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Dynamic recrystallization mechanisms and their transition in the Daling Thrust (DT) zone, Darjeeling–Sikkim Himalaya

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ABSTRACT

The Daling Thrust (DT) delineates a zone of intense shear localization in the Lesser Himalayan Sequence (LHS) of the Darjeeling–Sikkim Himalaya. From microstructural studies of deformed quartzite samples, we show a transition in the dynamic recrystallization mechanism with increasing distance from the DT, dominated by grain boundary bulging (BLG) recrystallization closest to the DT, and progressively replaced by sub-grain rotation (SGR) recrystallization away from the thrust. The transition is marked by a characteristic variation in the fractal dimension (D) of grain boundaries, estimated from the area–perimeter method. For the BLG regime, $D \approx 1.046$, which decreases significantly to a value as low as 1.025 for the SGR regime. Using the available thermal data for BLG and SGR recrystallization, we infer increasing deformation temperatures away from the DT in the hanging wall. Based on the quartz piezometer our estimates reveal strong variations in the flow stress (59.00 MPa to 16.00 MPa) over a distance of ~1.2 km from the DT. Deformation mechanism maps constructed for different temperatures indicate that the strain rates (10^{-12} S^{-1} to 10^{-14} S^{-1}) comply with the geologically possible range. Finally, we present a mechanical model to provide a possible explanation for the cause of stress intensification along the DT.

1. Introduction

The Himalayan thrust sequence displays four major continental scale, south-vergent thrusts: Main Central Thrust (MCT), Daling Thrust (~ Ramgarh Thrust ~ Sumar thrust) (DT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT), arrayed from north to south (Fig. 1). All of them splay from a basal detachment, called Main Himalayan Thrust (MHT) (Gansser, 1964; LeFort, 1975; Srivastava and Mitra, 1994; DeCelles et al., 2001; Avouac, 2003; Yin, 2006; McQuarrie et al., 2008; Larson et al., 2010; Bose et al., 2014). Our present study focuses upon the Daling Thrust (DT), exposed in the Lesser Himalayan Sequence (LHS) of the Darjeeling–Sikkim Himalaya (Fig. 1).

In the Darjeeling–Sikkim Himalaya, the Greater Himalayan Sequence and the Daling Group (Gr.) of rocks are the two principal litho-tectonic units that constitute the Tista Dome (Fig. 2a). The Greater Himalayan Sequence is bounded by the MCT to the south and the South Tibetan Detachment (STD) to the north, whereas the Daling Gr. occurs as a thrust sheet, bordered by the MCT in the North and the DT in the south. Recent tectonic models have (e.g. channel flow model) suggested that normal faulting along the STD as a partially coeval event with the thrust movement along the MCT (Beaumont et al., 2001; Grujic et al., 2002; Godin et al., 2006). A line of work in the Himalaya concentrates upon the development of thrust sequences in the LHS that constitutes the footwall of MCT. Using thrust–duplex models (Yu et al., 2015), most of these studies aim to reconstruct their geometrical dispositions and the kinematics in different transects of the LHS, e.g. Nepal (DeCelles et al., 2001), Bhutan (McQuarrie et al., 2008) and Darjeeling–Sikkim Himalaya (Bhattacharyya and Mitra, 2009). These models showcase the DT as an essential part of the duplex system. On the other hand, Bose et al. (2014) have recently reported field evidences in support of regional folding of the DT in multiple episodes of ductile deformations (Fig. 2b). They have proposed a superposed buckling model to explain the architecture of LHS structures.

A group of workers have adopted various rheological approaches for a better understanding of the deformation localization process along the major Himalayan thrusts, for e.g. MCT. Law et al. (2011, 2013) have predicted dislocation creep mechanisms and their control in structural weakening by crystallographic preferred orientation (CPO). Using c-axis fabric opening-angles they also constrained the deformation temperatures (510 °C to 610 °C) in the immediate hanging wall of the MCT. Conversely, Bhattacharyya and Mitra (2011) proposed a reaction-assisted syn-kinematic weakening mechanism. Despite a significant progress in the MCT study, the mechanism associated with shear localization in the footwall LHS, especially in the Sikkim Himalaya is yet to be fully explored. It is noteworthy that the DT is the most important tectonic zone in the LHS that has accommodated at least 50 km horizontal shortening during the Indo–Asia collision event between ~16 and 12 Ma

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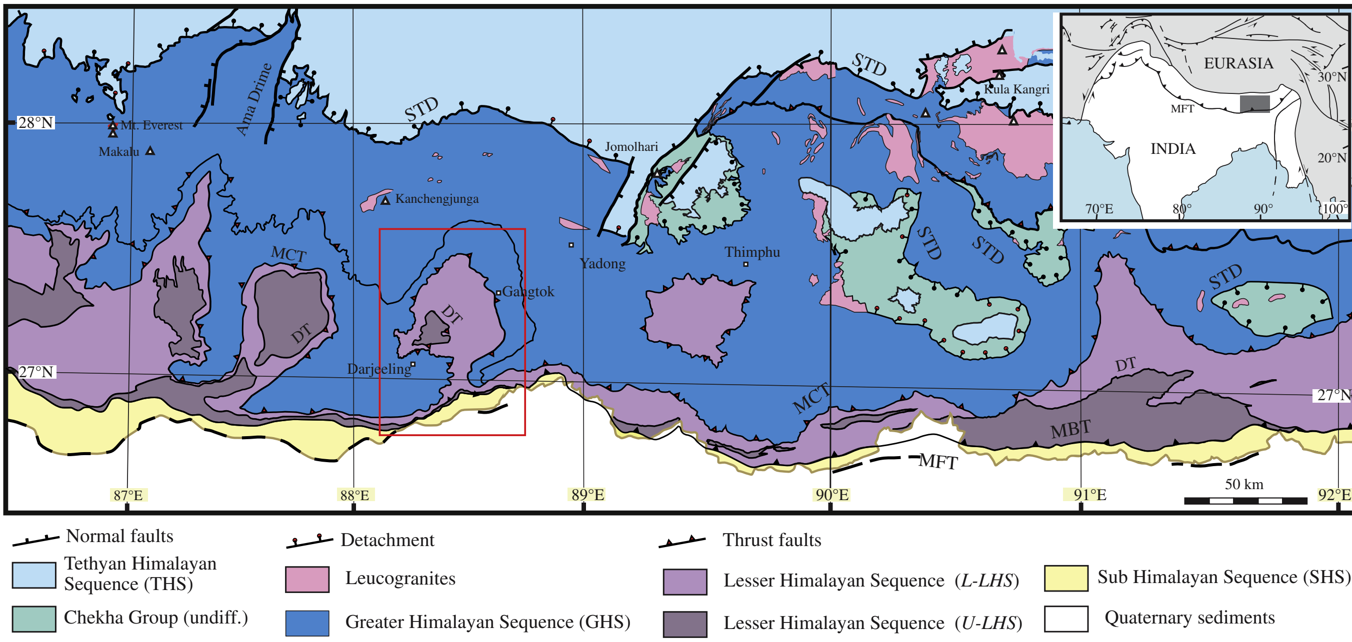

Fig. 1. Geological map of the eastern Himalayan fold-thrust belt showing broad lithotectonic units and their bounding thrusts. Red box demarcates the location of the Darjeeling–Sikkim Himalaya as our study area.
After Grujic et al., 2011.

(Pearson and DeCelles, 2005; Bhattacharyya and Mitra, 2009). Understanding the deformation localization along the DT is thus crucial for modeling the LHS tectonics, which is the main motivation of our present study.

We carried out field investigations on a number of transect across the DT, focusing upon ductile structures in the neighborhood of the DT. Using microstructural proxies our laboratory studies show the dominant grain-scale dislocation creep mechanisms, based on characterization of the dynamic recrystallization of quartz grains. We then delineate the spatial variations of recrystallization mechanisms across the Daling Thrust. From the available relations of these mechanisms with temperature and grain size, this study provides an estimate of the thermal and the differential flow stress conditions under which the DT has evolved.

2. Geological setting of the Lesser Himalayan Sequence (LHS)

In the Darjeeling–Sikkim Himalaya the LHS is a package of lithotectonic units that broadly bound between the Main Central Thrust (MCT) to the north and the Main Boundary Thrust (MBT) to the south (Fig. 2). The sequence covers a maximum width of about 80 km on a N–S transects. Stratigraphically, the LHS can be separated into two sub-divisions: the *Lower Lesser Himalayan sequence* (*L-LHS*) and the *Upper Lesser Himalayan sequence* (*U-LHS*) (Fig. 3), equivalent to those reported from Bhutan (Long et al., 2011a). The *L-LHS* mainly consists of the Daling Gr. of paleo-mid Proterozoic age, characterized by low-grade (lower to upper greenschist facies) metamorphism. *U-LHS* is an assemblage of unconformable stratigraphic horizons, such as late Palaeozoic Gondwana Gr. and Baxa Formation (Fm.) of Pre-Cambrian to Cambrian (?) age (Figs. 2a, b; 3). Their grade of metamorphism varies from lower greenschist facies to almost un-metamorphosed.

2.1. Daling Group

The lower Proterozoic rocks of the Daling Gr. comprise mainly meta-argillaceous sequences with intercalated quartzite. They are exposed in the Tista valley in the form of a mushroom shaped half window in map view (Fig. 2a). The group is characterized by a metamorphic inversion, showing almost un-metamorphosed rocks down the hills in south to upper greenschist facies rocks with the appearance of garnets at the base of MCT in the north (Acharyya and Ray, 1977; Acharyya, 1989; Dasgupta et al., 2004).

Within the Daling Gr. there are discrete, map-scale granitic bodies, called Lingtse granite. They occur, mainly with N–S trends at different tectonic levels (Fig. 2) and have a Lesser Himalayan affinity (Paul et al., 1996). Recent Pb207/Pb206 dating of this unit indicates a lower-Proterozoic age (~1836 Ma) (Mottram et al., 2014).

2.2. Baxa Formation

The Baxa Fm. consists of mainly quartzites and stromatolitic carbonate rocks of Late Proterozoic to early Cambrian age (Schopf et al., 2008). Stratigraphically, the Baxa Fm. overlies the Daling Gr. (Fig. 3).

2.3. Gondwana Group

They represent the youngest stratigraphic horizon in the Tista dome (Fig. 3). The Damuda Fm. that constitutes the Upper Gondwana overlies the early Permian Rangit Pebble Slate (RPS), which is equivalent to the Talchir Fm. of the Lower Gondwana. The coal-bearing sandstone-shale sequences with *Glossopteris* floral assemblages comprise the Damuda Fm. (Acharyya and Ray, 1977). Ray and Neogi (2011), have recently reported a thick new stratigraphic unit as Phongla Fm. This is considered to be equivalent to the diamictite bearing mudstone facies of basal Gondwana Rangit Pebble-Slate and parts of the Damuda Fm. (Fig. 2) (Bose et al., 2014). However, the stratigraphic status of this formation needs to be verified with either unambiguous paleontological evidences or geochronological data.

3. Macroscopic structures of The Daling Thrust (DT)

The Daling Thrust (DT) demarcates an orogenic scale tectonic contact between the *L-LHS* and *U-LHS* (Fig. 2). Earlier workers reported thrusts, e.g., the Tendong thrust on the northern side of the Rangit window and the Ramman–Rangit fault to the south (Raina, 1982). However, these thrusts appear to represent different segments of the DT. The DT crops out again in the mountain front region as shown in the structural