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New insights into the India–Asia collision process from Cretaceous paleomagnetic and geochronologic results in the Lhasa terrane

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ABSTRACT

To further constrain the India–Asia collisional process, a combined paleomagnetic and geochronologic study has been carried out on the Upper Cretaceous Jingzhushan Formation redbeds and the Lower Cretaceous Dianzhong Formation volcanic rocks dated at ~121–117 Ma from the Cuoqin area in the central Lhasa terrane. Stepwise thermal demagnetization successfully isolated reliable characteristic remanent magnetization (ChRM) directions that include dual polarity and pass positive fold tests at 95% and 99% confidence levels, indicating prefolding primary magnetizations. The tilt-corrected site-mean direction for 33 redbed sites is $D = 316.8°$, $I = 30.2°$ with $\alpha_{95} = 5.4°$, corresponding to a paleopole at 49.0°N, 344.3°E with $A_{95} = 5.3°$, and the other for 12 volcanic sites is $D = 350.5°$, $I = 25.5°$ with $\alpha_{95} = 7.7°$, corresponding to a paleopole at 70.5°N, 292.9°E with $A_{95} = 7.4°$. Our new paleomagnetic results, together with reliable Cretaceous paleomagnetic data obtained from the Lhasa terrane, demonstrate that the southern margin of Asia was located at ~15.1°N during the Cretaceous. Comparison with the apparent polar wander paths (APWP) of India and the Cretaceous–Paleocene paleopoles of the Himalayan terrane suggests that the India–Asia collision was likely a complex process, which consists of the collision of the Lhasa and Himalayan terranes at 54.0 ± 2.1 Ma, the longtime subduction of an intra-oceanic basin between the Himalayan terrane and the Indian craton from ~54.0 to ~40.4 Ma, and the collision of the Himalayan terrane and the Indian craton at 40.4 ± 4.1 Ma. Comparing with the Late Cretaceous average pole of the East Asia APWP reveals that a latitudinal convergence of 780 ± 240 km has taken place between the Lhasa terrane and East Asia (the Hexi corridor) since the India–Asia collision; the amount of latitudinal shortening deduced from paleomagnetic data is very consistent with the 600–1000 km accommodated by the Cenozoic fold and thrust belts between the Lhasa terrane and Hexi corridor.

1. Introduction

The India–Asia collision created the Himalayan–Tibetan Orogen, and thus provides a typical example for the study of continent–continent collision and associated intracontinental deformation within Asia (e.g., Yin and Harrison, 2000; Aitchison et al., 2007). The precise timing of the India–Asia collision is a key to constructing the evolution model of the Himalaya–Tibetan orogenic system (e.g., Aitchison et al., 2007). Noticeably, although many geologic and geophysical investigations have been carried out in the Himalayan–Tibetan Orogen and its neighboring regions in the last four decades (e.g., Chang and Zheng, 1973; Molnar and Tapponnier, 1975; Besse et al., 1984; Otofuji et al., 1989; Enkin et al., 1992; Meyer et al., 1998; Yin and Harrison, 2000; Tapponnier et al., 2001; Yang et al., 2002; Gilder et al., 2003; Huang et al., 2006; Wang et al., 2008; Yin, 2010; Zhu et al., 2011; Pan et al., 2012; Ran et al., 2012; Chatterjee et al., 2013; Zhu et al., 2013), the exact age of the India–Asia collision remains debated based on different methods, with estimates ranging from 70 Ma to 34 Ma (e.g., Besse et al., 1984; Rowley, 1996; Aitchison et al., 2000; Yin and Harrison, 2000; Aitchison and Davis, 2001; Ding et al., 2003; Mo et al., 2003; Ding et al., 2005; Zhu et al., 2005; Aitchison et al., 2007; Ali and Aitchison, 2008; Mo et al., 2008; Huang et al., 2010; Najman et al., 2010; Sun et al., 2010; Cai et al., 2011; Yi et al., 2011; Meng et al., 2012; Sun et al., 2012; Tang et al., 2013). Paleomagnetism can determine the plate paleolatitude as a way to constrain kinematic processes of plate movement, and thus can be used to constrain the age of the India–Asia collision by overlapping the paleolatitude of the northern margin of India with the southern margin of Asia (e.g., Chen et al., 2010; Dupont-Nivet et al., 2010; Sun et al., 2010; Yi et al., 2011; Meng et al., 2012; Tang et al., 2013). Because the Lhasa terrane was located along

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the southern margin of Asia prior to the Cenozoic India–Asia collision, Cretaceous and Paleocene–Eocene paleomagnetic data from the Lhasa terrane are essential to constrain the age of the India–Asia collision, as well as to estimate the amount of the post-collisional convergence within Asia. However, the reported paleomagnetic data from both volcanic and sedimentary rocks yield quite large uncertainties, with a significantly discrepant paleolatitudes ranging from 7°N to 32°N (e.g., Pozzi et al., 1982; Achache et al., 1984; Lin and Watts, 1988; Sun et al., 2008, 2010; Tan et al., 2010; Yi et al., 2011; Chen et al., 2012; Sun et al., 2012; Tang et al., 2013). These discrepant paleolatitudes provide the wide collision ages ranging from 65 Ma to 43 Ma, as well as the discrepant post-collisional shortening estimates ranging from 1900 km to only a few hundred kilometers. Because paleomagnetic records from volcanic rocks provide only spot readings of the geomagnetic field behavior (Tauxe, 1993), the large range of the observed paleolatitudes in volcanic rocks may reflect the secular variation of the geomagnetic field (e.g., Sun et al., 2012). Considering that compaction-induced inclination shallowing is generally present in sedimentary rocks (e.g., Gilder et al., 2001; Tan et al., 2003; Tauxe, 2005; Yan et al., 2005; Tan et al., 2007), the lower paleolatitudes observed in sedimentary rocks may thus partly be attributed to low-latitude bias due to inclination shallowing (e.g., Tan et al., 2010; Huang et al., 2013). Furthermore, the Lhasa terrane is long and narrow, with a width less than 300 km from south to north but a length more than 2000 km from east to west (Fig. 1). However, the reported Cretaceous and Paleocene–Eocene data mainly focus on the eastern part of the Lhasa terrane, with only four Cretaceous–Paleocene paleomagnetic data from its mid-western part have been published until recently (Chen et al., 1993, 2012; Meng et al., 2012; Tang et al., 2013). To better constrain the paleolatitude of the southern margin of Asia prior to the Cenozoic India–Asia collision, we carried out a combined paleomagnetic and geochronological study for the Upper Cretaceous Jingzhushan Formation (Fm) redbeds and the Lower Cretaceous Dianzhong Fm volcanic rocks in the Cuoqin area, central Lhasa terrane. Our new paleomagnetic data provide the necessary paleolatitude control on the southern margin of Asia.

2. Geological setting and sampling

The Qinghai–Tibet plateau is generally regarded as a collage of five terranes; from north to south these are the Kunlun–Qaidam, Sonpan-Ganze–Hoh Xil, Qiangtang, Lhasa and Himalayan terranes (Fig. 1). These terranes rifted from Gondwanaland and then accreted to the Asian continent (e.g., Dewey et al., 1988; Yin and Harrison, 2000; Metcalfe, 2013). The Lhasa terrane is now located between the Himalayan terrane on the south and the Qiangtang terrane on the north. Previous geological observations showed that it accreted onto the Qiangtang terrane of southern Asia during the Late Jurassic–Early Cretaceous, and was located at the southern margin of Asia before the Cenozoic India–Asia collision (e.g., Chen et al., 1993; Matte et al., 1996; Halim et al., 1998; Metcalfe, 2006; Chen et al., 2012).

The Upper Cretaceous Jingzhushan Fm, which is widely exposed in the Cuoqin sampling region (Fig. 2), is composed of purplish-red clastic sedimentary rocks intercalated with limestone on the top. Its thickness varies from several hundred meters to more than 1600 m. The Jingzhushan Fm is overlain unconformably by the Neogene Jiejunazhuo Fm redbeds, and lies over the Early Cretaceous Zenong Group (Gp) volcanic rocks. Fossils identified in this formation include *Orbitolina* (*Orbitolina* sp., *Orbitolina* (*Columnorbitolina*) cf. *alticonica* Zhang, *Orbitolina* (*Palorbitolina*) *complanata* Zhang, *Orbitolina* (*Orbitolina*) *bangoinica* Zhang) and small Foraminifera (*Cuneolina immatura* He, *Cuneolina camposaurii* Sartoni et Creascenti, *Psendocyclamina* sp., *Daxia cenomana* Cuvillier et Szakall, *Rotalipora* sp.), indicative of Late Cretaceous time (1:250,000 scale Cuoqin regional geological survey report (H45C001001), 2003). In addition to the Jingzhushan Fm redbeds, the Zenong Gp and Dianzhong Fm volcanic rocks are also widely exposed in the Cuoqin sampling area (Fig. 2). The Zenong Gp is mainly composed of gray volcanic lavas and pyroclastic rocks, with an average thickness more than 1000 m. Previous zircon U–Pb dating showed that the Zenong Gp volcanism began at ca. 130 Ma and ceased at ca. 110 Ma (Zhu et al., 2008). The Dianzhong Fm volcanic rocks are widely distributed along the southern margin of the Zenong Gp volcanic rocks, and

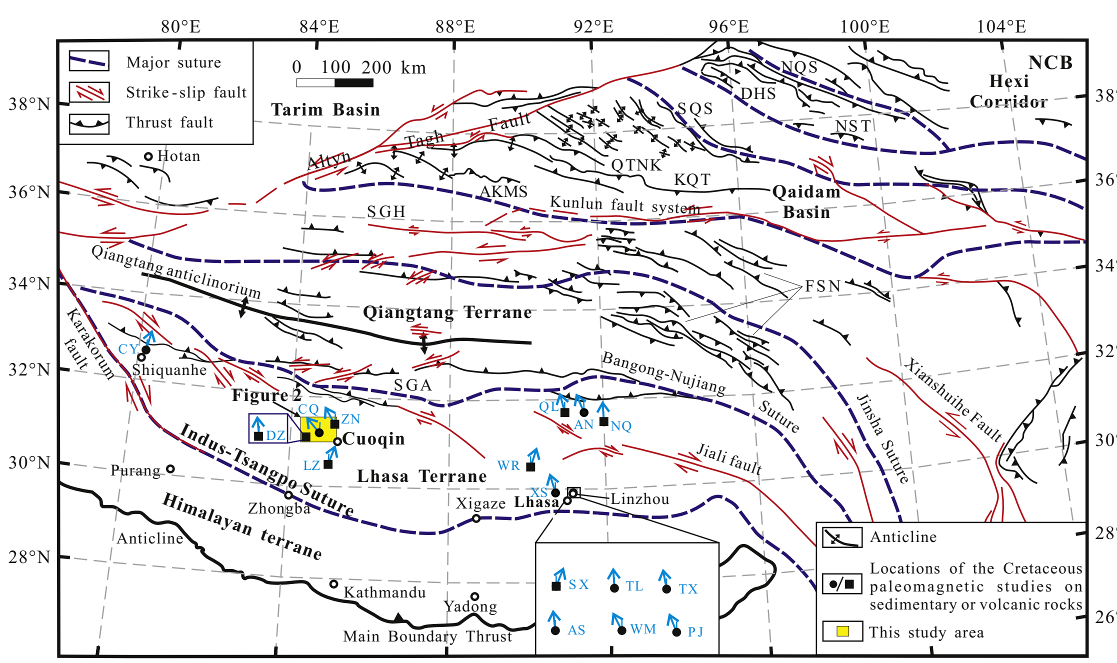

Fig. 1. Tectonic sketch map of Central Asia modified after Yin and Harrison (2000), showing sampling locations of previous Cretaceous paleomagnetic studies in the Lhasa terrane (for abbreviations see Table 3). Declination is indicated by arrows. A thin line indicates geographic north, and it is vertical because of the projection selected. Abbreviations: AKMS, Ayimaqin–Kunlun–Muztagh suture; DHS, Danghe Nan Shan suture; FSN, Fenghuo Shan–Nanqian fold and thrust belt; KQT, Kunlun–Qaidam terrane; QTNK, Qimen Tagh–North Kunlun thrust system; NCB, North China block; NQS, North Qilian Suture; NST, Nan Shan thrust belt; SGA, Shiquanhe–Gaize–Ando thrust system; SGH, Songpan-Ganzi–Hoh Xil terrane; SQS, South Qilian suture; NCB, North China Block.