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Ductile shearing to brittle thrusting along the Nepal Himalaya: Linking Miocene channel flow and critical wedge tectonics to 25th April 2015 Gorkha earthquake

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ABSTRACT

The 25th April 2015 magnitude 7.8 Gorkha earthquake in Nepal ruptured the Main Himalayan thrust (MHT) for ~140 km east-west and ~50 km across strike. The earthquake nucleated at a depth of ~15–18 km approximating to the brittle-ductile transition and propagated east along the MHT but did not rupture to the surface, leaving half of the fault extent still locked beneath the Siwalik hills. Coseismic slip shows that motion is confined to the ramp-flat geometry of the MHT and there was no out-of-sequence movement along the Main Central Thrust (MCT). Below 20 km depth, the MHT is a creeping, aseismic ductile shear zone. Cumulated deformation over geological time has exhumed the deeper part of the Himalayan orogen which is now exposed in the Greater Himalaya revealing a tectonic history quite different from presently active tectonics. There, early Miocene structures, including the MCT, are almost entirely ductile, with deformation occurring at temperatures higher than ~400 °C, and were active between ~22–16 Ma. Kyanite and sillimanite-grade gneisses and migmatites approximately 5–20 km thick in the core of the Greater Himalayan Sequence (GHS) together with leucogranite intrusions along the top of the GHS were extruded southward between ~22–15 Ma, concomitant with ages of partial melting. Thermobarometric constraints show that ductile extrusion of the GHS during the Miocene occurred at muscovite-dehydration temperatures ~650-775 °C, and thus brittle thrusting and critical taper models for GHS deformation are unrealistic. As partial melting and channel flow ceased at ~15 Ma, brittle thrusting and underplating associated with duplex formation occurred along the Lesser Himalaya passively uplifting the GHS.

1. Introduction

The Himalayan orogen is commonly interpreted as a crustal scale wedge, analogous to a critical taper (Yin and Harrison, 2000; Avouac, 2015; Bollinger et al., 2006), that formed as units detached from the underthrusting Indian plate were accreted to the southern margin of Tibet since the India-Asia collision started about 50 Ma ago (Figs. 1,2). The upper crust of the Himalaya is represented by the so-called Tethyan Himalaya, a sequence of Neo-Proterozoic to Cenozoic mainly sedimentary rocks showing intense folding and thrusting, crustal shortening and thickening, but generally not metamorphosed (Corfield and Searle, 2000). The middle crust is the Greater Himalayan Sequence (GHS) of highly metamorphosed and partially melted gneisses, migmatites and leucogranites all of which show Cenozoic metamorphism up to kyanite and sillimanite grade. Along the base of the GHS, metamorphic isograds are inverted along the Main Central Thrust zone (MCT) and along the upper contact isograds are right way-up beneath the South Tibetan Detachment (STD), an enigmatic low-angle, north-dipping normal fault (e.g. Burg and Chen, 1984; Searle, 2010, 2015; Law et al., 2011; Cottle et al., 2015a). The GHS was exhumed in the Oligocene - Miocene as a result of ductile shearing along the coeval MCT and STD ductile shear zones, by a process known as channel flow, the ductile extrusion of a mid-crustal layer of partially molten rocks (e.g. Beaumont et al., 2001; Grujic et al., 2002; Searle et al., 2003, 2010; Godin et al., 2006; Law et al., 2011; Cottle et al., 2015a, 2015b). The southernmost and structurally lower part of the Himalaya is the Lesser Himalaya, comprising a series of south-vergent thrust sheets emplacing the Himalaya over the Siwalik foreland basin sediments along the Main Boundary Thrust (MBT).

This paper attempts to link the deformation in the Greater Himalayan hinterland (Early Eocene – Early Miocene metamorphism and deformation) to the Lesser Himalaya foreland critical wedge (mid-Miocene – Recent) to the active thrusting as exemplified by the 25th April 2015 Gorkha earthquake rupture. The geometry of the Main Himalayan Thrust (MHT), the basal detachment that ruptured during the 25th April 2015

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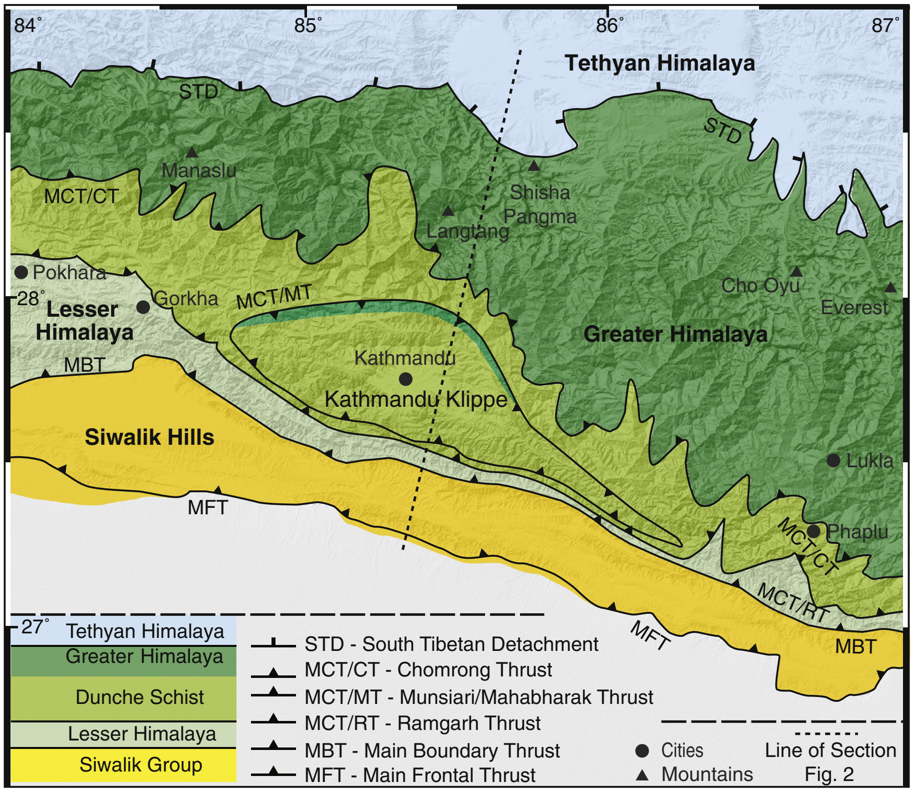

Fig. 1. Digital Elevation Model (DEM) of the central Nepal Himalaya, showing main structures metamorphic grade across the Langtang – Ganesh Himalaya. Greater Himalayan Sequence (dark green) includes amphibolite facies gneisses and schists, migmatites and leucogranites. ASTER GDEM is a product of METI and NASA. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Gorkha earthquake (Avouac et al., 2015; Elliott et al., 2016), is critical to the interpretation of the kinematic history the Himalaya.

Two major conflicts in Himalayan tectonics involve: (1) the discussion between proponents of Channel Flow along the Greater Himalaya (e.g. Beaumont et al., 2001; Grujic et al., 2002; Searle et al., 2003, 2006, 2010; Jessup et al., 2006; Godin et al., 2006; Streule et al., 2010) and proponents of the critical wedge taper model (e.g. DeCelles et al., 2001; Kohn et al., 2004; Kohn, 2008; Webb et al., 2011; He et al.,

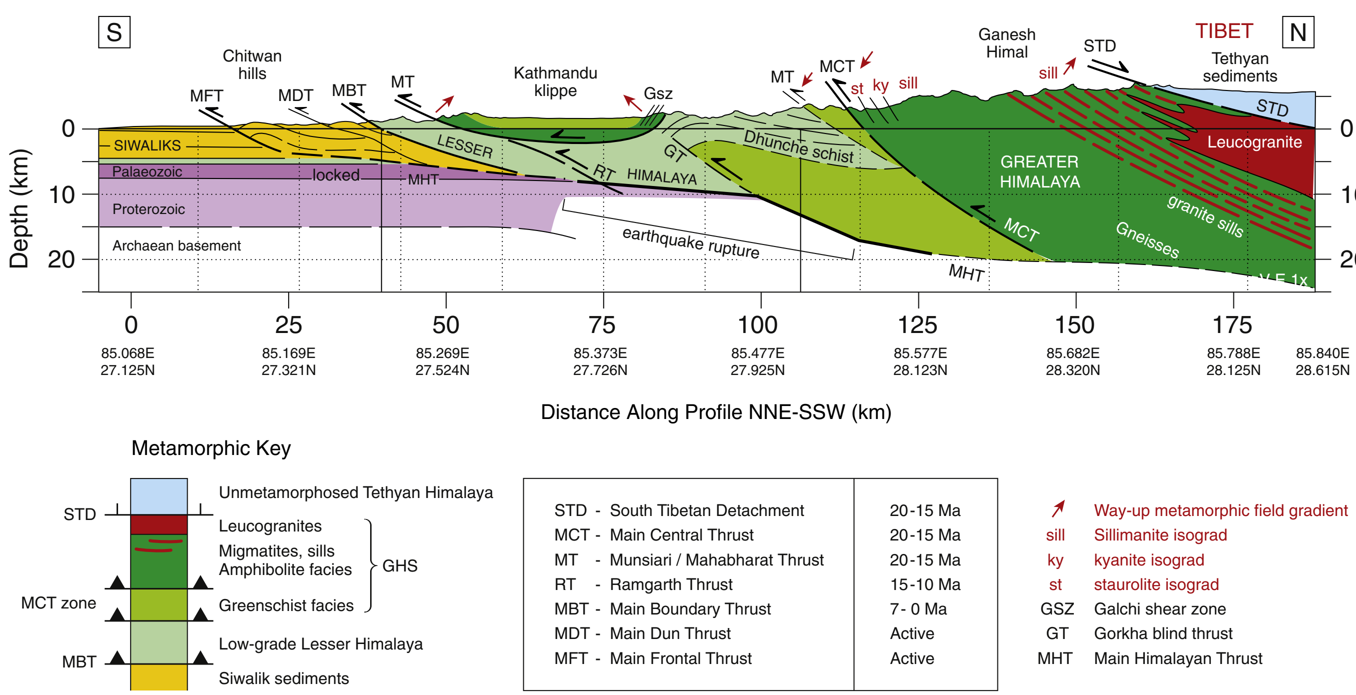

Fig. 2. Geological cross-section of the Langtang – Kathmandu Himalaya showing major structural units, metamorphic grade, thrust faults and extent of the rupture during the 25th April 2015 Gorkha earthquake.

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