# Kinematic model for the Main Central thrust in Nepal

D.M. Robinson* 
P.G. DeCelles — Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA
C.N. Garzione — Department of Earth and Environmental Sciences, University of Rochester, Rochester, New York 14627, USA
O.N. Pearson — Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA
T.M. Harrison — Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia
E.J. Catlos — School of Geology, Oklahoma State University, Stillwater, Oklahoma 74078, USA

## ABSTRACT

**We present a kinematic model for the Himalayan thrust belt that satisfies structural and metamorphic data and explains recently reported late Miocene–Pliocene geochronologic and thermochronologic ages from rocks in the Main Central thrust zone in central Nepal. At its current exposure level, the Main Central thrust juxtaposes a hanging-wall flat in Greater Himalayan rocks with a footwall flat in Lesser Himalayan rocks of the Ramgarh thrust sheet, which is the roof thrust of a large Lesser Himalayan duplex. Sequential emplacement of the Main Central (early Miocene) and Ramgarh (middle Miocene) thrust sheets was followed by insertion of thrust sheets within the Lesser Himalayan duplex and folding of the Main Central and Ramgarh thrusts during late Miocene–Pliocene time. Thorium-lead (Th-Pb) ages of monazite inclusions in garnets from central Nepal record the timing of coeval, progressive metamorphism of Lesser Himalayan rocks in the footwall of the Main Central thrust. Although this model does not rule out minor, late-stage reactivation of the Main Central thrust, major late Miocene reactivation is not required.**

**Keywords:** Main Central thrust, Ramgarh thrust, Himalaya, Nepal, Lesser Himalayan duplex.

## INTRODUCTION

Spanning the entire length of the Himalaya, the Main Central thrust has accommodated a significant fraction of the total shortening in the orogenic belt (see summaries in Hodges, 2000; Yin and Harrison, 2000). Despite many detailed studies, the kinematic history of the fault and its relationship to the other structures in the Himalaya remain poorly understood. Particularly intriguing are geochronologic and thermochronologic data from central and eastern Nepal that suggest major reactivation of the Main Central thrust, with perhaps as much as 40 km of slip during late Miocene–Pliocene time (Harrison et al., 1997, 1998; Catlos et al., 2001, 2002). Although out-of-sequence thrusting is ubiquitous in thrust belts, the resulting displacements are generally only a few kilometers (Boyer, 1992). The Himalayan thrust belt is commonly adopted as a paradigm for collisional orogens, so the possibility of extraordinary out-of-sequence slip on the Main Central thrust is worthy of careful consideration. In this paper we combine geochronologic and thermochronologic data from central Nepal with new structural data from western Nepal to develop a conceptual model that explains the Main Central thrust within the broader context of the entire thrust belt. Although the field and geochronologic data needed to test the model are not yet available from a single region of the Himalaya, we suggest that the model may explain many of the regional-scale structural and metamorphic characteristics of the Nepalese sector of the thrust belt.

## REGIONAL TECTONIC SETTING

The tectonostratigraphy of the Himalayan orogenic belt is divided into the Tibetan Himalaya, Greater Himalaya, Lesser Himalaya, and Subhimalaya zones (Fig. 1; Gansser, 1964). Separating the zones are major fault systems: the South Tibetan detachment system between the Tibetan and Greater Himalayas, the Main Central thrust between the Greater and Lesser Himalayas, and the Main Boundary thrust between the Lesser Himalaya and Subhimalaya. Other important structures include the Ramgarh and Main Frontal thrusts and the Lesser Himalayan duplex (Fig. 1).

The Greater Himalaya consists of a 5–20-km-thick assemblage of Late Proterozoic–early Paleozoic metasedimentary and metaigneous rocks (Pêcher, 1989; Schelling, 1992; Vannay and Hodges, 1996). The Lesser Himalaya in Nepal is composed of an ~10-km-thick succession of Proterozoic, upper Paleozoic, and Cretaceous–lower Miocene sedimentary rocks (e.g., DeCelles et al., 2000, 2001).

The peak metamorphic temperatures in the Greater Himalaya increase northward in an upsection direction from ~550 to ~800 °C (e.g., Pêcher, 1989; Ganguly et al., 2000; Vannay and Grasemann, 2001), accompanied by a northward-declining (Harrison et al., 1999; Guillot, 1999) field gradient in recorded peak pressure from ~10 kbar near the Main Central thrust to ~4 kbar near the South Tibetan detachment system. In the northern part of the Lesser Himalaya, the rocks have been metamorphosed to upper greenschist facies, and metamorphic isograds in the footwall of the Main Central thrust are inverted, progressing from chlorite to garnet in a northward direction (e.g., Harrison et al., 1998). The kinematic history of the thrust belt involved a general southward progression of main phases of thrusting from Eocene to present (Fig. 2; Ratschbacher et al., 1994; DeCelles et al., 2001).

## STRUCTURAL GEOMETRY

The Main Central thrust in Nepal is traditionally defined as a ductile shear zone that is several hundred meters to several kilometers thick with a top-to-the-south sense of shear (e.g., Brunel, 1986). The concept of the Main Central thrust zone was developed because in many places, lower greenschist facies Lesser Himalayan rocks grade into upper amphibolite facies Greater Himalayan rocks without an obvious structural break (Arita, 1983; Pêcher, 1989; Vannay and Hodges, 1996). Highly strained Lesser Himalayan rocks in the footwall of the Main Central thrust are commonly included in the Main Central thrust zone. The transition zone between unambiguous Lesser Himalayan and Greater Himalayan rocks contains a variety of metasedimentary rocks, including phyllite, schist (commonly graphitic), marble, and quartzite. Greater Himalayan rocks in western and central Nepal are divided into three units: a lower metapelitic unit, a middle metacarbonate unit, and an upper orthogneiss unit (LeFort, 1975).

Compositional layers and foliation in Greater Himalayan rocks dip 30°–60° north-northeast and generally strike parallel to the trace of the Main Central thrust (e.g., Frank and Fuchs, 1969; LeFort, 1975; Arita, 1983; Brunel, 1986; Schelling, 1992; Vannay and Grasseman, 2001; DeCelles et al., 2001). Although some layering in Greater Himalayan rocks is probably the result of cleavage transposition, the threefold lithostratigraphy can be traced in many transects >100 km across strike, and no evidence exists to support the presence of a regional isoclinal fold in these rocks. Moreover, thermobarometric data (e.g., Johnson et al., 2001) do not suggest a signif-

---

*Corresponding author.

*Geology;* April 2003; v. 31; no. 4; p. 359–362; 2 figures.

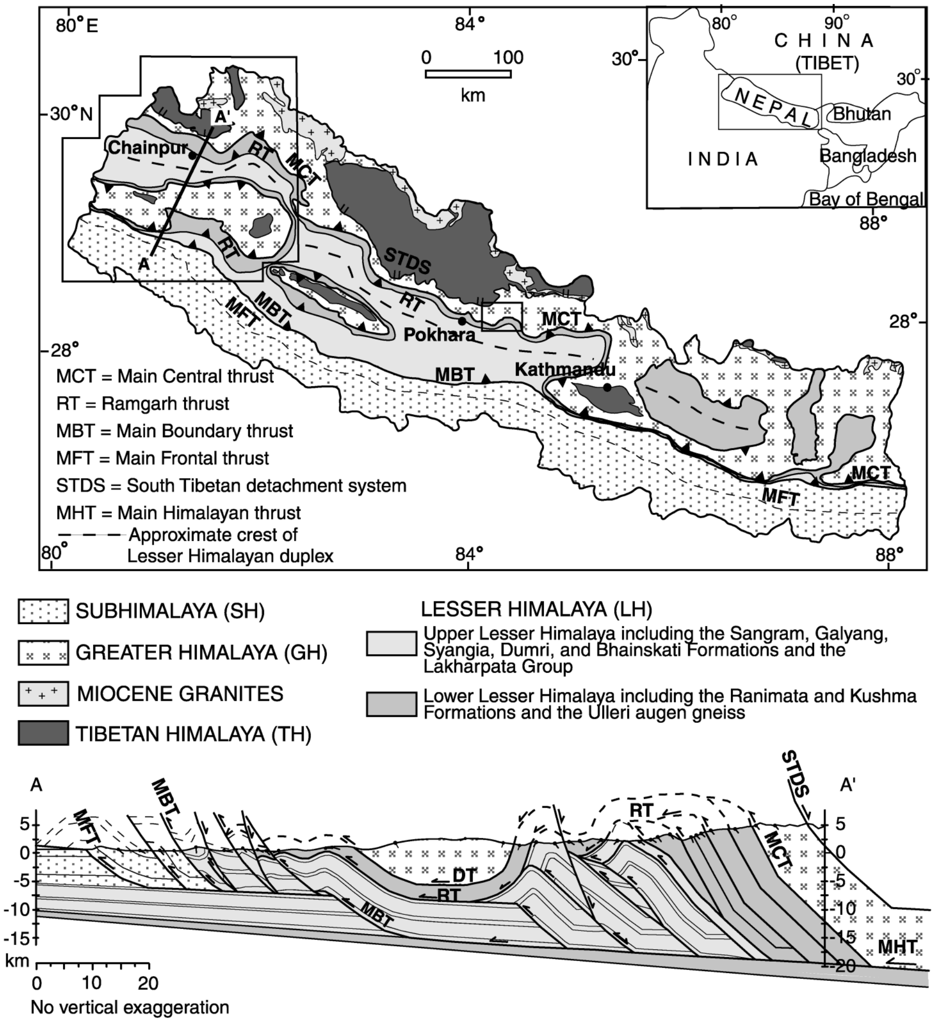

**Figure 1. A: Geologic map of Nepal showing major tectonostratigraphic zones, faults, and crystalline klippen of Greater Himalayan affinity. Box in western Nepal delineates area mapped by Robinson (2001), and line of cross section is marked by line A–A′. Box in central Nepal shows area sampled by Catlos et al. (2001). B: Generalized cross section from western Nepal showing major faults and tectonostratigraphic zones, modified from DeCelles et al. (2001). DT is Dadeldura thrust.**

icant change in peak pressures right above the Main Central thrust across the entire north-south width of exposure in the Greater Himalayan rocks. Therefore, we interpret the first-order, hanging-wall structure of the Main Central thrust to be a regional flat in the direction of tectonic transport.

Across most of Nepal and northern India, mapping shows that within ~20 km south of the Main Central thrust, bedding and foliation in Lesser Himalayan rocks also consistently dip northward at angles of 30°–60°. Although the Lesser Himalayan rocks (particularly the phyllites) are ductilely deformed, their stratigraphy is coherent, and structural facing directions are upright. Because fabrics in both the hanging wall and footwall of the Main Central thrust are parallel, this geometry requires that Greater and Lesser Himalayan rocks were once stacked vertically in a flat-on-flat geometry and were subsequently uplifted and tilted to the present northward-dipping orientation (Figs. 2B–2E). The regional-scale, flat-on-flat structural geometry is well preserved in the Arun Valley of eastern Nepal (Schelling, 1992), but is obscured in central and western Nepal because erosion has breached the Greater Himalayan rocks and Lesser Himalayan duplex (Johnson et al., 2001; DeCelles et al., 2001; Robinson, 2001). Despite this simple structural relationship, a widely held view exists in the literature that the Main Central thrust is a structural ramp.

## KINEMATIC MODEL

Figure 2 portrays a conceptual kinematic model for the Himalayan thrust belt. The model is developed from structural and stratigraphic data collected in western Nepal and geochronologic and thermobarometric data from central Nepal. With respect to the pressure-temperature (*P-T*) history of the rocks near the Main Central thrust, understanding the growth of the Lesser Himalayan duplex is critical because emplacement of thrust sheets within the duplex passively uplifted and tilted the overlying Greater Himalayan rocks into their steep northward dips.

In central and western Nepal (Johnson, 1994; Paudel and Arita, 2000; Robinson, 2001; DeCelles et al., 2001; Pearson, 2002) and northern India (Srivastava and Mitra, 1994), the Lesser Himalayan duplex has a hinterland-dipping, antiformal geometry. The roof thrust is the Ramgarh thrust in western Nepal (DeCelles et al., 2001), and the floor thrust is the Main Himalayan thrust (Hauck et al., 1998). In western Nepal, the growth of the duplex commenced with the emplacement of the Ramgarh thrust sheet along a regional footwall flat (Fig. 2C). Thrust sheets of Lesser Himalayan rocks were subsequently excised from the footwall and incorporated into the hanging wall of the floor thrust (Fig. 2D). The total slip was fed from the lower thrust flat to the upper flat, but individual thrusts in the duplex experienced only a faction of this total slip. As each new thrust sheet was incorporated into the duplex, all overlying rocks, including the Greater Himalayan rocks above the Ramgarh sheet, were folded into a broad antiform (Figs. 2D, 2E).

Many workers have considered rocks that we map as part of the Ramgarh thrust sheet and the northern limb of the Lesser Himalayan duplex in western, central, and eastern Nepal to be within the Main Central thrust zone (e.g., Paudel and Arita, 2000). Regional stratigraphic, structural, and isotopic studies confirm that these are Lesser Himalayan rocks (DeCelles et al., 2001; Robinson et al., 2001; Pearson, 2002). In western Nepal, garnet-bearing phyllite (equivalent to domains 2 and 3 of Catlos et al., 2001) is present in the Ramgarh sheet and in at least two additional thrust sheets within the duplex (Robinson, 2001; Pearson, 2002).

## IMPLICATIONS OF THE MODEL

The qualitative kinematic model (Fig. 2) makes several predictions that can be tested by existing thermochronologic, geochronologic, and metamorphic *P-T* data sets. First, the model predicts that pressures in the hanging wall of the Main Central thrust should decrease northward in an upsection direction. Harrison et al. (1999) and Guillot (1999) summarized data that indicate a northward-declining pressure gradient from ~8–10 kbar near the Main Central thrust to ~4 kbar near the South Tibetan detachment system. This pattern is consistent with regional metamorphism beneath the Tibetan Himalaya (Godin et al., 2001). Our model explains the northward decline in pressure as a result of passive northward tilting of the Main Central thrust sheet during growth of the Lesser Himalayan duplex.

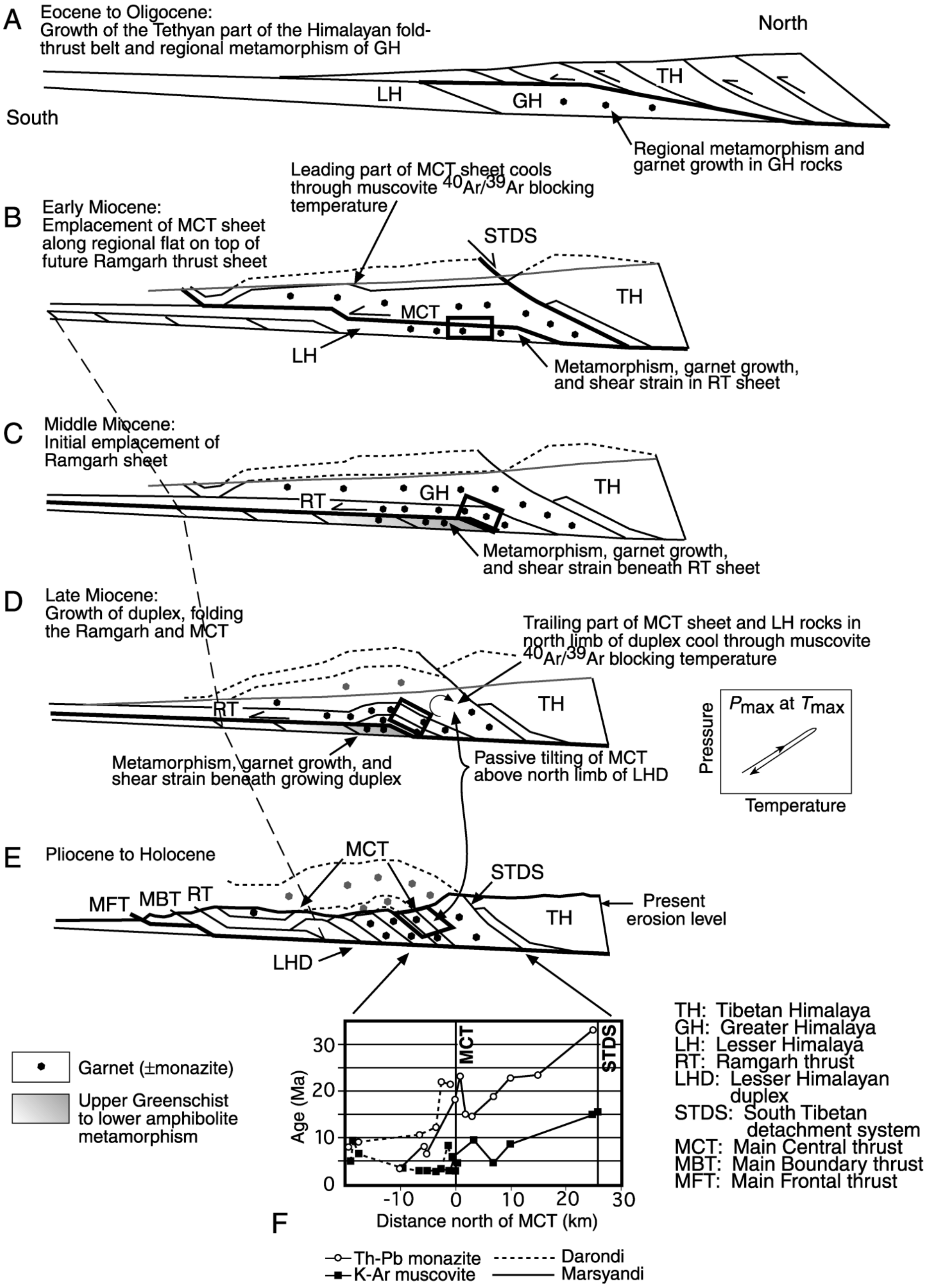

**Figure 2. A–E: Evolution of Himalayan thrust belt beginning in early Tertiary time. Bold lines mark active fault(s). Polygon highlights part of Main Central thrust currently exposed at surface. Lines of long dashes connecting B–E track location of reference point. D: Schematic pressure-temperature (*P*, *T*) path for each thrust sheet in duplex (after Kohn et al., 2001). F: Th-Pb monazite and $^{40}Ar/^{39}Ar$ muscovite ages plotted against distance of samples from trace of Main Central thrust, from Darondi and Marsyandi Kholas in central Nepal (after Catlos et al., 2001). Location of sample area is shown in Figure 1A. Arrows indicate approximate distribution of ages relative to schematic model.**

Second, the model predicts that peak pressures obtained in each successively emplaced thrust sheet of Lesser Himalayan rocks within the duplex should gradually decrease southward because of the gentle northward inclination of the Main Himalayan thrust and the northward increase in tectonic and topographic overburden. In other words, the inverted metamorphism in the footwall of the Main Central thrust is a consequence of structural imbrication (e.g., Kohn et al., 2001). Assuming a pressure versus depth gradient of 0.275 kbar/km, an original northward inclination of 2°–4° (Hauck et al., 1998), and a palinspastic length of rocks within the northern part of the duplex of ~200 km (DeCelles et al., 2001; Robinson, 2001), the strata now in the duplex would have recorded a northward increase in pressure from 1.92 to 3.85 kbar. With the onset of shortening in the Tibetan and Greater Himalayan zones, the likely tectonic and topographic overburdens would have raised the maximum pressure in the northern part of the duplex (i.e., within the Ramgarh thrust sheet) to ~6–8 kbar. Thus, imbrication and horizontal shortening would have juxtaposed rocks that were subjected to peak pressures ranging from ~3 kbar in the southern part of the duplex to ~8 kbar in its northern part. This predicted pattern matches the pressure gradient documented in Lesser Himalayan rocks beneath the Main Central thrust by Kohn et al. (2001) and Catlos et al. (2001).

Third, the model predicts that the age of peak metamorphism in Lesser Himalayan thrust sheets in the duplex should decrease southward. Emplacement of the Main Central thrust sheet (with its Tibetan thrust-belt overburden) along a regional thrust flat during early Miocene time (Fig. 2B) buried Lesser Himalayan rocks of the eventual Ramgarh thrust sheet to depths sufficient to produce garnet. Middle Miocene uplift and southward displacement of the Ramgarh sheet (plus its cover of Tibetan and Greater Himalayan rocks; Fig. 2C) buried Lesser Himalayan rocks that subsequently became thrust sheets within the duplex. Beginning in late Miocene time, emplacement of each thrust sheet in the duplex loaded footwall Lesser Himalayan rocks, in turn producing younger monazites and garnets (Figs. 2D, 2E). The predicted pattern of southward-decreasing age of metamorphism was documented by Harrison et al. (1997) and Catlos et al. (2001, 2002) from Th-Pb ages of monazite inclusions in synkinematic garnets from Lesser and Greater Himalayan rocks flanking the Main Central thrust in central Nepal. In the hanging wall of the Main Central thrust, monazite ages decrease southward from ca. 33 Ma to ca. 15 Ma (Fig. 2F), consistent with the hypothesis that ''Eohimalayan'' metamorphism of Greater Himalayan rocks was driven by crustal thickening in the Tibetan Himalaya. Monazite ages in Lesser Himalayan rocks to 7 km south of the Main Central thrust range from ca. 21 Ma to ca. 7 Ma (Fig. 2). The monazite ages in Lesser Himalayan rocks 7–20 km south of the Main Central thrust are ca. 7–8 Ma, and two samples yield anomalous ages of ca. 12 Ma and ca. 3 Ma. This southward decrease of the monazite ages has been explained by reactivation of the Main Central thrust and successive incorporation of Lesser Himalayan rocks into its hanging wall, forming the Main Central thrust zone (Harrison et al., 1998; Catlos et al., 2001). This process by which footwall rocks were transferred to the hanging wall of the active thrust system is kinematically consistent with growth of the Lesser Himalayan duplex (Figs. 2C–2E).

Fourth, the model predicts that individual thrust sheets of Lesser Himalayan rocks in the duplex followed hairpin-shaped *P-T* paths as they were first buried in the footwall and then incorporated into the duplex (Fig. 2D). These *P-T* paths were predicted by Harrison et al. (1998) and documented by Kohn et al. (2001) and Catlos et al. (2001) in Lesser Himalayan rocks to the south of the Main Central thrust.

Fifth, the model predicts that the upper part of the Greater Himalayan sequence cooled through the muscovite $^{40}$Ar/$^{39}$Ar blocking isotherm (~350 °C) during early to middle Miocene emplacement of the Main Central thrust sheet (Fig. 2B), and that the lower, trailing part of the Greater Himalayan sequence and the underlying Lesser Himalayan rocks would have cooled during late Miocene–Pliocene growth of the duplex (Figs. 2D, 2E). Rocks in the Kathmandu klippe cooled through the muscovite $^{40}$Ar/$^{39}$Ar blocking isotherm during early to middle Miocene time (Copeland et al., 1996; Johnson et al., 2001), whereas Greater Himalayan rocks to the north of the present trace of the Main Central thrust remained relatively hot until middle to late Miocene time (ca. 9–5 Ma; Catlos et al., 2001, and references therein). Lesser Himalayan rocks south of the Main Central thrust cooled through the ~350 °C isotherm between ca. 9 and 3 Ma (Catlos et al., 2002). These late Miocene–Pliocene cooling ages in Lesser Himalayan rocks may be the result of exhumation accompanying movement of the duplex thrust sheets over the main footwall ramp beneath the duplex.

Although we propose that large-scale, late Miocene–Pliocene reactivation of the Main Central thrust is not required by existing data, it remains plausible that out-of-sequence slip has taken place during late Miocene–Pliocene time on the Main Central thrust and faults in the duplex. Geomorphic and space geodetic studies suggest that the Main Central thrust may be active today (Hodges et al., 2001). Nevertheless, when considered within the framework of the entire Himalayan thrust belt, the combination of regional structural, thermobarometric, and geochronologic data suggests that the Main Central thrust formed as part of an overall southward progression of thrusting and has not been the site of extraordinary reactivation events.

## ACKNOWLEDGMENTS

Funding was provided by the U.S. National Science Foundation. We are grateful to Jibamitra Ganguly, three anonymous reviewers, and David Fastovsky for helping us to improve this manuscript.

## REFERENCES CITED

Arita, K., 1983, Origin of inverted metamorphism of the lower Himalaya, Central Himalaya: Tectonophysics, v. 95, p. 43–60.

Boyer, S.E., 1992, Geometric evidence for synchronous thrusting in the southern Alberta and northwest Montana thrust belts, *in* McClay, K.R., ed., Thrust tectonics: New York, Chapman and Hall, p. 377–390.

Brunel, M., 1986, Ductile thrusting in the Himalayas: Shear sense criteria and stretching lineations: Tectonics, v. 5, p. 247–265.

Catlos, E.J., Harrison, T.M., Kohn, M.J., Grove, M., Ryerson, F.J., Manning, C., and Upreti, B.N., 2001, Geochronologic and thermobarometric constraints on the evolution of the Main Central thrust, central Nepal Himalaya: Journal of Geophysical Research, v. 106, p. 16,177–16,204.

Catlos, E.J., Harrison, T.M., Manning, C., Grove, M., Rai, S.M., Hubbard, M.S., and Upreti, B.N., 2002, Records of the evolution of the Himalayan orogen from in situ Th-Pb ion microprobe dating of monazite: Eastern Nepal and western Garhwal: Journal of Asian Earth Sciences, v. 20, p. 459–479.

Copeland, P., LeFort, P., Ray, S.M., and Upreti, B.N., 1996, Cooling history of the Kathmandu crystalline nappe: $^{40}$Ar/$^{39}$Ar results: Himalayan-Karakoram-Tibet Workshop, 11th, Flagstaff, Arizona, Abstracts, p. 39.

DeCelles, P.G., Gehrels, G.E., Quade, J., LaReau, B., and Spurlin, M., 2000, Tectonic implications of U-Pb zircon ages of the Himalayan orogenic belt in Nepal: Science, v. 288, p. 497–499.

DeCelles, P.G., Robinson, D.M., Quade, J., Copeland, P., Upreti, B.N., Ojha, T.P., and Garzione, C.N., 2001, Regional structure and stratigraphy of the Himalayan fold-thrust belt, far-western Nepal: Tectonics, v. 20, p. 487–509.

Frank, W., and Fuchs, G.R., 1969, Geological investigations in west Nepal and their significance for the geology of the Himalayas: Geologische Rundschau, v. 59, p. 552–580.

Ganguly, J., Dasgupta, S., Cheng, W., and Neogi, S., 2000, Exhumation history of a section of the Sikkim Himalayas, India: Records in the metamorphic mineral equilibria and compositional zoning of garnet: Earth and Planetary Science Letters, v. 183, p. 471–486.

Gansser, A., 1964, Geology of the Himalayas: London, Wiley Interscience, 289 p.

Godin, L., Parrish, R.R., Brown, R.L., and Hodges, K.V., 2001, Crustal thickening leading to exhumation of the Himalayan metamorphic core of central Nepal: Insight from U-Pb geochronology and $^{40}$Ar/$^{39}$Ar thermochronology: Tectonics, v. 20, p. 729–747.

Guillot, S., 1999, An overview of the metamorphic evolution in central Nepal: Journal of Asian Earth Sciences, v. 17, p. 713–725.

Harrison, T.M., Ryerson, F.J., LeFort, P., Yin, A., Lovera, O., and Catlos, E.J., 1997, A late Miocene–Pliocene origin for the central Himalayan inverted metamorphism: Earth and Planetary Science Letters, v. 146, p. E1–E7.

Harrison, T.M., Grove, M., Lovera, O.M., and Catlos, E.J., 1998, A model for the origin of Himalayan anatexis and inverted metamorphism: Journal of Geophysical Research, v. 103, p. 27,017–27,032.

Harrison, T.M., Grove, M., Lovera, O.M., Catlos, E.J., and D'Andrea, J., 1999, The origin of Himalayan anatexis and inverted metamorphism: Models and constraints: Journal of Asian Earth Sciences, v. 17, p. 755–772.

Hauck, M.L., Nelson, K.D., Brown, L.D., Zhao, Z., and Ross, A.R., 1998, Crustal structure of the Himalayan orogen at ~90° east longitude from Project INDEPTH deep reflection profiles: Tectonics, v. 17, p. 481–500.

Hodges, K.V., 2000, Tectonics of the Himalaya and southern Tibet from two perspectives: Geological Society of America Bulletin, v. 112, p. 324–350.

Hodges, K.V., Hurtado, J.M., and Whipple, K.K., 2001, Southward extrusion of Tibetan crust and its effect on Himalayan tectonics: Tectonics, v. 20, p. 799–809.

Johnson, M.R.W., 1994, Culminations and domal uplifts in the Himalaya: Tectonophysics, v. 239, p. 139–147.

Johnson, M.R.W., Oliver, G.J.G., Parrish, R.R., and Johnson, S.P., 2001, Synthrusting metamorphism, cooling, and erosion of the Himalayan Kathmandu complex, Nepal: Tectonics, v. 20, p. 394–415.

Kohn, M.J., Catlos, E.J., Ryerson, F.J., and Harrison, T.M., 2001, Pressure-temperature-time path discontinuity in the Main Central thrust zone, central Nepal: Geology, v. 29, p. 571–574.

LeFort, P., 1975, Himalayas: The collided range, present knowledge of the continental arc: American Journal of Science, v. 275-A, p. 1–44.

Paudel, L.P., and Arita, K., 2000, Tectonic and polymetamorphic history of the Lesser Himalaya in central Nepal: Journal of Asian Earth Sciences, v. 18, p. 561–584.

Pearson, O.N., 2002, Structural evolution of the central Nepal fold-thrust belt and regional tectonic and structural significance of the Ramgarh thrust [Ph.D. thesis]: Tucson, University of Arizona, 230 p.

Pêcher, A., 1989, The metamorphism in the central Himalaya: Journal of Metamorphic Geology, v. 7, p. 31–41.

Ratschbacher, L., Frisch, W., and Guanghua, L., 1994, Distributed deformation in southern and western Tibet during and after the India-Asia collision: Journal of Geophysical Research, v. 9, p. 19,917–19,945.

Robinson, D.M., 2001, Structural and Nd-isotopic evidence for the tectonic evolution of the Himalayan fold-thrust belt, western Nepal and the northern Tibetan plateau [Ph.D. thesis]: Tucson, University of Arizona, 224 p.

Robinson, D.M., DeCelles, P.G., Patchett, P.J., and Garzione, C.N., 2001, The kinematic history of the Nepalese Himalaya interpreted from Nd isotopes: Earth and Planetary Science Letters, v. 192, p. 507–521.

Schelling, D., 1992, The tectonostratigraphy and structure of the eastern Nepal Himalaya: Tectonics, v. 11, p. 925–943.

Srivastava, P., and Mitra, G., 1994, Thrust geometries and deep structure of the out and lesser Himalaya, Kumaon and Garhwal (India): Implication for evolution of the Himalayan fold-and-thrust belt: Tectonics, v. 13, p. 89–109.

Vannay, J.-C., and Grasemann, B., 2001, Himalayan inverted metamorphism and syn-convergence extension as a consequence of a general shear extrusion: Geological Magazine, v. 138, p. 253–276.

Vannay, J.-C., and Hodges, K.V., 1996, Tectonometamorphic evolution of the Himalayan metamorphic core between Annapurna and Dhaulagiri, central Nepal: Journal of Metamorphic Geology, v. 14, p. 635–656.

Yin, A., and Harrison, T.M., 2000, Geologic evolution of the Himalayan-Tibetan orogen: Annual Review of Earth and Planetary Sciences, v. 28, p. 211–280.

Manuscript received 3 September 2002
Revised manuscript received 26 November 2002
Manuscript accepted 3 December 2002

Printed in USA