Journal of Asian Earth Sciences 146 (2017) 211–220

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Full length article

Pre-Himalayan tectono-magmatic imprints in the Darjeeling-Sikkim Himalaya (DSH) constrained by $^{40}Ar/^{39}Ar$ dating of muscovite

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ARTICLE INFO

Keywords:
Indo-Asia collision
Himalayan orogen
Pre-Himalayan deformation
^{40}Ar-^{39}Ar geochronology
Early Proterozoic mobile belt
Columbia supercontinent

ABSTRACT

The Lower Lesser Himalayan Sequence (*L-LHS*) in Darjeeling-Sikkim Himalaya (*DSH*) displays intensely deformed, low-grade meta-sedimentary rocks, frequently intervened by granite intrusives of varied scales. The principal motivation of our present study is to constrain the timing of this granitic event. Using $^{40}Ar/^{39}Ar$ geochronology, we dated muscovite from pegmatites emplaced along the earliest fabric in the low grade Daling phyllite, and obtained ~1850 Ma Ar-Ar muscovite cooling age, which is broadly coeval with crystallization ages of Lingtse granite protolith (e.g., 1800–1850 Ma U-Pb zircon ages) reported from the *L-LHS*. We present here field observations to show the imprints (tectonic fabrics) of multiple ductile deformation episodes in the *LHS* terrain. The earliest penetrative fabric, axial planar to N-S trending reclined folds, suggest a regional tectonic event in the *DSH* prior to the active phase of Indo-Asia collision. Based on the age of granitic bodies and their structural correlation with the earliest fabric, we propose that the *L-LHS* as a distinct convergent tectono-magmatic belt, delineating the northern margin of Indian craton in the framework of the ~1850 Ma Columbia supercontinent assembly.

1. Introduction

The Lesser Himalayan Sequence (*LHS*) constitutes a persistent linear tectonostratigraphic belt, rimming the southern margin of the Himalayan Mountain System. This sequence has evolved through a long geological time span since early Proterozoic (Long et al., 2011). Unraveling the major events prior to the Indo-Asia collision (Gehrels et al., 2003) has a significant implication in estimating the crustal shortening since early Eocene (~55 Ma; Yin, 2006; Ding et al., 2005; Zhu et al., 2005). Recent studies have shown influence of pre-Himalayan tectonic activities using several geological proxies (Gehrels et al., 2003, 2006; Cawood et al., 2007; Bhargava et al., 2011). However, the Himalayan versus pre-Himalayan tectonic contributions is still unclear. This study emphasizes on geochronological evidence from the Darjeeling-Sikkim Himalaya (*DSH*) in support of active tectonism and granite magmatism prior to the Indo-Asia collision event.

A series of published literatures on Himalayan tectonics shows that the Lesser Himalayan Sequence in the eastern Himalaya accommodated large crustal shortening during Indo-Asia collision mostly by three major large-scale south vergent thrusts, e.g.; Main Boundary Thrust (MBT), Daling Thrust (DT, ~Ramgarh Thrust ~ Shumar Thrust), and Main Central Thrust (MCT) (Fig. 1; Gansser, 1964; LeFort, 1975; Beck et al., 1995; Butler, 1995; Avouac, 2003; Bose et al., 2014; Ghosh et al., 2016). In the *DHS*, the Daling Thrust (DT) is one of the most important tectonic zone within the *LHS* that places the older Lower Lesser Himalaya (*L-LHS*) over the younger Upper Lesser Himalaya (*U-LHS*) (Ghosh et al., 2016) and estimated at least ~50 km of horizontal shortening along it from structural reconstruction, using thrust–duplex model (Bhattacharyya and Mitra, 2009) (Fig. 2). Interestingly, the *LHS* in the eastern Himalaya is punctuated by a number of orogen-transverse tectonic windows with the DT demarcating the boundary of the window (see Bose et al., 2014 for review) (Figs. 1 and 2). According to thrust-duplex model, such tectonic window developed as a consequence of laterally discontinuous antiformal thrust stacks (DeCelles et al., 2001; McQuarrie et al., 2008; Bhattacharyya and Mitra, 2009). But, this model cannot render any explanation for the occurrences of penetrative ductile deformation structures. Bose et al. (2014) have proposed a superposed buckling model to explain the structural architecture of the Lesser Himalaya. Integrating the effects of both brittle and ductile deformations, they particularly explore the causal effects of folds and faults in orogenic system in a later study (Ghosh et al., 2016). They

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http://dx.doi.org/10.1016/j.jseaes.2017.05.027
Received 15 July 2016; Received in revised form 19 May 2017; Accepted 20 May 2017
Available online 23 May 2017
1367-9120/

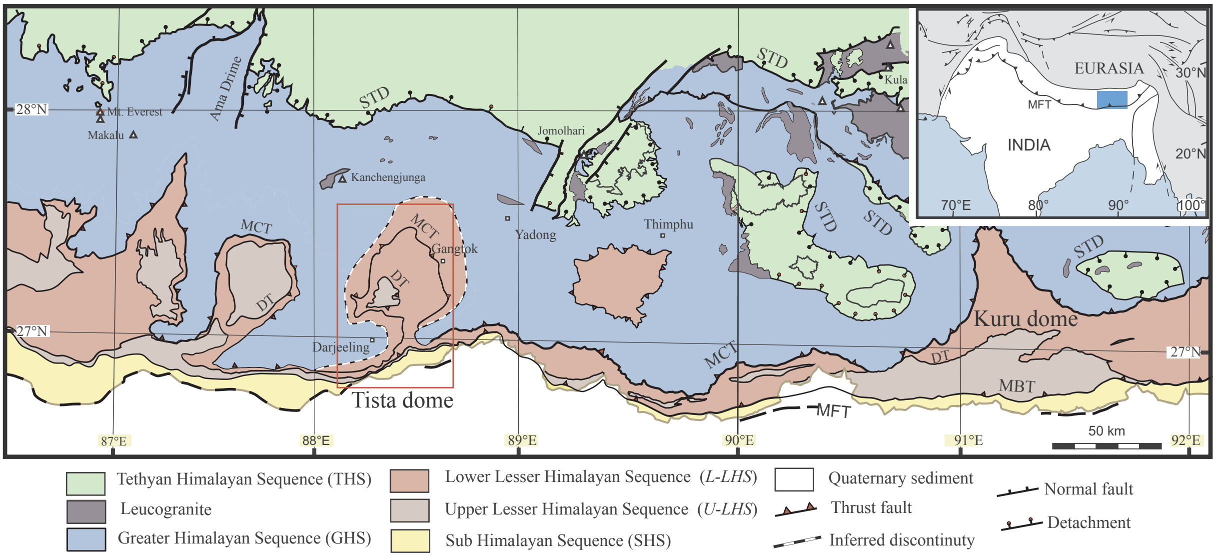

Fig. 1. Geological Index map of the Eastern Himalaya (modified after Kellett and Grujic, 2012). Study area shown in inset map and as red box in the Tista dome. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

have shown that a significant contribution of shortening was by ductile strains in multiple episodes (Bose et al., 2014), in addition to thrust-associated shortening.

Intense folding and thrusting during the collision event is likely to have erased most of the pre-Himalayan tectonic imprints. But several lines of studies have endeavored to recognize early structural evidence that survived profound Himalayan deformations. For example, Gehrels et al. (2003, 2006) have shown evidence of early Paleozoic tectonism from a field relationship of intrusive granite with deformed metasedimentary host rock of Greater Himalayan Sequence (*GHS*) lying to the north of the *LHS*. Using ^{206}Pb/^{238}U systematics they have analysed zircon crystals to date intrusive granites. Their concordant analysis yielded a mean age of 484 ± 10 Ma. Moreover, they have also dated pegmatitic biotite-muscovite granite that shares a strong foliation with the schistose host rock and obtained an even older age of 512 ± 11 Ma. In another study, Bhargava et al. (2011) recognized a distinct angular unconformity between the Cambrian and overlying Ordovician rocks from the *LHS* in Tons valley of Garhwal Himalaya. According to their study, early Paleozoic metamorphism and extensive emplacement of early Paleozoic granite and their exhumation also indicate a major thrusting event during the late Cambrian. These field relations, backed by geochronological data suggest substantial deformation prior to Indo-Asia collision event.

Another trend of research is focused to understand the pre-collisional tectono-magmatic setting of the *L-LHS* (McQuarrie et al., 2012). Several workers interpret *LHS* disposed along the northern edge of the Indian craton as a passive margin (Stöcklin, 1980; Valdiya, 1980; Schelling, 1992; McQuarrie et al., 2008; Brookfield, 1993; Upreti, 1999; Myrow et al., 2003; Gehrels et al., 2006). On the contrary, the presence of laterally extensive granite intrusions, overlapping U-Pb age clusters of crystalline (1780–1880 Ma) and detrital zircon ages (1800–1900 Ma) (Kohn et al., 2010) and mineralogy and chemistry of meta-sedimentary rocks collectively suggest the presence of a tectonically active arc setting. Understanding the geodynamic setting of the *LHS* during the early Proterozoic time thus seems to be fundamentally important for reconstruction of the supercontinent Columbia.

In this study we carried out a field investigation of pegmatite bodies as a possible proxy to the early Proterozoic tectono-magmatic event in the Daling Group of the Darjeeling-Sikkim Himalaya (*DSH)*. Earlier studies reported pre-Himalayan granite bodies from different regions in Eastern Himalaya (Kohn et al., 2010; Long et al., 2011; McQuarrie et al., 2012; Mottram et al., 2014a). This study focuses mainly on the lower part of the Lesser Himalayan Sequence (*L-LHS*) of DSH (Figs. 2 and 3). Using ^{40}Ar-^{39}Ar geochronology we dated muscovite from pegmatite bodies in the Daling Group, which yielded an age of ~1850 Ma. Based on this age constraint, we show a connection of the Daling belt with the early Proterozoic continental scale magmatic event in the framework of Columbia Supercontinent assembly.

2. Geological setting

2.1. Tectonostratigraphy

The *LHS* is divided into two broad sub-divisions: the Lower Lesser Himalayan Sequence (*L-LHS*) and the Upper Lesser Himalayan sequence (*U-LHS*) (Fig. 3). The *L-LHS* comprises the Daling Group that is intruded by the early Proterozoic Lingtse granite and its equivalents that presently occur as tectonised lenses and sheets (Acharyya, 1989; Dasgupta et al., 2004; Mottram et al., 2014a). On the other hand, the *U-LHS* comprises the Baxa Formation of late Proterozoic to Cambrian (?) age (Raha and Sastry, 1982; Schopf et al., 2008; Long et al., 2011) and late Paleozoic Gondwana Group (Acharyya and Ray, 1977; Figs. 2 and 3). The Baxa Formation unconformably overlies the Daling Group and underlies the Gondwana Group at the core of the Rangit Window (Raina, 1982; Acharyya and Ray, 1977; Bose et al., 2014; Figs. 2 and 3). Structurally, the *U-LHS* is tectonically overlain by *L-LHS* along the Daling Thrust (DT; ~Ramgarh Thrust) (Ray, 1976). The Main Central Thrust (MCT) is situated below the high grade gneisses of the Greater Himalayan Sequence *(GSH)* (Fig. 2) represented by a zone of inverted metamorphism (Acharyya, 1989; Dasgupta et al., 2004; Anczkiewicz et al., 2014; Mottram et al., 2014b; Chakraborty et al., 2016).

The Daling Group is mainly composed of low grade greasy and greenish phyllite, massive quartzite, greywacke and epidiorite. It consists of mica-schist, garnet mica schist and quartzite in relatively higher metamorphic grade. Tuffaceous-wacke in the Daling Group is locally called the 'gritty-schist'. Some quartz grains in greywacke are purple and blue tinted, and often rounded and embayed. These detrital quartz and feldspar grains in greywakes in cryptocrystalline matrix appear to be from low-grade volcanic source (Acharyya, 1980, 1989). The presence of meta-rhyolite has been also recorded from the Daling Group from East Bhutan (Long et al., 2011).

In the Darjeeling-Sikkim Himalaya (*DSH*), the age of the Daling Group has been constrained by U-Pb dating of crystalline, detrital zircon, which clusters with peaks at *c*. 1800–1900 Ma (Mottram et al., 2014a). The oldest zircon in this region yielded an age of 3600 Ma; however, no zircon gave rise to any age younger than 1700 Ma. The