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Cenozoic clockwise rotation of the Chuan Dian Fragment, southeastern edge of the Tibetan Plateau: Evidence from a new paleomagnetic study

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ABSTRACT

Late Eocene-early Oligocene red beds of the Ninglang Formation were sampled from 23 sites in the Yongsheng area, which comprises the northwestern part of the Chuan Dian Fragment (CDF) of the South China Block. The higher temperature components (HTC) were isolated by stepwise thermal demagnetization between ~300–680 °C and they passed the fold test. However, all the HTCs are of normal polarity, which appears to conflict with the frequent occurrence of reversed polarities during the late Eocene-early Oligocene, and therefore the possibility of remagnetization needs to be considered. Widespread secondary hematite was detected in the red beds that further indicates the remagnetization of samples. From the magmatic–metallogenic events in the sampling area, we propose an early Oligocene (~35 Ma) remagnetization event that was most likely related to porphyritic intrusions induced by fluid activity. Comparison of the pole calculated from the remagnetized remanent directions with the ~35 Ma paleomagnetic pole for Eurasia indicated that the degree of clockwise rotation in the Yongsheng area is 17.0 ± 4.1° relative to stable Eurasia. The rotation value is consistent at the 95% confidence level with results obtained from Paleogene and Cretaceous strata in other areas of the CDF. Paleomagnetic data indicate that a consistent clockwise rotation of 20.6 ± 6.3° occurred in different areas in the CDF: at Yongsheng, Zhupeng, Bailu, Dayao, Chuxiong west and Jianchuan. Careful analysis of the paleomagnetic data and the geometrical characteristics of the Ailao Shan–Red River shear zone indicates that the rotation process was separated into two discrete intervals: Approximately 11° of quasi-rigid clockwise rotation occurred between ~35 and 12.7 Ma compared to stable Eurasia, which may have been accompanied by strike-slip movement of the Ziyun-Luodian fault, caused by west-to-east compression induced by the northeastern indention of the Eastern Himalayan Syntaxis. Subsequently, a clockwise rotation of about 10° of the CDF with respect to stable Eurasia is inferred from the paleomagnetic results since 12.7 Ma, which is consistent with the change in the geometry of the Ailao Shan–Red River shear zone around the western Chuxiong Basin. The later CW rotation was related to shearing movement of the Xianshuihe–Xiaojiang fault.

1. Introduction

The Indian plate collided with the Eurasian continent at about 50 Ma (e.g., Jaeger et al., 1989; Klootwijk et al., 1985; Molnar and Tapponnier, 1975; Rowley, 1996; Yang et al., 2015; Yi et al., 2015). Consequently, about ~2500 km of crustal shortening has occurred between the Indian and Eurasian plates (e.g., Besse, 1986; Yang et al., 1998; Yi et al., 2015; Tong et al., 2017), but it is unclear how this convergence was absorbed during the collision. Three models have been proposed to explain the convergence: a 'tectonic escape' model (Avouac et al., 1993; Lacassin et al., 1997; Peltzer and Tapponnier, 1988; Tapponnier et al., 1982), a 'crustal flow' model (Royden et al., 1997, 2008), and a continuum deformation model (England and McKenzie, 1982; Houseman and England, 1986, 1993; Vilotte et al., 1986). These three tectonic deformation models were proposed for the nearby Tibetan Plateau, especially for its southeastern margin. Therefore, accurate measurement of the scale of crustal deformation is critical for assessing the kinematic and geodynamic models for this region.

Southeastern Tibet is composed of numerous tectonic blocks (e.g., the Tengchong Block, the Baoshan Block, and the Chuan Dian

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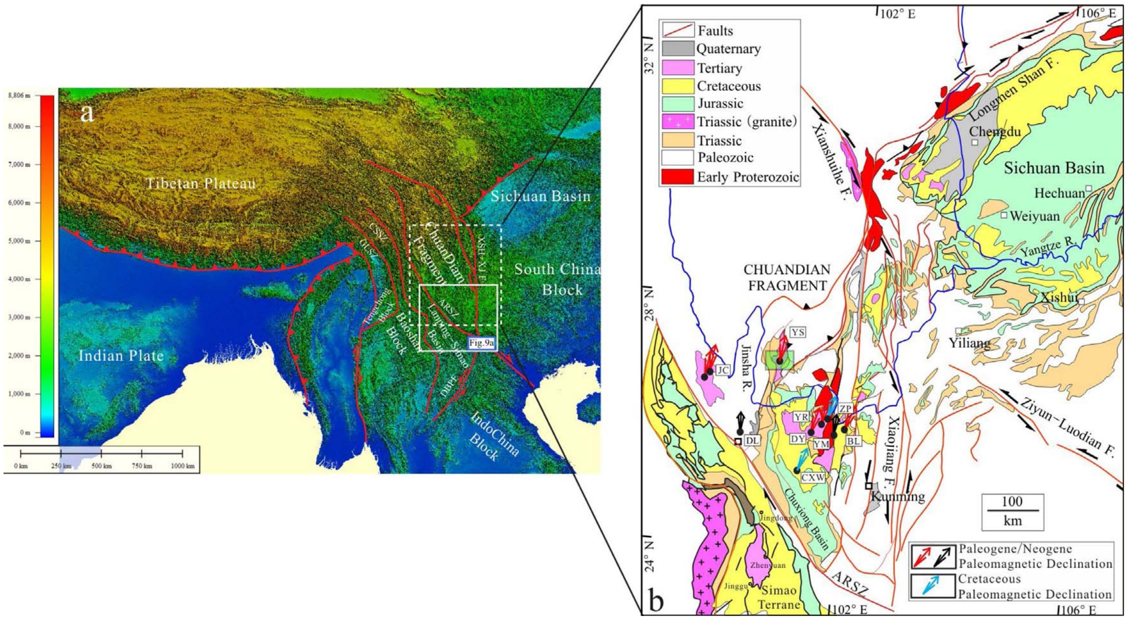

Fig. 1. (a) Schematic tectonic map of the Tibetan Plateau and surrounding areas. (b) Simplified geological map of the western part of the Yangtze Block (modified from Wang et al., 2014b). The green square indicates the sampling locality for this study, and the black dots and arrows indicate the areas where paleomagnetic results are available. Abbreviations: DL: Dali; JC: Jianchuan YS: Yongsheng; DY: Dayao; ZP: Zhupeng; BL: Bailu; YM: Yuanmou; CXW: Chuxiong West; GLSZ: Gaoligong shear zone; CSSZ: Chongshan shear zone; ARSZ: Ailao Shan–Red River shear zone; XSH–XJF: Xianshuihe–Xiaojiang fault; DBPF: Dien Bien Phu fault. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fragment; Fig. 1a). The Chuan Dian Fragment (CDF) is one of the most important mosaic blocks for understanding the intra–continental deformation behaviour during the collision of the Indian plate with the Asian continent. Because the CDF is located between the Indian plate and the stable part of the South China Block, it contains a record of the intra–continental deformation behaviour of the Asian continent. Previous paleomagnetic studies from the CDF suggest that this area has experienced different degrees of rotation and latitudinal translation during the penetration of India into Asia (Funahara et al., 1992; Otofuji et al., 1990, 1998; Tong et al., 2015; Yoshioka et al., 2003; Wang et al., 2016; Zhu et al., 2008). The interpretation of these results has given rise to disagreement about how the CDF behaved during the deformation. Funahara et al. (1992) and Otofuji et al. (1998) proposed that the differential rotation within the CDF reflected the large–scale continuous plastic deformation of the upper crust during the India–Asia collision. In contrast, Tong et al. (2015) proposed that ~20° of clockwise-rotation has occurred within the mid-western CDF since the middle Miocene, and that the eastern part underwent a different degree of rotational deformation since the Pliocene. Wang et al. (2016) support the view that there was relatively rigid mosaic block behaviour of the CDF during the rotation. The Xianshuihe–Xiaojiang fault (XSH–XJF), located to the east of the CDF, is arc-shaped, which can be fitted to a small circle with the Eular pole at the Eastern Himalayan Syntaxis (EHS). Wang et al. (2016) selected 11 reference points from the XSH–XJF and calculated that the displacement along the XSH–XJF fault is 171 ± 59 km, based on paleomagnetic data. In addition, results from GPS and geological observations show that the current deformation of the CDF and its surrounding blocks favour the model of a stronger, highly fragmented upper crust and mechanically weak lower crustal flow (England and Molnar, 1990; Gan et al., 2007; Shen et al., 2001, 2005; Xu et al., 2003; Zhang et al., 2004; Zhang, 2012).

Considering the significant differences between these models and the scarcity of paleomagnetic data from the northwestern part of the CDF, we selected the Yongsheng area for paleomagnetic investigation to provide further constraints on the deformation behaviour of the CDF.

2. Geological setting and sampling

Located in the southeastern Tibetan Plateau, the CDF is separated from the main part of the South China Block by the XSH–XJF system (Fig. 1a). Geological investigations of the Xianshuihe fault (XSHF) demonstrate ~80 km of sinistral offset since ~12 Ma (Burchfiel et al., 1995; Replumaz et al., 2001; Roger et al., 1995; Li et al., 2015; Wang et al., 1998) (Fig. 1b). The XSH–XJF system is offset from the Longmen Shan thrust belt by ~60 km (Jun et al., 2003; Wang et al., 1998), indicating that ~20 km of displacement was absorbed by the western Longmen Shan thrust belt. Located between the XSH–XJF fault and the Sichuan basin, the 300–km–long NW–SE striking Ziyun–Luodian fault (ZLF) plane dips to the NE (Fig. 1b). The sinistral offset of NE–SW–-trending secondary folds and faults along the ZLF demonstrate that the ZLF is a sinistral fault (Wang et al., 1998; Wang and Yin, 2009). The ZLF fault was active during the Late Triassic to late Neogene, producing 50–150 km of sinistral movement of Carboniferous sandstones and Permian basalts (Tang et al., 2014; Wang and Yin, 2009) (Fig. 1b). To the southwest, the Ailao Shan–Red River shear zone (ARSZ) constitutes the boundary between the CDF and Indochina Block (Wang et al., 2014a,b) (Fig. 1b). Detailed geochronological and geological studies indicate that the ARSZ is a left–lateral strike slip fault that was active from ~36 Ma to ~17 Ma (e.g., Cao et al., 2011). The rates of sinistral motion at Ailao Shan were 4–5 cm/yr from 27 to 17 Ma (Cao et al., 2011; Gilley et al., 2003; Leloup et al., 2001; Lu et al., 2012). The dextral offset since the late Miocene was estimated to be 20–57 km (Allen et al., 1984), 37 km (Tuc and Yem, 2001), 40 km (Schoenbohm et al., 2005, 2006) or 200–250 km (Leloup et al., 1995). The initial age of the right–lateral movement along the ARSZ is ~5 Ma (Replumaz et al., 2001) or ~8 Ma (Li et al., 2013).

The Ninglang Basin occupies the northwestern part of the CDF (Fig. 1b). The late Eocene-early Oligocene Ninglang Formation unconformably overlies the Jurassic Fengjiahe Formation (Fig. 2) (BGMRY, 1990, 1995). The Ninglang Formation consists of reddish–purple sandstones and mudstones and is divided into four parts: the upper part mainly consists of gray siltstone and muddy siltstone, and the middle, middle-lower and lower parts consist of purplish-red