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Early Eocene (*c.* 50 Ma) collision of the Indian and Asian continents: Constraints from the North Himalayan metamorphic rocks, southeastern Tibet

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ABSTRACT

Despite several decades of investigations, the nature and timing of the India–Asia collision remain debated. In the western Himalaya, the leading edge of the Indian continent was deeply subducted to mantle depths and experienced ultrahigh-pressure metamorphism in the Eocene at *c.* 50 Ma. In this paper, however, we demonstrate that the North Himalayan metamorphic rocks in the eastern Himalaya underwent Early Eocene (48–45 Ma) medium-pressure (MP) metamorphism due to shallow subduction of the Indian continent beneath southeastern Tibet. The studied garnet–kyanite–staurolite schists occur in the core of the Yardoi gneiss dome, the easternmost North Himalayan Gneiss Dome, and represent the upper structural level of the Higher Himalayan Crystallines (HHC). Petrology and phase equilibria modeling show that these rocks have mineral assemblages of Grt + Pl + Bt + Qz ± Ky ± St ± Ms that were formed under conditions of 7–8 kbar and 630–660 °C. Zircon U–Pb chronology shows that these rocks have peak-metamorphic ages of 48–45 Ma and protracted zircon growth, indicating that the collision between Indian and Asian continents must have occurred at *c.* 50 Ma in southeastern Tibet. Combining with available data, we suggest that the HHC represents a crustal section of the subducted and subsequently exhumed Indian continent. Due to shallow subduction of the continent during the Eocene, the middle to lower crust of the continent was subducted into depths of 40–60 km and underwent high-pressure (HP) and high-temperature (HT) granulite-facies metamorphism and intense anatexis, whereas the upper crust was buried to shallower depths of 20–30 km and witnessed MP metamorphism and intrusion of leucogranites derived from the lower structural level of the HHC.

1. Introduction

The Himalayan orogen, Earth's largest ongoing continent–continent collisional orogen, can be geographically divided into the northern Himalaya and southern Himalaya based on the high crest line (Yin, 2006). The southern Himalaya is composed of the Higher Himalayan Crystallines (HHC), the Lesser Himalayan Sequences (LHS), and the Sub-Himalayan Sequence (Siwalik Group) (Fig. 1). Most structures in the southern Himalaya are contractional and record crustal subduction associated with the collisional orogeny. The northern Himalayan domain, consisting of the Tethys Himalayan Sequences (THS) and the North Himalayan Gneiss Domes (NHGD, also called the Tethyan or North Himalayan metamorphic rocks), is characterized by early contractional and late extensional structures (e.g. Zhang et al., 2012).

The THS comprises the structurally highest units of the Himalayan orogen. As the earliest orogen-wide units to be accreted to Asia, they are uniquely placed to retain information regarding the formative stage of Himalayan orogenesis (Aikman et al., 2008). Available studies have proposed that these rocks presently exposed in the cores of the NHGD formed part of a mid-crustal channel that was laterally continuous with the HHC during the Oligo-Miocene, and therefore provides a record of Himalayan orogenesis (Chen et al., 1990; Lee et al., 2004; Lee and Whitehouse, 2007; Zeng et al., 2011; Zhang et al., 2012). However, the vast majority of studies to date have focused on the HHC in the southern Himalaya, in particular the central and western Himalaya. Relatively

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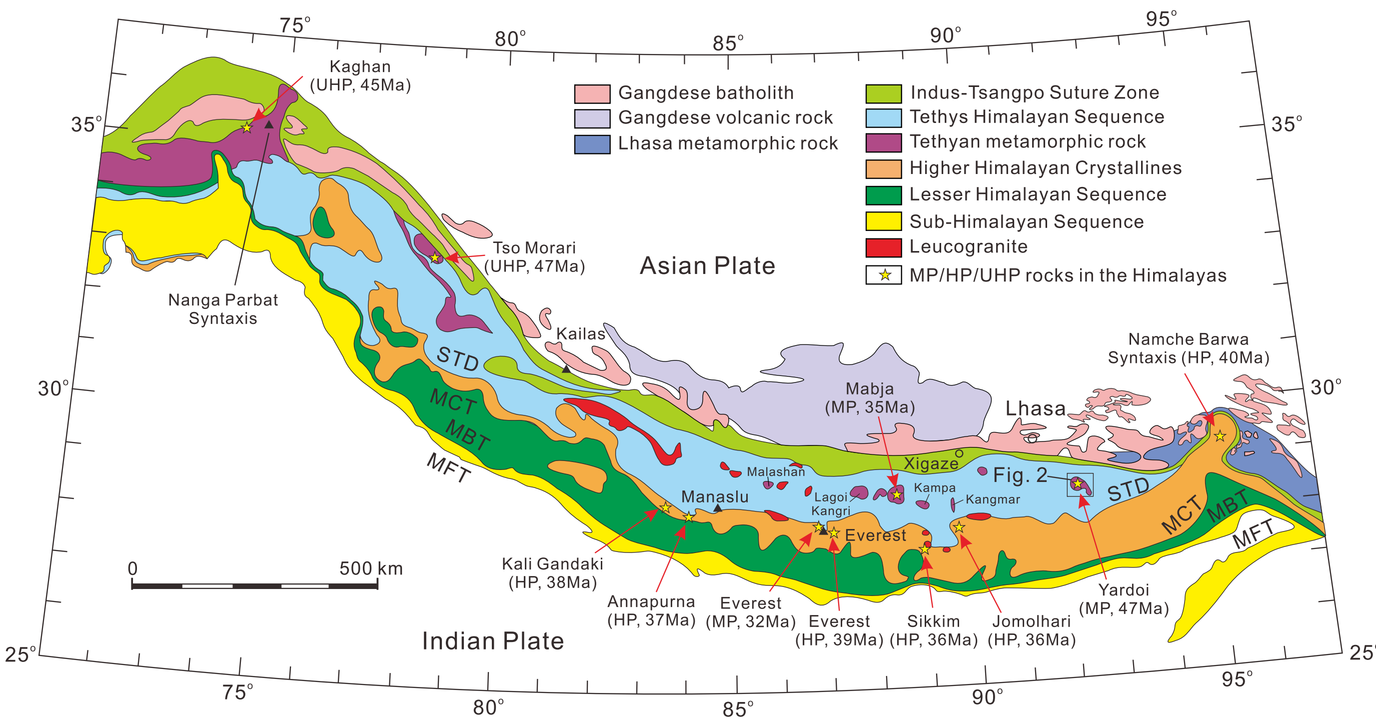

Fig. 1. Generalized geologic map of the Himalayan orogen (modified after Yin and Harrison, 2000; Guillot et al., 2008), showing locations and metamorphic ages of MP and UHP rocks in the northern Himalaya, and HP rocks in the southern Himalaya. Data sources: Annapurna (Kohn and Corrie, 2011), Everest (Cottle et al., 2009), Jomolhari (Regis et al., 2014), Kaghan (Kaneko et al., 2003), Kali Gandaki (Iaccarino et al., 2015), Mabja dome (Lee and Whitehouse, 2007), Namche Barwa Syntaxis (Zhang et al., 2015a), Sikkim and Yadong (Kellett et al., 2013; Rubatto et al., 2013), Tso Morari (Donaldson et al., 2013) and Yardoi dome (this study).

little is known about the THS and NHGD or the geological evolution of the eastern Himalaya. These and other factors limit the degree to which evolutionary models proposed for the Himalaya are comprehensive or valid (Aikman et al., 2008).

In this paper, we conduct a detailed petrological and geochronological study of the schists from the Yardoi gneiss dome in the eastern Himalaya. The results demonstrate that these rocks witnessed medium-pressure (MP) amphibolite-facies metamorphism at the Early Eocene (*c*. 47 Ma). Combining with available data, we suggest that (a) shallow subduction of the northeastern part of the Indian continent beneath southern Tibet resulted in MP metamorphism of the upper structural level of the HHC, and HP and HT granulite-facies metamorphism and partial melting of the lower structural level of the HHC, and (b) the collision between the Indian and Eurasian continents is diachronous along the orogenic strike with a final collision in the eastern Himalaya at *c*. 50 Ma. Therefore, our new results provide a key constraint on the nature and timing of the India–Asia collision in southeastern Tibet. Methods of the chemical analyses of mineral and whole-rock compositions, zircon U–Pb dating and phase equilibria modeling are described in Appendix A.

2. Geologic setting

The Himalayan orogen is divided into four litho-tectonic units separated by regional shear zones that roughly follow the trend of the main Himalayan Arc (Fig. 1; Yin and Harrison, 2000). From south to north in increasing structural height they are: the Sub-Himalayan Sequence (Siwalik Group) incorporated into the hanging wall of the Main Frontal Thrust (MFT); the Lesser Himalayan Sequence (LHS), separated from the underlying Siwalik Group by the south vergent Main Boundary Thrust (MBT); the Higher Himalayan Crystallines (HHC), a high-grade metamorphic sequence that has been extruded between the reverse sense Main Central Thrust (MCT) and normal sense South Tibetan Detachment System (STDS); and the Tethys Himalayan Sequence (THS).

The THS extends for more than 1500 km along the Himalayan orogen from Pakistan reaching the eastern syntaxis (Fig. 1). For nearly all of this length, the THS is bounded to the north by the Indus–Tsangpo Suture Zone and to the south by the north-dipping STDS. The THS comprise a deformed package of predominantly low-grade Paleoproterozoic to Eocene metasedimentary rocks thought to have been deposited along the northern margin of the Indian continent.

The North Himalayan Gneiss Domes (NHGD) expose a discontinuous series of domes across the northern Himalaya (Fig. 1). Some workers have referred to this belt as the north Himalayan antiform (e.g. Lee et al., 2004). Most of the domes are cored by granite plutons with ages of 43–10 Ma. The plutons are surrounded by deformed metasedimentary rocks and orthogneisses with protolith ages of *c*. 500 Ma, which are in turn overlain by the low-grade THS (Lee and Whitehouse, 2007). The contacts between the magmatic–gneissic cores and the overlying THS are detachment shear zones, representing exposures of the STDS in the northern Himalaya (Chen et al., 1990; Lee et al., 2004; Lee and Whitehouse, 2007).

The Yardoi gneiss dome, located in the easternmost region of the NHGD (Fig. 1), consists of a granite pluton in the core and three litho-tectonic units separated by two detachment faults (Fig. 2; Zhang et al., 2012). The uppermost unit above the upper detachment fault (UDF) is the THS which is mainly composed of a late Triassic flysch sequence, and was metamorphosed to slate and phyllite. The middle unit, bounded by UDF and the lower detachment fault (LDF), includes an upper subunit of garnet-bearing phyllite, and a lower subunit of garnet two-mica schist (Zhang et al., 2012). The lower unit beneath the LDF is the core of the dome which is composed of schists and gneisses with minor amphibolite. Another important component of the dome core is pegmatites, which occur along the gneissic foliation (Fig. 2). The inner core of Yardoi dome is occupied by a two-mica granite pluton with a crystallization age of *c*. 43 Ma (Zeng et al., 2011). The foliations in gneisses and schists are parallel to the LDF and define the shape of