Miocene dextral shearing between Himalaya and Tibet

Arnaud Pêcher
Laboratoire de Géologie Alpine, Université Joseph Fourier, Institut Dolomieu, 38031 Grenoble Cedex, France
Jean-Luc Bouchez
Laboratoire de Pétrophysique, Université Paul Sabatier, 38 rue des 36 Ponts, 31400 Toulouse Cedex, France
Patrick Le Fort
Laboratoire de Géologie Alpine, Université Joseph Fourier, Institut Dolomieu, 38031 Grenoble Cedex, France

ABSTRACT

The Main Central thrust zone is the major structural feature of the Himalayas. It was active during Miocene time and accommodated at least 100 km, and possibly as much as 300 km, of convergence between India and Tibet. We present evidence that late in the tectonic history, another large shear zone, located north of the High Himalayas (the North Himalayan shear zone), underwent a phase of dextral strike-slip motion. The most plausible explanation for this phase of motion is that it reflects the onset of extension in Tibet. It is usually thought that extension began about 2.5 Ma. The phase of dextral shear we report occurred between 25 and 15 Ma. If our explanation for this movement is correct, it places the onset of extension at least 12 m.y. earlier than previously thought.

INTRODUCTION

India and Asia collided about 50 Ma with the formation of the ophiolite-bearing Indus-Tsangbo suture zone. Further shortening due to the continuing northward migration of India resulted in contrasting tectonic patterns. In Tibet, shortening prompted a tremendous crustal thickening, almost doubling; grabens striking north-south mark an east-west extension, which is usually thought to have begun about 2.5 Ma (Armijo et al., 1986). Farther north and east in Asia, huge conjugate fault zones accommodate an overall eastward migration or rotation of Asia (Tapponnier et al., 1986; England and Molnar, 1990). In northern India, shortening was accommodated by slicing and stacking of rocks of the pre-Tertiary margin. This was responsible for the present Himalayas, erected on the back of the huge, south-verging thrust zone known as the Main Central thrust zone (Bouchez and Pêcher, 1981).

The limit between the two domains is not the Indus-Tsangbo suture, but roughly follows the northern slope of the High Himalayas. Recent studies show that mainly northward-directed extension predominates there: ductile normal shearing (Burg et al., 1984; Burchfiel and Royden, 1985; Herren, 1987) and north-verging folds (Caby et al., 1983) form collapse structures. This faulted zone, the North Himalayan shear zone, also called the North Himalayan fault, extends between the base of the Tibetan sedimentary series and the top of the Higher Himalayan crystalline rocks (the Tibetan slab).

The observations presented here consist of detailed structural and petrographic mapping from the western to central Himalayas, covering more than 10^4 km^2 in Zanskar, Garhwal, and mainly central Nepal. The mapping crossed the Main Central thrust pile, the top of the Tibetan slab, and the North Himalayan shear zone (see Fig. 1).

STRUCTURAL MARKERS IN THE HIMALAYAN TECTONIC-METAMORPHIC PILE

The broad features of the Main Central thrust zone are similar along most of the Himalayas. A pile of migmatitic gneisses 5–12 km thick (the Tibetan slab) is thrust over the nappes of the Lesser Himalayas along the Main Central thrust zone. This zone is several kilometres thick and affects the lower part of the Tibetan slab as well as the upper part of the Lesser Himalayan nappes (Bouchez and Pêcher, 1981).

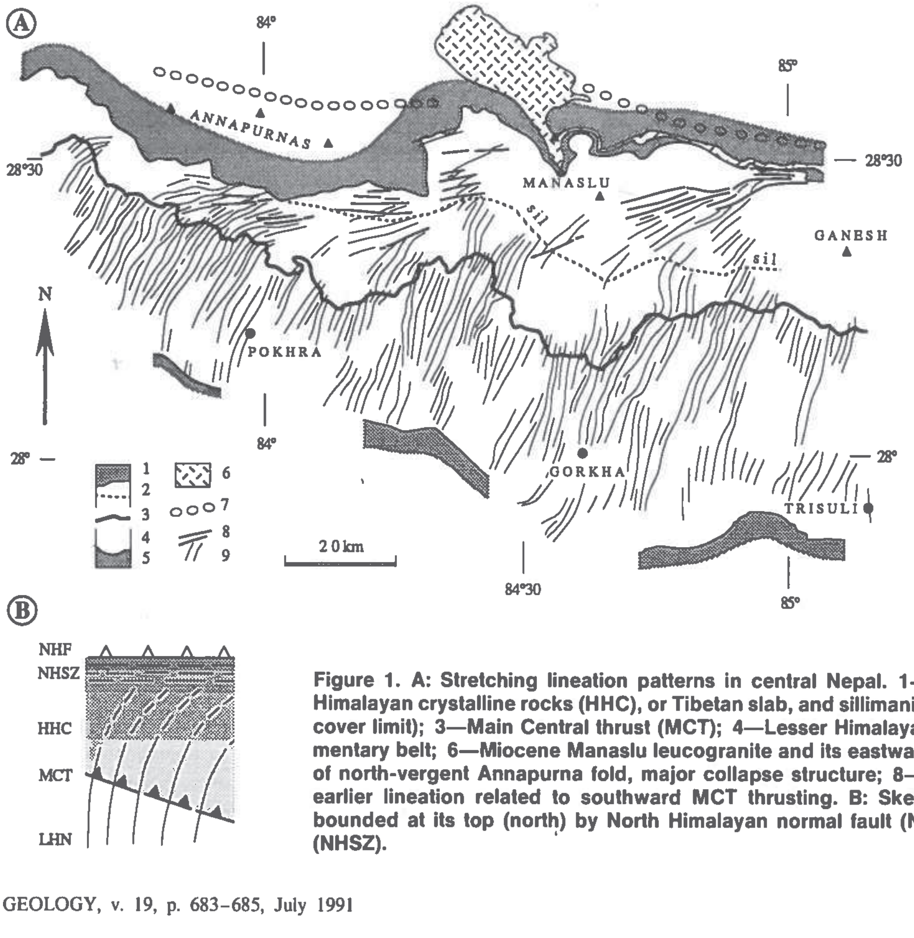

Figure 1. A: Stretching lineation patterns in central Nepal. 1—Tethyan sedimentary cover (TSS); 2—Higher Himalayan crystalline rocks (HHC), or Tibetan slab, and sillimanite isograd (sillimanite present up to sedimentary cover limit); 3—Main Central thrust (MCT); 4—Lesser Himalayan nappes (LHN); 5—Southern Himalayan sedimentary belt; 6—Miocene Manaslu leucogranite and its eastward prolongation (Chokkang arm); 7—axial trace of north-vergent Annapurna fold, major collapse structure; 8—late sillimanite lineation in dextral shears; 9—earlier lineation related to southward MCT thrusting. B: Sketch map of Higher Himalayan crystalline pile, bounded at its top (north) by North Himalayan normal fault (NHF), coeval with North Himalayan shear zone (NHSZ).

The Main Central thrust zone contains widely distributed penetrative microstructures that can be used as kinematic markers (Pêcher, 1976; Brunel, 1986): (1) ubiquitous, flat-lying to moderately dipping planar structures, in many places combined into S-C sigmoids, that always indicate a top-to-the-south sense of motion and (2) a conspicuous penetrative stretching lineation, best identified in the Lesser Himalayan nappes (i.e., below the Main Central thrust). Because of the high shear values, these lineations are assumed to record the main transport direction of the Main Central thrust pile. Our measurements from the western to central Himalayas (1 to 3 in Fig. 2) give calculated mean azimuths of this lineation that vary from about north-south in the Kishtwar window (south of Zanskar) to N10°E in Garhwal and N20°E in Nepal. They indicate that the bulk transport direction in the Main Central thrust pile is perpendicular to the belt in the central Himalayas and slightly oblique to it in the western Himalayas. This interpretation compares favorably with the average displacement vectors of India (Patriat and Achache, 1984; DeMets et al., 1990) between anomalies 6 (19.3 Ma) and 5 (8.9 Ma).

This linear shear fabric is clearly imprinted at the base of the Tibetan slab. Higher in the metamorphic pile, however, the fabric associated with southward shearing progressively fades out within 1 or 2 km. The stretching lineation becomes more difficult to see in the field or in thin section, being blurred by the high-temperature secondary recrystallization that develops around the sillimanite-in isograd. Where rotation criteria are still present, they indicate a south (or southwest) sense of shear, evidence of the early rotational deformation due to the Main Central thrust.

Still higher, where approaching the North Himalayan shear zone, the early fabric is commonly overprinted by a new fabric. The overprinting occurs in two different ways, best illustrated in Zanskar and central Nepal.

1. In Zanskar (Herren, 1987), where the southward bulk transport has also affected the lower Tibetan sedimentary series, as attested to by large-scale south-verging folds in the Tethyan cover, the Tibetan slab is made of a sequence of gneiss, nearly 20 km thick, almost completely overprinted by the low-pressure–high-temperature metamorphism. There, the upper Tibetan slab and lower Tibetan sedimentary series are pervasively overprinted by shear structures, most of which appear to postdate the emplacement of the Miocene leucogranitic lenses. The S-C sigmoids consistently indicate a normal-faulting, top-to-the-northeast movement. The shear direction, marked on the shear planes by penetrative stretching lineations, is from N40°E to N70°E, roughly perpendicular to the belt in this part of the chain. In the shear zone, the metamorphic isograds are very close, leading to a sharp but continuous metamorphic decrease from the Tibetan slab migmatites to the Tibetan sedimentary rocks.

2. In central Nepal (Burhi Gandaki valley section, east of Manaslu), ubiquitous, small-scale shear zones, plastered with fibers of sillimanite that grew during the high-temperature metamorphic stage, appear in the upper half of the Tibetan slab. The shear planes trend east-west and dip more steeply toward the north than do the foliation planes. Direction of movement is given by the fibers, and sense of movement is given by the local inflections of the early foliation, which indicate a clockwise strike-slip motion. These small-scale shear zones become denser and more penetrative higher in the Tibetan slab. In the uppermost hundreds of metres, the old foliation is completely overprinted by this new shear fabric, with characteristic dextral S-C sigmoids. A 15–25 Ma age for this dextral shearing is bracketed by (1) the age of the Manaslu granite (oldest measured ages, 25 Ma; Deniel et al., 1987), because the Chokkang arm granite, which branches into the Manaslu, becomes gneiss at close to solidus temperature near this shear zone; and (2) the oldest Ar/Ar mineral ages obtained in the top part of the Tibetan slab (15 Ma on biotite, P. Copeland, 1990, personal commun.), because the sillimanite fibers in the shears were formed before thermal decrease marked by those blocking temperatures.

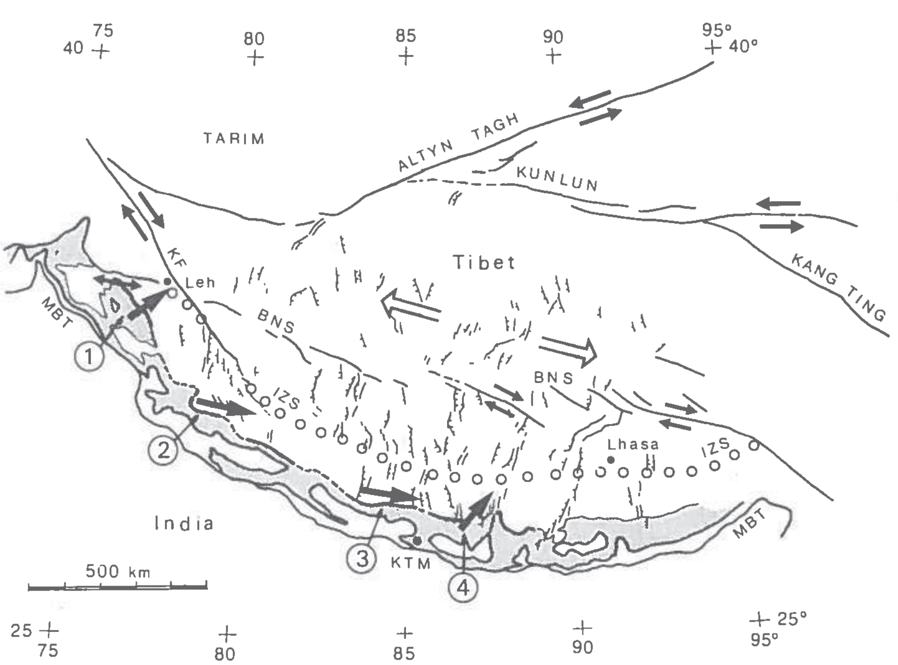

Figure 2. The Himalayas-Tibet system. KTM is Kathmandu; MBT is Main Boundary thrust. Patterned area is Tibetan slab, bounded to south and north, respectively, by Main Central thrust and North Himalayan shear zone. Heavy line shows boundary between Tibetan slab and Tibetan plateau (where it has been previously recognized as normal fault). Circled numbers 1 to 4 indicate Zanskar, Garhwal, central Nepal, and Nyalam sections, respectively. Line of circles shows 50 Ma Indus-Tsangbo suture zone (IZS). Main Quaternary tectonic features of Tibet: large strike-slip faults (BNS—Late Jurassic Banggong-Nujiang suture, reactivated in en echelon fault system; KF—Karakorum fault) and north-south grabens. Light arrows show present direction of extension in Tibet. Large, black, single arrows (just north of North Himalayan shear zone) indicate Miocene movement of Tibet with respect to Himalayas.

NORTH HIMALAYAN SHEAR ZONE DELINEATED BY STRAIN TRAJECTORIES IN THE TIBETAN SLAB

Two contrasted lineation patterns are evident in the Tibetan slab. The first, early, one is imprinted in the lower half of the Tibetan slab and has due north to N30°E trends controlled by convergence movement along the Main Centra thrust. The second, late, one is at the top of the Tibetan slab, trends N50°E to N110°E, and is coeval with normal faulting (Zanskar) and/or dextral shearing (central Nepal). The transition between these two patterns has been systematically traced by mapping the mineral stretching lineation across the metamorphic pile of centra Nepal (Fig. 1A). Figure 1 delineates the North Himalayan shear zone by the progressive rotation of the principal finite stretch axis between the Main Central thrust and the North Himalayan shear zone. This rotation is interpreted as reflecting a change from a transverse early Himalayan movement to a parallel-to-belt Miocene movement. However, because no globa change in the convergence direction since collision is documented, the observed rotation can-not be attributed to a change in the bulk convergence direction between India and Asia. Because the North Himalayan shear zone links a compressional southern domain to an extensional northern one, the rotation pattern is interpreted as due to clockwise shearing of the upper Tibetan slab. The progressive rotation in map view is attributed to penetrative reorientation of the early lineation, the later movement being localized into more discrete east-trending shear zones.

From west to east, several sections of the North Himalayan shear zone distributed along ~1200 km of the belt display features that are best explained by the eastward motion of Tibet relative to India.

In Zanskar (section 1, Fig. 2), dip-slip shearing predominates over strike-slip shearing. However, because the Himalayans here are oriented northwest-southeast, this normal faulting corresponds to a northern block moving to the northeast. East-west dextral shearing has also been recently documented a few tens of kilometres north of the North Himalayan shear zone, on the Sarchu fault (A. Steck, 1990, personal commun.).

In Garhwal (section 2, Fig. 2), the stretching lineation rotates from north-south close to the Main Central thrust to east-west at the top of the Tibetan slab. In map view (Pêcher and Scaillet, 1989), the pattern is very similar to that of central Nepal.

In eastern Nepal (section 4, Fig. 2), the normal faulting has also a dextral component (Brun et al., 1985).

DISCUSSION

The boundary between the metamorphic pile of the High Himalayas and the Tethyan cover rocks (the North Himalayan shear zone) constitutes the southern boundary of the Tibetan plateau, north of the Himalayan Mountains. This boundary is not only a zone of normal faulting but also a large zone of dextral shear parallel to the belt. If 5 km is the minimum thickness of the shear zone in central Nepal, the amount of eastward displacement of Tibet with reference to India could be several tens of kilometres.

The role of the North Himalayan shear zone during the Miocene evolution of Tibet may be explained in one of two ways.

1. Some models (Tapponnier et al., 1986; Davy and Cobbold, 1988; England and Molnar, 1990) emphasize the role of huge strike-slip faults, such as the Altyn Tagh sinistral fault to the north or the Karakorum Jiali dextral fault zone to the south, in accommodating, in Tibet, the global convergence, either by eastward extrusion or by block and fault rotation. In this perspective, the North Himalayan shear zone represents the southern boundary of the Tibetan block that was already extruding eastward during the Miocene.

2. Other models (England and Houseman, 1986, 1989; Houseman and England, 1986) emphasize the overall east-west ductile extension of the previously thickened Tibetan crust. If so, parallel-to-belt movements must take place at the junction between southern Tibet and northern India. Considering that Tibet is not bounded to the east and is bounded to its west by the Pamir-Karakorum heights, it is plausible that extension to the north of the Himalayas will be accommodated by dextral shearing, the shear amount increasing from west to east.

The timing of the Tibetan thickening, as well as the age of the initiation of grabens, is not well known. Nevertheless, the North Himalayan shear zone bounds the Tibetan graben belt on the south, and the shear intensity seems to increase from Zanskar to Nepal (normal faulting in Zanskar, whereas dextral shear predominates more to the east, even increasing from Garhwal to central Nepal). Those observations favor a contribution of Tibetan east-west extension to the formation of the North Himalayan dextral shear zone.

The North Himalayan shear zone draws attention to certain aspects of intracontinental collision tectonics: (1) it confirms the importance of crustal-scale block tectonics, with strain concentration on sharp block boundaries that can be very oblique to the general convergence direction; (2) such boundaries, well known to operate at upper crustal levels, are here shown to proceed at lower levels as large ductile shear zones; and (3) in the Himalayan collision, for which present block movements are fairly well documented (Tapponnier et al., 1986; Molnar and Lyon-Caen, 1989), similar mechanics and kinematics have apparently been working for a long period during the mountain building and the Tibet extension must have begun as early as Miocene.

REFERENCES CITED

Armijo, R., Tapponnier, P., Mercier, J.L., and Han, T., 1986, Quaternary extension in southern Tibet: Field observations and tectonic implications: Journal of Geophysical Research, v. 91, p. 13,803–13,872.

Bouchez, J.L., and Pêcher, A., 1981, Himalayan Main Central Thrust pile and its quartz-rich tectonites in central Nepal: Tectonophysics, v. 78, p. 23–50.

Brun, J.P., Burg, J.P., and Chen, G.M., 1985, Strain trajectories above the Main Central Thrust (Himalaya) in southern Tibet: Nature, v. 313, p. 388–390.

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

Burchfiel, B.C., and Royden, L.H., 1985, North-south extension within the convergent Himalayan region: Geology, v. 13, p. 679–682.

Burg, J.P., Brunel, M., Gapais, D., Chen, G.M., and Liu, G.H., 1984, Deformation of leucogranites of the crystalline Main Central Sheet in Southern Tibet (China): Journal of Structural Geology, v. 6, p. 535–542.

Caby, R., Pêcher, A., and Le Fort, P., 1983, Le grand chevauchement central himalayen: Nouvelles données sur le métamorphisme inverse à la base de la dalle du Tibet: Revue de Géologie Dynamique et Géographie Physique, v. 24, p. 89–100.

Davy, P., and Cobbold, P., 1988, Indentation tectonics in nature and experiment. 2. Continental Asia: Geological Institutions of University of Uppsala, Bulletin, v. 14, p. 143–162.

DeMets, C., Gordon, R.G., Argus, D.F., and Stein, S., 1990, Current plate motions: Geophysical Journal International, v. 101, p. 425–478.

Deniel, C., Vidal, P., Fernandez, A., Le Fort, P., and Peucat, J.J., 1987, Isotopic study of the Manaslu granite (Himalaya, Nepal): Inferences on the age and source of Himalayan leucogranites: Contributions to Mineralogy and Petrography, v. 96, p. 78–92.

England, P., and Houseman, G.A., 1986, Finite strain calculations of continental deformation: 1. Method and general results for convergent zones: Journal of Geophysical Research, v. 94, p. 3664–3676.

—— 1989, Extension during continental convergence, with application to the Tibetan Plateau: Journal of Geophysical Research, v. 94, p. 17,561–17,579.

England, P., and Molnar, P., 1990, Right-lateral shear and rotation as the explanation for strike-slip faulting in eastern Tibet: Nature, v. 344, p. 140–142.

Herren, E., 1987, Zanskar shear zone: Northeast-southwest extension within the higher Himalayas (Ladakh, India): Geology, v. 15, p. 409–413.

Houseman, G.A., and England, P., 1986, Finite strain calculations of continental deformation: 2. Comparison with the India-Asia collision zone: Journal of Geophysical Research, v. 91, p. 3651–3663.

Molnar, P., and Lyon-Caen, H., 1989, Fault plane solutions of earthquakes and active tectonics of the Tibetan Plateau and its margins: Geophysical Journal International, v. 99, p. 123–153.

Patriat, P., and Achache, J., 1984, India-Eurasia collision chronology has implications for crustal shortening and driving mechanisms of plates: Nature, v. 311, p. 615–621.

Pêcher, A., 1976, Geology of the Nepal himalaya: Deformation and petrography in the Main Central Thrust zone: Centre National de la Recherche Scientifique, Colloques Internationaux, no. 268, p. 301–318.

Pêcher, A., and Scaillet, B., 1989, La structure du Haut himalaya au Garhwal (Indes): Eclogae Geologicae Helevetiae, v. 82, p. 655–668.

Tapponnier, P., Peltzer, G., and Armijo, R., 1986, On the mechanics of the collision between India and Asia, *in* Coward, M.P., and Riess, A.C., eds., Collision tectonics: Geological Society of London Special Publication 19, p. 115–157.

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