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Paleomagnetic and geochronological constraints on the post-collisional northward convergence of the southwest Tian Shan, NW China

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Abstract

A combined paleomagnetic and geochronological study is reported of Paleogene basalt lavas and an intercalated red bed succession, comprising a minimum of 14 basalt flows and 10 red bed horizons in the Tuoyun Basin of the southwest Tian Shan Range, China. Two basalt matrix samples yield $^{40}Ar/^{39}Ar$ isochron ages of 58.5 ± 1.3 Ma (2σ, MSWD = 0.9) and 60.4 ± 1.3 Ma (2σ, MSWD = 1.7). These compare well with a previously published K–Ar dilution age of 61.7 ± 2.3 Ma for comparable Paleogene basalts and confirm that the younger pulse of magmatism in this basin is represented by both intrusive and extrusive activity. Demagnetization and component analysis identify a stable characteristic remanence (ChRM) with predominantly reversed polarity following removal of secondary remanence by peak demagnetization steps below 250–350 °C or 5 mT. Rock magnetic analysis identifies pseudo-single domain magnetite or titanomagnetite as carriers. The stable ChRM passes a fold test; it was probably acquired at the time of lava emplacement. Results from the bulk of the collection imply that paleomagnetic data from the upper and lower (~115 Ma) basalt series in the Tuoyun Basin are not distinguishable at the 95% significance level and indicate that this tectonic domain remained essentially stationary with respect to the Earth's spin axis for ~50 Ma prior to onset of the India/Asia collision in early Eocene times. It is therefore probable that no paleomagnetically detectable crustal shortening occurred in the southwest Tian Shan prior to collision. Paleomagnetic data sets from the Tuoyun Basin also show that little or no paleolatitude difference is present between the Tian Shan and the reference latitude of Eurasia at ~60 Ma. This supports previous evidence suggesting that central Asian blocks in the vicinity of the Tian Shan are unlikely to have experienced appreciable northward convergence relative to Eurasia since onset of the India/Asia collision and initiation of the Himalaya.

Keywords: Tian Shan; Tuoyun Basin; China; Paleomagnetism; $^{40}Ar/^{39}Ar$ dating; Paleogene; Basalt flows; Red beds; Indo-Asian tectonics

1. Introduction

The vast region of crust between northern India and central Asia has undergone a complex neotectonic (post-collisional) deformation driven by the continuing impingement of India into Asia, following final closure

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of the NeoTethys Ocean in early Eocene times some 50 Ma ago (Patriat and Achache, 1984). The intracontinental shortening and lithosphere thickening within Tibet and areas to the north has resulted in formation of the grand Tibetan Plateau and the Tian Shan Range (e.g. Molnar and Tapponnier, 1975; Patriat and Achache, 1984; Dewey et al., 1988; Le Pichon et al., 1992; Meyer et al., 1998; Yin and Harrison, 2000; Tapponnier et al., 2001). The crustal shortening budgets in Tibet and areas to the north derived from geophysical data (Patriat and Achache, 1984; Achache and Courtillot, 1984; Besse et al., 1984; Chen et al., 1991, 1992, 1993) and volumetric analysis (Le Pichon et al., 1992) imply that the overall convergence between India and Siberia since onset of the collision has been about 2700 km. These studies have suggested that some 1500 km of this convergence has occurred north of Tibet, ~1000 km has taken place north of Tarim, and some 600 km has occurred north of Junggar. However, expanding geological observations in Tibet and central Asia (e.g. Dewey et al., 1988, 1989; Avouac et al., 1993; Murphy et al., 1997; Yin and Harrison, 2000; Johnson, 2002, and references therein) indicate a deficit of at least several hundred km to some 1000 km when compared to this overall convergence of India and Asia (Johnson, 2002). The deficits could come partly from underestimates of pre-collisional shortening in Tibet and central Asia. Alternatively the estimates of shortening based on paleomagnetic data from red bed studies might have overestimated the overall convergence north of Tibet. This follows because sedimentary rocks are subject to compactional and depositional effects leading to shallowing of the magnetic inclination (e.g. Tauxe, 2005). This effect is the probable cause of a mean paleolatitude derived from sediments in this region some 11° lower than the paleolatitude defined from contemporaneous volcanic rocks (Gilder et al., 2003).

Since paleomagnetic studies have repeatedly shown significant shallowing of magnetic inclination in Cretaceous and Tertiary red beds from central Asia (e.g. Thomas et al., 1993; Westphal, 1993; Chauvin et al., 1996; Gilder et al., 1996, 2001, 2003; Cogné et al., 1999; Dupont-Nivet et al., 2002; Huang et al., 2004a), extension of paleomagnetic and geochronological studies to volcanic rocks in order to more reliably determine northward convergence within central Asian blocks following initial collision of India and Asia is an important objective. This follows because volcanic rocks are known to be largely or wholly immune from physical shallowing effects during formation and are generally recognized as faithful recorders of the ambient field (e.g. Collinson, 1983).

Direct comparison of paleolatitude data calculated from red bed and volcanic sites of central Asia (west of 85°E) suggests that paleolatitudes derived from volcanic rocks show no significant deviation with respect to the reference values predicted from stable Eurasia whereas the paleolatitudes of red beds are typically 10°–20° lower than those predicted from the reference values (Gilder et al., 2003). However, few Cenozoic volcanic results are reported from central Asia (Thomas et al., 1994; Otofuji et al., 1995; Meng et al., 1998 and Table 2 of Gilder et al., 2003) and some of them were obtained from only a small number of flows so the results are ambiguous. Li et al. (1995), for example, sampled nine sites from two Miocene basalt and trachybasalt flows from the Kangxiwa–Hongliutan area at the northern border of Tibet and found paleolatitudes near the expected values derived from the 10 Ma reference pole for Eurasia whereas Thomas et al. (1994) in another study from central Asia found much shallower than expected inclinations from two sites in a single ~50 Ma basalt flow and two sites in sediments baked by the flow. This latter result was interpreted as the record of a component of geomagnetic secular variation (GSV). Therefore, much more data from volcanic rocks with sufficient averaging of GSV in central Asia are clearly desirable to better constrain the northward movement of blocks during Alpine–Himalayan orogenesis.

The Tian Shan Range of central Asia links the Kazakhstan Block and Junggar Basin to the north with the Tarim Basin and Himalayan Orogen to the south (Fig. 1a); it was formed principally by convergent tectonism during Late Paleozoic times (Windley et al., 1990). It has been largely amagmatic since the Permian (Sobel and Arnaud, 2000). There are, however, a number of volumetrically small basaltic extrusive and intrusive units emplaced primarily within Mesozoic–Paleogene sediments (BGMRX, 1993; Thomas et al., 1994; Li et al., 1995; Sobel and Arnaud, 2000; Bazhenov and Mikolaichuk, 2002). In the Xinjiang Autonomous region of China, Mesozoic and Paleogene igneous rocks are reported from the Tuoyun Basin, northwest of Kashgar, where a ~300 m thick pile comprising two series of olivine basalts and some intrusive rocks has been identified (BGMRX, 1993; Li et al., 1995; Sobel and Arnaud, 2000). Gilder et al. (2003) isolated a stable magnetic component in 11 sites from basalt flows and 2 sites in baked sediments from the lower basalt series in the Tuoyun Basin. The emplacement of the succession is thought to have spanned a period of about half a million years and GSV is therefore likely to have been effectively averaged. The overall-mean direction of the basalt series and baked sediments shows insig-