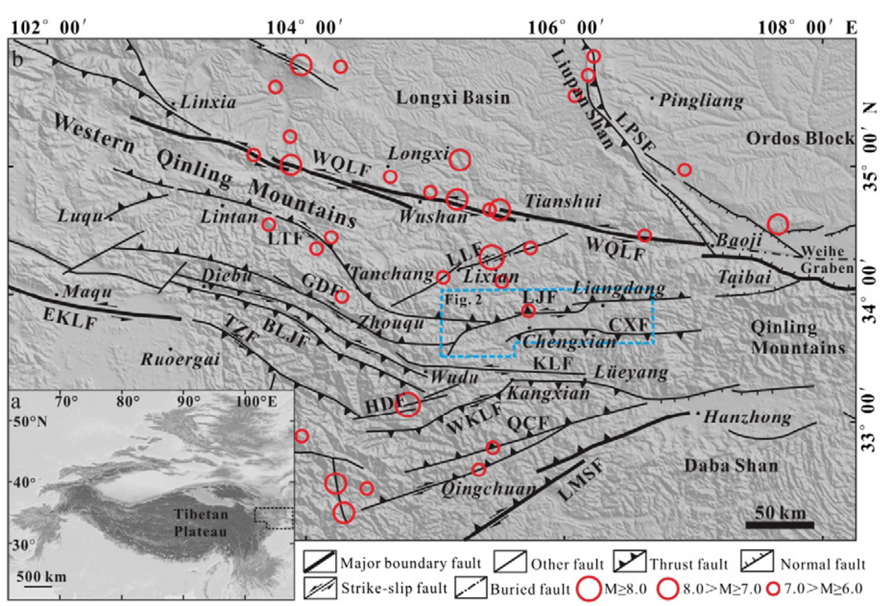

Fig. 1. Active fault of the western Qinling mountains. a. Index map including a shade digital elevation model (DEM) of the Tibetan plateau and its adjacent regions. The black dashed frame shows the range of panel b. b. Active fault and earthquakes of the western Qinling mountains. Abbreviated name fault in panel b: WQLF- the west Qinling fault; EKLF- the east Kunlun fault; LMSF- the Longmenshan fault; LPSF- Liupanshan fault; LLF- Lixian-Luojiapu fault; LTF- Lintan-Tanchang fault; LJF- Liangdang-Jiangluo fault; GDF- Guangganshan-Dieshan fault; CXF- the southern fault of Chenxian Basin; BLJF- Bailongjiang Fault; KLF- Kangxian-Lveyang Fault; HDF- Hanan-Daoqizi fault; WKLF- Wenxian-Kangxian-Lveyang Fault; QCF- Qingchuan Fault. Active faults are modified from 'Map of active faults in China' by Deng et al. (2003) and 'Map of active faults in north-eastern of Gansu province'by Zheng et al. (2013a) and Yuan et al. (2004).