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Geological observations in southeastern Zanskar and adjacent Lahul area (northwestern Himalaya)

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ABSTRACT

The paper deals with the stratigraphic and structural setting of the sedimentary sequence cropping out in southeastern Zanskar and adjacent Lahul areas. The Tibetan Zone succession of southeastern Zanskar consists of about 6000 m of sediments, Late Precambrian–?Eocene in age, arranged in two superposed slabs (Pughtal Unit, below, and Zangla Unit, above) tectonically resting upon the High Himalayan Crystalline.

The Pughtal sequence, mostly terrigenous with carbonate units in the Cambrian, Silurian and Carboniferous, is about 2500 m thick. It was deposited from ?Late Precambrian to Carboniferous or ?Early Permian. The Permian Panjal Traps constitute the "sole" of the Zangla Unit, whose sedimentary sequence, about 3000 m thick, mainly carbonatic, spans from Late Permian (Kuling Formation) to Middle Jurassic (Kioto Limestone) in eastern Zanskar. In the Zangla area Late Jurassic/Cretaceous formations (Spiti Shales, Giumal Sandstone, Chikkim Limestone) are also present. Towards northwest, the sequence ranges up to Paleocene (Spanboth Formation) and ?Eocene (Chulung La Slates).

RÉSUMÉ

Au nord de la Haute Chaîne, dans la partie septentrionale de l'Himalaya, la marge continentale indienne a vu plus de 6000 m de sédiments se déposer depuis l'Infracambrien jusqu'à l'Eocène. Lors de l'orogenèse himalayenne, ces sédiments ont été décollés de leur substratum originel, déformés et métamorphisés de manière différenciée suivant leur position. Ils reposent en contact tectonique sur la nappe cristalline du Haut-Himalaya. L'unité inférieure ou unité de Pughtal consiste, là où elle est complète, en plus de 2500 m de sédiments en partie détritiques terrigènes mais marqué par l'édification de plates-formes carbonatées au Cambrien, Silurien et Carbonifère. Dans cette unité on relève deux grandes séquences sédimentaires séparées par l'événement épirogénique et magmatique tardi-Cambrien (500 ma), contrecoup de l'orogenèse pan-africaine.

Un niveau massif de volcanites basaltiques permiennes – les Panjal Traps – forme la base ou sole de l'unité supérieure (nappe de Zangla). Cette unité, plissée de manière disharmonique, recouvre progressivement vers l'ouest des niveaux de plus en plus anciens de l'unité inférieure, niveaux eux-mêmes replissés en grands plis couchés kilométriques à vergence nord. Dans la partie occidentale (Ringdom) l'unité supérieure repose directement sur la nappe cristalline. Cette unité montre une série sédimentaire avec des carbonates de plate-forme bien développés au Trias supérieur et au Lias puis des sédiments surtout pélagiques et en partie détritiques terrigènes au Jurassique supérieur et au Crétacé. Dès la fin du Crétacé et jusqu'au Paléocène supérieur s'édifie à nouveau une plate-forme peu profonde. La série se termine par des couches continentales attribuées à l'Eocène. L'évolution géodynamique durant le Paléozoïque et le Mésozoïque est analysée. Il en ressort que la sédimentation, à partir de l'Ordovicien, est réglée plus par des grands cycles eustatiques que par des mouvements tectoniques ou épirogéniques régionaux (les orogenèses calédoniennes, hercyniennes et crétacées des auteurs).

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Introduction

During the summer 1981 a geologic reconnaissance was carried out in Zanskar (northwestern Himalaya, India). The itinerary is shown in Figure 1. The present paper is a general report of the expedition, after a preliminary note (BAUD et al. 1982a). Other papers, dealing with specific matters have been already issued or are in press (GAETANI et al. 1983; NICORA et al., in press).

Previous works

After STOLICKZA'S and LYDEKKER'S exploring journeys (1866 and 1880), the geologic research in the region marked time for a long period. Vigorous activity was resumed by Indian research parties in the seventies (many reports, several of them unfortunately unpublished) and, after 1976, by European parties (see FRANK et al., in press).

A lot of papers are devoted to the Indus Suture Zone while the Tibetan (= Tethys Himalaya) sedimentary sequence has been less studied. Like us, most workers crossed the Himalayan chain along the track Kargil–Keylong (Lahul) or vice versa (NANDA & SINGH 1977; NANDA et al. 1978; SRIKANTIA 1977; RAINA & BHATTACHARYYA 1977; SRIKANTIA et al. 1980). Total or partial N–S crossing of the Tibetan Zone sequence was made by FUCHS (1977, 1979, 1982a, b), GAETANI et al. (1980), GANESAN et al. (1981), BASSOULLET et al. (1983) in western Zanskar. GUPTA et al. (1970), SRIKANTIA et al. (1982) and BAUD et al. (1982b) crossed the eastern Zanskar. Others, like KANWAR & BHANDARI (1979) and KANWAR & AHLUWALIA (1979) studied the Sarchu area in northern Lahul.

The aims of the present paper are three:

— To describe briefly the sedimentary sequence, mainly from the Late Permian to Paleocene. Detailed data were mostly obtained on the interval Late Permian–Triassic, in which ten partial sections were measured (NICORA et al., in press).

— To interpret the pre-Himalayan geodynamic evolution of the area, as inferred by the sedimentary sequence.

— To substantiate the structural interpretation anticipated in BAUD et al. (1982a).

In the next chapters we will describe the sedimentary sequence and its structural setting in relation to the High Himalayan Crystalline.

Structural units and lithological sequences

A generalized stratigraphical section is presented in the figure 3.

The High Himalayan Crystalline

As shown by HONEGGER et al. (1982) and by FRANK et al. (in press), the High Himalayan Crystalline consists of a gigantic (hundreds of kilometers) southwest vergent nappe made of a mesograde complex, metamorphosed during the Himalayan Orogeny. It comprises:

— Precambrian to (at least) Jurassic metasediments (POWELL et al. 1973, HONEGGER et al. 1982),

— reworked old Precambrian basement (1800 m.y.) (FRANK et al. 1977),

— very Late Precambrian to Early Paleozoic granitoid intrusions and (?)migmatites (METHA 1977, 1978; POWELL et al. 1978).

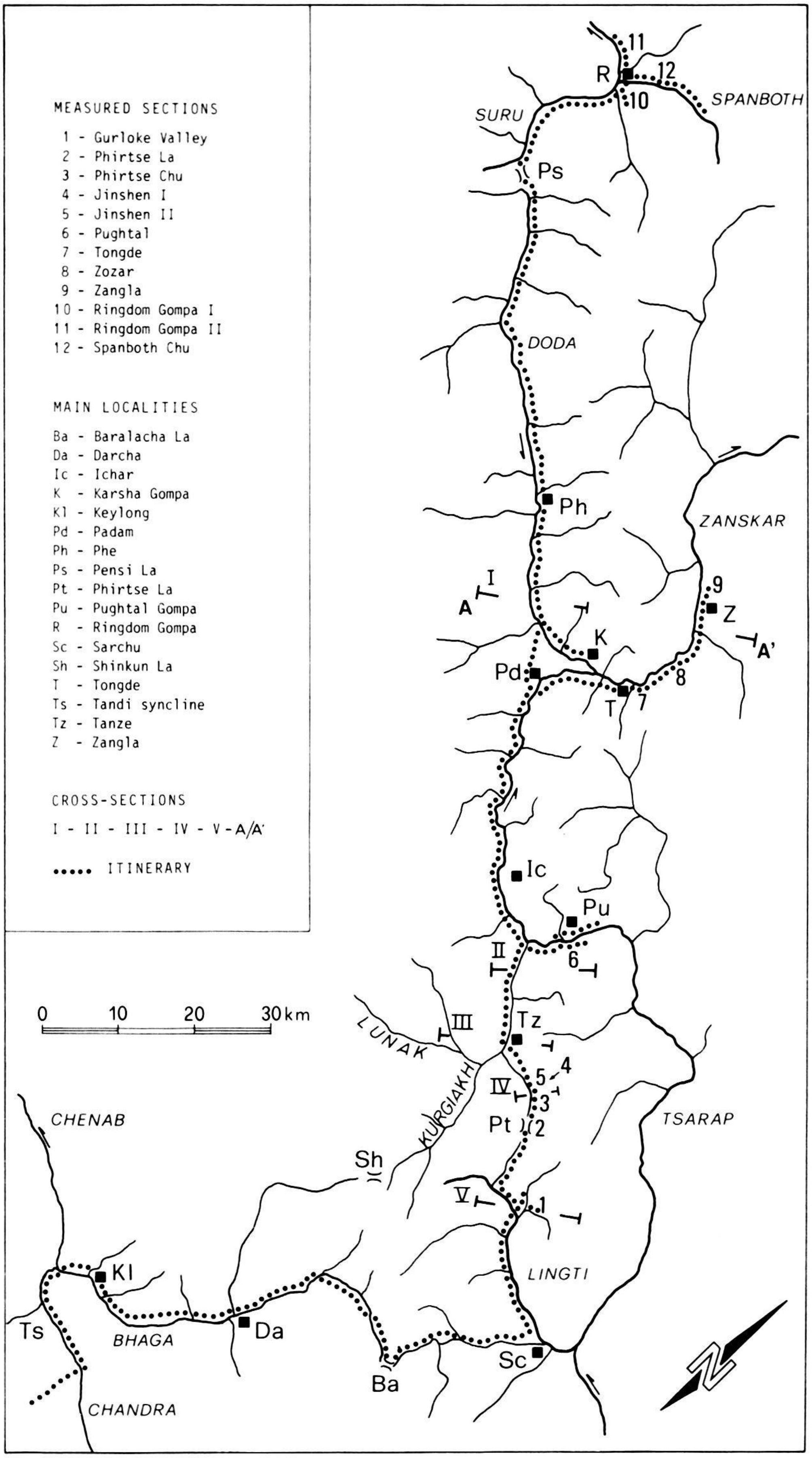

Fig. 1. Index map of the northern Lahul and Zanskar area, northwestern Himalaya, India. Itinerary, measured sections, cross-section location are shown.

The structure of the High Himalayan Crystalline (HHC) is dominated by tight isoclinal folds and shows a domal structure in the Suru area (TROMMSDORF et al. 1983). The HHC overlies a Lower Crystalline slab to the south and the Lesser Himalayan nappe complex in the Kishtwar and the Rampur windows as shown by FUCHS (1982a) and HONEGGER et al. (1982). To the northeast, the HHC disappears under the Late Precambrian to Paleocene sediments of the Tibetan Zone (BAUD et al. 1982a, b). The contact between the Crystalline (light coloured) and the Late Precambrian to Cambrian olive green slates of the Phe Formation (NANDA & SINGH 1977) is sharp and it is interpreted as the northeast-dipping thrust of the Pughtal Unit.

In our view, the HHC corresponds to a structural and metamorphic unit mainly developed during the Himalayan Orogeny. It is very different in meaning and does not correspond to the chronological definition of a Precambrian basement of the Tethys Himalaya as in the Vaikrita Group (HAYDEN 1904) or in the Giambal basement complex (SRIKANTIA et al. 1980) or in the Suru Formation (NANDA & SINGH 1977). The "autochthonist" model has been recently claimed also by THAKUR (1979, 1980), while POWELL et al. (1973, 1978), who firstly observed synclines with Paleozoic and Mesozoic metasediments pinched within the schists and gneisses, concluded that the Spiti synclinorium is a parautochthon, tectonically overriding the multiply deformed rocks of the Crystalline. We shall illustrate this situation that is accentuated in northern Lahul and southern Zanskar, where the sediments of the Tibetan Zone are in tectonic contact with the HHC (Fig. 2 and 12) and are separated in two distinct units (Pughtal and Zangla).

The sedimentary sequence of the Pughtal Unit

The Pughtal Unit sequence spans from the ?Late Precambrian to the Carboniferous or ?Early Permian west of Phirtse La. In the upper Lingti Valley only, also Permian to Middle Triassic sediments seem to be included in this unit (cross section V). It consists of at least 2500 m of mostly terrigenous sediments, with dolomitic and calcareous levels in the Cambrian, Silurian and Carboniferous. We suggest the Pughtal Unit is a nappe thrusted on the High Himalayan Crystalline, mainly cropping out in eastern Zanskar and in northern Lahul, and gradually disappearing below the frontal thrust of the Zangla Unit in the Doda Valley, western Zanskar. The widest exposures of the Paleozoic sequence crop out in northern Lahul, where the unit is about 20 km wide, measured against the strike, continuing eastwards in the upper Chandra Valley and in Spiti through the Kunzam La area (HAYDEN 1904; KANWAR & AHLUWALIA 1979; SRIKANTIA 1981).

Phe Formation and Karsha Formation (NANDA & SINGH 1977)

SRIKANTIA et al. (1980) introduced the terms Batal Formation and Kunzam la Formation for the same units. These names were already used in SRIKANTIA (1977), but not defined.

The Phe Formation is made of a monotonous succession of grey-green shales, sandstones locally with wave and linguoid ripples, greywackes, in beds of variable thickness. Pyritiferous, dark shales are also present. Total thickness over 1500 m. According to previous authors, the age is Late Precambrian to Cambrian.

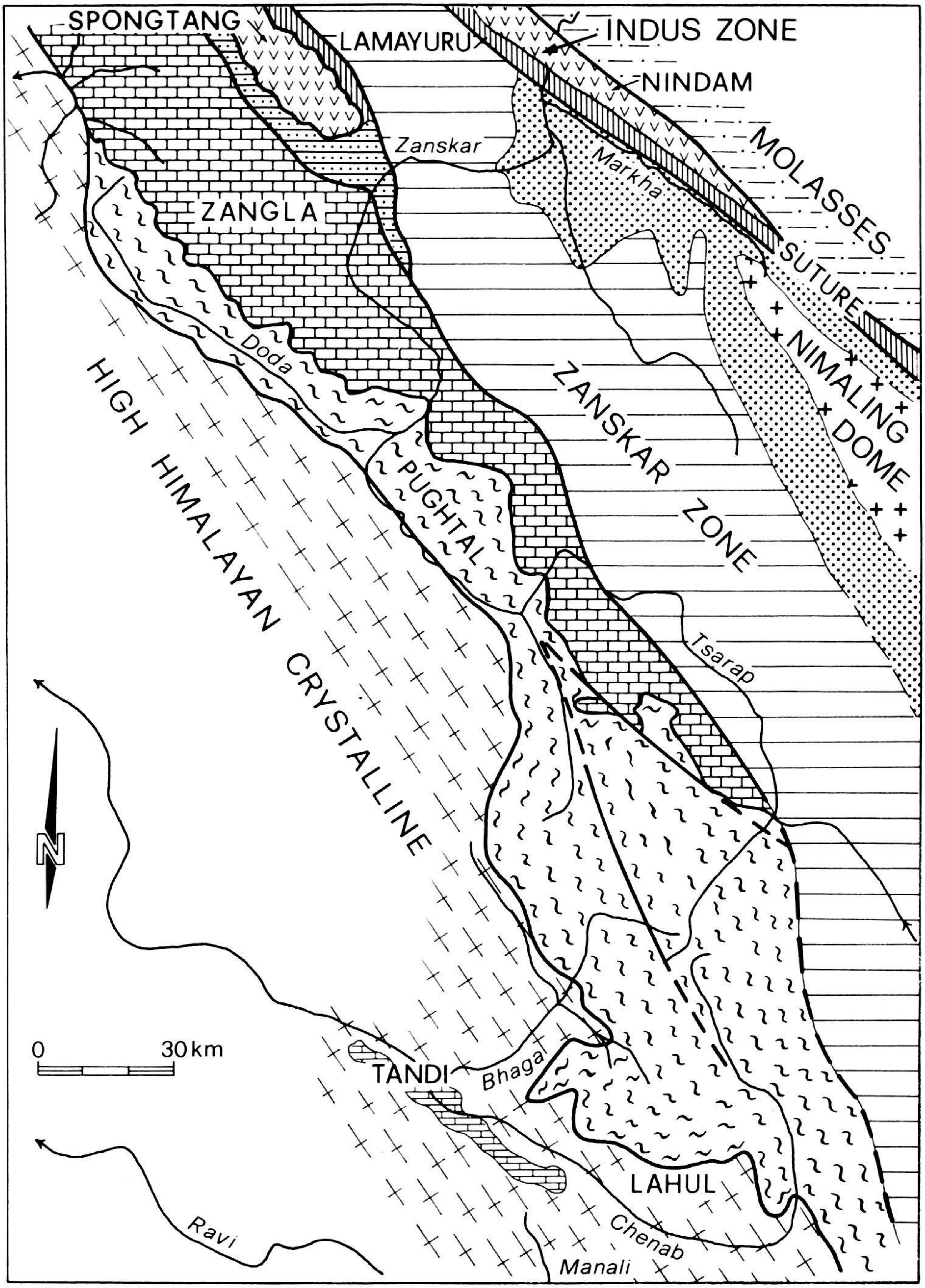

Fig. 2. The main tectonic units on the northern side of the High Himalayan Chain. The Pughtal and the Zangla Units are identified within the Tibetan Zone.

The Karsha Formation is characterized by the appearence of dolomitic beds. In the lower part they are interbedded in the slaty sequence, as 0.5–20 m thick intercalations of massive, brown weathered dolomites. Planar or hemispheroidal stromatolites are very common. In loose boulders west of Tanze (southeastern Zanskar) we observed possible remnants of Archaeocyatids. In the upper part, the yellow dolomites from a continuous horizon, some 200 m thick, extending from Tongde La (Ronchïl) and the Tsarap Valley to Lahul. Near Karsha Gompa the dolomitic levels interbedded with the terrigenous sequence are well developed. Above the dolomitic unit, more than 200 m of grey-green slates are preserved; it can be seen in front of Kuru, between Tanze and Purne. The age usually quoted is Middle to Late Cambrian (NANDA & SINGH 1977; SRIKANTIA 1977; SRIKANTIA et al. 1980). Few Trilobites were described by DUNGRAKOTI et al. (1974). On the likely occurrence of the Archaeocyatids also the Early Cambrian would be testified[4]).

Thaple Formation (NANDA & SINGH 1977)

This conglomeratic arenaceous unit unconformably overlies the dolomites and slates of the Karsha Formation. The coarser levels spread from Chandra and Bagha valleys in Lahul to Lunak area in Zanskar. They are missing in the Pughtal profile and further west, due to the tectonic overlapping. To the east, they are well-known in Spiti (HAYDEN 1904; SRIKANTIA 1981; FUCHS 1982a).

The polygenic conglomerates are mud-supported, with poorly rounded pebbles not exceeding 20 cm in size. The bedding is up to 10 m thick (usually 1–2 m), with sharp vertical and lateral changes to reddish, quartzose sandstones, often with high-angle cross-bedding. Most of the sequence, however, consists of red hematitic, moderately sorted, angular, immature, tourmaline-bearing litharenites (nomenclature after FOLK 1980, throughout this paper) or, towards the top, of reddish or greenish burrowed siltstones.

The terrigenous supply was likely derived from the underlying sedimentary sequence (dolomite and terrigenous rock fragments may be locally very abundant) but also from crystalline rocks (granitoid bodies, phyllites and quartzites, possibly even felsic volcanics). Thickness over 300 m. No fossils. Supposed age: Ordovician–Silurian.

SRIKANTIA et al. (1980) named this unit Thango Formation and included it in the Haimanta Group. We prefer to keep out the conglomerate/sandstone unit because it unconformably overlies the Cambrian succession.

Tachke Formation (SRIKANTIA et al. 1980)

In the upper valley of the Lingti, on the right bank of the river, a thin calcareous unit crops out. It does not seem to be very widespread, because in the Gurloke section

[4]) While the present paper was already in press, we received the work of GUPTA & SHAW (1982) who describe a small collection of Trilobites from the Lunak Valley (Zanskar). They attribute a Middle to Upper Cambrian age to the Phe Formation, an Upper Ordovician to Silurian age to the Karsha Formation and an early Late Silurian to early Middle Devonian age to the Thaple Formation. The latter is reported to conformably overlie the Karsha Formation and it is followed by the Muth Quartzite. However, it should be noted that HAYDEN (1904) found in Spiti a Caradoc fauna above the conglomeratic unit.

or in the Tanze section, red and pink sandstones and siltstones grade up directly to the Muth Quartzite. Authors quote a Silurian to Lower Devonian age for this unit[4]).

Muth Quartzite (STOLICZKA 1866)

This very typical unit of the Himalaya may be followed from Lahul to eastern Zanskar where it disappears below the frontal thrust of the Zangla Unit, northwest of Tanze. It consists of white, massive, mature quartzarenites with rusty weathering. Thickness over 200 m. Authors agree to assign a Devonian age to the Muth Quartzite. In Spiti, its top has been recently proved to be Late Devonian (AHLUWALIA et al. 1983).

Lipak Formation (HAYDEN 1908)

With a fairly sharp contact the arenaceous sequence is followed upward by black limestones (mudstones) in 25–50 cm thick beds, alternated with shaly, fissile, foetid limestones. Nodular limestones in 1–2 m thick beds, locally rich in Crinoids, end the sequence, that is 50–70 m thick in the Gurloke area. Similar figures are reported by JOSHI & ARORA (1979) in eastern Zanskar. KANWAR & AHLUWALIA (1979) instead quoted some 600 m for the Lipak Formation north of the Baralacha La.

In the Gurloke section, at 4710 m a.s.l., about 20 m above the bottom of the unit, 6 m of black marly limestones (packstones with abundant bioclasts, separated by mudstone/wackestone layers) contain a rich fauna of Brachiopods and Bryozoans. *Globochonetes, Tomiproductus, Hemiplectorhynchus, Spirifer, Syringothyris* are the genera recognized. They represent an assemblage of Early Carboniferous age widespread in western Himalaya (DIENER 1915; JOSHI & ARORA 1979; GUPTA & WATERHOUSE 1979).

Po Formation, Ganmachidam Formation

We paid no special attention to these two units, introduced respectively by HAYDEN (1904) and by SRIKANTIA et al. (1980). In the Gurloke section, about 15–20 m of calcareous sandstones, rusty in weathering, follow the Lipak black limestones. In turn, they are overlain for some 60–70 m of thickness by dark grey, well bedded limestones. At the very top, the limestones are represented by mudstones/wackestones with layers of crinoidal grainstones and rare brachiopods. The following sequence is mostly arenaceous (Ganmachidam Formation) with predominating high angle cross-bedded sandstones. Some of them are very fine to medium grained and lightly microconglomeratic, moderately sorted, subrounded, immature sublitharenites with sericitic–hematitic matrix. Quartz grains are mainly monocrystalline. K-feldspars and plagioclases are rare. Among the lithic fragments, quartz–sericite coarse siltstones, quartz-cemented quartzarenites and subordinate shales prevail over igneous and metamorphic rock fragments. Muscovite, blue and green tourmaline, zircon are the main accessory minerals. Polygenic conglomerates are less frequent. They are often mud-supported with rounded and moderately sorted pebbles up to 15 cm in size. According to the authors, these two units are Carboniferous, the top of the Ganmachidam Formation ranging perhaps up in the Early Permian.

The sedimentary sequence of the Zangla Unit

The Zangla Unit sequence spans from the Permian to ?Eocene, reaching a thickness of about 3000 m. Its base is usually made of the Panjal Trap volcanics (Permian), followed by a conformable sedimentary succession ranging from the Late Permian (Kuling Formation) to the Jurassic (Kioto Limestone) in eastern Zanskar. In the Zangla area, Late Jurassic–Cretaceous formations (Spiti, Giumal, Chikkim, Kangi La) are also present. In the west, from the Oma Chu to the Ringdom Gompa, the sequence ranges up to Paleocene (Spanboth Formation) and ?Eocene (Chulung La Formation). The attribution of the Lingshed area, east of the Spongtang Klippe, to the Zangla Unit, or to a northern, Lower Zanskar nappe needs further research (Fig. 2).

Panjal Traps (LYDEKKER 1883)

Junior synonyms: Ralakung Formation (NANDA & SINGH 1977); Phe Volcanics (NANDA et al. 1978); Phe Formation (SRIKANTIA et al. 1980).

This volcanic and subordinately volcanoclastic unit reaches its maximum thickness (2500 m) in Kashmir (GANSSER 1964; HONEGGER et al. 1982). In western Zanskar, the Traps are about 300 m thick; they get gradually thinner eastwards and wedge out in the Lingti Valley. Namely, they are present in the upper Lingti and on the western Gurloke bank, whilst they are absent on the east Gurloke side till Sarchu (GUPTA et al. 1970). The Panjal Traps are mainly silica-saturated or nepheline normative basalts belonging to the tholeitic and alkaline series (HONEGGER et al. 1982). A sample collected at the base of the Jinshen section (eastern Zanskar) has been analyzed by K. Honegger (ETH Zürich) and resulted to be a clinopyroxenite, with clinopyroxene and chromospinel. Secondary minerals are diopside, actinolite, chlorite, and epidote. Its low content in Al_2O_3 (9.70%) and Fe_3O_2 (1.47%), as well as the high content of MgO (23.24%), Ni (1051 ppm) and Cr (3005 ppm) strongly differs from the average Trap composition (HONEGGER et al. 1982, Table 1). This picrite-type rock is likely a xenolith. The Panjal Traps generally show extensive growth of secondary minerals and widespread overprinting by metamorphic paragenesis, with southeastward decreasing grade, from medium-low greenschist facies in Ringdom Gompa area (TROMMSDORFF et al. 1983). Peculiar of many layers of the unit are inch-sized amygdales filled by chlorite and often lined by rims of calcite, microgranular epidote and silica microspherulites.

Kuling Formation (STOLICZKA 1866)

Above the volcanic beds, a sedimentary sequence with variable thickness (30 m Jinshen; 55 m Pughtal) conformably follows. The lower part is made of whitish, well sorted, subangular immature to mature quartzarenite, with local enrichments of fossil fragments in 40–50 cm thick beds. Poorly bedded, brownish, burrowed quartzarenitic biomicrites, very rich in Brachiopods, follow. *Lamnimargus himalayensis* (DIENER) and *Spiriferella rajah* (SALTER) are very common. *Neospirifer* sp. ind. and *"Athyris"* sp. ind. are subordinate. Bryozoans, Gastropods, Pelecypod fragments and siliceous sponge spiculae are also present. Most of the Brachiopod internal moulds were enriched in Ca-phosphate very early in the diagenesis. The age of the *L. himalayensis* beds is here

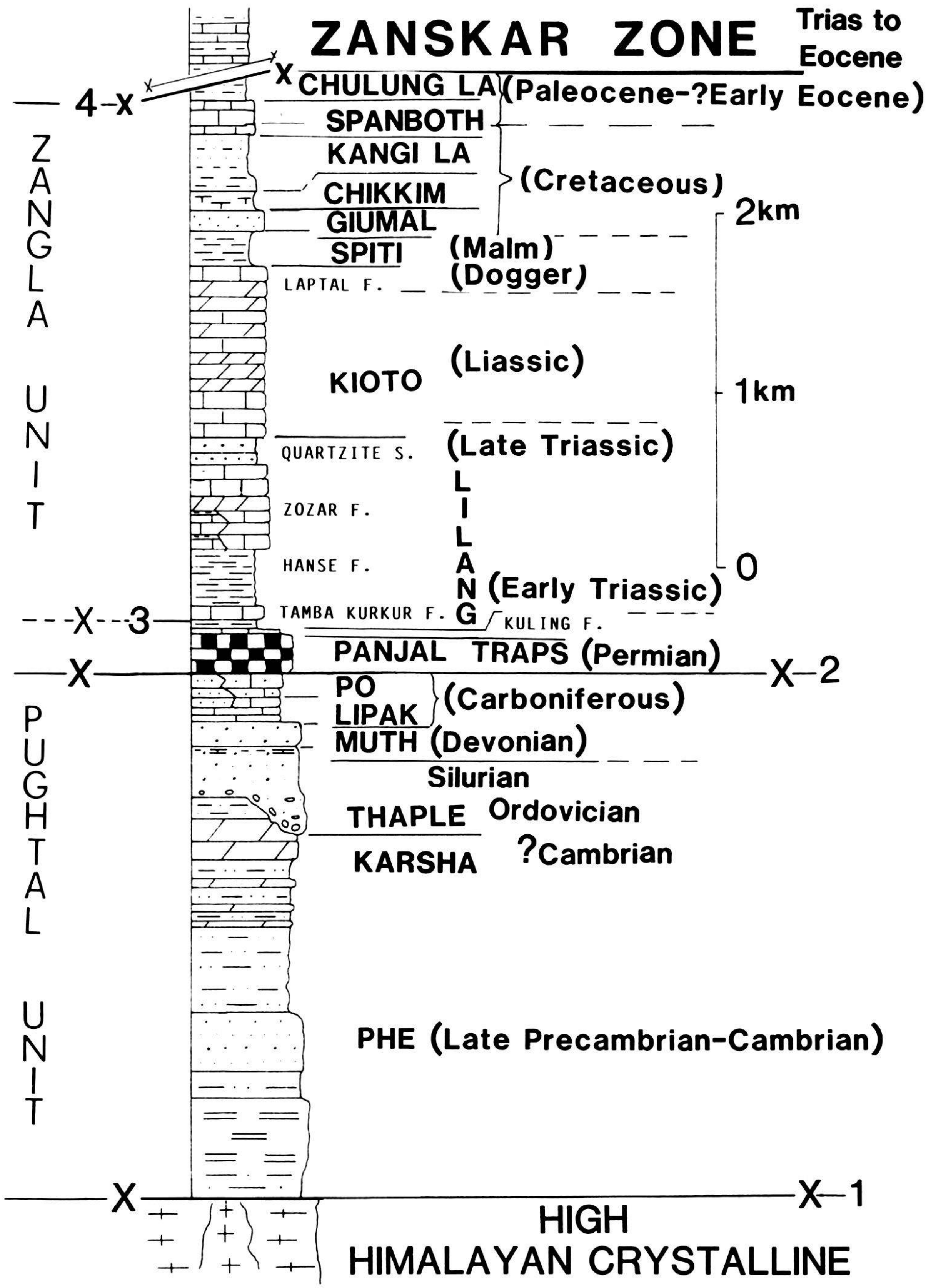

Fig. 3. The sedimentary sequence and the main thrust planes. 1 = lower thrust; 2 = upper thrust; 3 = main Triassic "décollement" level; 4 = thrust of the Zanskar nappes.

considered as Late Permian. The siliciclastic detritus mostly derived from granitoid rocks. Volcanic supply is limited to rare felsitic rock fragments. The sequence ends with fissile marly shales with phosphatic nodules (maximum thickness 17 m in Pughtal). The Kuling Formation represents a transgressive unit likely reaching a depth of 50–100 m.

Lilang Group (HAYDEN 1908)

The thick, mostly carbonate sequence resting on the Kuling Formation (Permian) and spanning till the Kioto Limestone ("Rhaetian"/Jurassic) is here indicated as Lilang Group in the sense as given by HAYDEN (1908). But the name of Lilang was earlier choosen by STOLICZKA (1866) for the Late Triassic of Spiti. Recently, SRIKANTIA et al. (1980) elevated it at the rank of a group including however the Kioto Limestone. The Lilang Group crops out all along the visited area, from Sarchu to the Ringdom Gompa with an average of thickness of about 1000 m.

Four lithostratigraphic units have been distinguished; from bottom to top they are:

1. *Tamba Kurkur Formation* (SRIKANTIA et al. 1980): The unit, spanning from the Scythian to the Anisian, consists at the base of nodular, grey bedded limestone (bioclastic mudstone/wackestone) followed by prevalent grey sandy, sericitic shales with rare limestone beds (bioclastic packstone/grainstone). They are covered by alternating shales and grey-brown nodular, thin bedded limestones (bioclastic wackestone) and black-brown bedded limestones (bioclastic wackestone) with subordinate shales. The thickness of the unit ranges from 40 m in the Jinshen area to 100 m in the Tongde area.

In the lowermost part *Hindeodus minutus* (ELLISON) (= *Anchignathodus typicalis* SWEET) and *Gondolella carinata* CLARK are present. This portion seems to be correlative with the *Otoceras* bed (MATSUDA 1981; BHATT et al. 1981). The presence of *Neospathodus dieneri* SWEET, *N. nepalensis* (KOZUR & MOSTLER) (= *N. labiatus* GOEL), *N. novaehollandiae* MCTAVISH, *N. spitiensis* GOEL *and Platyvillosus* sp., 3 m above the previous assemblage, marks the Dienerian (GOEL 1973). The Smithian is represented by *Neospathodus waageni* SWEET, *N.* aff. *waageni, N. dieneri* SWEET, *N.* cf. *novaehollandiae* MCTAVISH found 8 m higher.

Rich Ammonoid (mainly *Beyrichitidae* and *Ptychitidae*) and conodont faunas are present in the upper part of this formation that includes the whole Anisian. The youngest conodont fauna with *Gondolella eotrammeri* KRYSTYN marks the *Parakellnerites* Zone.

The passage to the overlying Hanse Formation is sharp in eastern Zankar (Jinshen–Pughtal area), where it is located between the black, nodular, bedded limestones at the top of the Tamba Kurkur Formation and the ash grey marls that characterize the base of the Hanse Formation. In the Tongde area, it is transitional, with gradual increase of shales.

2. *Hanse Formation* (SRIKANTIA et al. 1980): This portion of the Lilang Group is particularly well-developed in the Phirtse La–Jinshen area, whilst it seems to be reduced to northwest. This formation is characterized by three distinct lithofacies: at the base ash grey marls and black, platy, thin bedded limestones (bioclastic mudstone/subordinate packstone) with thin marly intercalations plenty of Daonellas (140 m), covered by grey, silty, fissile marls with isolated nodules sometimes containing Ammonoids (*Protrachyceras* ex gr. *archelaus* MOJSISOVICS) with metric intercalations of black, thin bedded limestones (bioclastic wackestone) locally rich in large crinoids. *Gondolella foliata inclinata* KOVACS and *G. trammeri* KOZUR of Late Ladinian age have been found at the base of this 40-m thick lithofacies. Black, bedded, packed, yellowish weathered

limestones (bioclastic mudstone to wackestone and subordinate intrabioclastic grainstone in the last 20 m) characterize the upper lithofacies that is extremely monotonous all over the total thickness (275 m).

The Tamba Kurkur and Hanse Formations represent mostly basinal sequences, but a decrease of depth is marked by an increase of bioclasts in the upper 20 m of the Hanse Formation.

3. *Zozar Formation:* We introduce the name Zozar Formation from the village of Zozar, on the Zanskar river, where the unit is well exposed for the sequence (about 400 m thick) between the Hanse Formation and the overlying Quartzite Series. The Nimaloksha Formation of SRIKANTIA (1981) applies to the mostly basinal marly lithosome of Spiti and in our view cannot be extended to the Zanskar area, where the Upper Triassic sequence consists of shallow-water carbonates.

The base of the Zozar Formation is made of few encrinitic beds followed by calcarenite layers characterized by the peculiar abundance of Trepostomata and Cryptostomata Bryozoans, along with Brachiopods, Gastropods, Pelecypods, Solenoporaceans, blue-green algae and rare coral fragments. A distinctive thick, white dolomitic bed follows. The overlying main body of the unit is formed by a monotonous sequence of cross-bedded calcarenites, sometimes intensely burrowed limestones, dolomitic limestones and stromatolitic dolomites. The topmost layer is a 5–10-m thick, white dolomitic bed followed by the first micaceous siltstone and quartzose sandstone layers.

The depositional environment was mainly subtidal, with increasing depth towards the east. Intertidal and brecciated supratidal beds are recurrent in the type area. Here, also one event of deeper-water sedimentation is witnessed in the middle part of the unit by a marly tongue about 10 m thick which yielded Conodonts of Carnian age (*Gondolella polygnatiformis* (BUDUROV & STEFANOV)). Age: Carnian to Middle Norian.

4. *Quartzite Series* (HAYDEN 1904): Junior synonym: Alaror Formation (SRIKANTIA et al. 1980). The unit is continuous throughout western Zanskar with constant features and thickness (about 120 m). In eastern Zanskar we never got at this part of the sequence. In the lowermost 20–30 m poorly sorted bio-, oo- and intracalcarenites with abundant crinoidal remains, and grey micaceous marls prevail over sandstones; a mostly arenaceous middle portion (25 m thick) follows. The upper part of the unit consists of quartzose bio- and oosparite layers, interbedded with micaceous marls. This interval yielded benthic foraminifera of Norian–Rhaetian age (*Involutina communis* (KRISTAN), *I. gaschei* (KOEHN-ZANINETTI & BRÖNNIMANN)). Carbonates extremely rich in *Neomegalodon,* mark by alternance the boundary to the overlying Kioto Limestone.

The Quartzite Series contain white to green, mostly fine and very fine grained, very well to moderately sorted, subangular to subrounded, immature to supermature sandstones; they are mostly subarkoses, cemented by either quartz, chlorite, alkali-feldspars or calcite, but more often with interstitial sericitic epimatrix. Quartzarenites are subordinate, confined to the top of the unit and to the base of the overlying Kioto Limestone. Ultrastable mineral fraction consists of zircon, titanium minerals and tourmaline even with distinct reworked overgrowths.

A cratonic, partly direct and partly polycyclic provenance of the siliciclastics is strongly suggested. The unit was deposited in shallow subtidal to beach environment during latest Norian–"Rhaetian" age (own data; GUPTA 1976, 1977).

Kioto Limestone (HAYDEN 1908)

Junior synonym: Simokhambda Formation (SRIKANTIA 1981). This thick calcareous/dolomitic unit constitutes a spectacular cliff-forming element of the landscape throughout the considered area. In the lower part it contains dolomitic limestones in 50–100 cm thick beds, rich in *Neomegalodon*, still interbedded with quartzarenites or subarkoses, and silty marls. A monotonous sequence of blue limestones in 2–5 m thick beds, often slightly foetid, follows. The *Lithiotis* facies has not been observed. Due to tectonics it is difficult to assess the thickness of the unit, which in the Zangla area could range between 600 and 900 m, whilst in the Ringdom Gompa area is about 400 m thick.

In the topmost part, beds very rich in belemnites crop out at the Zangla fortress. They could represent the Laptal Beds of HEIM & GANSSER (1939); however, we have no data on the subject.

Spiti Shale (STOLICZKA 1866)

The unit crops out from the Zangla area till the Ringdom Gompa area. It consists of splintery shales with nodules; arenaceous intercalations are present to the west. At Zangla the lower beds are full of belemnites. The thickness reaches 150 m at east, whilst it is greatly reduced at west, with only 10–30 m (own observations; FUCHS 1979, 1982b; BASSOULLET et al. 1983).

The depositional environment of the Spiti Shale was pelagic with anoxic conditions at the bottom. Authors assign an Oxfordian–earliest Cretaceous age to the unit.

Giumal Sandstone (STOLICZKA 1866)

The unit crops out from Zangla to Ringdom Gompa area, with an increasing thickness from about 200 m up to 300 m to the west.

The Giumal Sandstone consists of grey to green, often burrowed, locally cross or graded-bedded, very fine to fine grained, moderately to well-sorted, subangular to subrounded sandstones and intercalated layers of black shales.

In the Zangla area the lower 40 m of the unit are mature to immature illitic subarkoses (a 400-points counting after DICKINSON 1970, yielded Q_{89} F_6L_5 and $Q_{89}F_9L_3$, with a composite to total quartz ratio between 1.5 and 4%, fine-terrigenous and gneissic rock fragments, and a plagioclase to alkali-feldspar ratio close or less than unity). Cross-hatched microcline and tourmaline are the most distinctive accessory grains. The beds about 100 m above the base display an impressive enrichment in volcanic lithic fragments (felsitic equally or slightly more abundant than microlitic types). They are immature volcanic arenites ($Q_{31}F_{12}L_{58}$ and $Q_{40}F_9L_{51}$, with a volcanic to total lithic fragments ratio approaching unity and a plagioclase to alkali-feldspar ratio reaching even 5). Then the quartz increases again ($Q_{53}F_5L_{42}$) at the base of the major shaly intercalation, about 50 m thick and containing a coarse silt fraction of plagioclase–arkose composition. This trend is partly confirmed in the Ringdom area, where, however, the strong anchimetamorphic overprint limits the accuracy of the quantitative petrographic data.

The topmost beds of the unit north of Ringdom are immature calcarenitic sublitharenites ($Q_{82}F_2L_{16}$) rich in belemnites. They are followed by the Chikkim Limestone with a very clear-cut boundary.

The depositional environment of the Giumal Sandstone is controversial. The formation is bracketed between two pelagic, bathyal units. However, it lacks undisputable features pointing to deposition by turbidity currents, and it might have been deposited on an outer shelf 100–200 m deep. The petrographic composition suggests a mixed-source provenance. Superimposed to the likely triggering of cratonic rejuvenation by major eustatic regression events, a volcanic supply is very important in the middle-upper part of the unit. Radiometric data available at present, though somewhat controversial, exclude a suggestive relation with the onset of the huge basaltic effusion of the Deccan Traps, which span from Campanian to Paleocene (SRIVASTAVA 1983). More conservatively, a local source could be inferred, according to KANWAR & BHANDARI (1979) and RAINA & BHATTACHARYYA (1977) who reported volcanics injected or interbedded in the Spiti Shale in the surroundings of Sarchu. The nature of this magmatic events remains problematic.

The Upper Cretaceous and Paleocene/Eocene formations of the Zangla Unit have been recently analyzed in GAETANI et al. (1983). They will be shortly summarized here.

Chikkim Formation (STOLICZKA 1866)

Outcropping area: from Zangla to the Spanboth Chu. Lithology: well-bedded limestones, and grey marly limestones of pelagic environment. Thickness of about 90–100 m. Supposed age: Cenomanian–Coniacian.

Kangi La Formation (FUCHS 1977)

Outcropping area: Spanboth–Kangi La and Zangla. Lithology: dark grey marls, calcareous siltstones, shales; sandstones in the upper part. Thickness from 400 to 600 m. Environment from bathyal to sublittoral. Age: ?Santonian–Campanian–?earliest Maastrichtian.

Spanboth Formation (FUCHS 1982b)

Outcropping area: Spanboth Chu–Kangi La. Lithology: grey bioclastic calcarenites with abundant *Omphalocyclus* (1° Member); whitish to grey-green quartzarenites (2° Member); dark-grey well bedded limestones (mudstone/wackestone) locally rich in *Daviesina* (3° Member). Thickness: 120–140 m (1° Member); 15 m (2° Member); more than 200 m (3° Member). Environment sublittoral except for the 2° Member which could be of beach or even continental. Age: Maastrichtian–Paleocene.

Chulung La Slates (FUCHS 1982b)

Outcropping area: Spanboth Chu–Chulung La. Lithology: red and green siltstones and litharenites. Thickness over 100 m. Environment: ?continental. Age: ?Eocene.

Geodynamic interpretation of the Paleozoic and Mesozoic sequences

The sedimentary sequence of the Tibetan Zone was deposited on a continental crust throughout the Phanerozoic: Its history may be subdivided in three parts:
A. Late Precambrian to Ordovician
B. Silurian to Carboniferous–?Early Permian
C. Permian to Eocene

A. Late Precambrian to Ordovician

The Late Precambrian to Cambrian shale/sandstone thick succession has been recently interpreted as deposited in a "geosyncline" (SRIKANTIA 1977, 1981; SRIKANTIA et al. 1980; FUCHS 1982a, b). Internal stratigraphy and sedimentology are too sketchily known to firmly establish its geodynamic environment in the considered area. A very significant subsidence rate was in process and flysch deposition has been reported. However, the abundance of the stromatolitic layers, the possible Archaeocyatid remnants, the shallow-water ripple marks do not support the interpretation of a deep environment for the Karsha Formation and for the upper part of the Phe Formation. The Cambrian evolution ends with a regional uplift and erosion, from Spiti to eastern Zanskar. Moreover, several radiometric data around 550–500 m.y. were obtained on granitoid bodies in the High Himalayan Crystalline of Lahul and Zanskar (MEHTA 1977; HONEGGER et al. 1982). SRIKANTIA et al. (1980) claims that even the Gumboranjan Granite in Kurgiakh Valley intrudes Cambrian sediments and derived pebbles may be found in the Ordovician conglomerates. The latter, in Spiti, cut with angular unconformity the Cambrian (FUCHS 1982a).

The interpretation of this cycle constitutes one of the most challenging problems of the Himalaya. Evidence from the sedimentary succession could simply indicate an epirogenetic episode. However, radiometric ages on granitoids and/or migmatites and gneiss (MEHTA 1977; FRANK et al. 1977; BHANOT et al. 1979; HONEGGER et al. 1982; FERRARA et al. 1983) suggest that all over the High Himalayan Crystalline a very significant event occurred at about 550–500 m.y. It corresponds in time with the terminal episode of the Pan-African Orogeny (POWELL et al. 1978), while the correlation with the north-European Caledonian Orogeny (FUCHS 1981, FRANK et al., in press) seems to be less easy on chronological and spatial grounds. Should we begin to think, therefore, that a Pan-African event affected also northern India?

B. Silurian to Carboniferous

The second term, about 150 m.y. long, spans from the Silurian to Carboniferous and perhaps to the Early Permian. Mature quartzarenites, shallow water impure bioclastic limestones, frequent gaps, very low sedimentation rate, are features of a cratonic shelf. The depositional history does not support evidence for a mobile belt, preceding an orogenic episode as claimed instead by BHARGAVA (1980). The quoted unconformity (SRIKANTIA et al. 1980) is in fact a thrust plane. To explain the widespread occurrence of Upper Carboniferous sandstones or conglomerates we think necessary to consider also the erosive activity caused by the Gondwana ice cap.

C. Permian to ?Eocene

The third period of evolution represents the history of a portion of the inner part of the Indian Plate continental margin, facing the contemporary opening of the Neotethys. It starts with the effusion of the Panjal Traps, basalts of alkaline affinity, interpreted as expanded in rift zones (HONEGGER et al. 1982). This event could represent the beginning of the crustal extension, followed by the subsidence of the passive margin. Figure 4 gives tentative figures for sedimentation and subsidence rates, considered against the "sea level" curve of VAIL et al. (1977), modified after HARLAND et al. (1982).

The Panjal Traps are interpreted to fill grabens, capped by the transgressive (up to circalittoral) marine sediments of the Kuling Formation, as its sandstones seem to lack of basaltic rock fragments. The further collapse step happened in the Early Triassic, with pelagic, low rate sedimentation. Since the Ladinian, the sedimentary input largely increased, filling the basin up to sublittoral conditions. The subsidence rate, however, continued to be fairly high, to give room to the thick peritidal sequence of the Zosar Formation. A change in the sedimentary supply occurred with the Late Norian–"Rhaetian" Quartzite Series, connected with the sea-level drop and consequent rejuvenation of the Indian Craton (Fig. 5). The Quartzite Series apparently separate Mesozoic rocks in two sedimentary cycles. As to subsidence, instead, they are more homogeneous, with basement plus overloading subsidences only apparently slightly higher in the Triassic than in the Jurassic.

The drowning of the carbonate platform of the Kioto Limestone occurred during the Middle Jurassic. If we extend the subsidence rate of the Kioto to the Late Jurassic/earliest Cretaceous Spiti Shale, the latter will reach a deposition depth of about 500 m. If so, two environmental interpretations for the following Giumal Sandstones are possible: a) the subsidence rate substantially decreased during the Spiti Shale deposition or was even reversed in Lower Cretaceous; b) the shallow-water interpretation of the Giumal is incorrect and it represents a huge grain-flow fan in deeper water. In both cases, the sandstone peaks at the base and at the top of the unit could be linked to the sea-level fluctuations (Fig. 4).

The wedging out of the sandstones from Ringdom to Zangla till the Zumlung Unit of the northern Zanskar Zone (BAUD et al. 1982b) and the increase of the shaly intercalations would suggest a sandy supply from west, with isopic zones oriented about N–S. This pattern is also consistent with the facies distribution in Late Triassic time. Bathyal conditions resumed or were attained during the deposition of the Chikkim Formation. The passive margin fairly low subsidence (less than 2000 m of sediments in about 150 m.y.) lasted until the Late Cretaceous (Campanian). Intense sedimentation of the Kangi La Formation and Spanboth Formation (1° Member), together with the decrease of the subsidence, led to a reduction in the depth of the seafloor. It might be noted the rough correspondence of the timing of the base of the Kangi La Formation and the beginning of the Indian Plate flight before the Anomaly 34 (PATRIAT et al. 1982). The quartzarenitic horizon of the Spanboth Formation (2° Member) was controlled by the eustatic regression in the Late Maastrichtian (VAIL et al. 1977). Consequently it is assumed to be almost isochronous, not being linked to local uplifts (GAETANI et al. 1983). The final emersion during the Eocene, due to the India/Asia collision sealed this period.

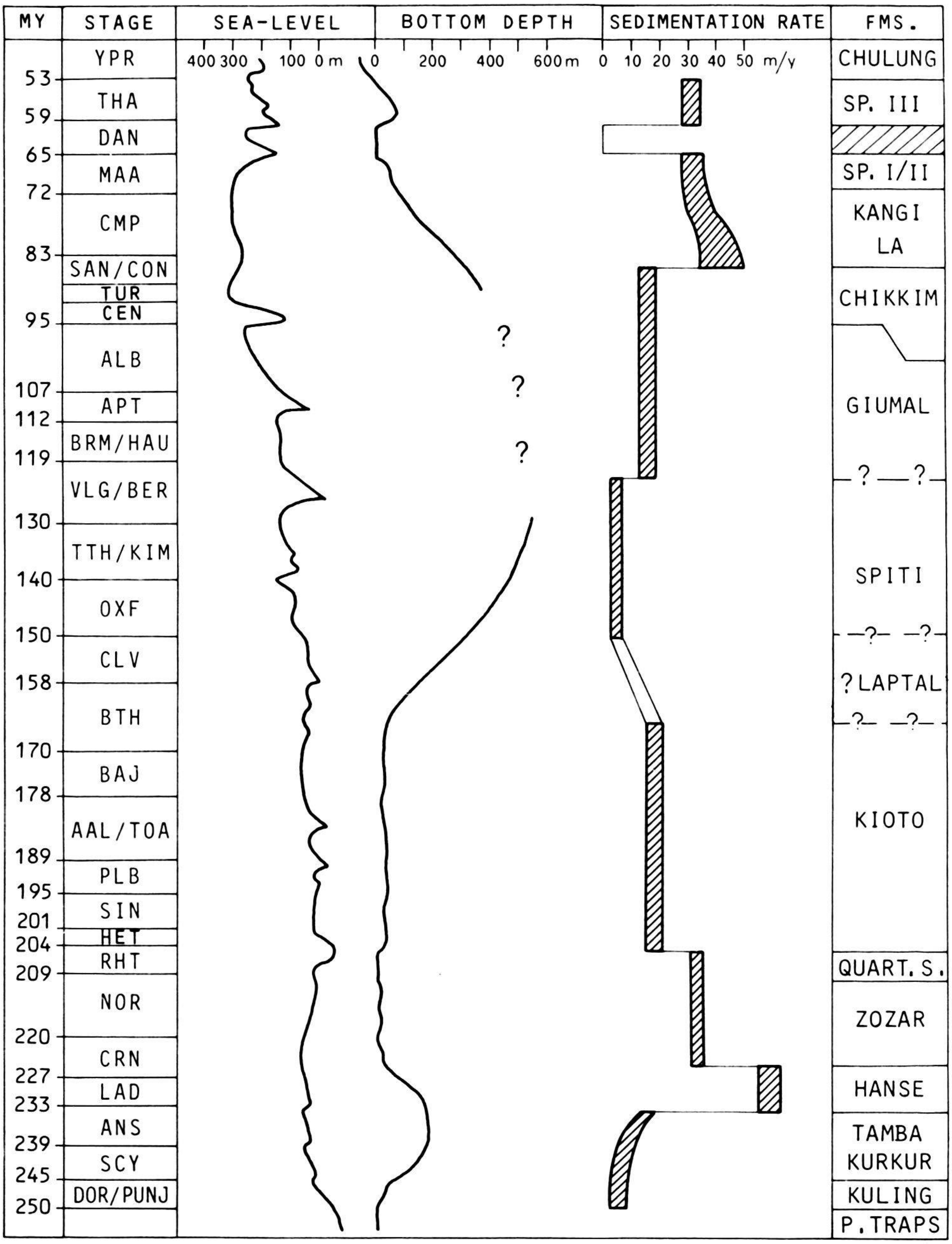

Fig. 4. Tentative evaluation of bottom depth and sedimentation rate in the interval Late Permian–Paleocene, plotted against sea-level fluctuations. Geochronic scale according to ODIN (1982), modified for the Ladinian/Carnian boundary. Sea-level linear plot from HARLAND et al. (1982), adapted to ODIN'S (1982) scale. Tectonic squeezing and overpressure prevent from correcting for sediment compaction and from calculating their loading, following the method proposed by SCLATER & CHRISTIE (1980). That is why the sediments have been decompacted by a standard value of 30%. For the interval Zozar Formation–Kioto Limestone the sedimentation rate is close to the total subsidence.

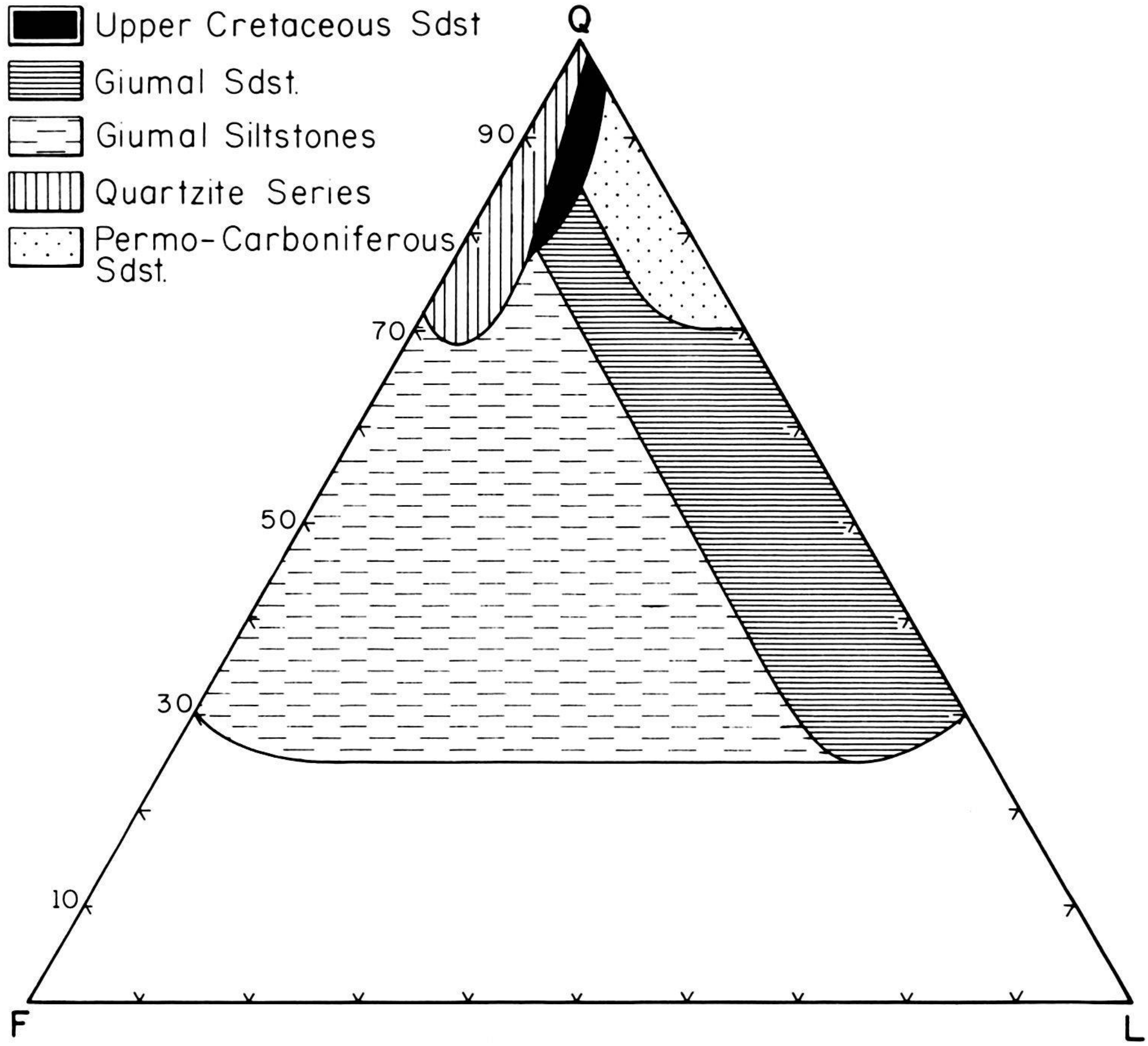

Fig. 5. QFL plots (DICKINSON & SUCZEK 1979) for the sandstones of the Tibetan Zone are only suggestive, due to the often very scanty samples. The Paleozoic sandstones fall in the field of Recycled Orogen, Foreland Uplift Provenance (Thaple and Ganmachidam Formations) and Continental Block, Craton Interior Provenance (Permian sandstones). Also for the Quartzite Series a Craton Interior Provenance is indicated. For the Giumal Sandstone, instead, a mixed Cratonic–Magmatic Provenance might be suggested. The Upper Cretaceous sandstones are again in the Craton Interior Provenance field, up to the very top of the Mesozoic (2° Member of the Spanboth Formation).

The structural framework of the sedimentary sequence

Along our field trip through Zanskar, we made several observations which allowed us to put forward a structural interpretation different from those previously proposed (GANSSER 1964, NANDA & SINGH 1977, SRIKANTIA et al. 1980, FRANK et al., in press). As we have briefly reported (BAUD et al. 1982a, BAUD 1983), also north of the High Himalayan Chain important overthrusts are present. We will illustrate the reasons of our interpretation mainly by pictures, geological profiles and sketches, drawn mostly from photographs (Fig. 6–12).

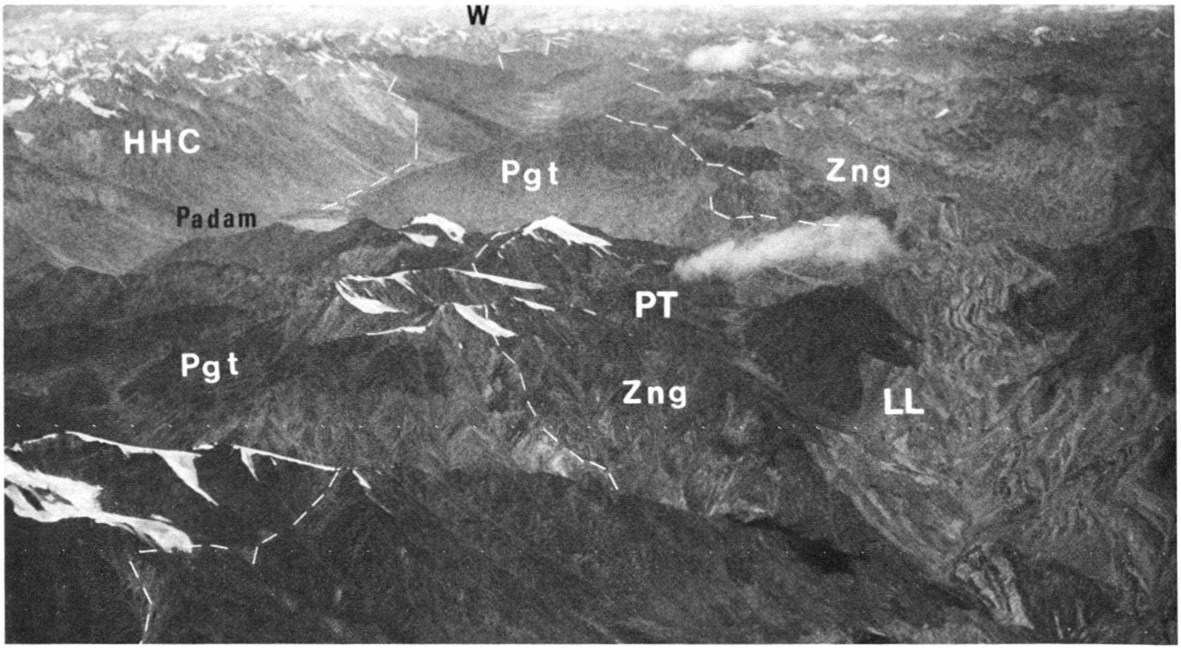

Fig. 6. General picture of the Central Zanskar from the Leshun Peak. The Pughtal (Pgt) Unit is divided from the High Himalayan Crystalline (HHC) by a steep tectonic contact. The thrust plane separating the Zangla (Zng) and the Pughtal Unit is instead moderately inclined. The Zangla Unit progressively conceals the underlying Pughtal Unit to the west. The "décollement" folds in the Lilang Group (LL) north of the Tongde La have to be noted; PT = Panjal Traps.

The Pughtal Unit

The Pughtal Unit consists of mainly Paleozoic sedimentary rocks, but the lowest unit with still clearly recognizable sedimentary structures (Phe Formation) reaches down to the Precambrian.

The Tibetan sediments were likely deposited upon an older continental crust (Rb/Sr Precambrian ages and high initial Sr isotopic ratio of the Cambrian granites) but the effect of a Cambrian (Pan-African) intrusive event is documented, and the Himalayan regional metamorphic overprint is prominent.

Moreover, we suggest that the lower contact of the unit is a northeast-dipping thrust of regional extent. It can be followed from the Chandra and Bagha Valleys in northern Lahul, where the dip is gentle (10–30°), to the upper Doda Valley, where it is much steeper (45–70°).

In our interpretation, the Pughtal Unit results from a himalayan pre- to synmetamorphic decoupling of the Tibetan cover from its now buried basement and possibly Proterozoic sediments. The structure of the Pughtal Unit is characterized by kilometric recumbent folds with axial planes generally dippling gently to the north, affecting both Cambrian (Karsha Formation, Fig. 8) and post-Cambrian units (up to the Muth and Lipak Formations, Fig. 7, 9). Therefore we cannot help interpreting the main deformation of the sequence as surely post-Early Carboniferous. The deformation was likely carried out at regional metamorphic conditions of very low to medium grade during the progress of the Himalayan Orogeny.

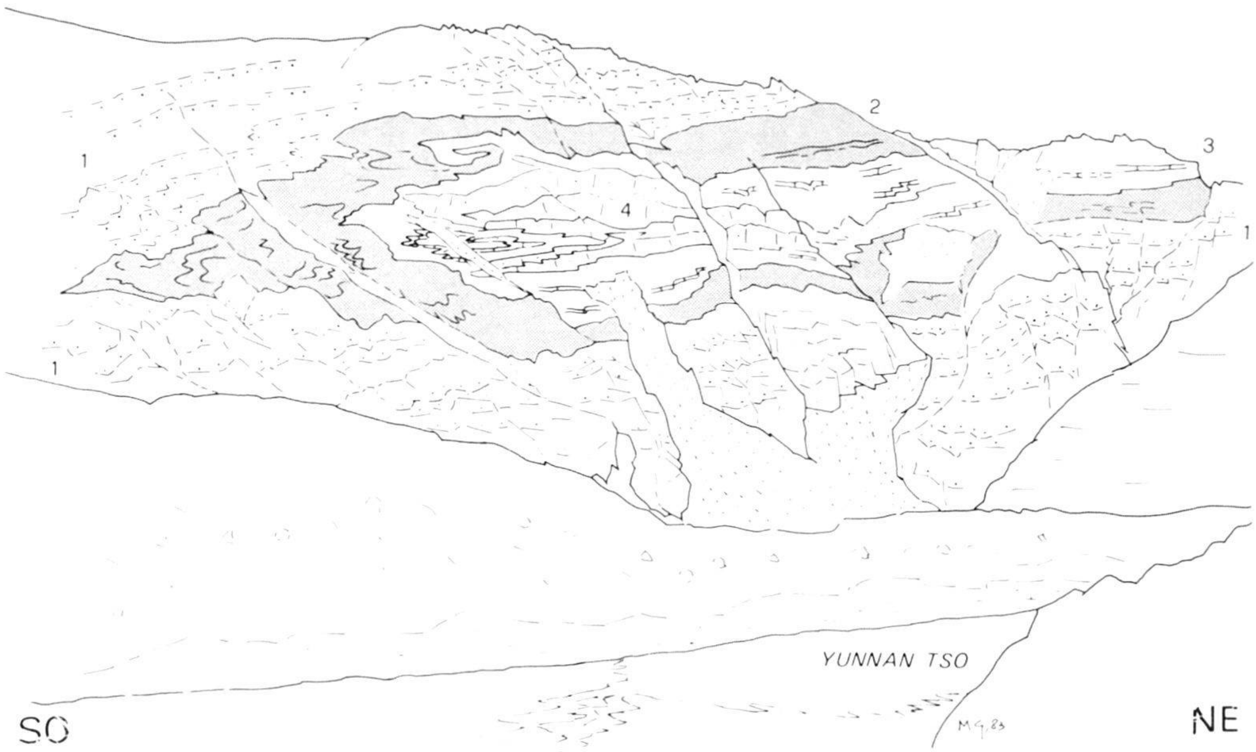

Fig. 7. Recumbent southwest vergent syncline in the Pughtal Unit of the Tibetan Zone, northern Lahul, Yunnan Valley, westside, north of the Yunnan Tso, between Baralacha La and Sarchu. 1 = Thaple Formation, 2 = Muth Quartzite; 3 = Lipak Formation; 4 = Po Formation + ?Ganmachidam Formation.

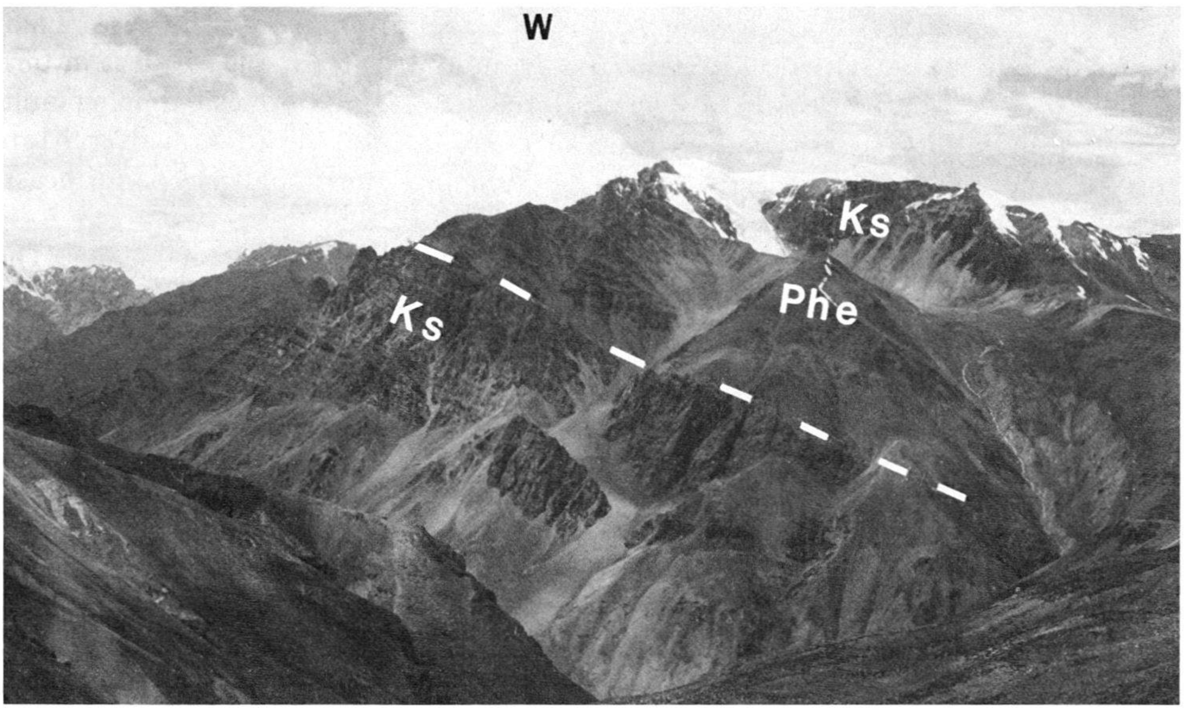

Fig. 8. Pughtal Unit of the Tibetan Zone. Recumbent anticline in the Karsha (Ks) Formation overthrusted by the Phe and Karsha Formations. Upper Valley of the Kurgiakh, southwest side, seen from the Phirtse valley.

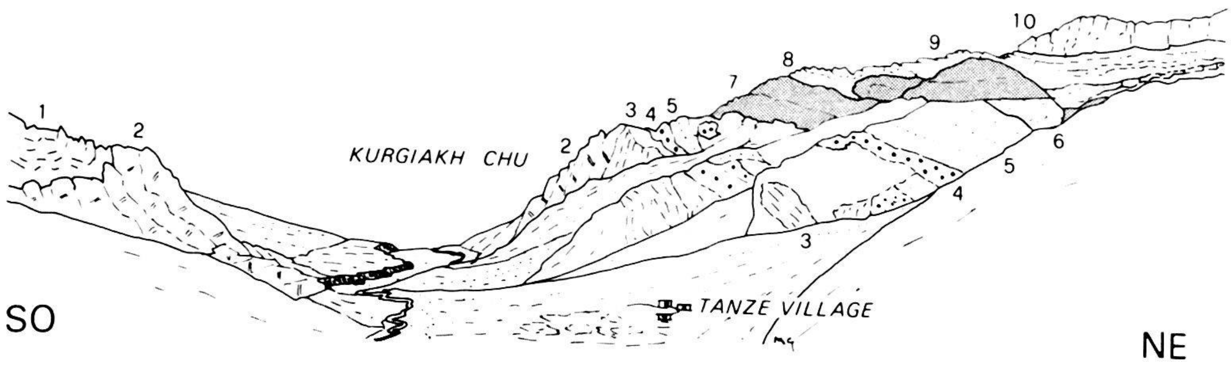

Fig. 9. The subhorizontal slab of the Zangla Unit rests tectonically upon a southwest vergent syncline/anticline in the Pughtal Unit. 1 = Phe Formation; 2 = Karsha Formation; 3 = Shales and siltstones of the upper part of the Karsha Formation; 4 = Thaple Formation; 5 = Muth Quartzite; 6 = Lipak Formation; 7 = Panjal Traps; 8 = Kuling + Tamba Kurkur Formation; 9 = Hanse Formation; 10 = Zozar Formation.

SRIKANTIA et al. (1980) described also low-angle imbricate thrusts within the Thango (Thaple), Muth, Lipak and Po Formations in the Lingti and Tanze areas. Late vertical faults with NW–SE trend cut the Pughtal Unit in the upper Chandra through upper Bagha Valleys, up to Chumik Marpo and Phirtse La areas, while the trend becomes WNW–ESE along the Lingti Valley (Fig. 2, 10). This very interesting area requires further detailed structural work.

The Zangla Unit

This unit overlaps progressively the Pughtal Unit from the Lingti Valley to the west, along a northeast shallow-dipping thrust plane, until west of the Pensi La it comes directly in contact with the HHC. To the northeast, the Zangla Unit is in turn tectonically overlain by the Zanskar Nappes, along a north- to northeast-dipping fault, described by FUCHS (1982b) in the area between Rusi La and the Zanskar river. More eastward, northeast of Zangla, it underlies the Zumlung Unit along a steep, northeast-dipping crush zone (BAUD et al. 1982b, 1983).

The base of the Zangla Unit is usually made of the competent Panjal Traps. The "détachement" zone occurs along incompetent Carboniferous horizons. The underlying structures of the Pughtal Unit are sharply cut and deformed by the thrusting processes (see Fig. 11 and 12). The Triassic rocks of the Zangla Unit display disharmonic folds with steep axial surfaces (Fig. 6). The deformation locally affected even the thrust plane, and thus they are later than the thrusting phase. The rigid Panjal Traps, instead, are cut in long slabs pushed one over the other ("écaillage") toward the south, as it can be well observed in the Karsha area (Fig. 11).

Large "décollements" are developed also within the Zangla Unit between the Panjal Traps and the marly lower Lilang. The latter, in the Tsarap gorge north of Pughtal, is affected by a closely spaced, vertical, N 160 trending slaty cleavage.

The deformation of the Lilang Group is less intense in the Phirtse La area, while the folds become tighter and then isoclinal with steep axial surfaces in Central Zanskar. Seemingly in response to the increasing temperature of deformation, the style becomes

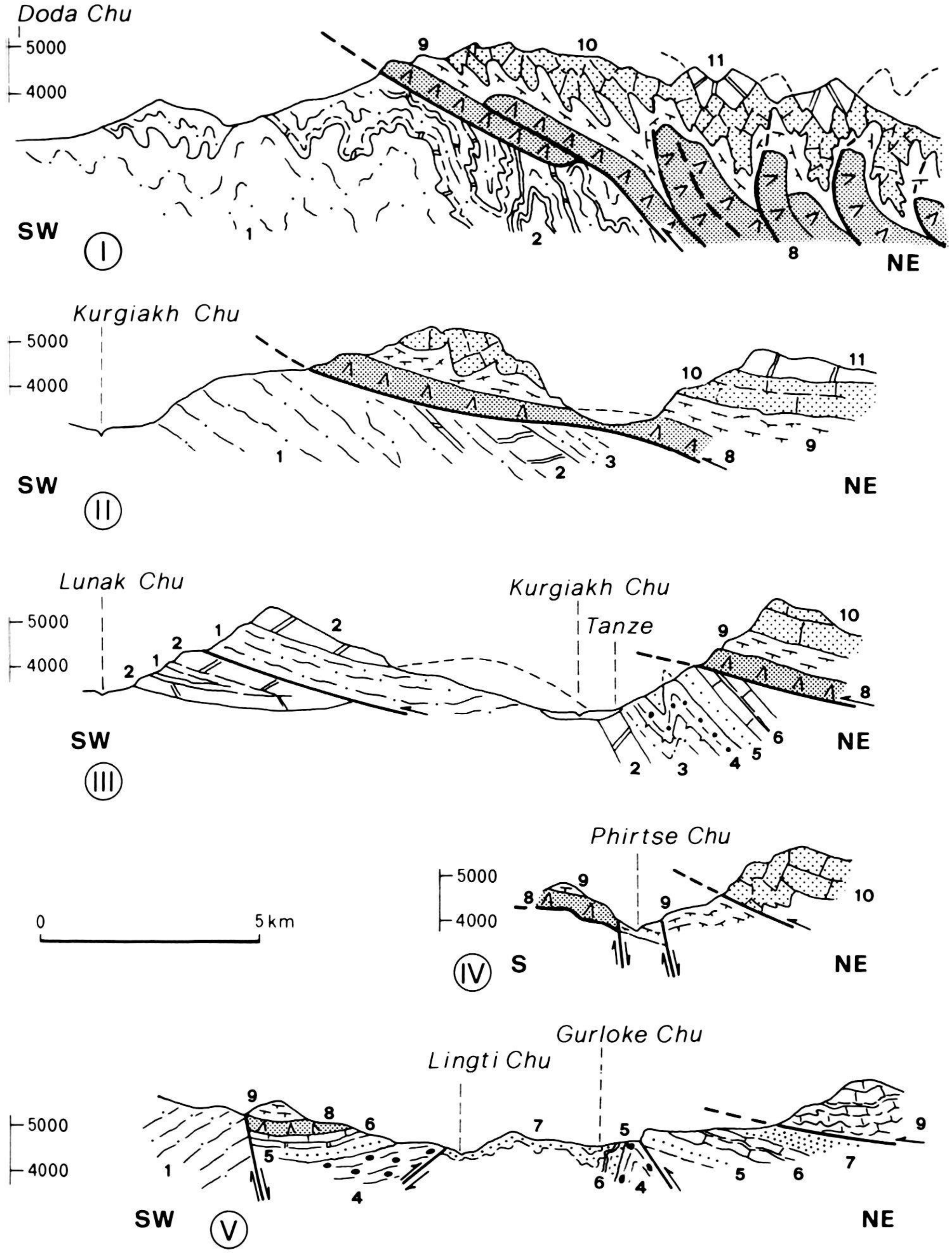

Fig. 10. Sections across the Pughtal/Zangla thrust. Location indicated in Figure 1. 1 = Phe Formation; 2 = Karsha Formation; 3 = Shales and siltites of the upper part of the Karsha Formation; 4 = Thaple Formation; 5 = Muth Quartzite; 6 = Lipak Formation; 7 = Po + Ganmachidam Formations; 8 = Panjal Traps; 9 = Kuling, Tamba Kurkur and Hanse Formations; 10 = Zozar Formation and Quartzite Series; 11 = Kioto Limestone.

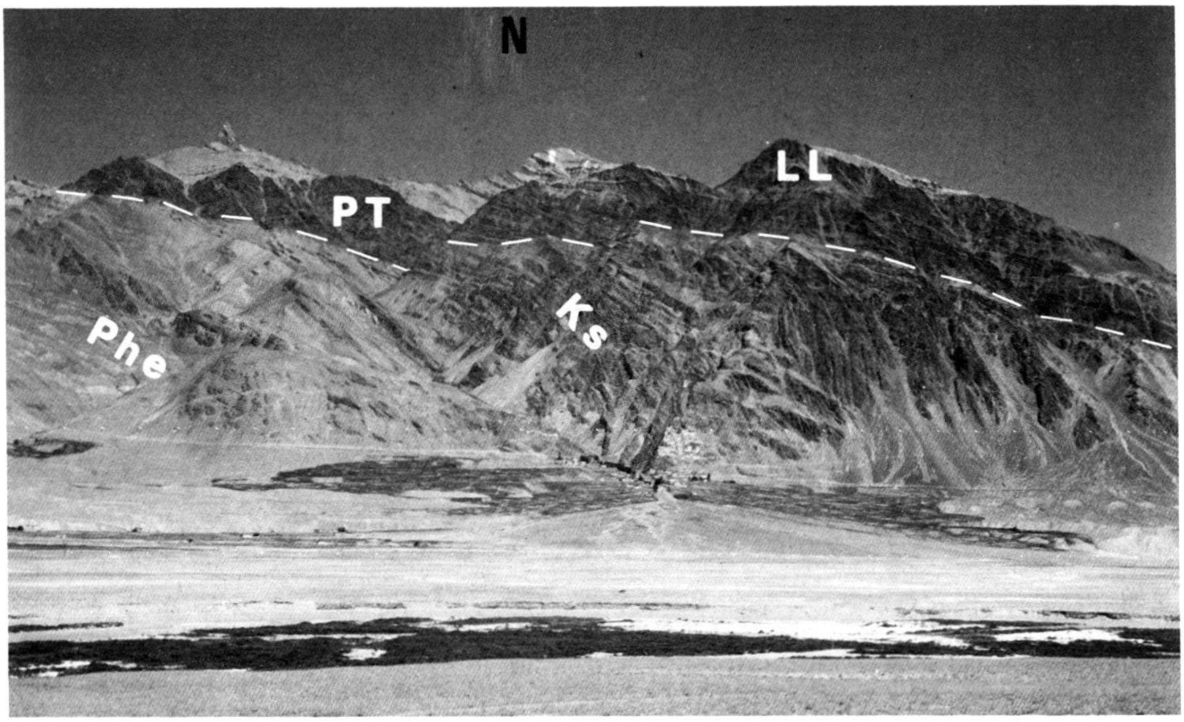

Fig. 11. The thrust of the Zangla Unit at Karsha Gompa. The underlying Karsha (Ks) Formation is isoclinally folded and the heads of the dolomite beds are sharply bent to the southwest by the advance of the thrust sheet. The slab of the Panjal Traps (PT) constitutes the rigid sole of the Zangla Unit. The overlying Lilang Group (LL) is instead characterized by "décollement" folding.

even more plastic at Ringdom, where the amplitude of the isoclinal folds increases, the axial plane is less steep, and it dips to the northeast. Higher in the sequence, within the Kioto Group, hectometric chevron folds are the prominent feature, while within the Cretaceous and Tertiary rocks tight folds with axial planes even horizontal or dipping to the north are developed.

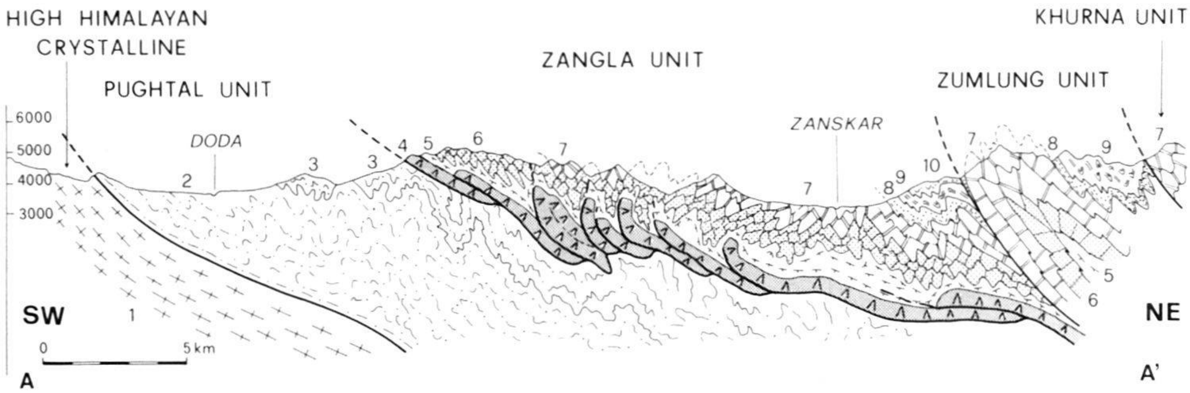

Fig. 12. General section across Central Zanskar, showing the geometrical relations and the structural interpretation of the Tibetan Zone. 1 = HHC; 2 = Phe Formation; 3 = Karsha Formation; 4 = Panjal Traps; 5 = Kuling, Tamba Kurkur and Hanse Formations; 6 = Zozar Formation and Quartzite Series; 7 = Kioto Limestone; 8 = Spiti Shale and Giumal Sandstone; 9 = Chikkim Formation; 10 = Kangi La Formation.

Microscopic observations

The rocks of the Zangla Unit are almost always strongly and pervasively deformed at microscopic scale. Pressure-solution processes and strained cements are prominent features, both in carbonate and in terrigenous rocks. In Permian, Upper Triassic and even Cretaceous sandstones the grain boundaries are mainly sutured; undulatory extinction and deformation bands and lamellae in quartz crystals developed after deposition. In the Ringdom area the temperature was high enough to allow the formation of very small newly-grown quartz crystals in the sites of maximum strain even at the very top of the Mesozoic sequence. CARTER et al. (1964) failed to obtain experimentally intense deformation of quartz below 300 °C; recrystallization took place only at even much higher temperatures.

We tried to assess the maximum temperatures reached by the Conodont Color Alteration Index (CAI) method (EPSTEIN et al. 1977, HARRIS 1979), and determined a CAI of 4½ or even 5 in most cases for the conodonts of the Lilang Group. Therefore, temperatures reaching 250–300 °C and even more in Ringdom area during the post-depositional heating of the Triassic rocks can be assumed. These cannot be ascribed to sedimentary burial alone, and thus tectonic burial necessarily played an important role. We conclude that the Mesozoic rocks of the Zangla Unit, that dip away from the medium/high grade reaching metamorphic core of the HHC, are anchimetamorphic rocks affected by the regional heating consequent to the structural overburding, due to the Himalayan Orogeny, at temperatures probably exceeding 200 °C even at the top of the unit.

Conclusions

The analysis of this Tibetan sedimentary sequence from Late Precambrian to ?Eocene has shown:

- an uplift and erosion phase during Late Cambrian/Ordovician time. This is an additional datum for the elusive problem of the final episode of the Pan-African Orogeny in the present Himalaya;
- the absence of evidence accounting for a Hercynian Orogeny;
- the behaviour of the Tibetan Zone as the passive continental margin of the Indian Plate from Late Permian to Paleocene.

The rifting phase began with the Panjal Trap effusion, inducing a marine transgression in the latest Permian. Pelagic conditions were reached in the Early Triassic. The intense sedimentation along with the decreasing subsidence led to the filling up of the basin and to peritidal conditions since the Middle Carnian. Shallow-water sedimentation went on until the Middle Jurassic, when the carbonate platform of the Kioto Limestone was drowned. The bathyal stage was reached in the Late Jurassic. After the siliciclastic event of the Giumal Sandstone, pelagic sedimentation was renewed. After the Campanian the seafloor depth was reduced by the intense sedimentation and the decreasing subsidence. The close of the Cretaceous is characterized by a regressive terrigenous event, and major gaps occur in the Lower Paleocene.

The sedimentation seems to have been controlled more by global eustatic cycles than by regional tectonic movements. The subsidence rate, in fact, never reached very high values in the Zanskar area, reflecting moderate stretching of the underlying continental crust only in the Middle Triassic. The terrigenous supply was mostly derived from the Indian Craton throughout the Phanerozoic, mainly during major eustatic regressions. The sandstone composition records a major uplift phase in the Ordovician and a problematic volcanic event in the ?Early Cretaceous. Fairly stable conditions prevailed all over the considered time, and thus the total thickness of the sequence is less than in typical "geosynclines".

As far as the structure is concerned, we suggest a model in which the Tibetan Zone sediments are not the sedimentary, but the tectonic cover of the High Himalayan Crystalline. This "allochthonist" interpretation could fully explain also the setting of the Tandi metasediments. The Tibetan sequence is interpreted as arranged in two units (Pughtal and Zangla).

The Pughtal Unit is characterized by a low grade metamorphic to anchimetamorphic overprinting and by kilometric recumbent folds. The Zangla Unit was deformed at an anchimetamorphic temperature (250 °C) with development of mainly disharmonic "décollement" folds in the lower level (Lilang Group), chevron folds in the Kioto Limestones and tight overturned folds in the upper levels (Cretaceous–Paleocene).

The large scale shortening processes and the main deformations of the sedimentary cover are related to:

- The decoupling of the sedimentary units and their carriage to the southwest. This post-Early Eocene event is considered as contemporaneous or slightly later than the obduction of the Spongtang Ophiolites upon the Zanskar Zone and consequent to the underthrusting of the distal Indian continental margin below the Asian plate.
- The "en chevron" to isoclinal folding and imbricate minor thrusting with resulting deformation of the major thrust planes.
- The latest backfolding and backthrusting appearing mainly in the western part of the considered area.

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