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The Eastern prolongation of the Zanskar Shear Zone (Western Himalaya)

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Key words: Himalayan tectonics, nappe tectonics, synorogenic extension, shear zone, normal faults, backfolds.

ABSTRACT

This paper aims to describe the possible SE extension of the Zanskar Shear Zone and its relation with other extensional and compressional structures. New structural and metamorphic data were collected in the Baralacha La, Yunam, Lingti region and a new geologic map of the studied area is proposed.

The new data reveal that an E-verging syncline (the Kenlung Serai fold), formerly interpreted as a late backfold is, in fact, related to an early northward underthrusting of India below Asia before the main NE movement related to nappes emplacement. This succession of movements is coherent with the displacement of India postulated by several authors from paleomagnetic data.

The well defined Zanskar Shear Zone can be followed towards the SE in a zone of low angle normal faults (the Tapachan normal fault zone) located at the front of the North Himalayan nappes. The change in style from a ductile shear zone to a set of low angle normal faults is related to a change of tectonic level and metamorphic grade. The location of these extensional structures at the front of the North Himalayan nappes as well as their tectonometamorphic history is totally similar to what is known farther NW for the Zanskar Shear Zone.

High angle normal faults such as the Sarchu faults are late structures related to vertical extrusion accommodated by doming. Late NE-verging backfolds develop mainly in the hanging wall of the high angle normal faults and are therefore associated with the doming event.

The new data are incorporated into a kinematic model for the "Crystalline nappe".

RESUME

Cet article décrit le prolongement vers le SE de la Zone de Cisaillement du Zanskar ainsi que ses relations avec d'autres structures en extension ou en compression. De nouvelles données structurales et métamorphiques provenant du secteur du Baralacha La, de la vallée de la Yunam et de celle de la Lingti ont été récoltées. Une nouvelle carte géologique pour la région en question est proposée.

Les nouvelles données montrent qu'un grand pli synclinal à vergence Est (le pli de Kenlung Serai), précédemment interprété comme un rétropli tardif, est en fait un pli précoce formé lors du sous-charriage vers le Nord de l'Inde sous l'Asie. Il est antérieur aux structures liées à la mise en place des nappes du Nord Himalaya vers le SW. Cette succession de mouvements est cohérente avec le déplacement de l'Inde mise en évidence par de nombreux auteurs grâce à des études paléomagnétiques.

La Zone de Cisaillement du Zanskar peut se suivre vers le SE dans une zone de failles normales à faible pendage qui affleurent dans le secteur de Tapachan. Cette zone de failles normales est située au front des nappes du Nord Himalaya dans le secteur du Baralacha La. Le passage d'une zone de cisaillement ductile à un ensemble de failles normales à faible pendage s'explique par le changement de niveau tectonique et le degré plus faible du métamorphisme. La localisation des structures en extension au front des nappes Nord Himalayenne ainsi que leur histoire tectonométamorphique est similaire à celle connue pour la Zone de Cisaillement du Zanskar décrite plus au NW.

Les failles normales à fort pendage, comme la faille de Sarchu, sont des structures plus tardives, principalement liées à l'extrusion verticale contemporaines de la formation de dômes. Des rétroplis tardifs à vergence NE se forment principalement au toit de ces failles normales et sont donc associés aussi à la phase de formation des dômes.

Ces nouvelles données sont intégrées à un modèle cinématique de la mise en place de la « Nappe Cristalline ».

Introduction

In the Himalayan continental collision range, several geologists such as Caby et al. (1983), Burg & Cheng (1984), Burchfield & Royden (1985), Herren (1985, 1987) or Searle (1986) demonstrated that major extensional structures were active contemporaneously with shortening and crustal thickening. "South Tibetan -" or "North Himalayan detachment" are names proposed respectively by Burchfiel & Royden (1985) and Pêcher (1991) for these extensional fault zones. Due to their location in the middle of the Himalayan range, we propose to use "Central Himalayan Detachment zone" as a general name for this type of structures.

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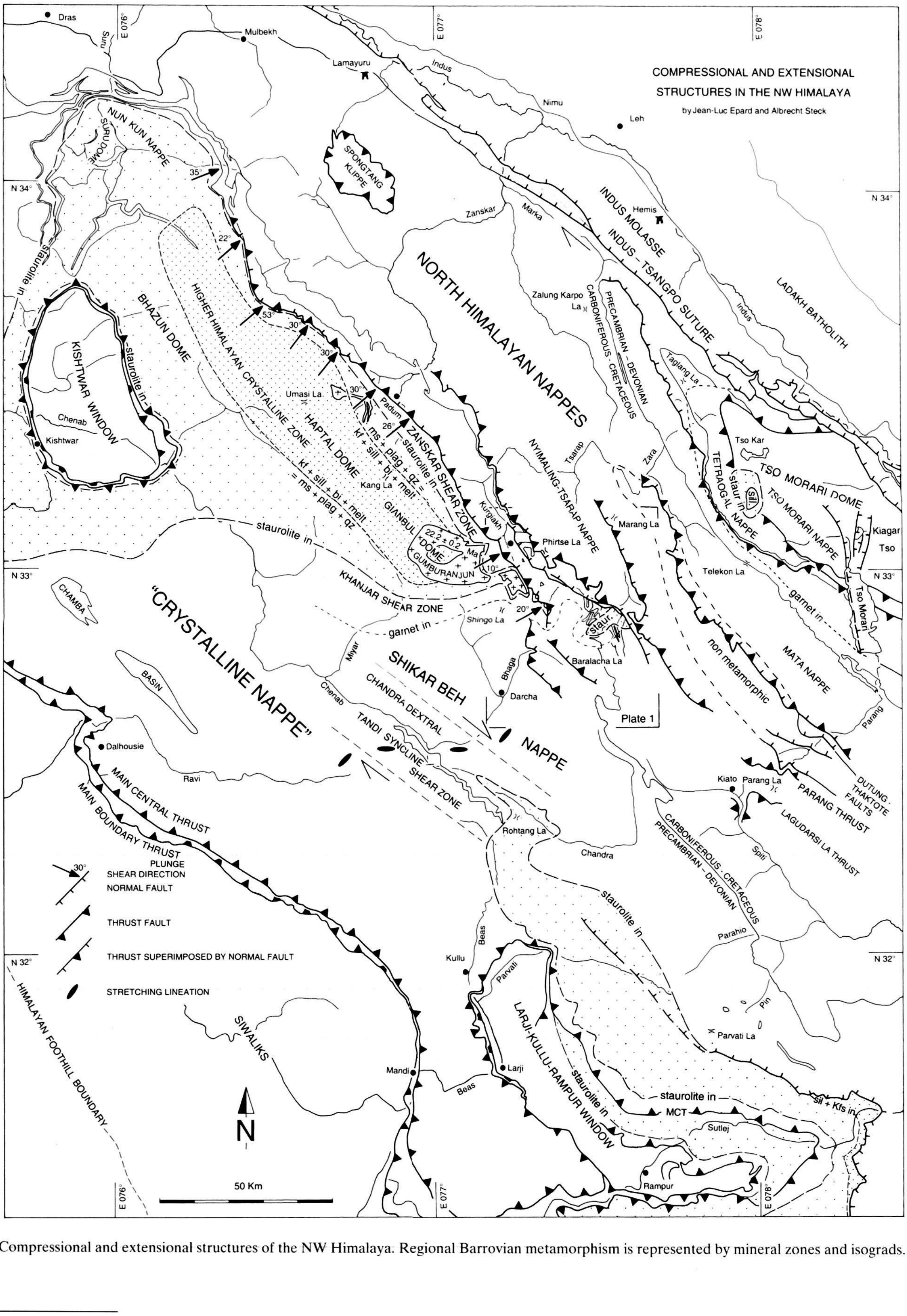


Fig. 1. Compressional and extensional structures of the NW Himalaya. Regional Barrovian metamorphism is represented by mineral zones and isograds.

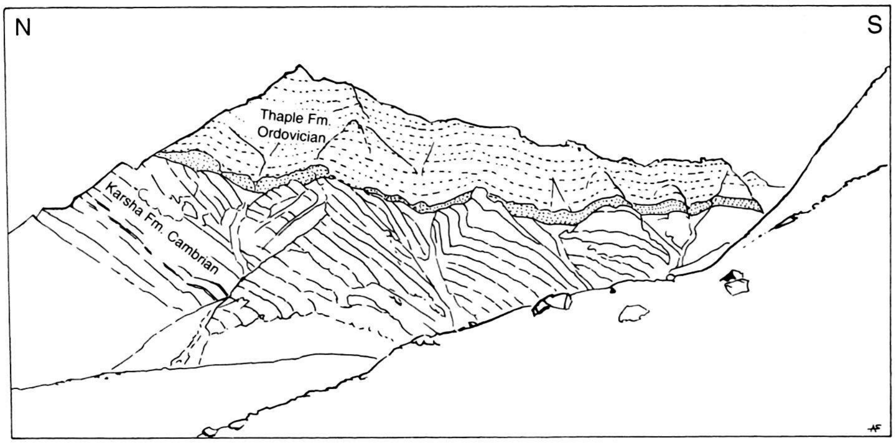


Fig. 2. Angular unconformity between the Cambrian Karsha and Ordovician Thaple formations in the upper Kamirup valley. The tilting of bedding in the Karsha formation is interpreted as related to synsedimentary normal faulting and block rotation during the deposition of the Thaple formation (Spring 1993).

In the north-western part of the Himalaya, the ductile normal Zanskar Shear Zone (Fig. 1) is one of this type of structure. It has been interpreted for the first time as a synorogenic extensional fault by Herren (1985, 1987), Gilbert (1986) and Searle (1986). This ductile Zanskar Shear Zone is responsible for the narrowing of the biotite and sillimanite isograds from an original distance of about 12 km to only 500m along the northern border of the Higher Himalayan Crystalline. This ductile shear zone represents the transition between the high grade metamorphic rocks of the Higher Himalayan Crystalline zone to the south and very low grade to non metamorphic sediments of the SW-verging North Himalayan nappes to the north. This extensional shear zone may be followed from the Suru valley to the west to the upper Kurgiakh valley to the east (Fig. 1). At Kurgiakh, the formation of the ductile structures has started at a depth greater than 25 km, as indicated by the maximum pressure of 10-12 kbar and temperature of about 750 °C measured on pre-existing mineral assemblages, by reactivation of the frontal SW-verging thrust faults of the Nyimaling-Tsarap nappe stack (Dèzes et al. 1999). Based on a geometric model, the displacement along the Zanskar Shear Zone has been estimated at about 35 ± 9 km by Dèzes (1999) and Dèzes et al. (1999). The age of the Zanskar Shear Zone is constrained by the synextensional intrusion of the Gumburanjun leucogranite dykes dated at 22.2 ± 0.2 Ma (U-Pb monazite age, Dèzes et al., 1999). The main ductile shearing occurred before 19.8 Ma as indicated by ^{40}Ar-^{39}Ar cooling ages on muscovite (closure temperature, 450°C) (Dèzes et al. 1999). The extensional movements along the Zanskar Shear Zone are also contemporaneous with the exhumation of the Higher Himalayan Crystalline zone as indicated by a rapid isothermal pressure drop from 10-12 kbar to 3-4 kbar (Dèzes et al. 1999). This extension was broadly coeval with the main SW-directed thrusting of the "Crystalline nappe" along the Main Central Thrust (MCT) (~23 Ma ago, Frank et al. 1977, Hubbard & Harrison, 1989, Hodges et al. 1996). These data indicate that combined thrusting at the base, and extension at the top of the Higher Himalayan Crystalline Zone, assisted the exhumation of the high-grade metamorphic domain in the core of the Himalayan orogen.

Unlike the MCT, which seems to be very continuous all along the Himalaya, the ductile Zanskar Shear Zone was known only as far as in the Upper Kurgiakh valley and related to the outcropping of the amphibolite facies metamorphic rocks of the Higher Himalayan Crystalline Zone (Fig. 1). The continuation of the extensional structures towards the SE and the precise relationships between ductile and brittle structures were unclear (Spring 1993, Vannay 1993, Dèzes 1999, Walker et al. 1999, Searle et al. 1999).

The aim of this paper is to present new structural and metamorphic data related to the southeastern extension of the Zanskar Shear Zone, its relations with other compressional and extensional structures in the region between the Kurgiakh, Lingti, Yunam and upper Bhaga valleys. The significance of these extensional structures for the Himalayan tectonics will be discussed as well. This study is based also on the new geologic map presented on Plate 1.

Stratigraphy of the Higher Himalaya

The sedimentary rocks of the studied North Indian continental margin belong to a single stratigraphic sequence ranging from Late Precambrian to Eocene age. A synthetic stratigraphic section up to the Late Jurassic Spiti Shales is shown on Plate 1 and is partly based on the work of Hayden (1904), Gansser (1964), Stutz & Steck (1986), Stutz (1988), Garzanti et al. (1986), Bagati (1990), Gaetani et al. (1990), Gaetani & Garzanti (1991), Spring (1993), Vannay (1993), Frank et al. (1973, 1995), Srikantia & Bhargava (1998), Steck (2003).

The base of the stratigraphic section is formed by a monotonous pile of over 10 km of shallow water submarine graywackes known as the Haimantas or Phe Formation (Griesbach 1891, Frank et al. 1995). It is followed by the Cambrian Karsha Fm (Nanda & Singh 1977) that corresponds to some hundreds up to one thousand meters thick alternation of graywackes, similar to those found in the Phe Fm, with yellow

Tab. 1. Structural evolution of the Higher Himalaya

Structural evolution of the High Himalaya in the upper Kurgiakh, Lingti, Yunam, Bhaga valleys and Baralacha La region			
TECTONIC EVENT	PHASE	STRUCTURE	SYMBOLE
North Himalayan Nappes	1	SSE-directed Kenlung Serai thrust with E-verging folds	S1, L1, F1
	2	W - SW-directed and verging Nyimaling-Tsarap nappe	S2, L2, F2
			S3, L3, F3
Central Himalayan	3	NE-dipping Zanskar shear zone and Tapachan fault zone	NF4
Detachment	4	NE- and SW-dipping Tanso and Sarchu normal faults	NF5
"Backfolds"		NE-verging folds	F6
Dextral Transpression	5	dextral strike-slip movements, N-striking faults	

dolomites and, locally, gray marbles. The Karsha Fm is topped by the Middle to Late Cambrian Kurgiakh Fm, mainly formed by shales, siltstones and sandstones (Garzanti et al. 1986). The Precambrian and Cambrian sediments are also intruded by Ordovician calc-alkalic granites and basic dykes (Mehta 1977, Frank et al. 1995, Stutz & Thöni 1987, Girard & Bussy 1999). Some hundreds meters of red cross-bedded conglomerates and sandstones, interpreted as submarine fluvial deposits of proximal river fan sediments, represent the Ordovician Thaple Formation (Hayden 1904). Locally, in the upper Kamirup valley, the Thaple and Karsha-Kurgiakh formations are separated by a clear angular unconformity as illustrated on Figure 2. We interpret this angular unconformity as induced by block rotation related to synsedimentary normal faulting (Spring 1993) and not by a Late Cambrian compressive orogenic event. The Thaple Formation is followed by about one hundred meters of pure white quartzites of the Silurian - Devonian Muth Formation (Stoliczka 1865). These siliciclastic littoral sediments pass upward to 500 m of lagoonal marls, limestones, dolomites and evaporites, Middle Devonian to Tournaisian in age (Draganits et al. 2002): the Lipak Fm (Hayden 1904). These shallow water deposits are followed by some tens of meters of sandstones and conglomerates of the Late Carboniferous Po Formation (Hayden 1904) and by the Early Permian conglomerates of the Chumik Formation (Gaetani et al. 1990). Early Carboniferous to Early Permian extensional or transtensional movements preceding the opening of the Neotethys ocean are testified by the intrusion of synsedimentary intra-plate basaltic and granitic dykes (Vannay & Spring 1993). One of these dykes, the Yunam granitic dyke, outcropping in the Yunam valley upstream of Sarchu, has been dated at 284 ± 1My (U-Pb age, Spring et al. 1993a). The deposition of continental flood basalts (Permian Panjal Traps) with agglomerate and pillow lava structures precedes the opening and subsidence of the Neotethys ocean. A thick series of several hundreds, up to one thousand meters of Permian to Late Triassic marls and limestones represent the deepening of the Neotethys margin. It is followed by up to 1000 m of Late Triassic to Liassic reef limestones and dolomites of the Kioto Formation (Hayden 1904) topped with some meters of brown sub-tidal Middle Jurassic ferrous oolites: the Laptal Beds (Heim & Gansser 1939). This formation is followed by the deposition of 100 – 200 meters of sandy marls of the Late Jurassic Spiti shales (Stoliczka 1865). These North-Indian upper-crust sediments are partitioned by NW-striking Ordovician, Carboniferous and Permian normal faults (Spring 1993, Vannay & Spring 1993, Steck et al. 1993).

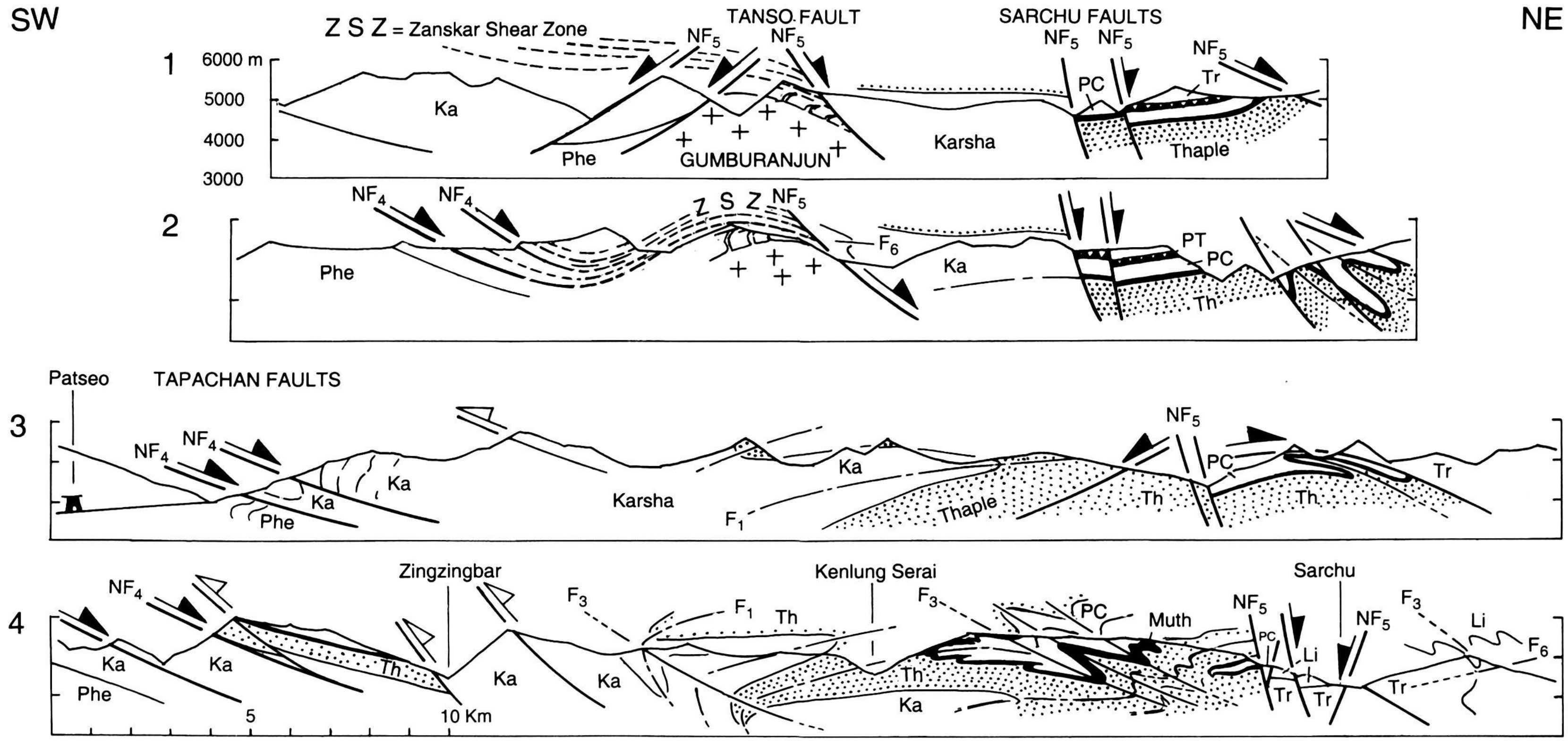
In the North-Indian passive margin of NW Himalaya, no unambiguous trace of a compressional orogenic event has been recorded in the stratigraphic series before the continental collision of India with Asia some 55-50 Ma ago (Bassoullet et al. 1984, Patriat & Achache 1984, Garzanti et al. 1987, Rowly 1996, De Sigoyer et al. 2000).

Tertiary deformation

The following section is a synthesis of our own observations and data collected by other authors in the area of the upper Kurgiak and Yunam valleys, the Baralacha La and the Chandra valley, as well as on the Tso Morari - Parang valley - Spiti transect (Spring & Crespo-Blanc 1992, Spring 1993, Vannay 1993, Vannay & Steck 1995, Dèzes 1999, Dèzes et al. 1999, Steck et al. 1993, 1998, Spring et al. 1993b). Structures related to a main structural event are brought together in a phase. The structural evolution we propose is summarized on Table 1.

Phase 1: The SSE-directed and E-verging Kenlung Serai fold F1

The isoclinal E-verging (or W-closing) Kenlung Serai fold is particularly well exposed at the left side of the Yunam valley, just downstream of Kenlung Serai (Plate 1, Fig. 3, 4, 5 of this paper and Fig. 8 in Baud et al. 1984). It is a syncline with Carboniferous black limestones of the Lipak Formation in its core. Its axial trend is roughly N-S. Due to its present day orientation and vergence, it was first interpreted as a late backfold (Spring & Crespo-Blanc, 1992, Spring 1993, Steck et al. 1993). However, this syncline is clearly overprinted by F3 folds related to the emplacement of the North Himalayan nappes (Fig. 5). Moreover, detailed structural work directly in the hinge of this fold shows that the axial plane foliation S1 and its associated extension lineation L1 are clearly early and superimposed by F3-S3 folds and schistosity. Well developed top to the S shear-sense criteria, observed in the porphyritic



Li = Liassic limestones
Tr = Triassic marls and limestones
PT = Panjal Traps
PC = Permo-Carboniferous sediments
Mu = Silurian-Devonian Muth quartzite
Th = Ordovician Thaple conglomerate
Ka = Cambrian Karsha graywackes
Phe = Precambrian-Cambrian Phe graywackes

Fig. 3. Geological sections through the investigated region. Position of the sections is given on Plate 1.

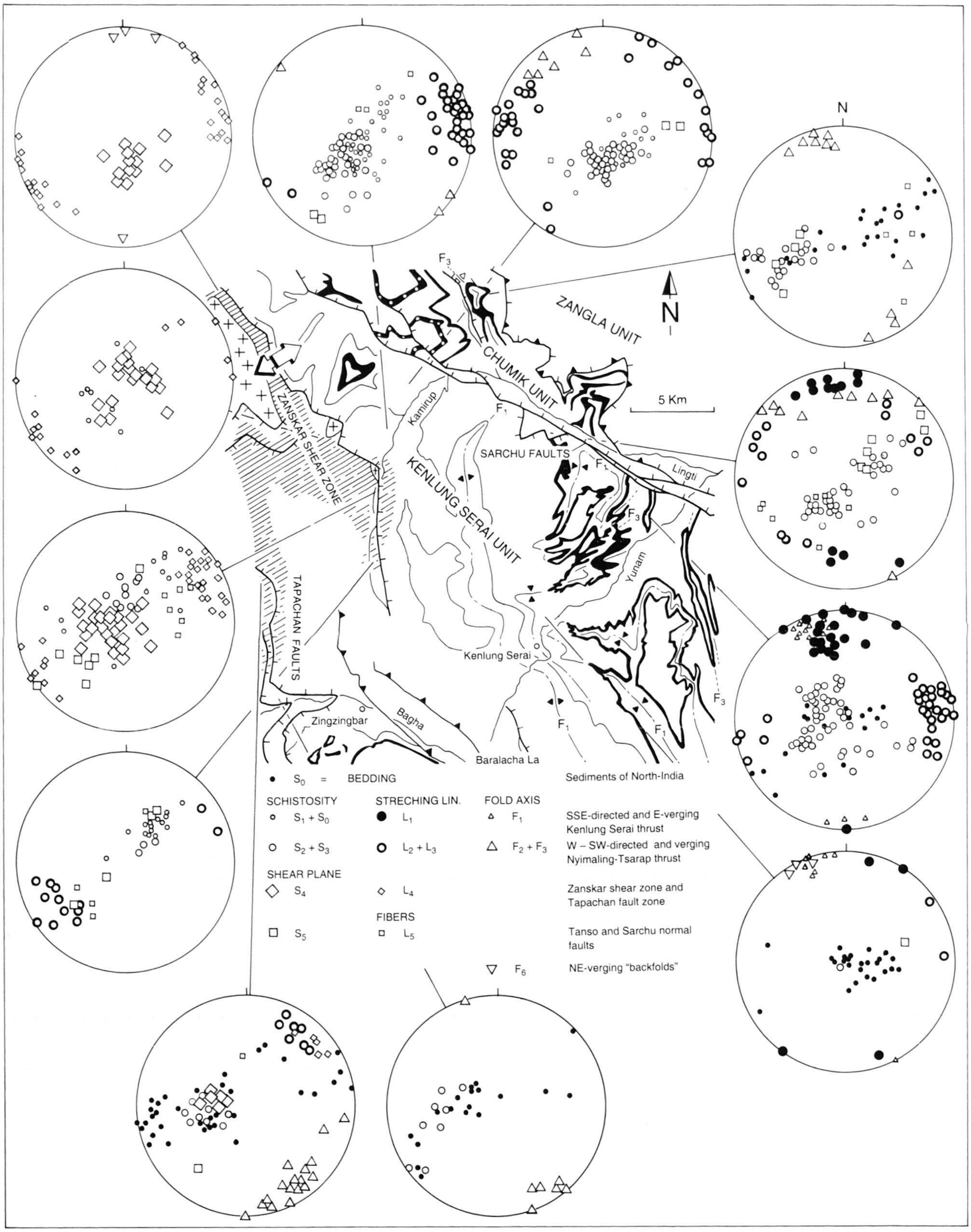


Fig. 4. Structural data from the investigated area (Lambert equal-area projection, lower hemisphere). Data from the SE part of the Zanskar shear zone are from Dèzes (1999).

Yunam granitic dyke, are associated with the L1 lineation and indicate that the Kenlung Serai fold has been formed during an early phase of southward thrusting. We suggest that the present day N-S trending orientation of the F1 fold axis is due to its transposition during the Phase 1 deformation. The succession of southward thrusting during phase 1 and southwest thrusting related to phase 2 is compatible with the movement of India deduced from paleomagnetic data (Patriat & Achache 1984; Klootwijk et al. 1985; Appel et al. 1995; Schill et al. 2001), indicating that the northward movement of India is followed, shortly after the first collision event, by an anticlockwise rotation of India leading to a NE-SW convergence with Asia.

This syncline is overlain by an E-vergent recumbent complementary anticline with Cambrian Karsha graywackes in its core (Plate 1 and sections 3 and 4 in Fig. 3).The top-to-the S shear-sense criterion, characteristic of S-vergent movement, allows us to clearly distinguish this first phase, from the early N-vergent deformation related to the Shikar Beh nappe observed southward and westward in the Tandi area or in the Miyar valley (Steck et al. 1993, 1999, Vannay & Steck 1995, Epard et al. 1995, Robyr et al. 2002).

Phase 2: W to SW verging North Himalayan nappes (Steck et al. 1993).

In the studied area, the North Himalayan nappes are represented by the Nyimaling-Tsarap nappe, an eastern equivalent of the Zanskar nappes of Bassoullet et al. (1983). It is described by Steck et al. (1993) as a stack of SW-directed imbricate thrust sheets related to SW-verging F_3 -folds (Figs 3, 4, 5 and 6).

Locally, for example in the upper Lingti valley, an older schistosity S2 can be observed, (Fig. 6). Bedding plane – schistosity cross-cutting relationships indicate that this structure is related to SW-verging movement. Usually, the early S_2-schistosity has been created without the development of associated F_2-folds and has been grouped together with the following F_3-S_3 structures under the same phase. The dominant SW-verging structures of the Nyimaling-Tsarap and the Mata nappes of the Tso Morari – Parang La transect are related to F_3-folds and to their S_3 schistosity (Plate 1, Figs. 3, 5 & 6). NE-dipping stretching lineations L_2 and L_3 and schistosities S_2 and S_3 (Fig. 4) have been formed by ductile deformation, detachment, folding and accretion of the upper Indian crust during its underthrusting below the Asian plate.

A Barrovian-type regional metamorphism is related to the overburden of the north Himalayan nappe stack (Zanskar, Nyimaling-Tsarap and Mata nappes (Fig. 1, Steck et al. 1993, 1998, De Sigoyer et al. 2000, Girard et al. 1999, Girard, 2001). The amphibolite facies grade rocks are now exposed in dome structures like in the Higher Himalayan Crystalline zone (Haptal dome), the Yunam valley and Tso Morari domes (Figs. 1 and 11). New data on metamorphism will be presented in a separate section.

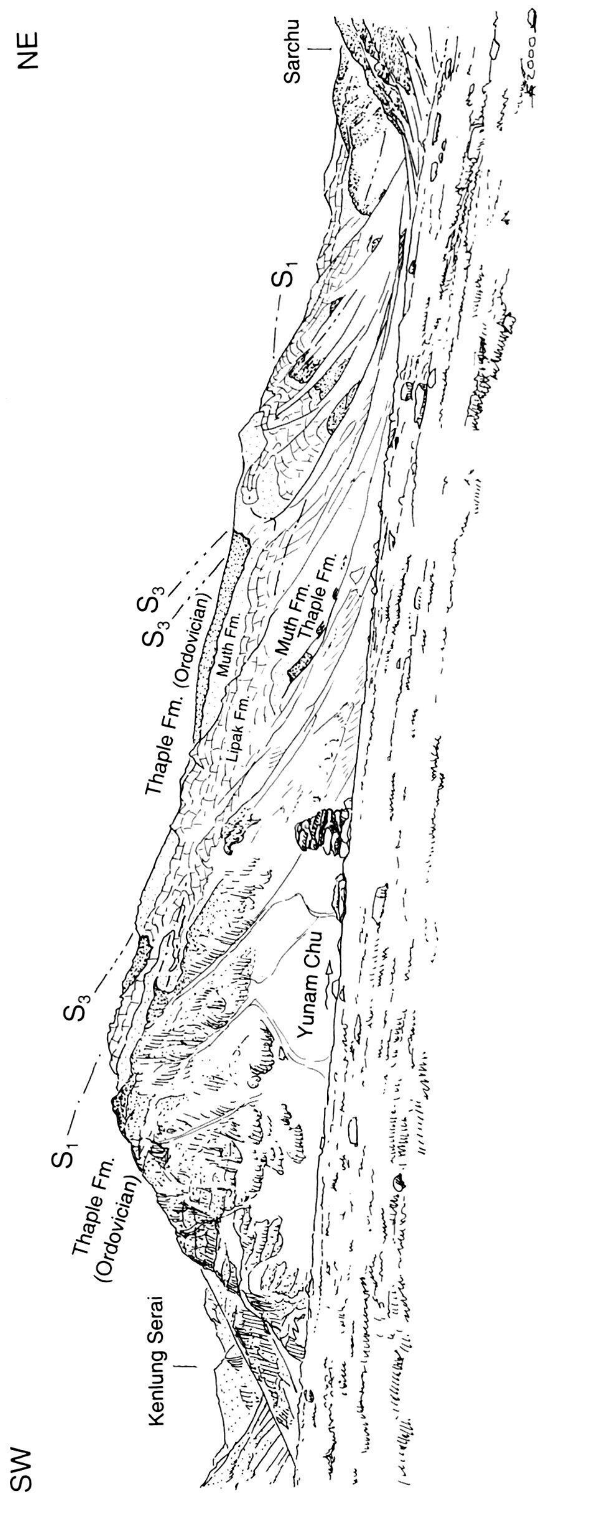


Fig. 5. F_1 – F_3 interference pattern exposed on the left side of the Yunam valley (Yunam chu) between Kenlung Serai and Sarchu.
The Early to Middle Carboniferous Lipak limestones and dolomites form the core of a huge W-closing isoclinal syncline. This oldest F_1-structure is refolded by the younger SW-verging F_3-folds related to the Nyimaling-Tsarap nappe front (see also Plate 1 and cross section 4 in Fig. 3).

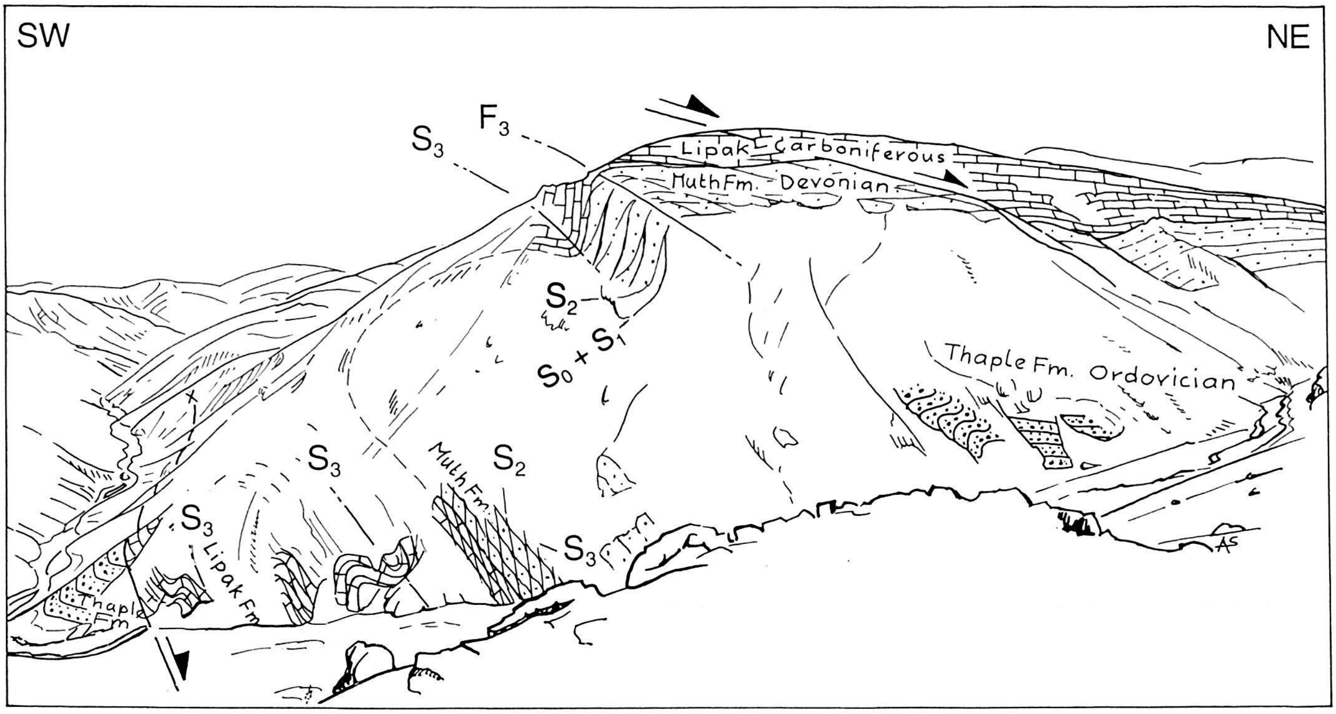


Fig. 6. SW-verging F_3-folds with a S_3-axial-surface schistosity in the front of the Zangla Thrust Sheet (Nyimaling-Tsarap nappe) in the upper Lingti valley. An older, SW-verging, S_2-schistosity is locally observed and is probably related to an early SW-directed stage of syn S_2 thrusting (cf. Steck et al. 1993). No folds related to this S2 schistosity have been observed. The F_3-fold is cut by younger NE-dipping normal faults NF5 associated to the Sarchu normal fault zone. This area corresponds to the NE end of section 2, Fig. 3.

Phase 3: The ductile Zanskar and Khanjar normal shear zones, the associated Higher Himalayan Crystalline zone (Haptal dome) and the Tapachan normal fault zone.

The Zanskar Shear Zone forms the zone of transition between the high grade metamorphic rocks of the Higher Himalayan Crystalline zone to the S and the low grade Tethyan sediments of the front of the Nyimaling-Tsarap nappe to the N. At the northeastern border of the Higher Himalayan Crystalline zone, the distance between the garnet, staurolite and kyanite isograds of the Barrovian regional metamorphism has been reduced to a width of about 500 m by deformation in the ductile normal Zanskar Shear Zone (Herren 1985, 1987, Gilbert 1986, Searle 1986). Pressure and temperature calculations by Dèzes et al. (1999) suggest that the original vertical distance was about 12 ± 3 km between these two isograds. The extension and formation of the Higher Himalayan Crystalline dome (Haptal dome) occurred under high temperature metamorphic conditions (Steck et al. 1999, Robyr 2002, Robyr et al. 2002).

Our new field data allows us to trace the extension of the Zanskar Shear Zone in the upper Kamirup valley. Its structural relationship with the Tertiary leucogranite intrusion (Gumburajun granite) and younger steep NE- and SW-dipping normal faults is illustrated in Fig. 3, sections 1 and 2 and in Fig. 7. Clear top to the NE shear-sense criteria, mainly σ-type objects and extensional boudinage can be observed in this shear zone. It has to be noted that, in our area, the thickness of the shear zone (a few hundreds meters) is significantly smaller than the 1km estimated by Dèzes et al. (1999) farther NW in the Kurgiakh valley.

The Bhaga valley axial depression, situated at the southeastern end of the Haptal-Gianbul dome, offers the opportunity to study in a presently horizontal, originally NW-dipping section, the change in the deformation style from a ductile high temperature deformation regime at a deep tectonic level (Higher Himalayan Crystalline zone) to the NW to a brittle environment in a higher tectonic level to the SE. Southeast of the Gumburanjun granite, the narrow ductile Zanskar Shear Zone passes to a low angle normal fault zone. This zone has been named the Tapachan fault zone after the name of a camping ground 5 km northward of Patseo in the upper Bhaga valley (Plate 1). The low angle normal faults partly reactivate preexisting frontal thrusts of the Nyimaling-Tsarap nappe in the Baralacha La and upper Chandra area (Plate 1, Figs. 3 and 8).

Similar low angle normal faults reactivate also some thrusts of other Nyimaling-Tsarap nappe units in the area between Sarchu and the Marang La (Spring 1993, Steck et al. 1993). To the E of the studied area, the Dutung-Taktote normal fault zone reactivates imbricate thrusts of the Mata nappe front (Steck et al. 1998, Girard et al. 1999, 2001). An estimation of

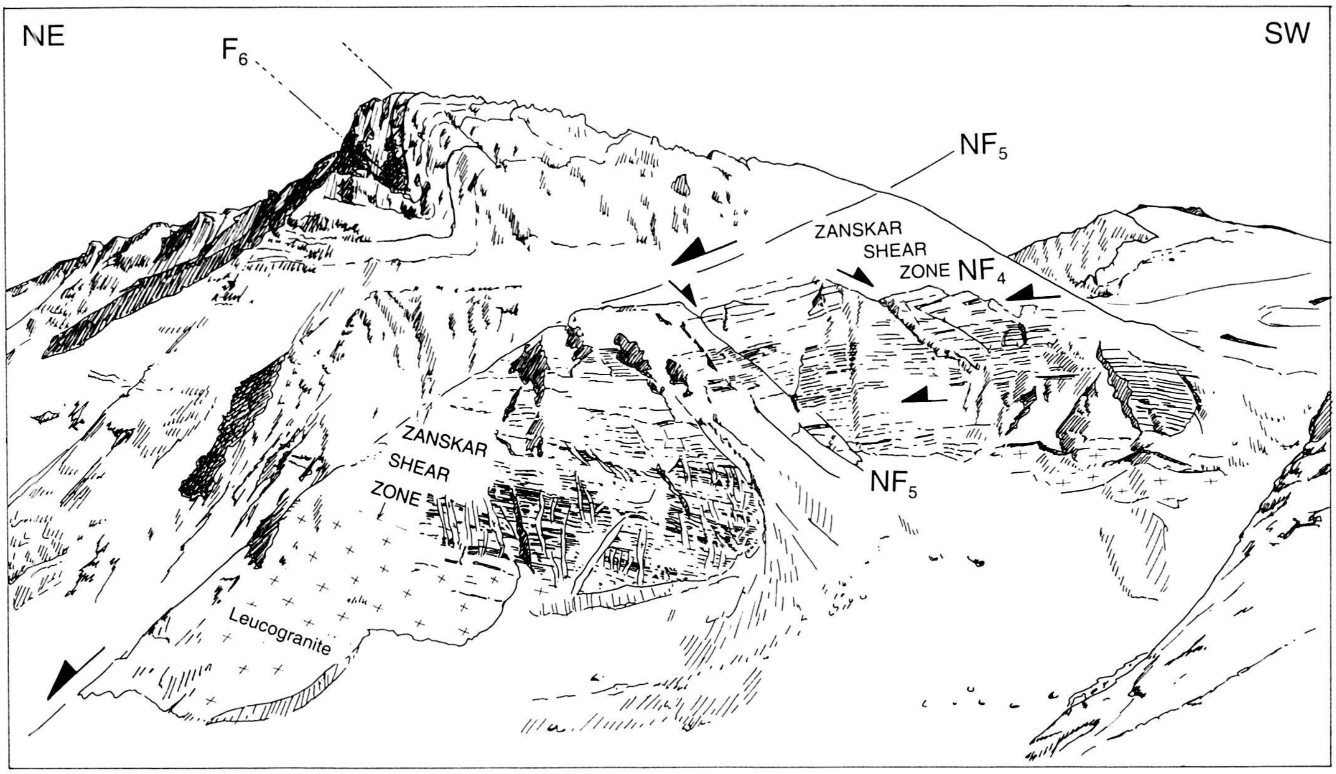


Fig. 7. Ductile extensional Zanskar Shear Zone NF_4 cut by two sets of conjugate normal faults NF_5 on top of the Tertiary leucogranite intrusion of the upper Kamirup valley. A NE-verging F_6-backfold has been created in the hanging wall (Cambrian Karsha Fm) of the NE-dipping main normal fault (difference in elevation of about 500m between the high summit and the bottom of the valley).

the total extension accommodated by these discrete normal faults is not possible due to the lack of good stratigraphic or metamorphic markers. These normal faults are not the direct extension of the Zanskar Shear Zone. However, we propose that their significance with respect to the Himalayan tectonics is equivalent.

The SW-dipping Khanjar Shear Zone in the upper Miyar valley is a normal shear zone at the SW-border of the Higher Himalayan Crystalline zone, in the roof of the "Crystalline nappe" (Steck et al. 1999, Robyr 2002, Robyr et al. 2002). Its chronological relation with the Zanskar Shear Zone is not clear. It could be a conjugate (contemporaneous) shear zone.

Phase 4: NE-dipping normal faults and conjugate SW-dipping faults and associated dome structures.

The Zanskar Shear Zone is cut by younger and steeper normal faults as the NE-dipping Tanso fault in the upper Kurgiakh valley (Plate1, Figs. 3, 4). In the Kamirup valley, the eastern extension of the Zanskar Shear Zone is also cut by a younger, NE-dipping, as well as by a conjugate SW-dipping high angle normal faults (Fig. 7). Similar, steep NE-dipping normal faults form the Sarchu fault zone along the Lingti valley, farther to the E (Figs. 3, 7 and 9). In this region, the pre-existing NE-dipping imbricate thrust faults of the Nyimaling-Tsarap and Mata nappe front are often followed by low angle extensional faults (phase 3) and cross-cut by younger steep NE-dipping normal faults of the Sarchu fault zone (phase 4). These faults are locally associated to conjugate SW-dipping normal faults (Figs. 3, 4, 7 and 9). These late faults have been formed under brittle, low grade metamorphic conditions at high tectonic levels. They accommodate not only an horizontal extension but also a significant amount of vertical movement.

These late brittle normal faults participate to the formation of late dome structures at the southeastern extension of the Gianbul dome.

NE-verging, so-called "backfolds" F_6.

In a late stage of the Himalayan deformation cycle, the frontal thrusts of the Nyimaling-Tsarap nappe are affected and overturned by NE-verging folds with a horizontal or SW-dipping axial surface considered as "back-folding" (Fig. 10). These NE-verging open folds are often developed in the hanging wall of high angle normal faults, but no clear cross cutting relationship can be observed. This type of situation can be observed to the N of the Sarchu fault (Lingti valley, Fig. 10) or in the upper Kamirup valley (Fig. 7). This association of back-folding and

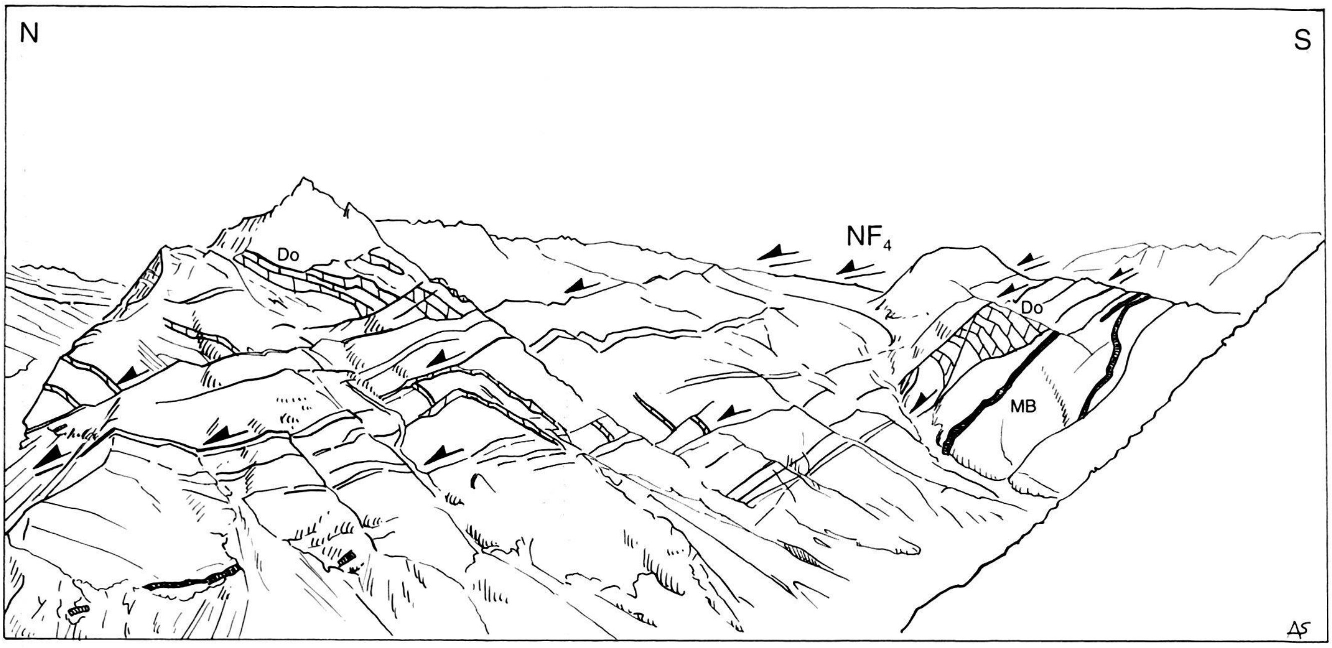


Fig. 8. The Tapachan normal fault zone: a zone of discrete and brittle extensional normal faults developed on older thrust faults of the Nyimaling-Tsarap nappe front. Carboniferous basaltic dykes (in black) are intruded in graywackes and dolomites of the Cambrian Karsha formation. Mountain side is about 1000 m high.

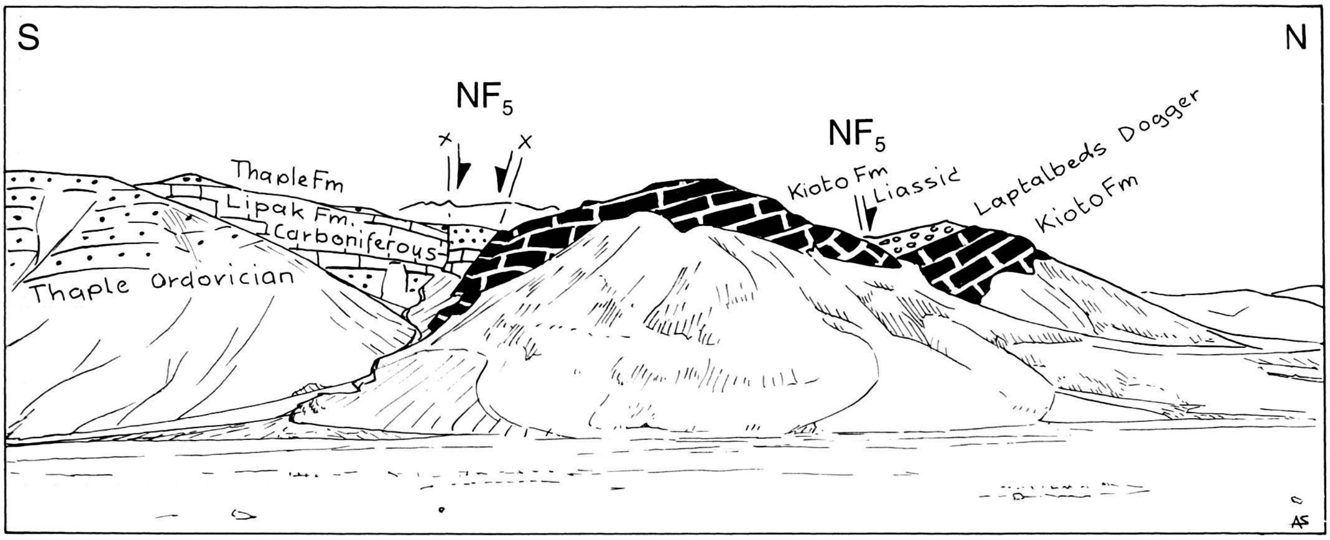


Fig. 9. Conjugate high-angle normal faults NF_5 of the Sarchu fault system exposed W of Sarchu at the confluence of the Yunam and Lingti valleys.

high angle normal faulting suggests a similar age and contemporaneous evolution of the two types of structure. It is therefore possible that some of these late backfolds have to be considered as detachment folds formed above a high angle normal fault acting as a detachment horizon. This deformation is responsible also for bringing in a vertical position the thrust faults and SW-verging F_3-folds in the Baralacha La area and upper Chandra valley (Plate 1; Fig. 24 in Steck et al. 1993) as well as for the back rotation of the Taktsi fold in the Kun Zam La region (Fig. 13 in Wyss et al. 1999).

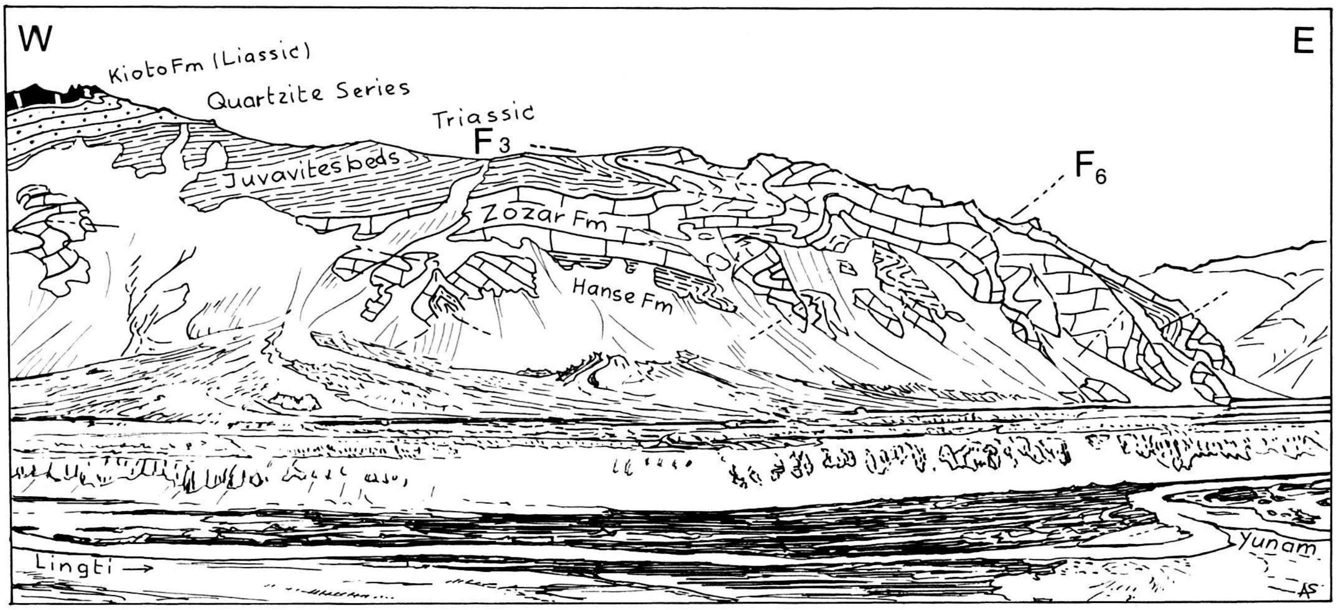


Fig. 10. SW-verging F_3-folds at the Zangla Thrust front (Nyimaling-Tsarap nappe), refolded by younger NE-verging F_6-folds. The outcrop is located N of the Lingti and W of the Yunam rivers near Sarchu in the hanging wall of the Sarchu faults (Fig. 9). The ridge is about 500-700m high. The area corresponds to the northeastern end of section 4, Fig. 3.

Phase 5: Diffuse zones of dextral strike-slip movements and N-S oriented graben structures.

Diffuse zones of dextral strike-slip movements are developed in the NW-oriented Chandra and Chenab valleys, the Chandra dextral shear zone (Vannay & Steck 1995) and in the steep zone along the Indus – Tsangpo Suture (Fig. 1, Stutz & Steck 1986). These late zones of dextral strike-slip and N-S oriented graben structures, as the Kiagar Tso and Tso Morari graben are probably related to the same phase of late and still active dextral transpression that affect the entire Himalayan range between the MCT and the Indus-Tsangpo Suture. This very late dextral transpression is perhaps also responsible for the large scale, E-W oriented, Chamba - Tandi – Bhaga - Tso Morari axial depression and for the formation of late axial culminations revealed by the Larji-Kullu-Rampur and Kishtwar windows (Fig. 1, Steck et al. 1993, 1998).

Metamorphism

In the studied area, three phases of metamorphic crystallisation may be distinguished:

- a contact metamorphism in metapelites in the vicinity of a mafic dyke intruded in contact of the Early Permian Yunam granite sheet;
- a prograde Barrovian type regional metamorphism generated by the formation of the Palaeocene – Eocene Nyimaling-Tsarap nappe stack and
- a retrograde metamorphic crystallisation associated with the Early Miocene Zanskar Shear Zone.

Contact metamorphism

A contact metamorphism related to the intrusion of the Early Permian Yunam granitic dyke can be locally observed. Lozenge shaped white mica pseudomorphs after chiastolite (andalusite) porphyroblasts with their characteristic graphitic inclusion crosses have been observed within a distance of a few decimetres from a mafic dyke related to the Yunam granite intrusion (Spring et al. 1993b).

Barrovian regional metamorphism related to the Palaeocene – Eocene Nyimaling-Tsarap nappe stack.

This prograde Barrovian metamorphism is associated with the overburden of the SW-directed Nyimaling-Tsarap nappe stack (Spring 1993, Spring et al. 1993b, Steck et al. 1993). The regional distribution of index minerals is illustrated on Figure 11. Our new data modifies and completes the metamorphic maps proposed by Spring (1993), Spring et al. (1993b), Vannay (1993), Steck et al. (1993), Dèzes (1999) and Dèzes et al. (1999).

The regional metamorphism of the Higher Himalayan Crystalline zone is only in its northern part produced by the North Himalayan nappe stack (Dèzes et al. 1999, Vance & Harris, 1999). In its central and southern part, the regional metamorphism is related to the NE-directed Shikar Beh nappe stack, which is also responsible for the metamorphism of the upper Kullu valley (Epard et al. 1995, Dèzes et al. 1999, Steck et al. 1999, Robyr et al. 2002).

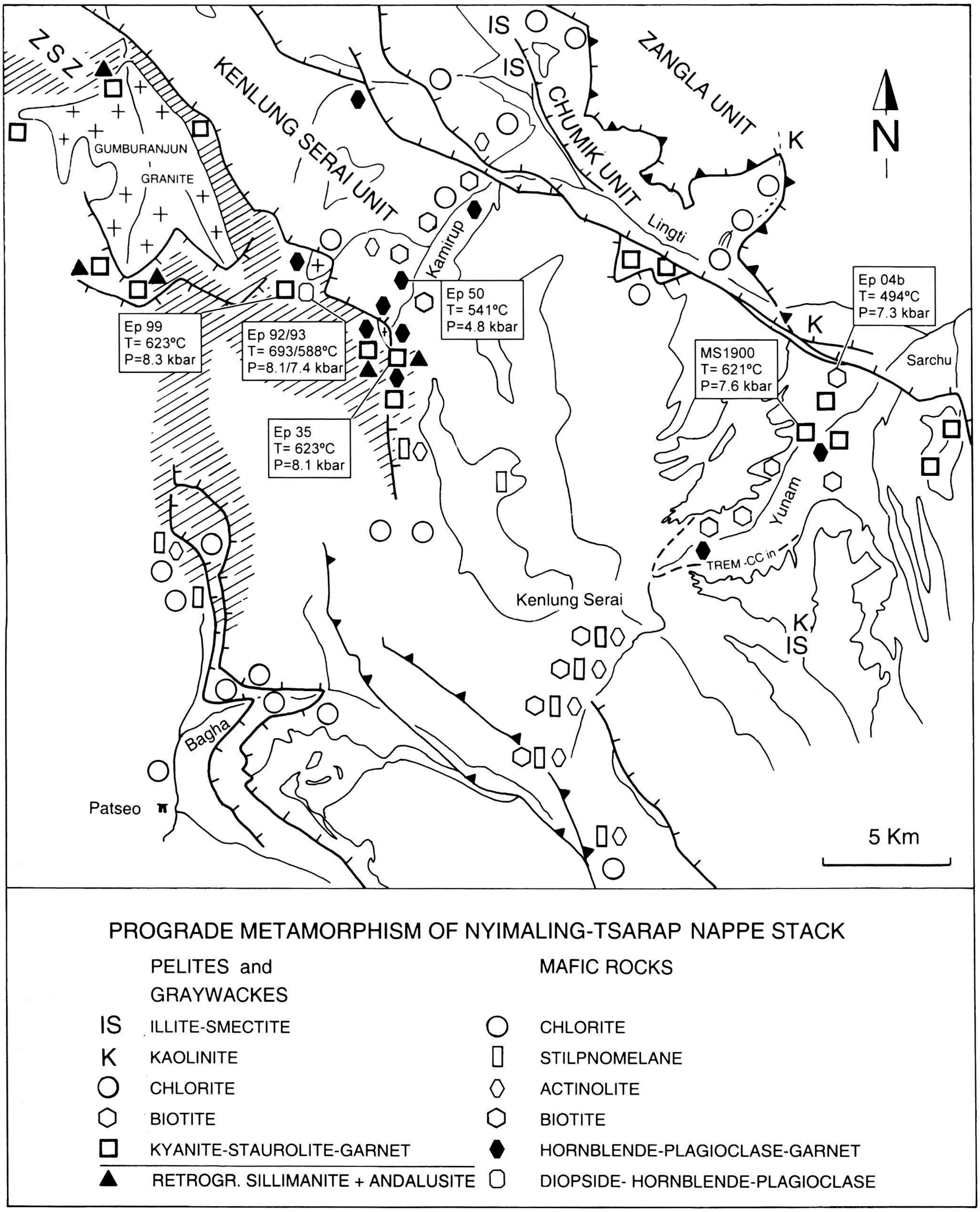


Fig. 11. Regional distribution of index minerals of the Barrovian metamorphism related to the Nyimaling-Tsarap nappe stack. Temperature and pressure estimates are obtained using the Thermocalc software (Powell & Holland, 1994).

Tab. 2. P-T estimates in the Kamirup-Lingti-Yunam area.
P and T calculated with THERMOCALC software (Powell and Holland, 1994). σT and σP are the overall uncertainties at 1σ confidence level; corr. Is the correlation between the uncertainties on T and P; n is the number of independent reactions; sigfit refers to a measure of the scatter in residuals of the enthalpies and activities normalized by their uncertainties.

Samples	Mineral assemblage	T [°C]	σT	P [kbar]	σP	corr.	sigfit	n
Ep 04b	gr, bi, mu, ma	**494**	62	**7,3**	1,5	-0,458	0,91	4
Ep35	gr, bi, pl, mu, std, ky	**623**	15	**8,1**	0,9	0,604	1,04	8
Ep 50	gr, bi, pl, hb	**541**	64	**4,8**	1,1	0,519	1,19	6
EP 92	gr, bi, pl, hb	**693**	78	**8,1**	1,2	0,633	1,25	7
Ep 93	gr, bi, pl, hb, diop	**588**	46	**7,4**	1,1	0,662	1,15	9
Ep 99	gr, bi, pl, mu, std, ky	**623**	14	**8,3**	0,8	0,605	0,82	8

The lowest grade of regional metamorphism is found in the Zingzingbar-Patseo area where an albite-epidote-chlorite-phengite ± calcite assemblage is observed in Early Carboniferous mafic dykes described by Vannay & Spring (1993) and Steck et al. (1993). In similar mafic rocks, along the Yunam valley section, the evolution from greenschist facies, in the Baralacha La area in the SW to amphibolite facies downstream Kenlung Serai is marked by the following mineral assemblages:

- albite-epidote-chlorite-phengite-stilpnomelane-actinolite±biotite;
- plagioclase-hornblende±biotite+chlorite.

In the Yunam valley, the beginning of the amphibolite facies is also demonstrated by the apparition of a tremolite-calcite association in siliceous dolomites of the Ordovician Thaple Formation. In pelitic rocks, a higher amphibolite facies grade is shown by a quartz-plagioclase-muscovite-biotite-staurolite-kyanite ± garnet association, a few kilometres southward of the Sarchu fault zone. The highest metamorphic grade in the studied area is indicated by the association of plagioclase-hornblende-diopside-biotite-garnet-titanite in a mafic layer of the upper Kamirup valley.

In addition, microprobe data were collected on specific samples in order to estimate the pressure-temperature conditions. The main results are summarized in Table 2 and Fig. 11. Characteristic compositions of minerals are given in Appendix.

Sample Ep04b is from the Yunam valley, in the footwall of the Sarchu normal fault zone. It was collected close to other sample with a garnet, biotite, staurolite, kyanite mineral assemblage, typical for amphibolite grade metapelitic rocks. It contains an infrequent association of garnet, biotite, muscovite and margarite. The temperature estimate for this sample (~500 °C) roughly at the limit between greenschist and amphibolite facies corresponds to the northern limit of the small window of amphibolite facies rocks in the Yunam valley (Fig. 1) as revealed by kyanite-staurolite-garnet bearing rocks (Fig. 11) and confirmed by thermobarometric data (sample MS1900, Schlup, pers. com.).

Samples Ep35, 92, 93 and 99 were collected in the Zanskar Shear Zone or in its footwall in the upper Kamirup valley. The P and T estimates for these samples are the highest and are compatible with the mineral assemblages. Sample Ep50 was collected a few kilometres downstream in the Kamirup, in the hanging wall of the Zanskar Shear Zone. The decrease in P and T with respect to the four previous samples is the confirmation that the Zanskar Shear Zone extends towards the SE into the Kamirup by strongly influencing the geometry of the metamorphic limits. The influence of this structure is also revealed by retrograde mineralogical assemblages as described in the following section.

The regional Barrovian metamorphism of the North Himalayan Nappe stack has been studied in the Tso Morari dome by Girard (2001) and dated at 47-45 Ma by De Sigoyer et al. (2000). In the Suru area, rotated garnets related to this metamorphism, give younger Sm-Nd ages of 33 Ma (Vance & Harris, 1999).

Early Miocene retrograde metamorphism related to the Zanskar Shear Zone.

In the studied area, the metamorphic zones are cross-cut by the Tertiary Gumburanjun intrusion and its eastern extension exposed in the upper Kamirup valley. They have been deformed by late extensional structures of the Zanskar Shear Zone, the Tapachan faults and younger cross-cutting normal faults (Tanso and Sarchu faults). A pronounced retrograde crystallisation is related to the extensional shear structures of the Zanskar Shear Zone exposed on the right bank of the upper Kamirup. Kyanite and staurolite are partially replaced by pseudomorphs of white mica and some chlorite. Garnet and biotite are often transformed to chlorite. New blasts of andalusite crystallise together with fibrous sillimanite, the latter was formed at the expense of biotite. Some white mica and chlorite pseudomorphs may be formed after cordierite, a mineral of the decompression path that has been collected by Dèzes et al. (1999) in the upper Kurgiakh valley. The succession of kyanite – sillimanite – andalusite and cordierite suggests a retrograde metamorphism by tectonic decompression during the Zanskar Shear Zone extension, uplift and erosion. These observations of crystallisation during decompression, in a zone of top-to-the NE extensional shearing, similar to that described by Dèzes et al. (1999) in the upper Kurgiakh valley, confirm that a branch of the ductile Zanskar Shear Zone continues in the upper Kamirup valley. The presence of syn - kinematic high temperature mineral assemblages, with sillimanite and andalusite in the Zanskar Shear Zone suggests that these metamorphic rocks remained under high temperature conditions between the Eocene Nyimaling-Tsarap nappe emplacement and the cooling related to the Early Miocene "Crystalline nappe" extrusion.

Discussion

Nappe formation in the Western Himalaya

In the north-west Indian Himalaya, two distinct nappe systems may be distinguished along a transect between the MCT and the Indus-Tsangpo suture: the North Himalayan nappes and the "Crystalline nappe" or High Himalayan nappe (Steck 2003) including the early formed Shikar Beh nappe (Fig. 12).

The North Himalayan nappes of a Palaeocene – Eocene age occupy the northeastern part of the Himalayan range limited by the Indus-Tsangpo suture to the NE and their frontal thrusts to the SW. Two successive directions of thrusting are observed in the Yunam valley, in the frontal thrusts and folds of the Nyimaling-Tsarap nappe. During phase 1, the thrusting is directed towards the S and is parallel to a pronounced stretching lineation L_1 and to the axis of E-verging isoclinal folds F_1. These early folds are deformed by the main SW-verging F_2-F_3 folds associated with NE-SW oriented stretching lineations L_2-L_3 parallel to thrusting direction (phase 2). This succession of N-directed then NE-directed underthrusting of the Indian plate may be related to the movements of India during its collision with Asia (first northward followed by an anticlockwise rotation) as suggested by paleomagnetic studies (Patriat & Achache 1984, Klootwijk et al. 1985, Appel et al. 1995, Schill et al. 2001).

The Lower Miocene so-called "Crystalline nappe" forms the southwestern part of the Higher Himalaya and is limited by the Central Himalayan detachment zone to the NE and the Main Central Thrust to the SW. The Main Central Thrust is also outcropping in the Kishtwar and Larji-Kullu-Rampur windows allowing an estimation of at least 120 km for the movement along the MCT. The Central Himalayan detachment is represented by the Zanskar Shear Zone and corresponds, like the MCT, to a zone of strong shear strain. The directions of extrusion, extension in the roof and thrusting at the base of the "Crystalline nappe", are parallel (Fig. 1). Several mechanisms have been proposed to explain nappe extrusion in a context of continental collision: extrusion driven by buoyancy forces, extrusion of a wedge shaped body and combined single and pure shear deformation (Burchfiel & Royden 1985, Chemenda et al. 1995, 2000, Escher & Beaumont 1997, Grujic et al. 1996, Vannay & Grasemann 1998, Dèzes et al. 1999, Grasemann et al. 1999, Steck 2003). The Shikar Beh nappe is an important NE-directed early Himalayan nappe structure that has been integrated in the younger SW-directed "Crystalline nappe". The structures of the Shikar Beh nappe (Steck et al. 1993, Epard et al. 1995, Steck et al. 1998, 1999, Wyss et al. 1999, Robyr et al. 2002) are not present in the investigated area and for this reason are not discussed in this study.

The Zanskar Shear Zone and its south-east extension

The Zanskar Shear Zone represents the main extensional structure of the Central Himalayan extensional detachment zone of the NW Himalaya (Herren 1985, 1987, Searle 1986, Dèzes et al. 1999). It follows the pre-existing ductile thrust zone at the base of the North Himalayan nappes (Nyimaling-Tsarap and Zanskar nappes) (Fig. 12). It is therefore suggested that the presence of highly ductile metamorphic rocks at the base of the more rigid North Himalayan nappe stack favoured the formation of a zone of detachment on top of the extruding "Crystalline nappe".

Our data demonstrate that the Zanskar Shear Zone does not end in the Kurgiakh valley but continues in the upper Kamirup valley. From this point it is bent southward around the Gianbul dome (Plate 1 and Fig. 3) but it is not totally refolded by this late structure on the contrary of what was postulated by Dèzes (1999). Therefore the SW-dipping Miyar thrust zone on the southern side of the Gianbul dome is not the equivalent of the NE-dipping Zanskar normal shear zone on the northern side of the dome. Based on different arguments, Robyr (2002) and Robyr et al. (2002) came to the same conclusions. From the Kamirup, the Zanskar Shear Zone can be followed into a zone of low angle normal faults we have named the Tapachan normal fault zone, located in the front of the Nyimaling-Tsarap nappe. This fault zone corresponds to the southeastern extension of the Zanskar shear zone formed under a more brittle regime. Low angle normal faults that are parallel to, or reactivate pre-existing thrusts, are not restricted to the frontal part of the Nyimaling-Tsarap nappe, but can also be observed northward, up to the Marang La (Spring, 1993, Steck et al., 1993). On a transect SE of the Haptal-Gianbul dome, the extensional movement accommodated by the Central Himalayan detachment is distributed on numerous structures. Extensional movement along the Zanskar Shear Zone was estimated at about 35 km by Dèzes et al. (1999). Total extensional movement accommodated by the low-angle fault system, SE of the Haptal-Gianbul dome is difficult to estimate but could be of the same order.

Vertical movement associated to normal faults

The phase of low angle normal faulting is followed by a phase of high angle normal faulting. The Tanso and Sarchu normal faults are two examples of this type of structure. It implies that the low angle normal faulting and shearing that accommodate mainly an horizontal extension related to the "Crystalline nappe" extrusion, is followed by high angle normal faulting that accommodate also a significant amount of vertical movement related to doming. This doming event can be related to a late step of nappe extrusion. In our opinion, the position of the Haptal dome and its SE-extension, the Gianbul dome, is mainly controlled by the tectonic unroofing due to the extension along the Zanskar shear zone, allowing a vertical uplift of the ductile rocks of the internal part of the "Crystalline nappe" at the front of the overlying North Himalayan nappes (Fig. 12).

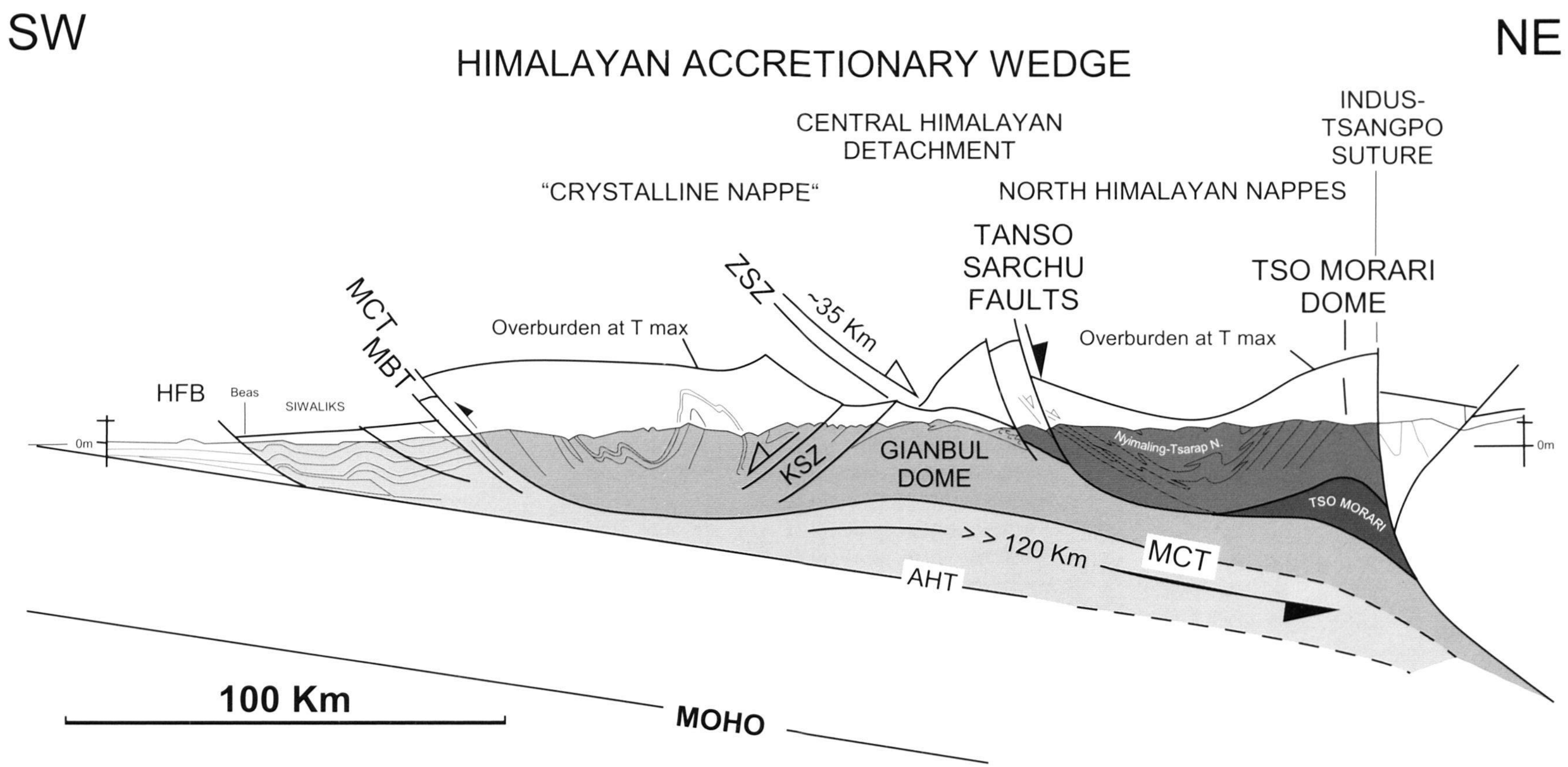


Fig. 12. General section of the Himalyan range from the frontal thrusts to the Indus-Tsangpo suture (Himachal Pradesch – Kashmir area). Central Himalayan Detachment includes the Zanskar Shear Zone (ZSZ), the Tanso and Sarchu high angle normal fault zones. Position of the Gianbul dome (SE extension of the Haptal dome) at the front of the Nyimaling-Tsarap nappe is related to the unroofing of ductile metamorphic rocks of the Crystalline Nappe by the Zanskar Shear Zone. The ductile Khanjar Shear Zone (KZS) is also related to doming. Position of the Moho is projected from the Bhutan area (Hauck et al. 1998). Section at depth is speculative.
HFB: Himalayan Frontal Boundary; MBT: Main Boundary Thrust; MCT: Main Central Thrust; AHT: Active Himalayan Thrust.

Kinematics of the "Crystalline nappe" emplacement and dome formation

The new data presented in this paper can help to better constrain part of the complex kinematics of the "Crystalline nappe" that can be summarized as follows.

- Underthrusting of the external domain (Lesser Himalaya) along the MCT. The initiation of movement along the MCT is not well constrained. We propose that the first movement along the MCT immediately follows the Eocene North Himalayan nappes formation (Schlup et al. 2003) and accommodates the ongoing convergence between India and Asia. This phase should be older than 21 Ma and can correspond to a jump from the underthrusting of the future "Crystalline nappe" domain under the North Himalayan nappe stack to a more external position around 30 Ma ago. This phase is driven mainly by subduction with no significant relief production and therefore it is not accompanied by molasse deposition.
- Extrusion of the "Crystalline nappe" accompanied by a significant relief formation and therefore by molasse deposition (Dharamsala and Murree formations, 21-13 Ma, DeCelles et al. 1998a, b, Najman & Garzanti 2000). The extrusion of the nappe is produced by internal deformation, movement along the Zanskar Shear Zone (22-19 Ma) and other low angle normal faults of the Central Himalayan Detachment zone, as well as thrusting along the MCT (24-19 Ma, cooling ages).
- Dome formation in the internal part of the "Crystalline nappe" (Haptal-Gianbul dome) limited by high angle normal faulting and shearing. The position of the dome is controlled by the exhumation of ductile metamorphic rocks at the front of the Nyimaling-Tsarap nappe. The SW directed extrusion of the "Crystalline nappe" is partly relayed by local vertical extrusion in the dome area. Movement on the MCT can continue during this phase.

Conclusion

Synorogenic extension is widely recognized in the recent literature as a key problem for the Himalayan tectonics. The precise description and location of the structures that accommodate the extension as well as their kinematic relationship with compressional structures are essential for the comprehension of the emplacement process and kinematics of the "Crystalline nappe" for example.

Our new data allows us to follow the Zanskar Shear Zone southeast in a zone of low-angle normal faults, the Tapachan normal faults, that reactivate in part the frontal thrusts of the Nyimaling-Tsarap nappe in the Baralacha La area. The Tapachan fault zone is therefore the more brittle equivalent of the ductile Zanskar Shear Zone. Low angle normal faults that reactivate, or are parallel to compressional structures can be found also N and E of the studied area (Fig. 1). Although they do not represent the direct extension of the Zanskar Shear Zone, their significance with respect to the Himalayan tectonics is probably similar. The importance of low angle normal faults has been probably underestimated because they could be difficult to detect without a detailed structural field study and the cumulative movement along these faults is hard to estimate due to the lack of good stratigraphic or metamorphic marker.

The high angle normal faults such as the Sarchu normal fault are clearly later structures as they crosscut the low angle normal shear zone or faults. They form conjugate sets and are not folded around the dome. They accommodate not only a horizontal extension but also a significant amount of vertical extrusion related to doming. Therefore, the extrusion of the "Crystalline nappe" is a combination of two types of movement. One is related to the a low angle extrusion towards the SW between the MCT and the Zanskar Shear Zone, the other is related to vertical extrusion due to doming accommodated in part by high angle conjugate normal faults or shear zones. The so-called backfolds (late NE-verging folds in the hanging wall of the normal faults) seem to be related to this later event. These backfolds have to be distinguished from other E or ENE verging folds such as the Kenlung Serai fold that are associated to an early N-directed underthrusting of India below Asia before the main SW-verging phase of the Nyimaling-Tsarap nappe emplacement.

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Appendix I

Temperature and pressure estimations were calculated using the THERMOCALC software (Powell & Holland 1994). Mineral analyses were performed on the Cameca SX50 microprobe of the "Institut de Minéralogie et Géochimie" of the Lausanne University. The following operating conditions were used: acceleration voltage of 15 kV and a beam current of 20 nA for garnet, 15 nA for biotite, muscovite, margarite, staurolite, plagioclase, hornblende and diopside. Representative analyses are given in the following tables.

EP 04b

	garnet	biotite	muscovite	margarite
SiO2	36.56	34.90	46.60	30.79
TiO2	0.05	1.54	0.33	0.11
Al2O3	20.27	18.78	35.11	49.06
Cr2O3	0.04	0.05	0.06	0.04
FeO	31.50	19.50	1.34	0.98
MnO	4.17	0.06	0.02	—
MgO	1.84	9.69	0.84	0.22
CaO	4.90	—	—	11.35
Na2O	—	0.10	0.57	1.43
K2O	—	9.48	9.95	0.07
Total	99.33	94.10	94.82	94.05

EP 92

	garnet	biotite	plagioclase	hornblende
SiO2	37.95	39.72	45.79	48.79
TiO2	0.07	0.82	—	0.20
Al2O3	20.88	14.57	33.66	6.77
Cr2O3	0.03	0.05	—	0.09
FeO	20.28	16.14	0.57	15.52
MnO	3.30	0.56	—	0.90
MgO	2.04	14.03	—	11.82
CaO	15.02	—	17.09	11.94
Na2O	—	0.06	1.31	0.77
K2O	—	9.43	0.46	0.51
Total	99.57	95.38	98.88	97.31

EP 35

	garnet	biotite	plagioclase	muscovite	staurolite
SiO2	36.97	35.90	62.39	46.68	28.84
TiO2	0.04	1.69	—	0.58	0.71
Al2O3	20.54	19.57	23.44	36.48	54.27
Cr2O3	0.05	0.07	—	0.03	0.05
FeO	30.53	17.36	0.12	0.84	11.95
MnO	4.82	0.24	—	0.02	0.42
MgO	3.19	10.58	—	0.63	1.80
CaO	3.59	—	4.72	0.01	—
Na2O	—	0.14	8.89	1.19	0.02
K2O	—	9.59	0.11	8.77	0.01
Total	99.73	95.14	99.67	95.23	98.07

EP 93

	garnet	biotite	plagioclase	hornblende	diopside
SiO2	37.84	37.85	44.89	44.68	52.13
TiO2	0.07	2.46	—	0.69	0.02
Al2O3	20.68	16.11	34.77	12.70	0.26
Cr2O3	0.06	0.07	—	0.02	0.04
FeO	20.17	18.48	0.12	15.65	12.89
MnO	3.33	0.46	—	0.57	1.14
MgO	1.24	11.29	—	9.71	9.76
CaO	16.32	—	17.85	11.81	23.59
Na2O	—	—	1.04	1.08	0.07
K2O	—	9.23	0.11	0.98	—
Total	99.71	95.95	98.78	97.89	99.9

EP 50

	garnet	biotite	plagioclase	hornblende
SiO2	37.12	35.90	48.46	46.49
TiO2	0.10	1.85	—	0.36
Al2O3	20.50	16.31	32.43	9.42
Cr2O3	0.04	0.08	—	0.08
FeO	27.05	19.82	0.11	16.15
MnO	5.71	0.27	—	0.65
MgO	1.91	11.03	—	10.54
CaO	7.46	—	15.35	12.11
Na2O	—	0.10	2.53	0.95
K2O	—	9.33	0.17	0.67
Total	99.89	94.69	99.05	97.42

EP 99

	garnet	biotite	plagioclase	muscovite	staurolite
SiO2	37.11	35.93	61.77	46.44	28.69
TiO2	0.05	1.60	—	0.48	0.61
Al2O3	20.47	19.18	23.89	36.39	54.12
Cr2O3	0.04	0.06	—	0.03	0.03
FeO	32.4	17.73	0.17	0.84	12.99
MnO	3.25	0.13	—	0.01	0.39
MgO	3.08	10.92	—	0.61	1.79
CaO	3.56	—	5.21	—	—
Na2O	—	0.18	8.65	1.45	—
K2O	—	9.27	0.09	8.81	0.02
Total	99.96	95.00	99.78	95.06	98.64

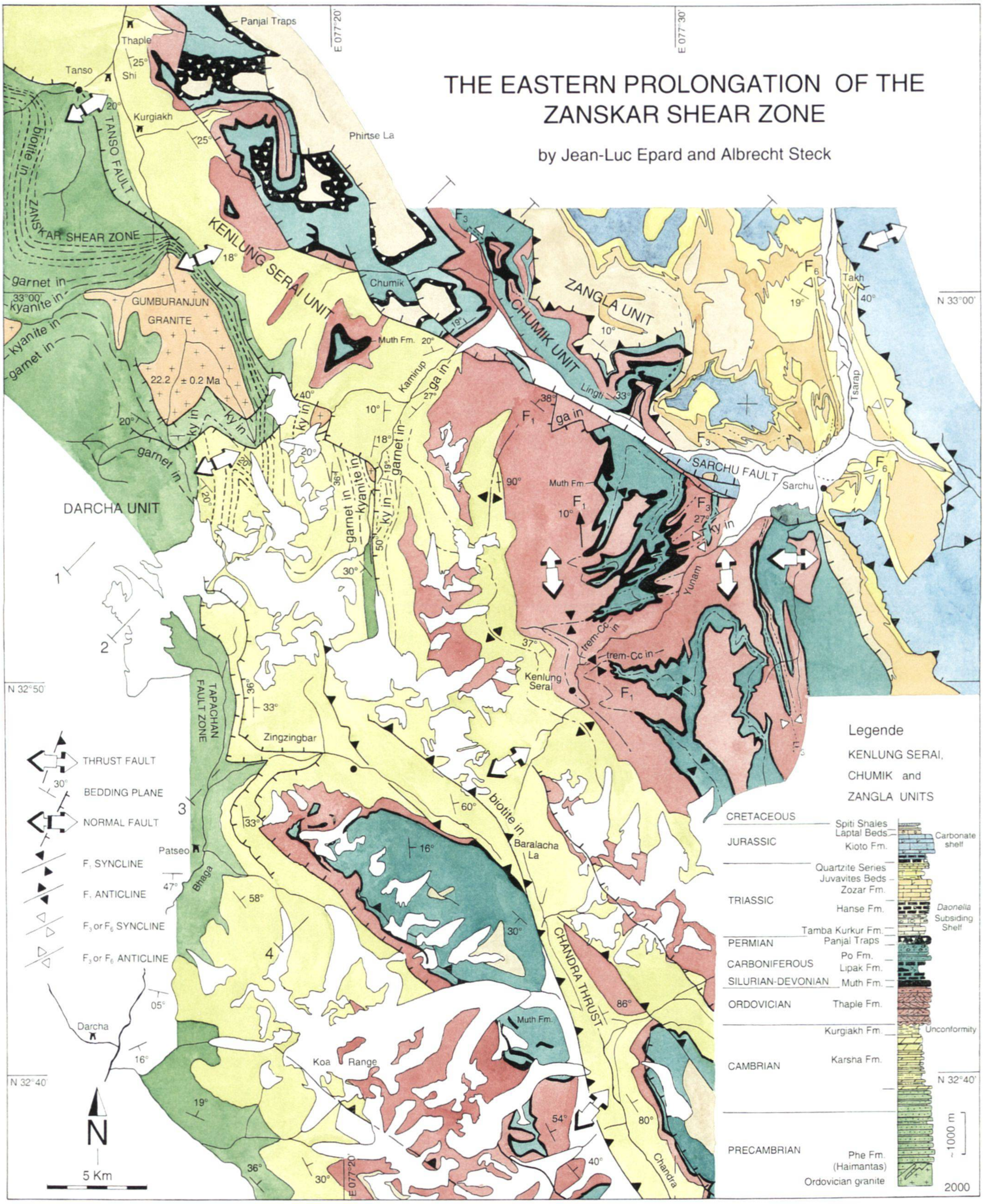
Appendix II

List of main localities mentioned in the paper.
Coordinates for valleys and rivers correspond to position of the name on the maps.

Localities	Figure #	Coordinates	Comments
Bhaga	Plate 1	E077°16' N32°45'	River
Baralacha La	Plate 1	E077°25' N32°46'	Pass
Chandra	Plate 1	E077°30' N32°37'	River and valley; dextral shear zone
Chenab	Fig. 1	E076°41' N32°41'	River and valley
Dutung-Taktote	Fig. 1	E078°18' N32°30'	Normal fault zone in Parang valley
Gianbul	Fig. 1	Cf. Haptal	SE extension of Haptal dome
Gumburanjun	Plate 1	E077°16' N32°59'	22 Ma Leucogranite
Haptal	Fig. 1	E077°40' N33°20'	Dome
Kamirup	Plate 1	E077°22' N32°58'	River and valley
Khanjar	Fig. 1	E076°54' N32°56'	Shear zone
Kenlung Serai	Plate 1	E077°27' N32°50'	Camping ground, phase 1 syncline
Kiagar Tso	Fig. 1	E078°18' N33°06'	Lake N of Tso Morari
Kullu (Kulu)	Fig. 1	E077°06' N31°57'	City
Kurgiakh	Plate 1	E077°14' N33°04'	River and valley; upper Cambrian Fm
Lingti	Plate 1	E077°28' N32°57'	River and valley
Parang (La)	Fig. 1	E078°21' N32°36'	River and valley, pass
Marang La	Fig. 1	E077°33' N33°08'	Pass
Miyar	Fig. 1	E076°42' N32°48'	River and valley, thrust zone
Patseo	Plate 1	E077°16' N32°46'	Camping ground
Sarchu	Plate 1	E077°34' N32°55'	Camping ground, fault zone
Suru	Fig. 1	E076°58' N34°22'	River and valley, NE Haptal dome
Tandi	Plate 1	E077°00' N32°32'	Village, syncline of Shikar Beh n.
Tanso	Plate 1	E077°13' N33°05'	Village, fault
Tapachan	Plate 1	E077°17' N32°48'	Camping ground, fault zone
Tso Morari	Fig. 1	E078°19' N32°50'	Lake, dome
Yunam	Plate 1	E077°30' N32°52'	River and valley, granitic dyke
Zinzingbar	Plate 1	E077°20' N32°48'	Camping ground

Plate 1

Geologic map of the Baralacha La, Yunam, Lingti and Kamirup valleys at the eastern end of the Zanskar Shear Zone. White: glaciers and Quaternary deposits.


THE EASTERN PROLONGATION OF THE
ZANSKAR SHEAR ZONE
by Jean-Luc Epard and Albrecht Steck
Legende
KENLUNG SERAI,
CHUMIK and
ZANGLA UNITS
CRETACEOUS
Spiti Shales
Laptal Beds
JURASSIC
Kioto Fm.
Carbonate shelf
Quartzite Series
Juvavites Beds
Zozar Fm.
TRIASSIC
Hanse Fm.
Daonella
Subsiding Shelf
Tamba Kurkur Fm.
PERMIAN
Panjal Traps
CARBONIFEROUS
Po Fm.
Lipak Fm.
SILURIAN-DEVONIAN
Muth Fm.
ORDOVICIAN
Thaple Fm.
Kurgiakh Fm.
Unconformity
CAMBRIAN
Karsha Fm.
PRECAMBRIAN
Phe Fm.
(Haimantas)
Ordovician granite
~1000 m
2000
THRUST FAULT
BEDDING PLANE
NORMAL FAULT
F1 SYNCLINE
F1 ANTICLINE
F3 or F6 SYNCLINE
F3 or F6 ANTICLINE
N
5 Km
DARCHA UNIT
ZANSKAR SHEAR ZONE
TANSO FAULT
KENLUNG SERAI UNIT
ZANGLA UNIT
CHUMIK UNIT
SARCHU FAULT
TAPACHAN FAULT ZONE
CHANDRA THRUST
GUMBURANJUN GRANITE
22.2 ± 0.2 Ma
Panjal Traps
Thaple
Tanso
Shi
Kurgiakh
Phirtse La
Chumik
Muth Fm.
Kamirup
Lingti
Sarchu
Takh
Tsarap
Yunam
Kenlung Serai
Zingzingbar
Patseo
Bhaga
Baralacha La
Koa Range
Darcha
Chandra
biotite in
garnet in
kyanite in
ky in
ga in
trem-Cc in
E 077°20'
E 077°30'
N 33°00'
N 32°50'
N 32°40'