The leading edge of the Greater Himalayan Crystalline complex revealed in the NW Indian Himalaya: Implications for the evolution of the Himalayan orogen

A. Alexander G. Webb*
An Yin
T. Mark Harrison
Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics, University of California–Los Angeles, Los Angeles, California 90095-1567, USA
Julien Célérier Research School of Earth Sciences, Australia National University, Canberra, ACT 2601, Australia
W. Paul Burgess Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics, University of California–Los Angeles, Los Angeles, California 90095-1567, USA

ABSTRACT

The three Himalayan lithologic units, the Lesser Himalayan Sequence, the Greater Himalayan Crystalline complex, and the Tethyan Himalayan Sequence, have a specific structural correlation with the Main Central thrust and South Tibet detachment in the central Himalaya. There, the Main Central thrust places the Greater Himalayan Crystalline complex over the Lesser Himalayan Sequence, and the South Tibet detachment places the Tethyan Himalayan Sequence over the Greater Himalayan Crystallines. Although this division has formed the basis for all Himalayan tectonic models, it fails to explain aspects of the geology of the western Himalaya where the Main Central thrust places the Tethyan Himalayan Sequence directly above the Lesser Himalayan Sequence. Our mapping in NW India shows that this relationship results from southward merging of the Main Central thrust and South Tibet detachment. This finding, in conjunction with observed alternating shear senses on the South Tibet detachment, is inconsistent with the wedge-extrusion and erosion-induced channel-flow models (both require only top-to-the-N motion on the South Tibet detachment) but is consistent with a tectonic-wedging model.

Keywords: Himalaya, South Tibet detachment, Main Central thrust, tectonic wedge.

INTRODUCTION

The ~2500-km-long Himalayan orogen is widely thought to consist of only three major units: the Lesser Himalayan Sequence (LHS; mainly low-grade Proterozoic metasediments), the Greater Himalayan Crystalline complex (GHC; largely high-grade paragneisses and migmatite), and the Tethyan Himalayan Sequence (THS; dominantly low-grade late Proterozoic to Eocene shelf sediments) (Heim and Gansser, 1939). In the central Himalaya, the LHS and GHC are separated by the Main Central thrust, and the GHC and THS are separated by the South Tibet detachment (LeFort, 1996) (Fig. 1). However, in the western Himalaya (west of 77°E), the Main Central thrust places THS rocks directly over LHS metasediments (e.g., Yeats and Lawrence, 1984; Frank et al., 1995; Pogue et al., 1999) (Fig. 1). Several scenarios have been advanced to explain this different relationship (e.g., Thakur, 1998; DiPietro and Pogue, 2004; Yin, 2006), but uncertainty regarding the position of the South Tibet detachment in many locations in the NW India Himalaya (cf. Fig. 1 of Searle et al. [1999] and plate 1 of Steck [2003]) limits efforts to understand its significance. This paper summarizes the results of field work undertaken in the western Himalaya that lead to an interpretation that explains this relationship but that challenges current views of Himalayan thrust tectonics.

GEOLOGY OF THE ROHTANG LA AREA

Our field area is located in the Rohtang La area northwest of the Kulu Window (Figs. 1 and 2). Although the South Tibet detachment can be traced from Nepal to this area, its westward extension is poorly defined (Fig. 2) (Choudhuri et al., 1992; Vannay and Grasemann, 1998; Jain et al., 1999), which had led to various interpretations including connection with the Zanskar shear zone (Searle et al., 1999) and termination in the Rohtang La area (Steck, 2003). We mapped the position of the South Tibet detachment by tracking its deformation zone, metamorphic grade changes across the fault, and marker beds along the fault.

Typically, the South Tibet detachment shear zone is hundreds of meters thick and exhibits both top-to-the-NE and top-to-the-SW shear-sense indicators (also see Jain et al., 1999). This contrasts to the top-to-the-SW motion associated with the Main Central thrust ductile shear zone below. In general, gneisses are common below and schists are prevalent above the South Tibet detachment. Although garnet is present both above and below the South Tibet detachment, kyanite and/or sillimanite are diagnostic of the South Tibet detachment footwall. Following Vannay and Steck (1995) and Wyss et al. (1999), we used graphitic quartzite and discontinuous lenses of calc-silicate schists in the THS as marker beds to trace the South Tibet detachment hanging wall. Intrusive contacts around Cambrian-Ordovician granites in the South Tibet detachment hanging wall are undeformed, whereas the same contacts in the South Tibet detachment footwall are intensely transposed by ductile folding.

At Rohtang La, the South Tibet detachment shear zone preserves ductile shear fabrics including top-to-the-SW S-C fabric, top-to-the-NE sigma augen, top-to-the-NE and top-to-the-SW shear band cleavage, and top-to-the-SW folds (Fig. 3). The top-to-the-NE shear fabrics overprint top-to-the-SW shear fabrics (also see Jain et al., 1999). A sharp contact between mylonitic augen gneiss below and garnet schist above is present in the South Tibet detachment shear zone, which we interpret as the South

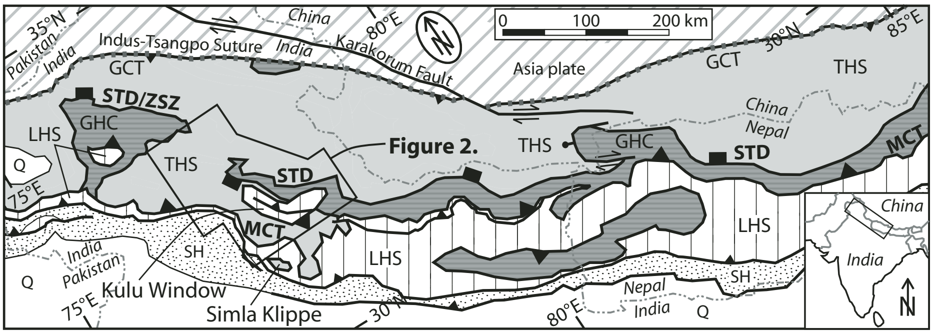

Figure 1. Map of central and western Himalaya compiled from DiPietro and Pogue (2004), Valdiya (1980), Yin (2006), and references for Figure 2. GCT—Great Counter Thrust; GHC—Greater Himalayan Crystalline complex; LHS—Lesser Himalayan Sequence; MCT—Main Central thrust; Q—Quaternary alluvium; SH—Sub-Himalayan Sequence; STD—South Tibet detachment; THS—Tethyan Himalayan Sequence; ZSZ—Zanskar shear zone.

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*E-mail: awebb@ess.ucla.edu.

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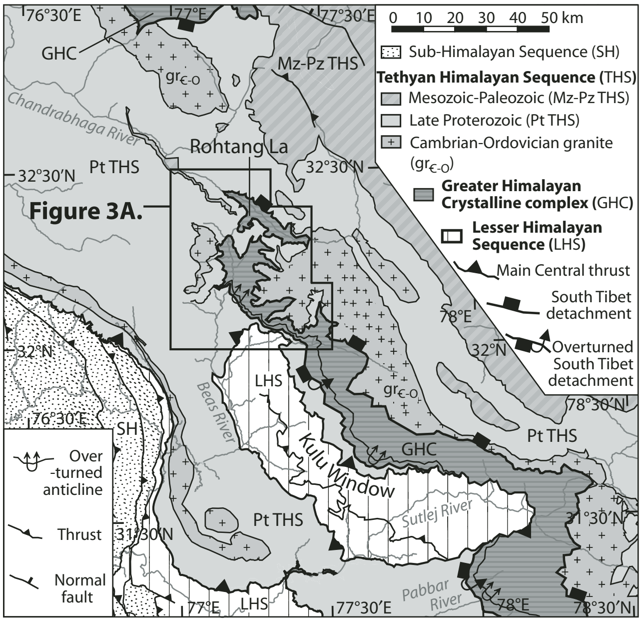

Figure 2. Map of Kulu Window region (after Frank et al., 1973, 1975; Sharma, 1977; Vannay and Steck, 1995; Vannay and Grasemann, 1998; Wyss et al., 1999; our own observations, and additional references in the GSA Data Repository[1]).

Tibet detachment fault. The South Tibet detachment can be traced south of Rohtang La into the south-verging overturned Phojal anticline (i.e., the Phojal Nappe of Frank et al., 1973) along the west bank of the Beas River (Fig. 3A). The South Tibet detachment is overturned in the Phojal anticline (Figs, 3A and 3B) as indicated by the folding of (1) the gneiss-schist contact that marks the fault and features top-to-the-NE sigma augen and top-to-the-NE C′ shear band cleavage (Fig. 3C), (2) the hanging-wall marker units of graphitic quartzite and calc-silicate schist, and (3) mineral isograds directly above and below the fault (e.g., Frank et al., 1973; Epard et al., 1995). Although the original geometry of the isograds may not have been sub-horizontal (e.g., Le Fort, 1975), the subparallel relationship between our mapped South Tibet detachment and the regional isograds north of the anticline (i.e., Frank et al., 1973) is consistent with overturned folding of the South Tibet detachment at this location.

The overturned South Tibet detachment can be traced southeastward from the Phojal anticline to the northern edge of the Main Central thrust Kulu Window near Manikaran (Fig. 3A). Using our lithologic and metamorphic criteria, we have extended the mapped location of the South Tibet detachment southeast from Manikaran for another 50 km by correlation with the same gneiss-schist contact mapped by Sharma (1977). Still farther east, the overturned South Tibet detachment must merge with the Main Central thrust along the northeastern margin of the Kulu Window because the schist in the South Tibet detachment hanging wall pinches out west of the well-studied Sutlej River section where Greater Himalayan Crystalline gneiss is exposed continuously between the Main Central thrust and the South Tibet detachment (e.g., Vannay and Grasemann, 1998) (Fig. 2). Thus, the merging of the South Tibet detachment and Main Central thrust in map view defines the tip line of a southward-tapering GHC wedge (Fig. 3B). The overturned South Tibet detachment and Phojal anticline are eroded over the Kulu Window and reappear at the southeast side of the window, which we mapped along the Pabbar River (Fig. 2). The overturned South Tibet detachment there can be well constrained by metamorphic-grade variation across the fault and the South Tibet detachment hanging-wall marker units.

DISCUSSION

The South Tibet detachment makes a sharp U-turn in map view at Rohtang La, changing from a gently west-dipping structure to a NE-dipping overturned fault that merges with the Main Central thrust (Fig. 2). Overturned folding may have been caused by distributed top-to-the-SW shear across the Main Central thrust zone, suggesting that the South Tibet detachment became inactive prior to cessation of motion on the Main Central thrust. This is consistent with age constraints showing that both faults were active in the early Miocene, but Main Central thrust slip may extend to the middle Miocene (Catlos et al., 2002; Vannay et al., 2004).

The three-layer division of the Himalaya has been explained by wedge-extrusion, channel-flow, and general-shear models (Burchfiel and Royden, 1985; Grujic et al., 1996; Vannay and Grasemann, 2001; Nelson et al., 1996; Beaumont et al., 2001). Note that the Nelson et al. (1996) channel-flow model differs from that of Beaumont et al. (2001) in that the latter predicts India crust to be subducted and then return to the surface without transporting Asian rocks to the present Himalayan range. This physical process may be more appropriately characterized as corner flow (see Cloos, 1982). None of these models explain our observed southward merging of the Main Central thrust and South Tibet detachment, but instead require the Main Central thrust and South Tibet detachment to be surface faults. The tunneling stage of channel flow of Beaumont et al. (2001) is compatible with the observed Main Central thrust–South Tibet detachment branch line geometry, but fails to explain two key kinematic observations. First, its predicted top-to-the-N South Tibet detachment kinematics is inconsistent with the observed alternating top-to-the-N and top-to-the-S shear fabrics in the South Tibet detachment zone in NW India and throughout the Himalaya (e.g., Patel et al., 1993; Hodges et al., 1996; Grujic et al., 2002; Robinson et al., 2006; this study). Second, channel-flow tunneling requires slip on the South Tibet detachment and Main Central thrust to vanish at their branch line where the tunnel terminates, which is inconsistent with >100 km of Main Central thrust slip south of the Main Central thrust–South Tibet detachment branch line as constrained by the distance between the Kulu Window and the Simla Klippe (Fig. 1).

To reconcile the new observation for the Main Central thrust–South Tibet detachment relationship and the alternating shear motion on the South Tibet detachment, we propose that the GHC was emplaced as a tectonic wedge (see Fig. 10 of Price, 1986) via southward slip on the Main Central thrust and alternating top-to-the-N and top-to-the-S motion on the South Tibet detachment (Fig. 4) (Yin, 2006). Depending on the displacement boundary condition at the back side of the GHC thrust sheet, sense of shear along the South Tibet detachment could have alternated between top-to-the-N and top-to-the-S (Figs. 4B and 4C). Even when motion along the South Tibet detachment was top-to-the-N, the THS moved southward with respect to the LHS (Figs. 4D, 4E, and 4F). The top-to-the-N South Tibet detachment motion may link to top-to-the-N slip on the Great Counter thrust along the Indus-Tsangpo suture (Figs. 1 and 4H) (e.g., Yin et al., 1994). The Great Counter thrust forms the roof thrust of a second south-directed tectonic wedge, the Asia Plate (see Fig. 4H). The alternating insertion of the two tectonic wedges could have produced the temporally varying shear sense on the South Tibet detachment (Figs. 4A–C and 4H).

Although some parts of the Himalaya show multiple alternations in shear-sense along the South Tibet detachment (e.g., Hodges et al., 1996), the dominant pattern is a sequential change from top-to-the-S to top-to-the-N shear on the South Tibet detachment (e.g., Patel et al.,

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[1] GSA Data Repository item 2007235, additional references in support of Figure 2, is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

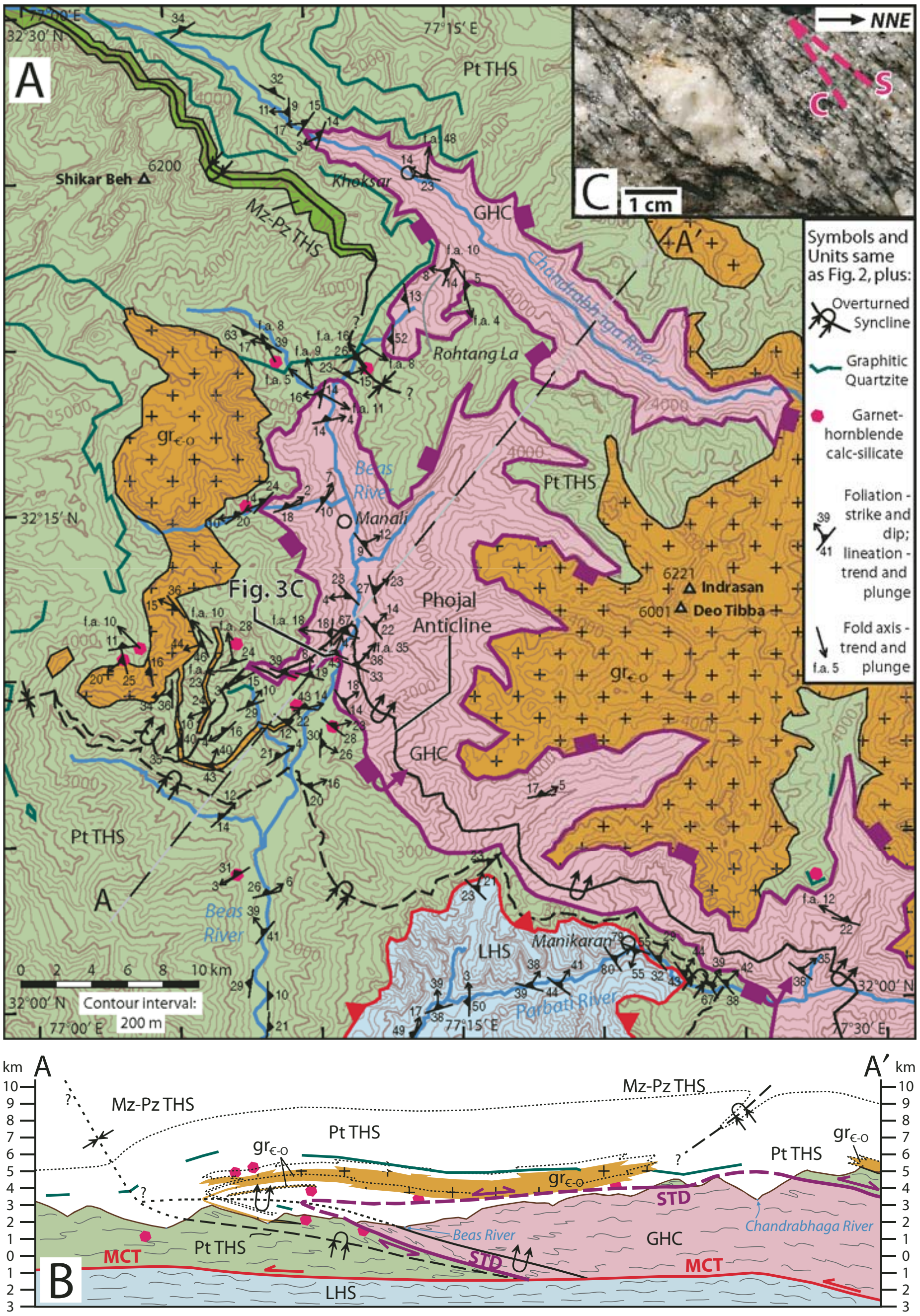

Figure 3. A: Geologic map of Rohtang La area, based on our mapping, as highlighted by strike and dip symbols, and a compilation of work from Frank et al. (1973, 1995), Vannay and Steck (1995), Wyss et al. (1999), and Wyss (2000). B: Geologic cross section of Rohtang La area. C: Top-to-the-NNE mylonitic gneiss, view to WNW. Location is shown in A.

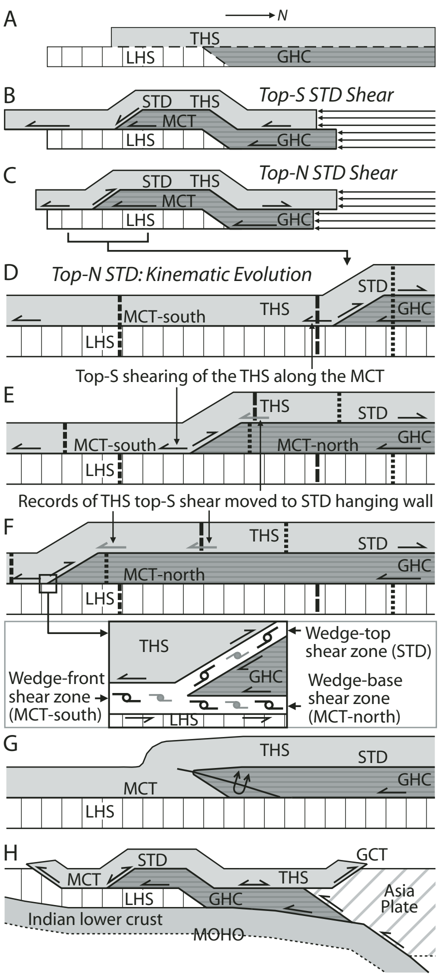

Figure 4. Tectonic wedge model for GHC emplacement, involving top-to-the-S Main Central thrust slip and alternating top-to-the-N and top-to-the-S slip along STD. A: Predeformation geometry. B: GHC emplacement during top-to-the-S faulting along South Tibet detachment. C: GHC emplacement during top-to-the-N faulting along South Tibet detachment. Despite top-to-the-N relative motion along South Tibet detachment, note that THS is consistently thrust south with respect to LHS. D–F: Top-to-the-N slip along South Tibet detachment transfers records of top-to-the-S shear from Main Central thrust hanging wall to South Tibet detachment hanging wall. Records of top-to-the-S shear from Main Central thrust–south are shown in gray. In inset, active shear indicators are shown in black. G: Late distributed shear during motion on Main Central thrust may overturn the South Tibet detachment. H: Schematic diagram of early Miocene development of Himalaya, involving two tectonic wedges (Price, 1986) inserted to south: GHC and Asia plate. Thrust emplacement of both wedges can produce temporally varying shear sense along South Tibet detachment. GCT—Great Counter Thrust; GHC—Greater Himalayan Crystalline complex; LHS—Lesser Himalayan Sequence; MCT—Main Central thrust; STD—South Tibet detachment; THS—Tethyan Himalayan Sequence.

1993; Jain et al., 1999; Grujic et al., 2002). Uniformly top-to-the-N South Tibet detachment slip could produce this pattern because records of top-to-the-S shear from the upper part of the wedge-front shear zone (Main Central thrust–south) would have been transported to the wedge-top shear zone (South Tibet detachment) across the Main Central thrust–South Tibet detachment branch line (see Figs. 4D–4F). Thus, the early Main Central thrust top-to-the-S shear fabrics would have been overprinted by the later South Tibet detachment top-to-the-N shear fabrics.

The discovery of the Main Central thrust–South Tibet detachment branch line has important implications for explaining along-strike variation of the Himalayan geology and its relationship to exhumation. Because the erosional pattern of the Himalaya may be asymmetric, with an eastward increase in the magnitude of exhumation (Finlayson et al., 2002), it is possible that the Main Central thrust–South Tibet detachment branch line is preserved in the western Himalaya but eroded away in the central Himalaya (Fig. 1).

CONCLUSIONS

Field mapping in the NW India Himalaya reveals southward-up merging of the South Tibet detachment and Main Central thrust and a complex South Tibet detachment slip history alternating between top-to-the-N and top-to-the-S shear. These observations are inconsistent with existing Himalayan models, but they are consistent with a tectonic-wedging model (Price, 1986). They also help to explain the change in structural correlation between the major Himalayan faults (Main Central thrust and South Tibet detachment) and the Himalayan units (Lesser Himalayan Sequence, Greater Himalayan Crystalline complex, and Tethyan Himalayan Sequence) from the central to western Himalaya: the Main Central thrust places the GHC over the LHS in the central Himalaya, but it juxtaposes the THS over the LHS in the western Himalaya. This variation can be attributed to an eastward increase in the magnitude of exhumation resulting in differential preservation of past orogenic architecture. This implies that the along-strike variation of Himalayan geology may not be a result of a change in deformation mechanism but a consequence of spatially varying erosion.

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