GEOLOGICAL NOTES

Southern Tibet Detachment System at Khula Kangri, Eastern Himalaya: A Large-Area, Shallow Detachment Stretching into Bhutan?

M. A. Edwards,[1] A. Pêcher,[2] W. S. F. Kidd, B. C. Burchfiel,[3] and L. H. Royden[3]

Department of Geological Sciences, State University of New York at Albany, 1400 Washington Avenue, Albany, New York 12222, U.S.A.
(*e-mail: edwards@geologie.uni-wuerzburg.de*)

ABSTRACT

A new map and cross sections of the Khula Kangri and Kankar Pünzum–Monlakarchung High Himalayan ranges in the Tibet-Bhutan frontier area are presented from integration of unpublished mapping from the summit section of Khula Kangri and new remote sensing together with previous mapping. The ranges define an orographic bifurcation of the High Himalaya that results in a north-south repetition of the main geological section and coincides with the morphological repetition. The Southern Tibet Detachment System that juxtaposes the Tethyan sedimentary rocks against the gneisses and granites of the High Himalayan Crystalline can be continuously traced around both ranges and is not imbricated. Postdetachment kilometer-scale flexure and faulting account for the features of the observed bifurcation. The true map extent of the Khula Kangri and Monlakarchung-Passalum granite batholiths is now apparent. We propose that the two plutons are part of the same originally continuous body.

Introduction

The Southern Tibet Detachment System (STDS; also North Himalayan Normal Fault; Burg 1983) marks the structural contact in the Himalayan orogen between the High Himalayan Crystalline rocks (HHC; containing typically sillimanite gneisses and leucogranite) and overlying Tethyan sedimentary rocks (Burg 1983; Burg et al. 1984; Herren 1987; Pêcher 1991; Burchfiel et al. 1992; Edwards et al. 1996). The STDS is a pan-Himalayan feature (fig. 1) that represents several tens of kilometers of net normal fault throw. The data and hypotheses we present here arise from the compilation of recent geological investigations in the area of the Khula Kangri massif in an attempt to further constrain the STDS in this eastern part of the Himalaya, across the Tibet-Bhutan frontier (fig. 2). Because of the political and logistical difficulties for access to the area, we have attempted an archival geologic map of the area (fig. 3 and housed in the Cornell University INDEPTH archives). This is produced from both new and previously published data (Burchfiel et al. 1992; Pêcher et al. 1994; Edwards et al. 1996) and combined with detailed interpolation using previously unavailable satellite imagery (Thematic Mapper [TM]) and topographic data and some observations by Gansser (1983) from Bhutan.

The Khula Kangri massif is part of the High Himalaya situated north of Bhutan, wholly within Tibet (figs. 1, 2). The geology appears to be similar to other High Himalaya massifs: it comprises gneisses intruded by leucogranite and locally capped by sedimentary rocks identified as Mesozoic and grouped with the Tethyan (Burchfiel et al. 1992; Bureau of Geology and Mineral Resources of Xizang [Tibet]

Manuscript received November 30, 1998; accepted April 28, 1999.

[1] Present address: Institut für Geologie, Technische Universität Bergakademie Freiberg, Bernhard-von-Cotta Strasse 2, 09596 Freiberg, Germany.

[2] Centre National de la Recherche Scientifique, Unité Mixte de Recherche 5025, Institut Dolomieu, 38031 Grenoble, CEDEX, France.

[3] Department of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, Massachusetts 02130, U.S.A.

[The Journal of Geology, 1999, volume 107, p. 623–631] 0022-1376/1999/10705-0006$01.00

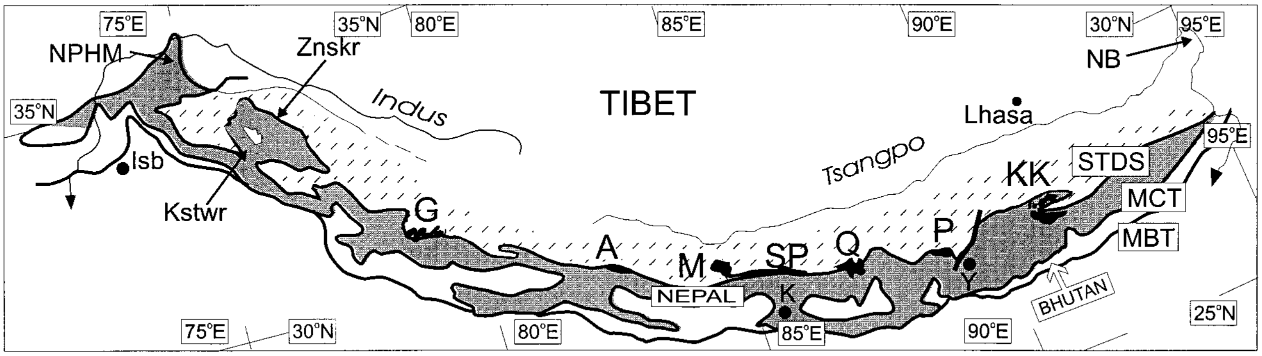

Figure 1. General geologic map of Himalayan chain. *Gray*, Higher Himalaya Crystalline sequence (HHC). *Hatched*, Tethyan sedimentary sequence. *White*, Lesser Himalayan sequences (where part of Main Central Thrust footwall). *Black*, High Himalayan granite plutons with letters identifying associated high peaks. *G*, Gangotri; *A*, Annapurna; *M*, Manaslu; *SP*, Shisha Pangma; *Q*, Mt. Everest; *P*, Pauhunri; *KK*, Khula Kangri; *NPHM*, Nanga Parbat Haramosh Massif; *Isb*, Islamabad; *Kstwr*, Kishtwar window; *Znskr*, Zanskar; *K*, Kathmandu; *Y*, Yadong; *NB*, Namche Barwah; *STDS*, Southern Tibet Detachment System; *MCT*, Main Central Thrust; *MBT*, Main Boundary Thrust.

Autonomous Region 1993). In the Gonto La Valley (fig. 2), the contact between the Tethyan rocks and the High Himalaya Crystallines (including the leucogranite) is a low-angle STDS detachment fault (the Gonto La detachment; Edwards et al. 1996). This is consistent with descriptions of other High Himalaya areas (e.g., Gansser 1964, 1983; Burg 1983; Burchfiel et al. 1992). Dissimilar in this case is the occurrence of a second mountain range, the Kankar Pünzum–Monlakarchung (KPMK) Range to the south. Within this second mountain range, large amounts of sedimentary rocks overlie the HHC/leucogranite. This apparent morphological and geological duplication of the crest of the High Himalaya, briefly noted by Dietrich and Gansser (1981), might be taken to suggest that the STDS is also duplicated.

Morphology

In this part of Himalaya, using topography described in Fielding et al. (1994), a morphological discrimination into five groups is clearly apparent from north to south. Farthest north is the Tibet plateau, which, in this area, averages >5000 m and consists of Tethyan sedimentary rocks. Locally, it is interrupted by the valleys of the Yadong-Gulu rift system (Armijo et al. 1986), e.g., the Nieru Valley half rift (Cogan et al. 1998). Next comes the southern edge of the Tibet Plateau. This is marked by the abrupt topographic change to the High Himalayan Masang Kang–Khula Kangri Range ("Tibet-Bhutan frontier Himalaya" of Edwards et al. 1996), where main summits, mostly consisting of granite, are >7000 m. It coincides with the northern surface trace of the STDS. Next is the southern flank of the Khula Kangri massif. This plunges steeply to the Chatang Valley and is marked by several steep south-dipping faults (figs. 3, 4). Next is the Chatang Valley. Its southern side rises abruptly to become the Kankar Pünzum–Monlakarchung Range, another granite-dominated high range (Gansser 1983). Taken together, the Khula Kangri and the Kankar Pünzum–Monlakarchung ranges define a bifurcation in the crest of the High Himalaya, changing at about 90.4°E. Finally, south of the Kankar Pünzum–Monlakarchung Range, the surface falls away to where the crystalline rocks are exposed in central Bhutan (e.g., Gansser 1983; Grujic et al. 1996).

Geology

We divide the geology into three main units that coincide with the three main morphological portions relevant to this study. From north to south, they are the Khula Kangri Range, the Chatang Valley, and the Kankar Pünzum–Monlakarchung Range.

Khula Kangri Range. The Khula Kangri Range forms the northern portion of the High Himalaya. In the western Khula Kangri massif (fig. 3), the Gonto La Valley provides a north-south cross section >15 km long and >2 km deep (fig. 4*A*) in places that exposes the two-mica tourmaline Khula Kangri leucogranite along most of the valley (Edwards et al. 1996). In the southern part of the section, the granite terminates at an intrusive contact with the HHC.

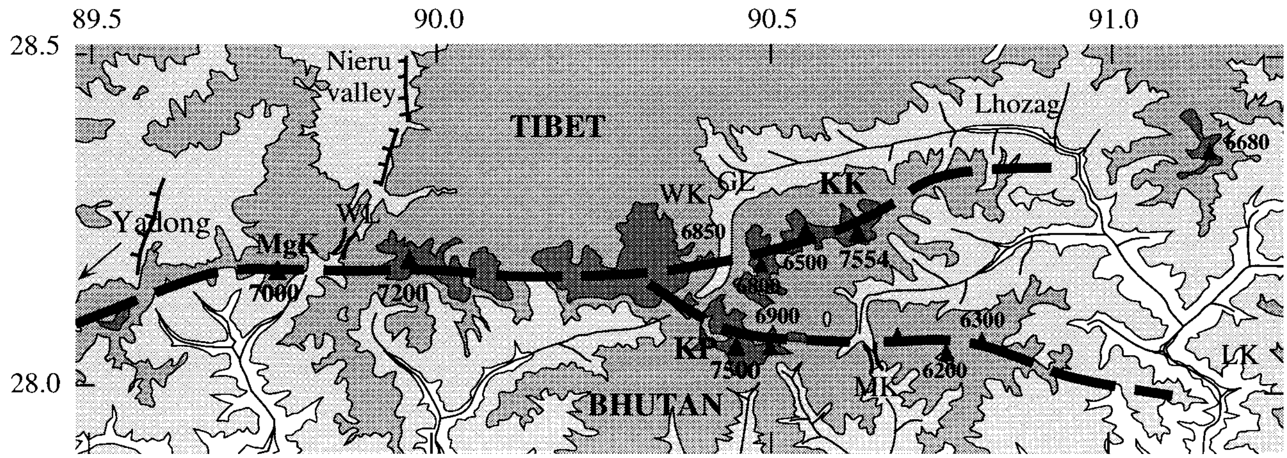

Figure 2. Regional topographic map of Tibet-Bhutan frontier area Himalaya immediately east of Yadong-Gulu rift system. Numbers are degrees east (89.5, etc.), or north (28.0, etc.). Contour interval: 1000 m; darkest shading is >6000 m (>7000 m not discriminated). Fine lines are approximate trace of main rivers. Thick dashed line is approximate line of high peaks. Selective peaks and passes are shown: *WL*, Wagye La; *MgK*, Masang Kang; *WK*, Wang Ka; *GL*, Gonto La; *KK*, Khula Kangri; *KP*, Kankar Pünzum; *MK*, Monlakarchung La; *LK*, La Kang. Note that bifurcation in line of high topography (High Himalaya) is coincident with repetition of main High Himalaya geologic sequence. Khula Kangri Range is north fork, Kankar Pünzum–Monlakarchung Range is south fork.

To the east of the Gonto La Valley are our new field data from what we term the Khula Kangri summit section. Most of the area exposes leucogranite that has the same appearance as the granite exposed in Gonto La. It has an observed thickness of >2.5 km (fig. 4*B*) and, in the northernmost part of the section, locally intrudes the High Himalayan migmatitic gneisses that are capped by dark calcareous schists. More commonly, the granite directly intrudes the sediments. The irregularly shaped intrusive contact can be clearly followed in the landscape, from 4500 m to the northern part of the section to approximately 7400 m close to the summit of Khula Kangri, where a small layer of dark rock caps the top of the western summit ridge. In this Khula Kangri summit section, a very obvious metamorphic aureole can be observed in the sedimentary rocks. Within black schists, growths of biotite + garnet + staurolite + sillimanite are developed very close to the contact. These pass to large chiastolitic andalusite over several hundred meters thickness. Also common are granitic sills and lenses, meters to tens of meters in thickness, that are close to, and parallel with, main granite intrusive contact.

The easternmost part of the Khula Kangri Range is exposed immediately east of Lhozag, along the Lhozag–La Kang traverse conducted by Burchfiel et al. (1992), where a >6-km section of the Khula Kangri granite is found (fig. 4*C*). At its northern margin, the granite intrudes into, and locally metamorphoses, dark, probably Tethyan, slates. Approximately 600 m north of this contact at location *C* (fig. 3) is a ~40° N-dipping normal fault (Burg 1983; Burchfiel et al. 1992; Edwards et al. 1996) regarded (Burchfiel et al. 1992; Edwards et al. 1996) as a part of the Dzong Chu Fault (DCF), a late fault of the STDS described elsewhere (Burchfiel et al. 1992; Edwards et al. 1996). Guillot et al. (1995), investigating metamorphic equilibrium geobarometry of footwall and hanging wall rocks at location C, obtained respective values of 440 ± 60 and 290 ± 40 MPa.

The only existing published field data for the wall forming the southern side of Khula Kangri are remote observations by Gansser (1983) from Monlakarchung La (fig. 3) and Gwen La (~15 km east of fig. 3 map limit). Interpretation of TM imagery and topography allows good interpolation of the outline and distribution of the Khula Kangri granite between these outcrop constraints. This has notably been of most use to trace the southern margin of the Khula Kangri granite. Gansser (1983) described leucogranite sheets of tens to hundreds of meters thick within the HHC of the southern wall of the Khula Kangri massif and reported this as the total extent of granite at Khula Kangri. Our observations show that the actual exposure of the granite is orders of magnitude greater (>750 km^2) and that the Khula Kangri massif is dominated by the granite of the Khula Kangri pluton.

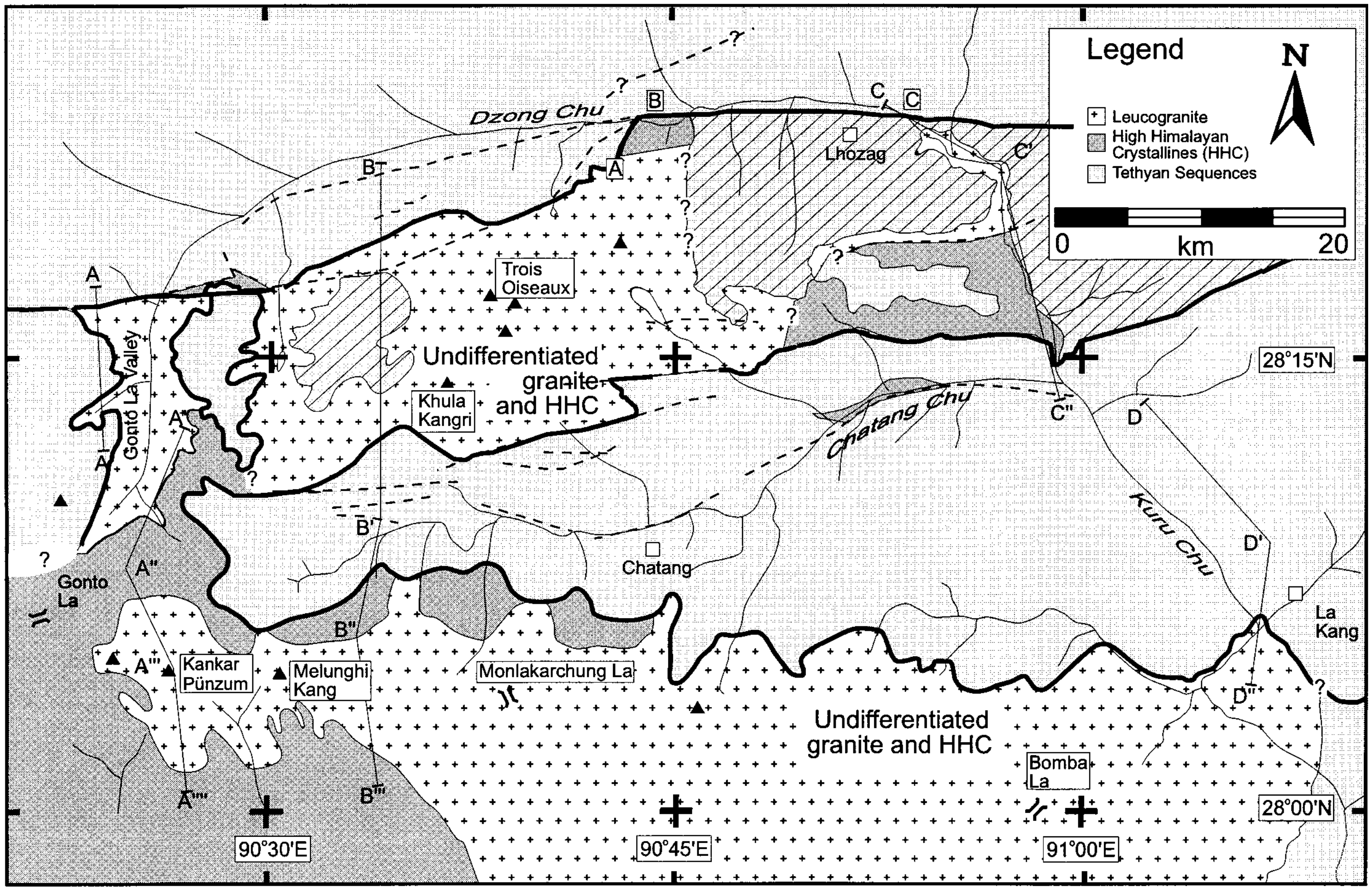

Figure 3. Summary of archival geologic map of Khula Kangri and Kankar Pünzum–Monlakarchung massifs. *Plus pattern*, leucogranite; *light gray*, Tethyan (Mesozoic) sedimentary rocks; *gray hatch*, phyllites intruded by granite and below STDS; *dark gray*, High Himalayan Crystalline rock (*HHC*); *A–A′*, etc., are cross-section locations. Letters in square boxes are locations referred to in text. Thick black line marks STDS. Dashed black lines are other faults. Question marks indicate specific uncertainty. Southern limit of Monlakarchung-Pasalum leucogranite differs in places from Gansser (1983) map because of projection of Gansser field photos and sketches onto our digital topography. General structural trends are in figure 4 (see also original "strip maps" of Burchfiel et al. 1992 and Edwards et al. 1996). For a digitized version, contact M. A. Edwards, W. Kidd, and Project INDEPTH at Cornell University, Ithaca, New York (http://www.geo.cornell.edu/geology/INDEPTH).

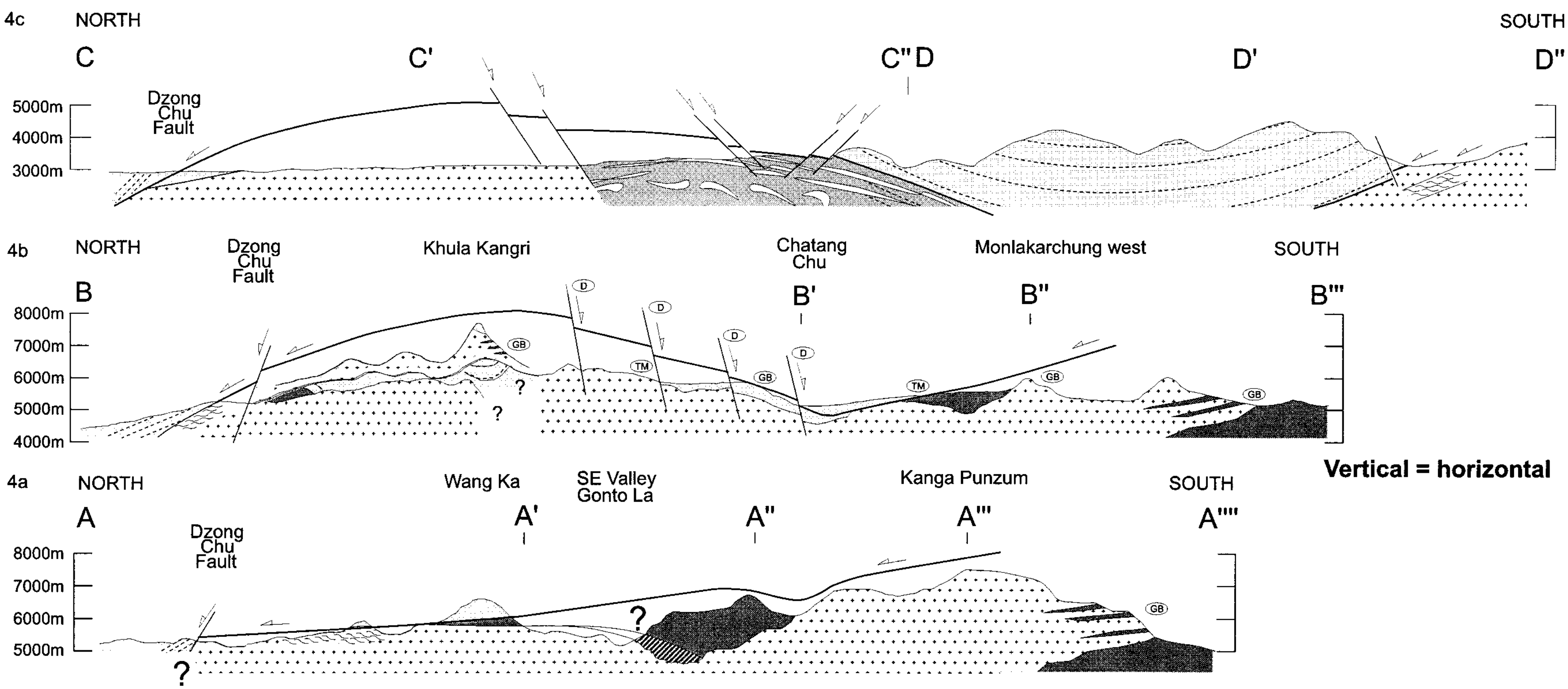

Figure 4. *A–C*, Geologic cross sections continuous across both massif areas. Shading as in figure 3. In HHC, lozenges and thin lenses, respectively, are augen-type or leucogranite sills where observed. Dashed line indicates principal fabric trends measured locally. Geology where interpreted is indicated by *GB* for Gansser (1983) in Bhutan or *TM* for interpolation from the Thematic Mapper image. Faults marked with *D* are approximate locations based on digital topographic data. *A*, Cross section *A–A''''* is from the Dzong Chu Fault (DCF), through Gonto La Valley to south of Kankar Pünzum (*A–A''* is after Edwards et al. 1996). *B*, Cross section *B–B'* includes previously unreported data from the Khula Kangri summit section and trends from the DCF to southwest of Monlakarchung La. Peak of dark rocks at summit of Khula Kangri is not differentiated on main map. *C*, Cross section *C–C''–D–D''* is from Lhozag to La Kang, after Burchfiel et al. (1992).

Chatang Valley. From Gwen La and from Monlakarchung La in the Kankar Pünzum–Monlakarchung Range (figs. 2, 3), Gansser (1983) identified a belt of extensive black slates and phyllites in the Chatang Valley. These dark rocks are clearly identifiable on the TM and are easily traced to the confluence of the Chatang Chu with the Kuru Chu. This confluence area forms a portion within the detailed north-south geologic section of Burchfiel et al. (1992) that crosses both ranges. The section defines a broad synform of Mesozoic age shales and slates a few kilometers thick (fig. 4*C*). Mapping by the Bureau of Geology and Mineral Resources of Xizang (Tibet) Autonomous Region (1993) is rather coarse but consistent insofar as the map for the area shows a patch of Mesozoic age sedimentary rock in the Chatang Valley region.

In the Gonto La Valley section (fig. 4*A*), extensive black phyllites are found everywhere in the detachment hanging wall. In the southern valley, the hanging wall sediments are synformally folded (Edwards et al. 1996). This observation is clearly visible on the TM, and we can identify these rocks as part of the continuous belt of dark rocks all along the Chatang Valley.

The Kankar Pünzum–Monlakarchung Range. Gansser (1983) mapped and described the approximate southern boundary (structural base) of the Monlakarchung-Passalum two-mica leucogranite pluton that makes up much of this range and described the intrusive margins with the HHC (fig. 3).

In the eastern Kankar Pünzum–Monlakarchung Range, near the village of La Kang, Burchfiel et al. (1992) have described an extensive two-mica–tourmaline granite structurally below Tethyan sedimentary rocks of the Chatang Valley. It is identical to both the Khula Kangri leucogranite and to Gansser's (1983) description of the Monlakarchung-Passalum granite. The granite is observed to continue for many kilometers to the west and to the south into Bhutan. Although Burchfiel et al. (1992) loosely grouped this with the Khula Kangri pluton, our mapping and TM interpretation show that it is a separate body at the surface. Moreover, TM interpretation shows this granite as a conspicuous pale body that is continuous between La Kang and the numerous localities where the Monlakarchung-Passalum pluton was observed by Gansser (1983). We have consequently modified Gansser's (1983) delimitation of the northern margins of the Monlakarchung-Passalum pluton (fig. 3). This has been redrawn from projection of Gansser's (1983) sketches and photos onto topographic surfaces to constrain map traces, in conjunction with TM interpolation and the Burchfiel et al. (1992) field observations at La Kang.

Extensive HHC is observed (Edwards et al. 1996) on the southern wall of Gonto La. In this wall, which forms the northern side of Kankar Pünzum, granite intrudes the HHC gneisses. This is consistent with similar relationships documented by Gansser (1983) on the immediate south side of Kankar Pünzum. In addition, the HHC can be recognized on the TM as a pale band that continues to the southeast, toward Monlakarchung, where the granite is recognized.

We conclude that the crystalline rocks that form the Kankar Pünzum–Monlakarchung Range are continuous from the point of the morphological bifurcation of the range (near Gonto La) to tens of kilometers southeast of La Kang. For the most part, the crystallines are dominated by the Monlakarchung-Passalum leucogranite, whose surface outcrop area is now seen to be >1500 km^2. Both the petrography and the tectonic setting (i.e., intrusive into the HHC gneisses of the uppermost Himalaya) of this granite are typical of High Himalayan Miocene leucogranites. For this body, however, there exists no published age. An age exists, however, for the Khula Kangri leucogranite: from the central part of the Gonto La section, Edwards and Harrison (1997) obtained a crystallization age of 12.5 ± 0.15 Ma.

Structure of the Crystalline-Sedimentary Rock Contact

Our mapping indicates that the HHC-Tethyan sedimentary rock contact can be followed as a continuous feature across the two branches of both Himalayan ranges. The contact has the form of an originally continuous surface that is now gently buckled (~10-km wavelength) and cut locally by various minor, E-W-trending, steep faults. The apparent duplication of the High Himalaya is not a product of tectonic imbrication, and the two discrete Himalayan branches do not correspond to a structural repetition and superposition of the upper part of the Himalayan sequence within a single tectonostratigraphic column. We interpret the contact as an STDS detachment extending across both ranges (fig. 4). We now describe the HHC-Tethyan sedimentary rock contact in Gonto La Valley, in the Khula Kangri summit section, and along the Lhozag–La Kang section.

Gonta La Valley and Khula Kangri Summit Section. In Gonto La Valley, the contact is documented (Edwards et al. 1996) as a major top-to-north, low-angle detachment fault of >15-km displacement, the Gonto La detachment (fig. 4*A*). Isolated outcrops of the Gonto La detachment are found in adjacent minor valleys farther east (fig. 3), where the granite and Tethyan rocks are cut by small, down-to-north normal faults that strike ~60°–130° E. We regard these minor faults as splays of the DCF.

East of Gonto La, in the Khula Kangri summit section (*B*–*B‴* in figs. 3, 4*B*), the Tethyan-HHC contact is mostly an intrusive contact (see "Khula Kangri Range" above). In the northern part of this section, however, the Tethyan-HHC contact is clearly seen to be a detachment, in that it is marked by a granitic footwall with a strong postmagmatic S-C fabric. The main high-strain fabric dips 10°–30° to the north or northwest, with stretching lineation oriented toward 350°. Kinematic structures record a clear top-to-north sense of shear. Structurally below are discrete S-C mylonitic horizons tens of meters thick. These horizons are less steep than the main contact but also display a north-south stretching lineation and a top-to-north sense of shear.

The kinematics of the structures here in the Khula Kangri summit section, on both the main contact and the underlying shear zones, are consistent with the Gonto La detachment footwall, where top-to-north shear sense granite mylonite fabric dips ~10° to the north and stretching lineations plunge ~10° toward 350° (Edwards et al. 1996). We note, however, that our new data from the Khula Kangri summit section allows us to constrain a gradual west-east steepening of the northward dip of the detachment.

In the southern part of the Khula Kangri summit section, where granite intrudes Tethyan rocks, the detachment position is above the granite and "intra-Tethyan." This reopens the "Palaeozoic problem" (see also Burchfiel et al. 1992; Edwards et al. 1996), i.e., the apparent absence of several kilometers of the Palaeozoic part of the Tethyan column. We do not rediscuss the issue here.

Interpolation of the detachment contact between our outcrop observations using TM allows the detachment to be traced east of the Khula Kangri summit section, where the main surface of the detachment can be recognized from topography in the vicinity of and, hence, between the mapped areas. These new data and interpolation indicates that the west-east steepening of detachment surface progressively continues to location *A* (fig. 3), where it dips ~35° N.

At location *B* (fig. 3), an exposed section of the STDS top-to-north high strain fabric in the HHC is truncated by the Dzong Chu Fault, which locally dips ~40° to the north (location *B*, fig. 3).

Lhozang–La Kang Section. Along the Lhozag–La Kang section (fig. 4*C*; originally mapped by Burchfiel et al. 1992), the easternmost parts of the two ranges are exposed. In this section, the Tethyan sedimentary rocks of the Chatang Valley (mostly dark phyllites) are observed to form a broad synform between the two crystalline belts. Within the N-dipping dark phyllites in the La Kang area, the main stretching lineation plunges 5°–20° toward 020°–030°, exhibits a clear top-to-NNE (normal) sense of displacement, and was termed "L2" by Burchfiel et al. (1992). The phyllites are structurally above the Monlakarchung-Passalum leucogranite, and the contact is a N-dipping surface that seems to be associated with a garnet isograd mapped in the overlying phyllites (Burchfiel et al. 1992). However, horizons of mylonite, tens of meters thick and notably parallel to the upper contact of the granite body, are found in the upper part of the granite. As in Khula Kangri summit section, shear-related lineation plunges north-northwest. Burchfiel et al. (1992) report lineation measurements plunging 5°–25° toward 315°–340°; shear sense is top-to-north. This lineation set postdates the NE-plunging L2 lineations in the overlying metasedimentary rocks. The regional contact between the granite and the Tethyan rocks is regarded by Burchfiel et al. (1992) as a major detachment, and we note that, with the exception of the earlier NNE–directed lineation, the structure of the upper contact Monlakarchung-Passalum pluton is similar to that of the Khula Kangri pluton.

In the northern half of this eastern section, the Tethyan-crystalline contact across the Khula Kangri Range is more complex. On the southern flank of the Khula Kangri Range, where the Chatang Valley Tethyan rocks structurally overlie HHC, a detachment has not been described. However, based on the observed large metamorphic contrast, previous researchers (Burchfiel et al. 1992; Edwards et al. 1996) inferred a detachment to be located here. This contact is recognizable on the TM image, and it can be traced around the western end of the dark rocks of the Chatang synform (fig. 3). Where the Lhozag–La Kang section of Burchfiel et al. (1992) crosses the southern flank of the Khula Kangri Range, a handful of E-W-trending steep normal faults are present. The faults can be recognized on the TM by color contrast and on topographic imagery by hypsometry variation. Integration of these criteria allows us to recognize steep south-dipping faults all along the southern flank of the Khula Kangri Range. We interpret these as extensional faults similar to, and part of, a suite that includes the south-dipping faults of the Lhozag–La Kang section (Burchfiel et al. 1992).

On the northern flank of the Khula Kangri Range in this Lhozag–La Kang section, the detachment is apparently not seen, and the granite-Tethyan contact is intrusive. Near Lhozag, ~600 m north of the granite intrusive contact, the fault at location *C* (fig. 3) must represent the map trace of the final STDS (discussed in Edwards et al. 1996).

Interpretation of Mechanisms

We interpret the two Himalayan ranges as being originally joined as one. The fold wavelength that culminates in the main Chatang synform is observed to increase from west to east (fig. 4*A*–*C*). This overall mechanism has caused kilometric wavelength, low-amplitude bending of the detachment surface and accompanying offset on steep normal faults, whose respective amplitude and assumed net displacement show an overall increase from west to east. In our model, the apparently buckled STDS is therefore not a product of any significant north-south shortening that is younger than STDS extension but is a product of local flexure and faulting. A fold and fault retrodeformation across the two ranges (with unbending of the detachment and removal of fault displacement) restores the two ranges to a single, more typical Himalayan range where HHC gneisses are intruded by various leucogranite bodies and cut by a single, continuous, gently N-dipping STDS detachment surface. The two plutons are therefore not regarded as anomalous insofar as Himalayan batholiths are often described as subhorizontal lenses of a few kilometers thickness, formed by coalesced leucogranite dikes (e.g., Scaillet et al. 1995). Although the surface area of the two plutons is apparently large, the mean thickness of each body is but a few kilometers.

The NNE–plunging lineation that predates the NNW–plunging lineation at La Kang is not seen anywhere else in the Khula Kangri and Kang Pünzum-Monlakarchung areas (however, see "Wagye La" descriptions in Burchfiel et al. 1992), although Edwards et al. (1996) discussed linking the La Kang earlier NNE–plunging suite of lineations with their early (preplutonism) detachment at Gonto La. If the NNE–plunging lineation set is restricted to the La Kang area and yet represents a large displacement, there could be a significant local modification to the overall magnitude of normal fault throw.

It is noteworthy that the surface trace of the STDS (and Tethyan/HHC contact) forms a tight meander that defines a major "Z-bend" in the area of the two ranges. This is highly unusual when viewed in context with the overall orogen, where the STDS trace along the high Himalaya rarely departs from a generally planar surface (discounting north-south normal fault offsets; e.g., Dingye or Yadong Cross Structure; Burchfiel et al. 1992). The only other example of such a meander is near Ghurla Mandhata/Api (Gansser 1964; Murphy et al. 1997).

Conclusion

Our integrated mapping interpretation of topographic and TM data and reexamination of Gansser (1983) data allows us to identify and interpret the following hitherto unrecognized features: (1) There is an eastward bifurcation in the crest of high peaks that results in a geomorphological and coincident geological repetition in this part of the High Himalaya. (2) The lithology, metamorphic contrasts, nature of plutonism, and structural evolution of both ranges are similar. (3) These similarities are a result of eastward increasing kilometric scale flexure and fault offset of a previous single "parent" range younger than the regional north-south extension that formed the STDS detachment; the two ranges can be restored to the familiar High Himalayan sequence. (4) The map view repetition is not caused by post-STDS regional north-south shortening that imbricates the upper Himalayan section; a continuous STDS surface exists across both ranges, the map trace of which forms a large Z-bend; and there is no structural repetition.

ACKNOWLEDGMENTS

Fieldwork by M. A. Edwards and W. S. F. Kidd, Thematic Mapper imagery, and archiving supported by National Science Foundation grants to Project INDPETH. Fieldwork conducted by A. Pêcher was part of a 1992 French Alpine Club expedition to Khula Kangri. Fieldwork conducted by B. C. Burchfiel and L. H. Royden was the 1989 portion of a project funded under an NSF grant. We thank Mike Searle, Djordje Grujic, and Jean-Pierre Burg for reviews. A belated thanks to Marin Clark for producing the topo maps.

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