Tectonophysics 667 (2016) 87–107

Contents lists available at ScienceDirect

Tectonophysics

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

Extrusion vs. duplexing models of Himalayan mountain building 2: The South Tibet detachment at the Dadeldhura klippe

Dian He [a,*], A. Alexander G. Webb [b], Kyle P. Larson [c], Axel K. Schmitt [d]

[a] Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803, USA
[b] School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK
[c] Earth and Environmental Sciences, University of BC Okanagan, Kelowna V1V 1V7, Canada
[d] Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095, USA

ARTICLE INFO

Article history:
Received 25 February 2015
Received in revised form 15 July 2015
Accepted 11 November 2015
Available online 25 November 2015

Keywords:
Himalayan orogen
Tectonic model
South Tibet detachment
Duplexing
Extrusion

ABSTRACT

Himalayan mountain building has been dominantly explained by two types of models: extrusion and duplexing. To elucidate possible roles of these mechanisms during emplacement of the Himalayan crystalline core, we investigate an area speculated to contain the southern leading edge of the crystalline core: the northeastern margin of the Dadeldhura klippe, western Nepal. We found an ~700 m thick, primarily top-to-the-north shear zone within the klippe; we term this as the Tila shear zone. The shear zone occurs within a right-way-up metamorphic field gradient, and separates footwall gneiss from hanging wall schist. Similarly, deformation temperatures estimated from quartz and feldspar microstructures and quartz *c*-axis fabrics indicate a right-way-up thermal gradient of ~77–189 °C/km. U–Pb zircon dating of post-kinematic leucogranite dikes suggests that ductile shearing along the Tila shear zone occurred prior to ~17–14 Ma. We correlate the Tila shear zone to the South Tibet detachment (STD) on the basis of consistent structural fabrics (shear sense), lithologies, metamorphism, and deformation timing. This interpretation, in combination with regional constraints, indicates southwards-increasing proximity of the STD (Tila shear zone) and the Main Central thrust (MCT). These two shear zones are separated by ~3 km of structural section in the northern portion of our study area, and become close to within ~1 km of separation, in the southern portion. Interpolation suggests that the STD (Tila shear zone) and MCT merge 15 ± 10 km southwest of our study area. The increasing-to-south proximity and potential merger of the two shear zones suggest that the STD formed as a backthrust from the MCT. This interpretation contrasts with the long-standing normal fault interpretation of the STD. Because the STD and MCT bound the Himalayan crystalline core, these findings document crystalline core emplacement at depth via tectonic wedging. This kinematic evolution is consistent with duplexing, but not extrusion to the surface.

1. Introduction

Two general types of mountain-building models have been proposed to explain many phases of development of the Himalaya in response to India–Asia collision: extrusion (e.g., Burchfiel and Royden, 1985) and duplexing (e.g., Bollinger et al., 2004). The proposed extrusion models involve exhumation of mid-crustal material to the surface between surface-breaching faults, with a thrust fault below and a normal fault above (e.g., Beaumont et al., 2001; Burchfiel and Royden, 1985; Godin et al., 2006; Hodges et al., 2001). Duplexing models involve accretion of material from the underthrusting Indian plate to the over-riding orogen (e.g., Bollinger et al., 2004; Herman et al., 2010; Konstantinovskaia and Malavieille, 2005; Robinson et al., 2003; Schelling and Arita, 1991). The two model types are not mutually exclusive — material can be accreted from the down-going plate and also funneled to the surface between two bounding faults in the over-riding plate. The extrusion models do feature one exclusive aspect, however: nearly all Himalayan extrusion models require ≫10 km normal-sense slip along a specific structure, the South Tibet detachment (STD), which separates the Himalayan crystalline core from the lower grade overlying rocks along the length of the orogen (Fig. 1A) (e.g., Beaumont et al., 2001; Burchfiel and Royden, 1985; Burchfiel et al., 1992; Godin et al., 2001; Grujic et al., 1996; Hodges et al., 1992, 2001; Kohn, 2008; Long and McQuarrie, 2010).

In most recognized exposures, the STD occurs as a dominantly top-to-the-north, north-dipping shear zone that was active in the early and middle Miocene, and arguably even until the Pliocene to Recent (e.g., Burchfiel et al., 1992; Burg et al., 1984; Cottle et al., 2007; Hodges et al., 1992, 1996; Hurtado et al., 2001; McDermott et al., 2013; Rana et al., 2013; Searle, 2010). This geometric and kinematic pattern leads most workers to interpret the STD as a high-slip, orogen-parallel, syn-convergence normal fault, which is argued to

---

* Corresponding author at: Shell International Exploration and Production Inc., 3333 Hwy 6 South, Houston, TX 77082, USA.
E-mail address: dian.he@shell.com (D. He).

http://dx.doi.org/10.1016/j.tecto.2015.11.014

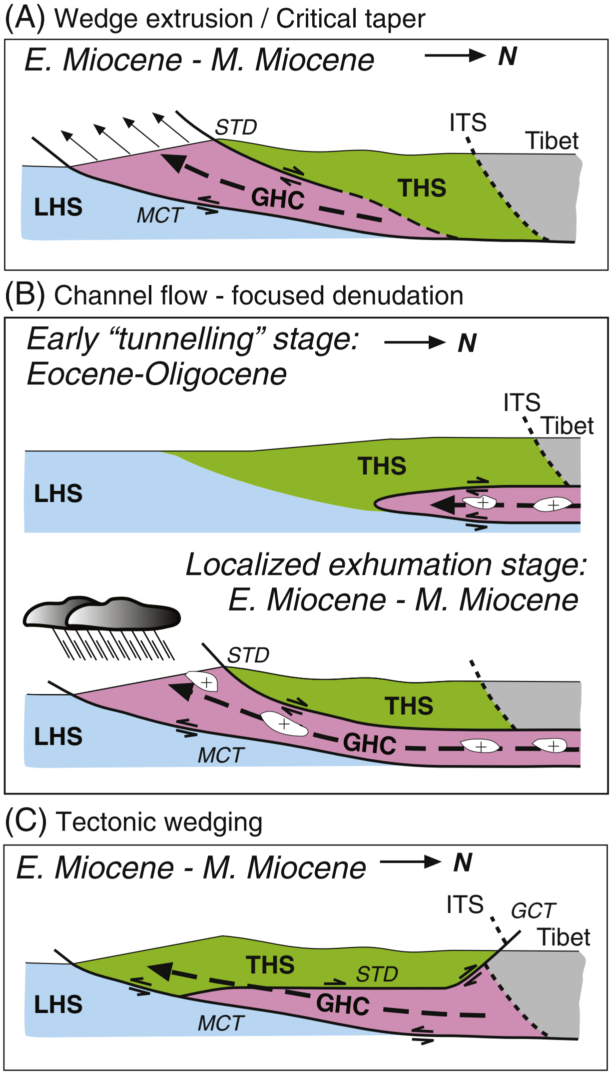

Fig. 1. Himalayan tectonic models for the emplacement of the Greater Himalayan Crystalline complex modified from Webb et al. (2011a). Note that, in the channel tunneling stage of the channel flow — focused denudation model, the STD geometry (top boundary of the tunnel) is largely flat and emanates from the basal thrust (base of the tunnel) and feeds a top-to-the-north thrust. LHS — Lesser Himalayan Sequence; GHC — Greater Himalayan Crystalline complex; THS — Tethyan Himalayan Sequence; MCT — Main Central thrust; STD — South Tibet detachment; GCT — Great Counter thrust; ITS — Indus-Tsangpo suture.

have 10s or 100s of km of slip (e.g., Cooper et al., 2012). This normal faulting concept has been widely exported to ancient orogenic belts that feature antithetic shear zones (e.g., Sevier orogen — Hodges and Walker, 1992; Wells, 1997; Grenville orogen — Selleck et al., 2005; Jamieson et al., 2007; Rivers, 2008; Canadian Cordillera — Brown and Gibson, 2006; Kuiper et al., 2006; Australia's Petermann orogen — Raimondo et al., 2009; Tanzania — Fritz et al., 2009). Such structures have not been observed in other active advancing convergence zones — perhaps the closest comparable structure is the Cordillera Blanca detachment fault of the Peruvian Andes, but this has much less slip and lateral extent (Giovanni et al., 2010).

Modeling and field-based investigation of the Himalaya over the past ~14 years have increasingly suggested that the STD may be a backthrust for part (e.g., Beaumont et al., 2001) or all (e.g., Webb et al., 2007) of its motion history. This interpretation is implicitly inherent in channel flow modeling, which shows translation of the crystalline core as a two-phase process involving (1) southwards tunneling of high-grade rocks below the STD, followed by (2) extrusion of these rocks to the surface with the STD as the upper bound of the extrusive zone (Fig. 1B) (Beaumont et al., 2001; Kellett and Grujic, 2012). During the first phase of this process, the STD is a sub-horizontal, top-to-the-north fault that emanates from the basal thrust at the leading edge of the tunnel; therefore, the geometry and kinematics of the STD are consistent with backthrusting (Fig. 1B). Similarly, synthesis of existing geometric constraints along the length of the orogen led Yin (2006) to suggest that the STD may have functioned as a backthrust for most of its history. Regional tectonic investigations in the western and central Himalaya support this view, documenting STD geometry across the southern portions of the Himalaya consistent with the root zone of a backthrust (He et al., 2015; Leger et al., 2013; Webb et al., 2007, 2011a, 2011b). A corresponding tectonic wedging model does not require any normal slip along the STD (Fig. 1C) (Webb et al., 2007).

The STD backthrust interpretation has far-reaching implications because the STD is the source of orogen-parallel, syn-convergence normal faulting concepts that have been widely applied to many other orogens. Viability of a backthrust STD model would motivate re-evaluation of syn-convergence normal faulting concepts and associated extrusion models worldwide. The backthrust model makes a clear prediction: where the crystalline core is preserved across the southern Himalaya, the STD-backthrust root zone should be similarly preserved. Here we investigate a possible root zone exposure across the northeastern margin of the Dadeldhura klippe, western Nepal, via integrated structural mapping, microstructural, quartz *c*-axis fabric, and geochronological studies.

This contribution is the second in a three-paper series, which explores the question of relative contributions of extrusive and duplexing tectonics in the Himalaya across different regions and geologic periods. The first paper (Yu et al., 2015) examines middle Miocene to Recent Himalayan deformation in NW India. The present work offers new data on the Miocene tectonics of the Main Central thrust (MCT) and STD in western Nepal and interrogates the viability of the backthrust STD model. The third paper (He et al., 2015) investigates similar questions as the present work in central Nepal, and it also incorporates recent findings of faults subdividing the crystalline core into a synthesis model showing duplexing dominating Himalayan mountain building from Oligocene to Present.

2. Geological background

2.1. Orogenic framework

At first order, the Himalayan orogen is widely recognized as a three unit-two fault stack (e.g., Hodges, 2000; Yin, 2006). The three major units of the Himalayan orogen – the Lesser Himalayan Sequence, the Greater Himalayan Crystalline complex, and the Tethyan Himalayan Sequence – have been variably defined in terms of structural positions, metamorphic grades, and stratigraphic ages (e.g., Hodges, 2000; Searle et al., 2008; Upreti, 1999; Yin, 2006). These three units are commonly considered by largely fault-based definition because of indistinguishable detrital zircon age distribution and protolith lithologies (e.g., McKenzie et al., 2011; McQuarrie et al., 2013; Myrow et al., 2003, 2009; Webb et al., 2011a, 2013; Yin et al., 2010). In this definition, the Greater Himalayan Crystalline complex is bounded by the Main Central thrust (MCT) below and the STD above; the Lesser Himalayan Sequence is the pre-Cenozoic MCT footwall, and the Tethyan Himalayan Sequence occupies the STD hanging wall (Fig. 2) (e.g., Searle et al., 2008; Yin, 2006). Within this framework, the Greater Himalayan Crystalline complex is commonly taken to be synonymous with the "crystalline core" of the orogen. Below we describe this basic framework as well as frontal klippen (such as the Dadeldhura klippe), which may be incorporated into the basic framework in one of at least five ways (Section 2.2).

There are some disagreements in the literature regarding definitions of the MCT and STD (see review of Yin, 2006). The MCT has been mapped at differing structural levels by a variety of criteria, such as a lithological contact (e.g., Heim and Gansser, 1939); differences in