Earth and Planetary Science Letters 486 (2018) 41–53

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Magnetostratigraphy of the Fenghuoshan Group in the Hoh Xil Basin and its tectonic implications for India–Eurasia collision and Tibetan Plateau deformation

Chunsheng Jin[a,b,*], Qingsong Liu[a,c,d,**], Wentian Liang[e], Andrew P. Roberts[f], Jimin Sun[a,b], Pengxiang Hu[a,f], Xiangyu Zhao[a], Youliang Su[a], Zhaoxia Jiang[a], Zhifeng Liu[a], Zongqi Duan[a], Huihui Yang[a], Sihua Yuan[g]

[a] *Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, People's Republic of China*
[b] *Center for Excellence in Tibetan Plateau Earth Sciences, Chinese Academy of Sciences, Beijing, People's Republic of China*
[c] *Department of Ocean Science and Engineering, Southern University of Science and Technology, Shenzhen, People's Republic of China*
[d] *Laboratory for Marine Geology, Qingdao National Oceanography Laboratory for Science and Technology, Qingdao, People's Republic of China*
[e] *State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, People's Republic of China*
[f] *Research School of Earth Sciences, The Australian National University, Canberra, ACT, Australia*
[g] *Department of Earthquake Science, Institute of Disaster Prevention, Langfang, People's Republic of China*

ARTICLE INFO

Article history:
Received 21 October 2017
Received in revised form 24 December 2017
Accepted 14 January 2018
Available online xxxx
Editor: A. Yin

Keywords:
magnetostratigraphy
sediment accumulation rate
Hoh Xil Basin
Fenghuoshan Group
Tibetan Plateau
Tanggula Thrust System

ABSTRACT

Early Cenozoic plate collision of India and Eurasia was a significant geological event, which resulted in Tibetan Plateau (TP) uplift and altered regional and global atmospheric circulations. However, the timing of initial collision is debated. It also remains unclear whether the TP was deformed either progressively northward, or synchronously as a whole. As the largest basin in the hinterland of the TP, evolution of the Hoh Xil Basin (HXB) and its structural relationship with development of the Tanggula Thrust System (TTS) have important implications for unraveling the formation mechanism and deformation history of the TP. In this study, we present results from a long sedimentary sequence from the HXB that dates the Fenghuoshan Group to ∼72–51 Ma based on magnetostratigraphy and radiometric ages of a volcanic tuff layer within the group. Three depositional phases reflect different stages of tectonic movement on the TTS, which was initialized at 71.9 Ma prior to the India–Eurasia collision. An abrupt sediment accumulation rate increase from 53.9 Ma is a likely response to tectonic deformation in the plateau hinterland, and indicates that initial India–Eurasia collision occurred at no later than that time. This remote HXB tectonosedimentary response implies that compressional deformation caused by India–Eurasia collision likely propagated to the central TP shortly after the collision, which supports the synchronous deformation model for TP.

1. Introduction

Collision between the Indian and Eurasian plates produced concomitant uplift of the Tibetan Plateau (TP) and its basin-ridge geomorphological systems (e.g., Yin and Harrison, 2000; Li et al., 2015b). As the world's largest and highest plateau, TP surface relief has significant dynamic and thermal effects on atmospheric circulation and on regional and global climate (e.g., Raymo and Ruddiman, 1992; Dupont-Nivet et al., 2007). Timing of initial India–Eurasia collision is much debated. Studying the initial India–Eurasia collision is vital for understanding continental collision, dynamic mechanisms of TP uplift, and intra-continental deformation. Over recent decades, the timing of initial India–Eurasia collision has been studied using constraints from stratigraphy, sedimentology, paleomagnetism and magnetostratigraphy, igneous and metamorphic petrology, and structural geology. Variable ages have been proposed for the initial collision from the Late Cretaceous to the Late Eocene, and even the Oligocene (e.g., Hu et al., 2016, and references therein). However, various methods result in different definitions and timings for initial collision. Most collision

---

[*] Corresponding author at: Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, People's Republic of China.

[**] Corresponding author at: Department of Ocean Science and Engineering, Southern University of Science and Technology, Shenzhen, People's Republic of China.

E-mail addresses: csjin@mail.iggcas.ac.cn (C. Jin), qsliu@sustc.edu.cn (Q. Liu).

https://doi.org/10.1016/j.epsl.2018.01.010

ages are derived from areas around the Himalaya terrane. The disparate ages complicate assessment of the timing of initial collision. In addition, a long-standing controversy remains between two end-member models with respect to Cenozoic TP deformation history (Chang et al., 2015). One prevailing view is of diachronous progressive north-northeastward growth with an oblique stepwise rise (e.g., Tapponnier et al., 2001). Another is that widespread deformation occurred over the whole TP at or shortly after the onset of India–Eurasia collision (Yin and Harrison, 2000; Yin et al., 2002, 2007, 2008a, 2008b; Fang et al., 2013). In a proto-TP model, it is suggested that the central plateau was elevated first, and then subsequently propagated to the north and south isochronously, respectively (Wang et al., 2008, 2014; Li et al., 2015b). With regard to Cenozoic history, it remains unclear whether the TP was deformed either progressively northward or synchronously as a whole (Yin et al., 2002).

Whatever the deformation mechanisms for the TP, large numbers of Cenozoic sedimentary basins that developed concomitantly in and around the TP are attributed to have formed in association with intracontinental deformation and TP uplift due to India–Eurasia collision. Mountain uplift would result in exhumation and erosion, leading to deposition in adjacent sedimentary basins. Sediments in these basins preserve important information about spatiotemporal deformation patterns and uplift histories of surrounding mountains and of the TP. Compared to basins on the TP margins on which TP growth models are based, few data come from the central plateau, which restricts knowledge of TP growth processes so that further work in central areas is needed to identify the precise timing of basin evolution and deformation history.

As the largest basin in the TP hinterland, the Hoh Xil Basin (HXB) demarcates the northern proto-plateau margin (Wang et al., 2008, 2014; Li et al., 2015b). It lies in a region that links the main plateau (Lhasa and Qiangtang blocks) and remote basins on the northeastern TP margin, such as the Qaidam Basin. The HXB is a foreland basin that developed under the control of the Tanggula Thrust System (TTS), with its onset age constrained by the basal age of the Fenghuoshan Group (FHSG) (Wang et al., 2008; Li et al., 2012). The south-dipping TTS caused 89 km (60%) of south-northward shortening and resulted in rapid Eocene and Oligocene uplift of the Tanggula Shan (Li et al., 2012). Thus, understanding structural relationships between TTS development and the HXB has important implications for unraveling the formation mechanism and growth history of the entire TP.

Continuous sedimentation from the late Cretaceous to Miocene (Staisch et al., 2014) provides an excellent record for studying HXB development, its relationship with the TTS, and remote response to India–Eurasia collision. The Cenozoic history of the HXB has been established by analyzing thickness variations of lithological units, paleocurrent analysis, lithofacies patterns, and magnetostratigraphic studies (Liu and Wang, 2001; Liu et al., 2001, 2003; Wang et al., 2002; Li et al., 2012). Dating of the strata is crucial, yet the HXB chronology remains debated. The problem is mainly with the FHSG, which has been assigned Early Cretaceous (Li and Yuan, 1990), Late Cretaceous (Li et al., 2015a), entire Cretaceous (Zhang and Zheng, 1994), and even early Tertiary (Yin et al., 1990; Liu et al., 2003) ages based mainly on biostratigraphy and magnetostratigraphy, respectively. However, most reported palynological studies do not provide details of palynomorph assemblages, fossil abundances, and accurate sample positions (Staisch et al., 2014), which restricts dating of strata and produced a misleading magnetostratigraphic interpretation. These studies lack consensuses and call for more detailed work to identify the precise timing of the FHSG. From the palynological compilation of Staisch et al. (2014) for the FHSG, a biostratigraphic age range of 100–56 Ma is indicated. Together with a radiometric age of a tuff in the Erdaogou area, they reinterpreted the magnetic stratigraphy of Liu et al. (2003) to obtain an 85–51 Ma depositional age range for the FHSG. In this study, we present a new radiometric age of a tuff layer within the FHSG and a new high-resolution magnetostratigraphic record with the aim of: 1) determining an accurate age of the FHSG; 2) constraining the activity history of the TTS; and 3) constraining the timing of initial India–Eurasia collision and the TP deformation model since the Late Cretaceous.

2. Geological setting and stratigraphy

HXB lies across the central Baya Har terrane and the northern Qiangtang terrane, which spans the Jinsha River Suture Zone, and strikes approximately east–west. It is bounded by the Kunlun Mountains to the north and by the Tanggula Shan to the south, respectively. It is the largest interior basin in the TP hinterland, occupying an area of ~101,000 km^2 with an average elevation of >5,000 m. The pre-Cretaceous sedimentary basement of the HXB consists of Carboniferous, Permian, and Triassic slate, phyllite, metasandstone, and limestone (Zhang and Zheng, 1994). Sedimentary strata of the HXB since the late Mesozoic consist of the FHSG (since Upper Cretaceous), Tuotuohe Formation (Paleocene–Eocene), Yaxicuo Formation (Oligocene), Wudaoliang Formation (Miocene), and the Quguo Formation (Pliocene) (QIGS, 2005). The FHSG consists mainly of grey-violet-fuchsia sandstone, mudstone, and conglomerate, intercalated grey-green Cu-bearing sandstone, dark-grey bioclastic limestone, and grey gypsum (Liu and Wang, 2001; Liu et al., 2001). The Tuotuohe Formation mainly consists of fuchsia-brick red sandstone and conglomerate, interbedded with bioclastic and sandy micrite (QBGMR, 1989; QIGS, 2005). The Yaxicuo Formation consists mainly of alternating sandstone and mudstone with intercalated grey layered and tubercular gypsum. The Wudaoliang Group consists mainly of lacustrine carbonate rocks with minor black oil shale (Liu and Wang, 2001; Liu et al., 2001). The Tuotuohe, Yaxicuo, and Wudaoliang Formations are reportedly conformable (e.g., QBGMR, 1989; QIGS, 2005). However, other field observations indicate that the Wudaoliang Formation is unconformable with the underlying Yaxicuo Formation (Liu and Wang, 2001; Liu et al., 2001; Staisch et al., 2014). Strata of the FHSG, Tuotuohe, and Yaxicuo Formations are deformed strongly, whereas the Wudaoliang Formation has only been subjected to minor tilting (Liu and Wang, 2001; Liu et al., 2001; Wang et al., 2002; Li et al., 2012).

3. Sampling and measurements

3.1. Sampling

The FHSG is situated mainly in the central to southern HXB and is interpreted to represent fluvial, lacustrine, and fan-delta depositional environments (Liu and Wang, 2001; Liu et al., 2001). Deposition of the FHSG has been considered to indicate initiation of HXB sedimentation at *ca* 52 Ma based on magnetostratigraphy (Liu and Wang, 2001; Liu et al., 2001, 2003; Wang et al., 2002; Li et al., 2012, 2013). In this study, paleomagnetic samples were collected from two sections (dipping northward) (Fig. 1). Section A (34°31′13.86″N, 92°43′49.20″E) has a thickness of 4391 m, and is exposed near the Erdaogou area in three segments. The lithostratigraphy of Section A is characterized by 4 intervals: the 0–900 m interval consists mainly of alternating sandstone, siltstone, and mudstone, and intercalated gypsum; the 900–1400 m interval is dominated by mudstone; the 1400–4100 m interval consists of alternating sandstone, siltstone, and intercalated mudstone; the interval above 4100 m is dominated by sandstone and