Riv. It. Paleont. Strat.	v. 91	n. 4	pp. 443–478	Febbraio 1986

STRATIGRAPHY OF THE TETHYS HIMALAYA IN ZANSKAR, LADAKH
INITIAL REPORT

MAURIZIO GAETANI*, RAFFAELE CASNEDI**, ELISABETTA FOIS*, EDUARDO GARZANTI*, FLAVIO JADOUL*, ALDA NICORA* & ANDREA TINTORI*

Key–words: Stratigraphy, Sedimentology, Paleozoic, Mesozoic, Paleogene, Himalaya, India, Ladakh.

Abstract. The preliminary results of the 1984 Italian Geological Expedition to Zanskar are given as a general account of the stratigraphy of the Tethys Himalaya succession. The sedimentary sequence has been subdivided in three parts, from Late Precambrian to Eocene.

The *Late Pan–African Episode* (Late Precambrian–Ordovician) is represented by a complete sedimentary cycle. In pre–Middle Cambrian times, terrigenous to carbonate tidal flat facies (Phe and Karsha Fms.) record an overall relative sea–level rise during the thermal subsidence of a passive continental margin. In the Middle Cambrian, the drowning of the Karsha platform, with transition to offshore shales and turbidites (Kurgiakh Fm.) testifies to the formation of a deep–water basin. In the Ordovician, continental red beds were laid down by a braided–river system draining a newly–formed mountain belt (Thaple Fm.).

The *Epicontinental Stage* (Late Ordovician–Late Carboniferous) is characterized by low sedimentation rates under transitional to shallow–marine conditions. The white sandstones of the Muth Quartzite (Devonian) are followed by the fossiliferous dark carbonates of the Lipak Fm. (Early Carboniferous). Finally, a gypsum interval of Carboniferous age, which represents a major "décollement" horizon in the Tanze area, is overlain by Late Carboniferous shallow–marine to deltaic clastics (Po Fm.). Imbricate thrusts affect this part of the succession.

The *Passive Continental Margin Stage* (Permian–Eocene) begins with basaltic flows (Panjal Traps) followed by a hybrid arenite unit, capped by a dark shale level (Kuling Fm., latest Permian). The Triassic starts with pelagic and condensed nodular limestones (Tamba Kurkur Fm., Scythian–Anisian). Important clay influx occurred during the Ladinian, when a thick marly–limestone unit was deposited (Hanse Fm., Ladinian–?Carnian). The latter is overlaid by peritidal carbonates (Zozar Fm., Carnian–Norian), followed by terrigenous sedimentation prograding on a shallow inner shelf ("Quartzite Series", Norian–?Rhaetian). The carbonate platform resumed in the latest Triassic and Early Jurassic, probably lasting till the beginning of the Dogger (Kioto Limestone). After a major sedimentary gap, chamosite/goethite oolites, shales and sandstones were deposited in the Callovian (Ferruginous Oolite Fm.), followed in the Late Jurassic by clay sedimentation on a mid–outer shelf only episodically disturbed by storm events (Spiti Shale). Marked increase in terrigenous detritus brought by deltaic systems onto the shelf characterized the Early Cretaceous, when an important volcanic episode affected the continental margin (Giumal Sandstone). During the following transgressive stage (Turonian–Early Campanian), the grey nodular limestones of the

* Dipartimento di Scienze della Terra dell'Università degli Studi di Milano, Via Mangiagalli 34, Milano, Italia.

** Dipartimento di Scienze della Terra dell'Università di Pavia, Corso Strada Nuova 65, Pavia, Italia.

– Ricerca finanziata dal MPI 40 %. Progetto "Geologia NW Himalaya e Karakorum".

Chikkim Fm. and the coeval multicoloured pelagic limestones of the Fatu La Fm. were deposited. A renewal of terrigenous influx determined the progradation of the thick Kangi La Fm. (Campanian–Early Maastrichtian). A carbonate ramp resumed in the Late Maastrichtian, capped by deltaic quartzarenites, and by open to restricted shelf carbonates of Paleocene–earliest Eocene age (Spanboth Fm.). The passive margin sequence is capped by subaerial fluvio–deltaic red beds (Chulung La Fm.) derived from volcanic rocks of the active margin, and thus marking the final welding of the Indian Plate against Eurasia.

Introduction.

This is the initial report of the Italian Geological Expedition to Zanskar (NW Himalaya) carried out in August and September 1984 (1). The itinerary from Ringdom Gompa to Darcha in Lahul is shown in Fig. 1. The present paper deals with the stratigraphy of the sedimentary sequence, ranging from Late Precambrian to Early Eocene. It crops out northeast of the High Himalayan Crystalline and belongs to the Tethys Himalaya Zone.

Following the interpretation of Baud et al. (1984) and Casnedi et al. (1985), the Tethys Himalaya succession of Zanskar can be subdivided in three parts: 1) the Late Pan–African Episode (Late Precambrian–Ordovician); 2) the Epicontinental Stage (Late Ordovician–Late Carboniferous); 3) the Passive Continental Margin Stage (Permian–Eocene). For the previous knowledges on the area we refer to Baud et al. (1984).

Two short papers on stratigraphy have already been published. The first one on the Late Permian/Early–Middle Triassic (Nicora et al., 1985) and the second on the Middle Jurassic (Jadoul et al., 1985). An account on the main elements of the structure (Gaetani et al., 1985) and an abstract on the Lower Paleozoic sedimentology (Casnedi et al., 1985) have also been issued. A more advanced paper on the sedimentological evidence of the Late Pan–African Episode in the Early Paleozoic is presently in press (Garzanti et al., 1985).

The Late Pan–African Episode.

Geological observations carried out on the Phugtal Nappe in the Kurgiakh –Phugtal area allow to present new evidence on the lowermost Paleozoic sedimentary evolution (Fig. 2).

Phe and Karsha Formations. (RC, EG, FJ).

The Phe Fm. (at least 800 m thick) consists of grey micaceous siltstones prevailing over very fine–grained and moderately sorted subarkoses. Both wave and current ripples are commonly observed, along with mudcracks and slump features. Cross–bedded sand bars and channelized units also occur. The age is latest Precambrian to Early Cambrian according to most previous Authors.

(1) This paper is first of all a common effort of the staff of the expedition. Initials refer to those Authors who mostly worked out the single stratigraphic units.

The Karsha Fm. is made of sandstones, siltstones and dolomites (Mauling Member, about 400 m thick) passing upward to massive dolomites (Thidsi Member, 200–300 m thick) and bedded carbonates (Teta Member, 70–160 m thick). The Mauling Member consists of very fine–grained subarkoses and micaceous siltstones with intercalated rusty dolomites in beds up to 15 m thick. Cross–bedded sand bars and current ripples show multimodal paleocurrent patterns. The Thidsi Member is made of amalgamated beds of grey dolomites,

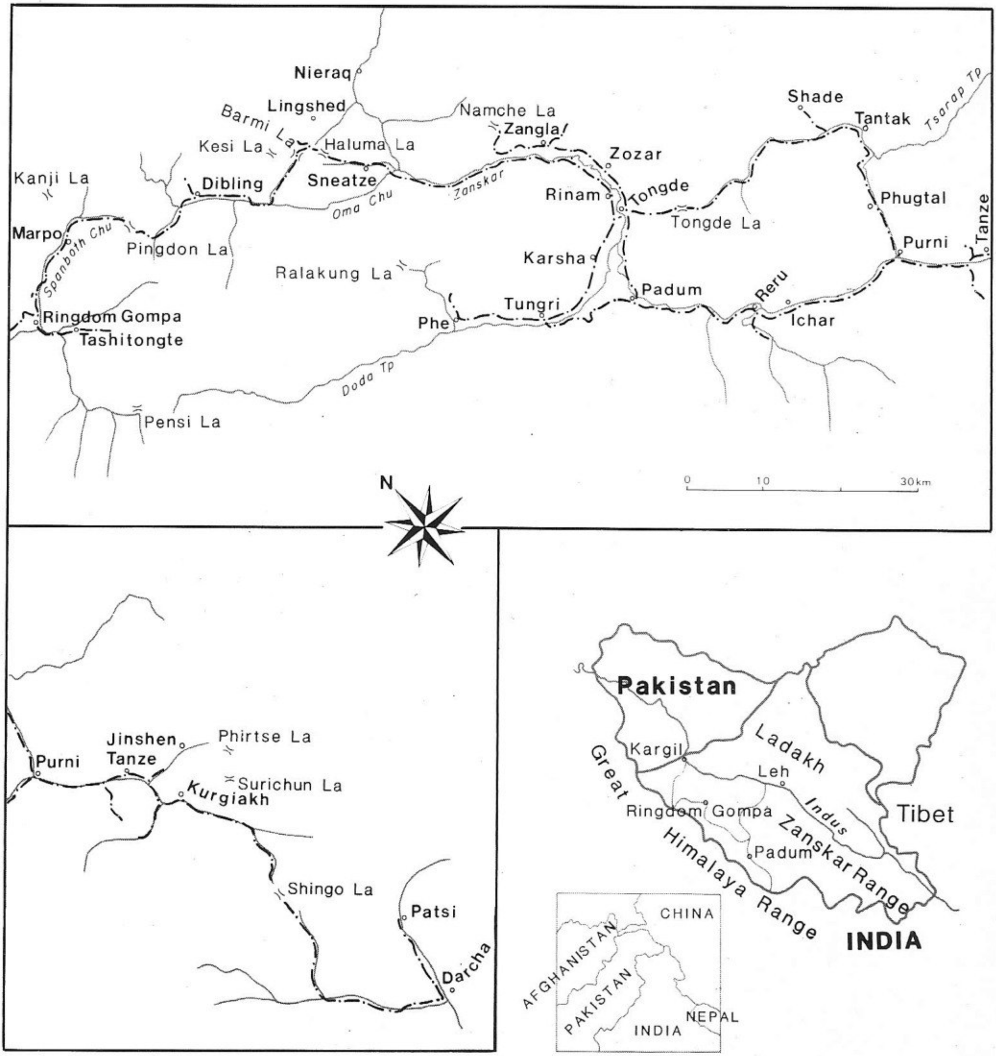


Fig. 1 – Index–map of the investigated area with the itineraries followed by the different parties of the Italian Expedition, from Ringdom Gompa to Darcha. Geographic name spelling according to Pegasus map (1983).

locally separated by pyritic shales. Bioturbated micrites with bioclastic lenses and metric algal mounds (*Epiphyton* boundstones; Fig. 3) are associated with subordinate fenestral deposits. The Teta Member consists of nodular and bedded carbonates with dark–green pelitic intercalations progressively increasing upward in thickness and abundance. Domal blue green Algae hemispheroids, thrombolite mounds, tabular and reticulate stromatolites are common in the lower part. The age is Early–?Middle Cambrian according to stratigraphic position.

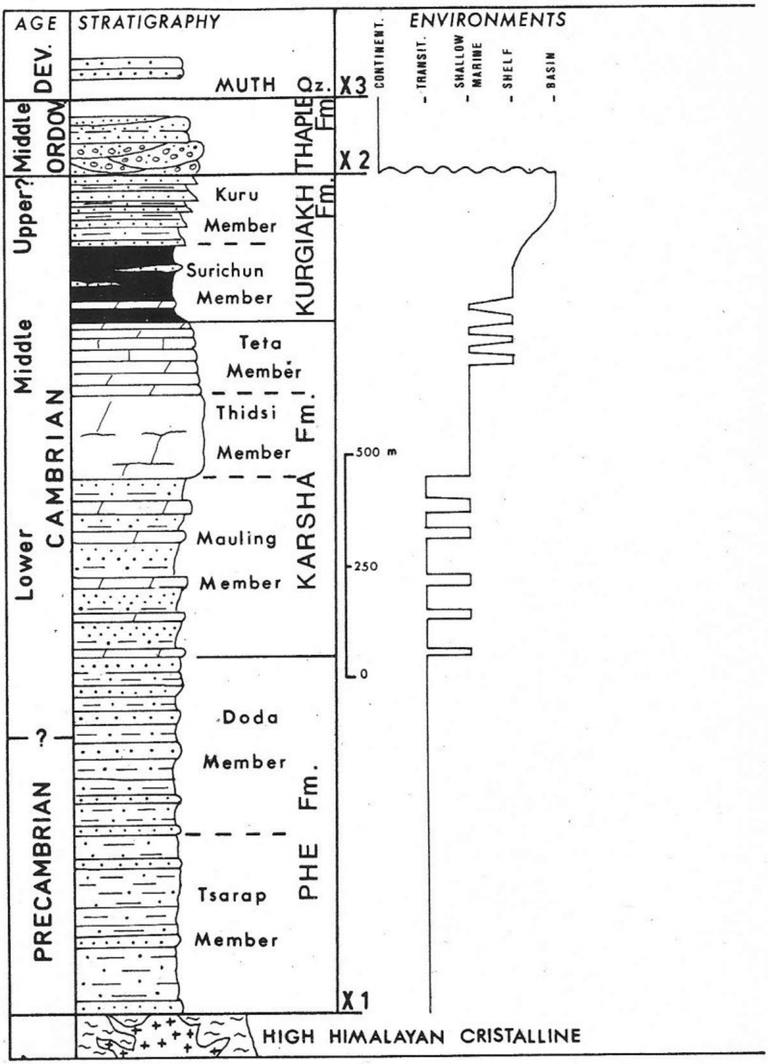
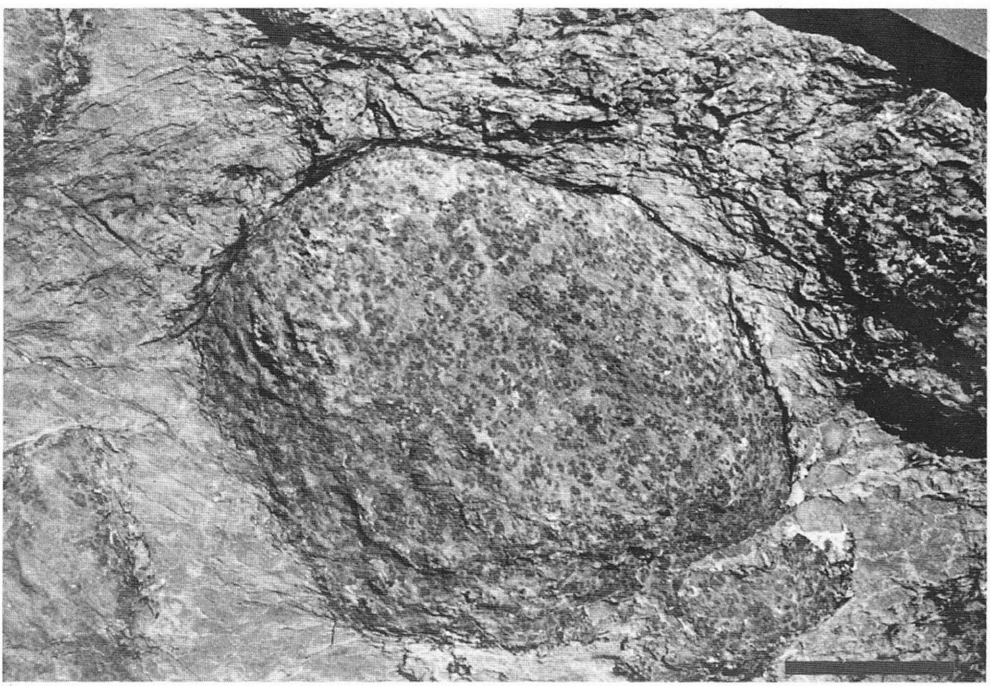


Fig. 2 – Lower Paleozoic stratigraphic scheme and basic environment interpretation. X1, X2, X3, mark major faults dissecting the sequence.

The Phe and Karsha formations were deposited on a tidal flat, as shown by the widespread occurrence of rhythmic sand/mud ripple–bedded units and bidirectional cross–lamination. Sandstone mineralogy indicates provenance from the craton interiors of a continental block and a passive margin setting (Dickinson & Suczek, 1979). The interbedded and overlying dolomites mark stages of low terrigenous influx in a shallow subtidal to intertidal environment. The Teta Member records a gradual increase of water–depth from peritidal to outer shelf nodular facies (Fig. 4).

Kurgiakh Formation. (RC, FJ, EG).

The Kurgiakh Fm. can be subdivided in a lower shaly part (Surichun Member, about 150 m thick) containing Middle Cambrian trilobites (H.B. Whittington, pers. comm.) and an unfossiliferous upper silty/sandy sequence (Kuru Member, at least 150 m thick). The age of the unit is thus Middle to ?Late Cambrian. The Surichun Member consists of dark bioturbated pelites with intercalated nodular dolomites and a few basaltic tuff layers. The Kuru Member is a thickening–coarsening upward megasequence of thin–bedded greenish siltstones characterized by Tb–d Bouma sequences passing upwards to thick–bedded, very fine–grained subarkoses. The Kurgiakh Fm. records the transition



from shelf and slope sedimentation in poorly oxygenated waters to non–channelized distal turbidites. The sedimentary evolution thus testifies active tectonic subsidence which largely exceeded sedimentation rates.

Thaple Formation. (EG, RC).

The Thaple Fm. (at least 150 m thick) is always bound by fault contacts in the Kurgiakh Valley, whereas in the Spiti region the conglomerates directly overlay equivalents of the Karsha Fm. with angular unconformity (Hayden, 1904). A Middle Ordovician age is assumed for the unit, since in Spiti the marine beds overlying the conglomerates contain a Caradoc fauna (Hayden, 1904). The lower part consists of mostly framework–supported cobble conglomerates separated by discontinuous lenses of cross–laminated weak red sandstones. Higher in the sequence, medium–grained and moderately sorted dusky red litharenites with trough cross–lamination prevail over conglomeratic sandstones and very fine–grained sandstones alternating with siltstones. Mud is virtually lacking. The section is closed by reddish yellow, fine–grained and moderately well–sorted, cross–bedded quartzose litharenites overlain by

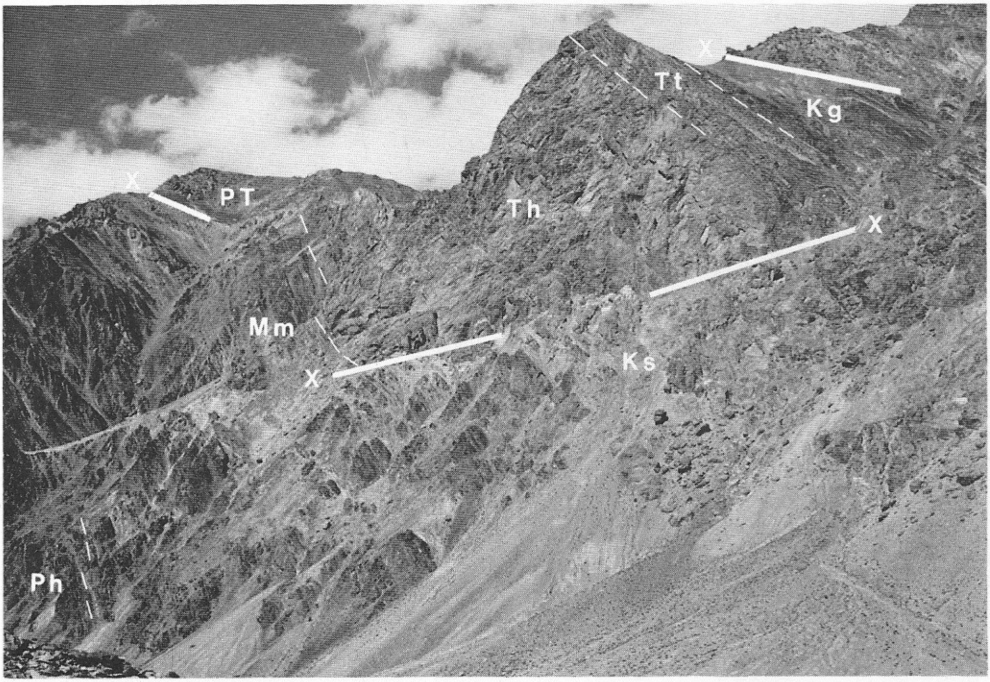


Fig. 4 – The Cambrian sequence in the Tanze area in front of Kuru. Ph = Phe Fm.; Ks = Karsha Fm. including Mauling Mb. (Mm), Thidsi Mb. (Th), Teta Mb. (Tt); Kg = Kurgiakh Fm.; PT = Panjal Traps; X – X = faults.

pebbly sandstones. The sedimentary structures and vertical arrangement of lithofacies in fining–upward cycles point to a subaerial alluvial environment, passing from alluvial fan to braid–plain. The Thaple sandstones are sedarenites rich in dolomitic and terrigenous rock fragments, indicating provenance from uplifted sedimentary sequences. This orogenic event can be tentatively dated as Late Cambrian–Early Ordovician and correlates with the emplacement of Late Pan– African granitoids (1).

The Epicontinental Stage.

The long interval between the molassic Thaple Fm. (Ordovician) and the Panjal Trap volcanics (Permian) is represented by a shallow–marine to deltaic quartzarenite/carbonate succession a few hundred m thick. The reduced subsidence rate and the sedimentary facies testify to stable platform conditions between the end of the Pan–African Event and the beginning of the Himalayan Cycle.

Muth Quartzite. (EG).

A 50 m thick section, tectonically overlying pebbly sandstones of the Thaple Fm., has been measured above Tanze, but the unit was not studied in detail. The Muth Formation consists of submature to supermature, quartz–cemented white quartzarenites in beds 10 cm to more than 1 m thick. Mega-ripple cross–bedding is the prominent sedimentary structure, indicating E–ward main paleocurrent direction. Sandstones are fine to medium–grained (maximum grain size in the coarse sand range), well to moderately sorted and subrounded. They commonly show two distinct grain size modes (coarse mode at 300 to 500 μm, either largely prevailing over or subordinate to a fine mode at 150 to 200 μm) and lack detrital matrix. Quartzose detritus is exclusive, with very low polycrystalline to total quartz ratio (C/Q $\approx$ 2%), sporadic unstable clasts altered to illite and rounded ultrastable heavy minerals. Post–depositional recrystallization of stretched quartz cements is widespread. Newly –grown crystals tend to invade strained detrital grains and both quartzose framework and cements are replaced by late–diagenetic deformed calcite. Undulosity and polygonization of quartz increase close to the basal fault contact. The upper boundary between white cataclastic microconglomerates (quartz-arenitic angular clasts exceeding 1 cm in size) and marly limestones with calcareous microbreccias of the Lipak Fm. is sharp.

---

(1) We note that our timing and interpretation of the Cambro–Ordovician succession is greatly different from Gupta's ideas on the same area (Gupta, 1977, 1981; Gupta & Shaw, 1982).

The studied section corresponds to the upper member of the Muth Quartzite described by Mukherjee & Dasgupta (1972), who give a Middle Devonian age and infer an eolian depositional setting from lack of fossils and bimodal grain size distribution. Banerjee (1974) suggests a beach environment for the unit, probably influenced by eolian processes. The ultrastable composition points to multicyclic provenance from older sandstones ultimately derived from craton sources (Suttner et al., 1981).

Lipak Formation. (FJ).

This formation crops out in the Tanze–Kurgiakh area where it is strongly deformed by the Himalayan fold–thrust tectonics. It develops under two superposed different lithologies. Dark grey limestones below and white gypsum with black limestone interbedding above (Fig. 5).

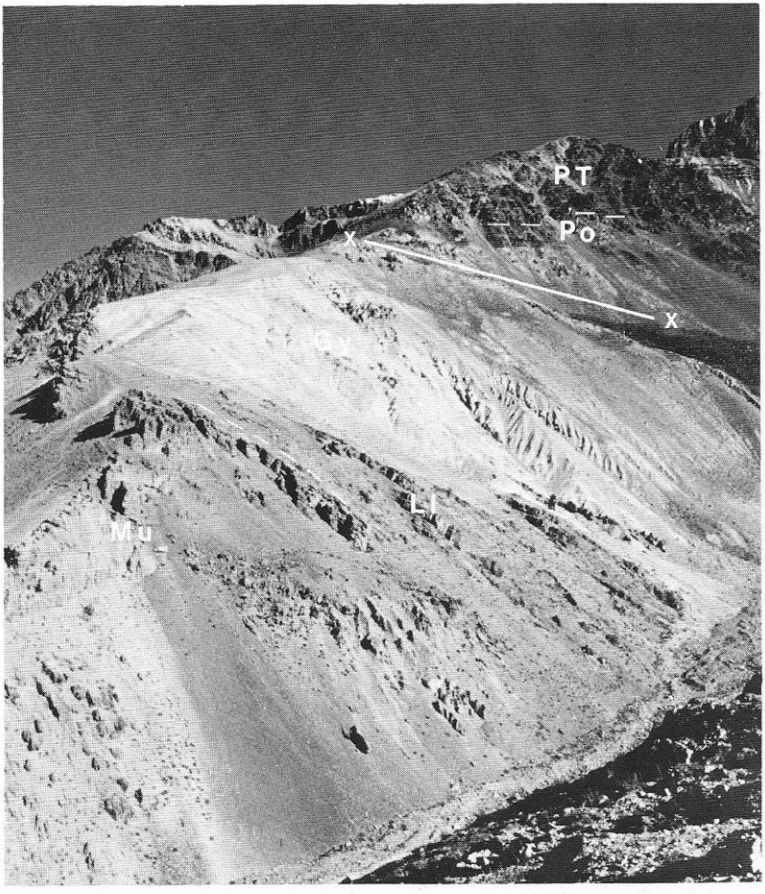


Fig. 5 – Gypsum facies in the Lipak Fm. NW of Tanze. Mu = Muth Qz.; Ll = Lipak Fm. limestone facies, Gy = Gypsum; Po = Po Fm.; PT = Panjal Traps; X – X = Main basal thrust of the Zangla Nappe.

Limestone facies.

A section has been studied in the Tanze area, about 100 m thick, and a few other observations have been made in the same area. The contact with the underlying Muth Quartzite may be transitional with few meters of dark grey arenites intercalated with white quartzarenites. It may be also sharp with black silty limestones immediately above whitish microconglomerates.

The lithology is rather homogeneous, but a few lithozones may be distinguished, bottom to top:

a) thin bedded and lenticular, dark intraclastic packstones associated with planar beds of mudstone–wackestone with rare stromatolites;

b) dark grey wackestone–mudstone with intrabioclastic packstones locally very rich in bioclasts and whole fossils (brachiopods, crinoids, bivalves);

c) dark and burrowed mudstone–wackestones associated with thin beds of sandstones and rare mud–supported conglomerates.

According to previous Authors (Srikantia et al., 1980; Baud et al., 1984) an Early Carboniferous age is assumed for this unit. This facies represents a shallow subtidal environment, possibly an open to restricted carbonate shelf.

Gypsum facies.

Previous Authors already recognized gypsum lenses in the upper part of the Lipak Fm. in the area of Tanze (Tanze Fm., Member A of Nanda & Singh, 1977; Srikantia et al., 1980). However, we would stress the thickness of the gypsum facies. It crops out in tectonic slices at the base of the Zangla Nappe. Both the contacts are affected by «décollement» tectonics (Fig. 5). Wherever observed, the gypsum facies overlies the limestone facies.

Two partial sections (41 and 58 m thick) have been measured in the two main lithozones, bottom to top:

a) thin–bedded, black mudstones with intercalated grey intrabioclastic packstones (ostracods, crinoids) with graded bedding, parallel lamination and wave ripples. Few bioturbated fossiliferous wackestones are present. Pelecypods and gastropods occur in the lower part of the section, while several specimens of a *Tomiproductus*–like productid, reaching up 25 mm in length, were collected 7 m below the first gypsum layer (identification by H.H. Brunton, London).

b) White pure layered gypsum (X–ray data), 20–23 m thick.

Age. The genus *Tomiproductus* ranges from the Middle Tournaisian till the Early Visean. Consequently, the gypsum layers seem to be Early Carboniferous in age.

This part of the Lipak Fm. represents a regressive sequence, with transition from inner shelf to sabkha environments.

Po Formation. (FJ, EG).

The Po Fm. crops out in the Tanze–Phugtal area, where it is always tectonically involved at the base of the Zangla Nappe. Its estimated thickness reaches about 70 m. The unit was not studied in detail, but three lithozones may be recognized from bottom to top:

a) well–bedded, dark–grey sandstones with subordinate silty marls. Lenticular beds frequently display parallel or low–angle cross–lamination (Fig. 6). Few bioclastic layers and burrows are present at the base. Thickness about 20 m;

b) fine to medium–grained, well to moderately well–sorted, submature to mature white quartzarenites in metric lenticular layers are interbedded with black shales (0.5 to 2 m thick). The sandstone beds typically show scoured bases locally overlain by thin conglomerate layers with clay chips. Poorly preserved moulds of *Linoproductidae* were found. Quartzose detritus is largely

predominant, but feldspar grains altered to illitic patches (Wilson & Pittman, 1977) may be present. Polycrystalline to total quartz ratio is low (C/Q ≈ 5%). Post–depositional deformation is documented by strained quartz grains and extensive recrystallization of quartz cements. Thickness about 10 m;

c) very fine–grained, moderately sorted and immature grey subarkoses in massive beds or displaying parallel–lamination are interbedded with dark siltstones. A mafic ash tuff layer was sampled at the base of this interval above Phugtal. The sandstones contain small amounts of felsitic volcanic rock fragments along with polysynthetically–twinned plagioclase grains and angular to rounded ultrastable heavy minerals. Thickness about 25 m. This lithozone may be missing above Tanze, due to either erosion prior to the Panjal Trap volcanic event or tectonic deformation.

Fossils in the Po Fm. are rare and not age–diagnostic. A Late Carboniferous age may be inferred from stratigraphic position. Sedimentary features suggest deposition on a shallow epicontinental shelf (lithozone a), followed by more proximal deltaic environments (lithozone b). Sandstone mineralogy points to partly polycyclic provenance from craton sources. Petrographic data also record basaltic volcanism in progress during the deposition of the upper Po Fm., possibly related to the onset of the major rifting event that affected Gondwanaland in the Late Paleozoic (Trommsdorff et al., 1982).

The Passive Continental Margin Stage.

The chiefly Mesozoic passive margin succession of the Zanskar Tethys Himalaya begins with the Permian Panjal Traps. These lava flows are related to continental rifting, followed by the final opening of the Neotethys ocean. The latest Permian–Early Triassic deepening sequence records the initial high thermal subsidence of the continental margin, whose evolution was later on chiefly controlled by eustatic changes and their relation with the supply of terrigenous detritus from the Indian craton versus carbonate production. This long and composite history lasted about 200 Myr, until the final welding of the Indian Plate against Eurasia in the Early–Middle Eocene (Fig. 7).

Panjal Traps. (MG, EG, AT).

The Traps consist of a series of superposed lava flows continuous throughout Zanskar. We never observed terrigenous or carbonatic sediments interbedded with the lavas. The three superposed slices present between Tongde La and Tongde are tectonically separated by respectively brachiopod and ammonite–bearing Late Permian and Early Triassic sediments of the Kuling and Tamba Kurkur formations (Gaetani et al., 1985, fig. 1). Consequently we interpret as tectonic also the corresponding slabs cropping out on the opposite side of the Zanskar Valley, between Karsha and Rinam. We have no petrographic data on the unit, but we collected a few samples from discordant mafic dykes cutting all underlying Precambrian to Carboniferous sediments.

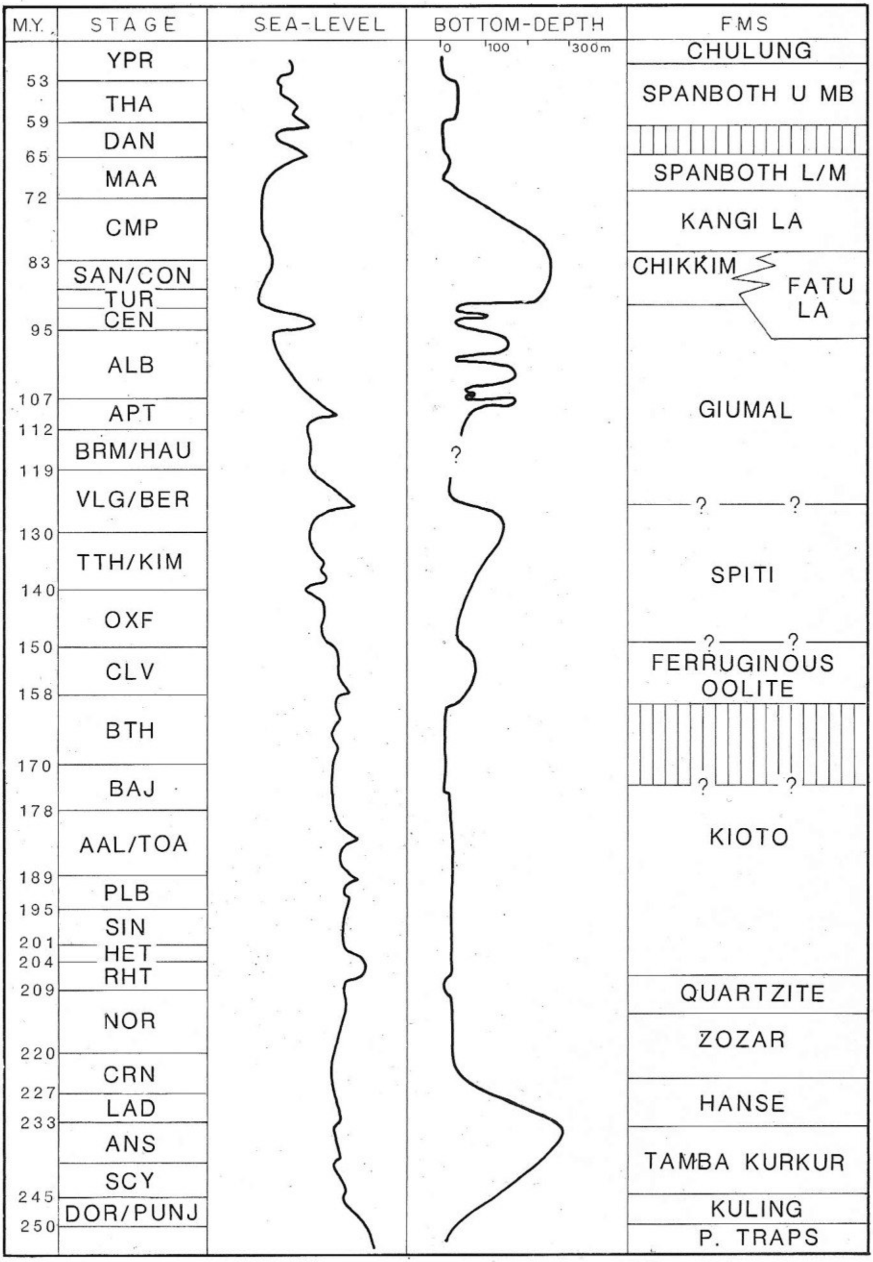


Fig. 7 – Stratigraphic scheme of units from Permian to Eocene, deposited under passive margin conditions. Sea–level linear plot from Harland et al. (1982) adapted to Odin's (1982) scale.

The dykes were extensively altered in greenschist facies (albite, chlorite, calcite, epidote), but primary magmatic texture with phenocrysts of plagioclase and orthopyroxene (possibly also clinopyroxene) is recognizable. Other minerals are ilmenite, sphene, quartz and subordinate biotite and apatite. Major chemical elements indicate a basaltic composition with tholeiitic–subalkaline affinity and compare well with known Panjal Trap volcanics (Tab. 1). Among trace elements, Ni and Cr are depleted compared to ocean floor basalts. Ni values higher than Co, a typical character of Panjal Trap flows in Zanskar, suggest that olivine and Cr–spinel have been totally removed from the magma. Ti–Zr–Y and TiO_2/Zr plots (Pearce & Cann, 1973) also compare well with Zanskar Panjal Traps, suggesting a within–plate tectonic setting (chemical and petrographic information from written communication by K. Honegger, ETH, Zürich).

MAFIC DYKES CUTTING THE KARSHA FORMATION

Major Elements			Trace Elements (ppm)					
SiO_2	42.2	42.8	La	= 11	0	Co	= 60	64
TiO_2	2.2	1.7	Sc	= 33	41	Ni	= 95	77
Al_2O_3	16.9	14.8	Nb	= 10	6	Cu	= 46	102
Fe_2O_3	14.9	15.0	Y	= 34	32	Cr	= 28	13
MnO	0.2	0.2	Ga	= 13	11	V	= 158	196
MgO	6.7	6.0	Zn	= 85	87	Zr	= 146	105
CaO	4.5	7.0	Rb	= 10	14	Ba	= 139	107
Na_2O	3.4	2.5				Sr	= 184	103
K_2O	0.3	0.4						
P_2O_5	0.3	0.2	Ti	= 13309	10372			
H_2O +	4.1	3.6	Ba/Y	= 4.1	3.3			
CO_2	2.9	4.2	Y/Nb	= 3.4	5.3			
			Ti/Cr	= 475	797			
Total	98.6	98.4						

Tab. 1 – Chemical analysis by X–ray fluorescence spectrometry of two Panjal Trap basaltic dykes (by K. Honegger). Analyzed dykes were sampled in the middle–lower (first value) and base (second value) of the Mauling Member (Karsha Fm.) a few km east of Tanze along the path to Phirtse La. The first sample comes from the inner zone and the second from the border of the dyke.

Kuling Formation. (MG, EG, AT).

The Kuling Fm., up to 55 m thick, is a sandy/shaly unit with minor carbonate content, lying everywhere on the Panjal Traps. It develops in three parts. At the base a mostly sandstone unit (5–25 m) made by sublitharenites in poorly defined beds of 10–100 cm. They may contain bioclasts with brachiopods, bryozoans, gastropods and echinoderms. A discontinuous horizon of arenaceous bioclastic limestone and hybrid arenite rich in brachiopods and bryozoans follows. *Lamnimargus himalayensis* (Diener) and *Spiriferella rajah* (Salter) characterize the fauna. The sequence is everywhere capped by dark carbonaceous shales, with black carbonate/phosphatic nodules. Maximum thickness

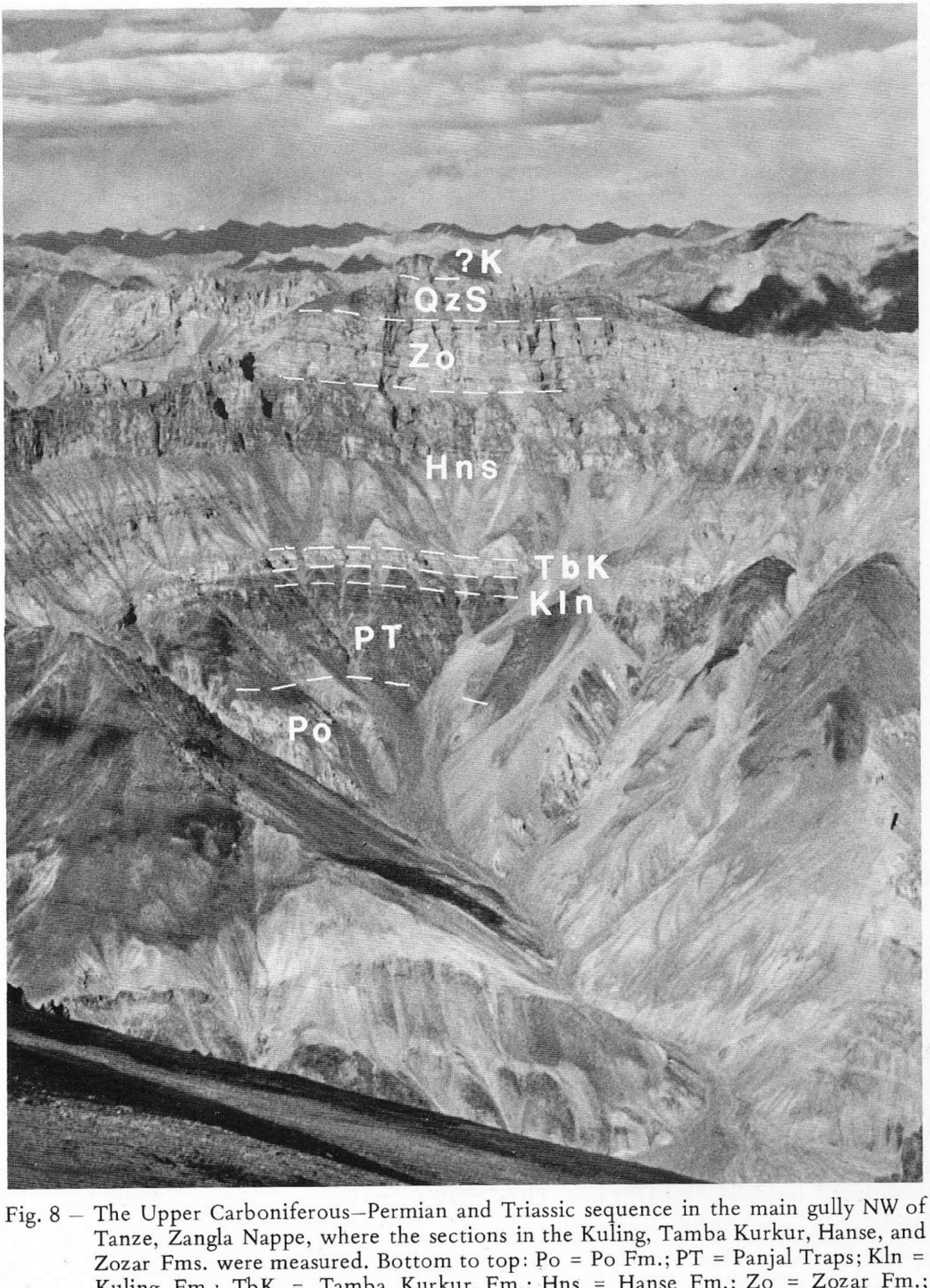


Fig. 8 – The Upper Carboniferous–Permian and Triassic sequence in the main gully NW of Tanze, Zangla Nappe, where the sections in the Kuling, Tamba Kurkur, Hanse, and Zozar Fms. were measured. Bottom to top: Po = Po Fm.; PT = Panjal Traps; Kln = Kuling Fm.; TbK = Tamba Kurkur Fm.; Hns = Hanse Fm.; Zo = Zozar Fm.; QzS = Quartzite Series Fm.; K = Kioto Fm. To be noted the dramatic increase in the sedimentation rate with the Ladinian Hanse Fm., after the low rate of the latest Permian and Scythian/Anisian.

of the shales is 21.5 m, but often this horizon is tectonically cut out. The age of the brachiopod/bryozoan level is thought to be Late Permian, possibly Dorashamian (Nicora et al., 1985). The Kuling Fm. represents a transgressive sequence in a break–up context. The shaly deposition is controlled by the peculiar phenomena that occurred near the P/T boundary.

Tamba Kurkur Formation. (AN, MG).

The Tamba Kurkur Fm. continuously crops out from Tashitongte at west to Tanze area at east, usually 50–60 m thick, with maximum of about 100 m in the Tongde area. Four sections have been measured and sampled (Fig. 9). The formation consists of three distinct members, bottom to top:

1) nodular, grey, thin to medium bedded bioclastic mudstone/wackestones, locally packstones, with shaly intercalations (sericitic shales with rare planar bioclastic packstone/grainstones characterize the upper part of this member at west (Ralakung and Tongde). Maximum thickness 20 m. *Claraia concentrica* Yabe and ammonoids (*Ophiceras*) in the lower part.

2) Grey massive to thick bedded nodular mudstone/wackestones (5–15 m).

3) Nodular, dark grey, medium bedded mudstones to wackestones, subordinated packstones. In the upper part increase of the shales and rare grey–green tuffitic layers (10–20 m).

These three members are characteristically developed in the Phugtal–Tanze–Jinshen area, where they are perfectly correlatable to the Spiti sequence (Nicora et al., 1985). At west (Tongde and Ralakung), the development of the members is less distinct, because of increasing of the terrigenous supply. In the two lower members the whole Scythian is well documented by means of conodonts (Baud et al., 1984; Nicora et al., 1985). As already pointed out, the first Scythian conodont fauna is represented by the *Gondolella carinata*/ *Hindeodus minutus* assemblage zone, present since the very base of the first member. *Gondolella timorensis* Nogami, in the upper part of the second member, marks the Scythian/Anisian boundary. In the upper member the Anisian is developed. *Gondolella eotrammeri* Krystyn of Late Anisian age was found at the top of the formation and represents the youngest conodont fauna. The ammonoid fauna is particularly abundant in the third member, where a Pelsonián fauna has been collected. The assemblage is dominated by *Hollandites* spp. and by *Ptychites rugifer* (Oppel). Poor hints to the presence of the Illyrian are given by a few specimens of the genus *Judicarites*.

The Tamba Kurkur Fm. represents a pelagic sedimentation in upper bathyal condition with low sedimentation rate. Westwards, however, significant clay supply modified this pattern, especially during the Anisian.

Hanse Formation. (AT).

The formation continuously crops out from Ringdom Gompa to Phirtse La. It reaches more than 400 m in thickness. Being the most ductile unit, it

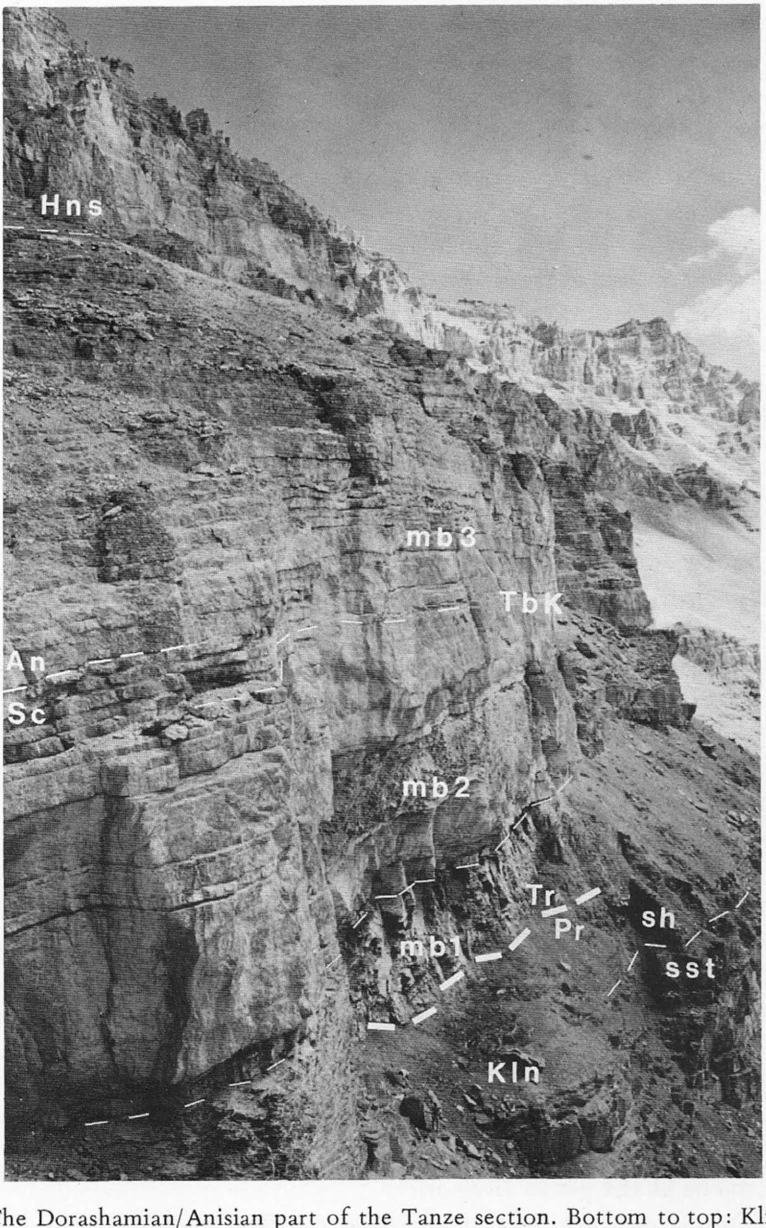


Fig. 9 – The Dorashamian/Anisian part of the Tanze section. Bottom to top: Kln = Kuling Fm. with sandstone (sst) and shale (sh) lithozones; TbK = Tamba Kurkur Fm. with its three members; Hns = Hanse Fm. Chronostratigraphic boundaries: Pr/Tr = Permo–Triassic; Sc/An = Scythian/Anisian.

forms spectacular folds in the lower part of the Zangla Nappe, where it is also affected by minor thrusts. Our data are concentrated in the Tongde La and in the Tanze areas, where a composite section was measured (Fig. 10). Westwards, in the Ringdom Gompa area, it is too metamorphosed.

Three members may be recognized, from bottom to top:

1) marly limestones and ash grey shales and marls. Thickness about 70 m at Tanze and 140 m around Tongde. The limit with the underlying Tamba Kurkur Fm. is transitional, with increase of the clay content. Platy thin bedded dark marly mudstones give place to ash grey shales and marls, locally rich in *Daonella*. *D. indica* Bittner, *D. lommeli* (Wissmann), and *D.* cf. *caudata* Mojsisovics have been collected from periglacial eluvium, probably covering the layers in situ.

Fig. 10 – The Hanse Fm. in the section of Tanze. TbK = Tamba Kurkur Fm.; Hns = Hanse Fm. with its three members; Zo = Zozar Fm. The asterisk indicates the spot where Upper Ladinian ammonites were found.

2) Nodular limestones, intercalated with the black marls. Thickness about 170 m. This member is characterized by levels of black nodular wackestones, in medium beds, 2–5 m thick, intercalated with the marls and shales. The limestone levels are more frequent and thicker in the lower part, where few *Daonella indica* Bittner and *D. lommeli* (Wissmann) have been found. In the upper part of this member, ammonites were found in a level correlatable to the one already quoted at Phirtse La (Baud et al., 1984) (Fig. 10). *Protrachyceras longobardicum* (Mojsisovics), *Joannites klipsteini* (Mojsisovics), *J. tridentinus* Mojsisovics, *Rimkinites nitiensis* Diener, and *Anolcites laczkoi* Diener indicate a Late Ladinian age.

3) Black or dark grey nodular or platy mudstones, thick bedded. This member reaches a maximum thickness of about 275 m in the Tanze–Phirtse La area, whilst towards NW it becomes thinner and thinner. No fossils were found in this member.

The age of the Hanse Fm. spans from the Ladinian possibly into the Carnian, because of the great thickness of the third member.

A pelagic outer shelf is inferred for most of the Hanse Fm. The uppermost part of the unit records a transition to shallow water carbonate environment. The abundant clay supply favoured muddy and totally or partially anoxygenic bottoms. The Hanse Fm. records a turning point in the evolution of the passive margin, which afterwards was controlled by lower thermal subsidence.

Zozar Formation. (EF, FJ, EG).

The Zozar Fm. crops out continuously throughout Zanskar from Ringdom Gompa to the Phirtse La area. Five sections (Tashitongte, Zangla, Tongde La, Phugtal, Tanze) have been studied. Only at Tanze a complete section has been measured, which gave a total thickness of 157 m (Fig. 11). The figure would confirm a decrease in thickness of the unit from NW toward SE (Baud et al., 1984).

The boundary with the black nodular marly mudstones of the topmost Hanse Fm. is transitional. In some 10 m intercalations of dark fine bioclastic packstones become more abundant. A change in colour from black to brown, thicker beds and more abundant packstones lacking fine terrigenous supply, mark the bottom of the Zozar Fm. The characteristic bryozoan–crinoid packstone typical of the base of the unit is often but not always present.

The unit consists of two distinct lithozones, from bottom to top:

a) well bedded light grey mudstone/wackestones and intrabioclastic packstones. The upper portion of the lithozone may be characterized by mudstone/wackestones or marly limestones (Tongde La, Tanze). Thickness of the lithozone 60–80 m;

b) medium to thick beds of white dolomites with planar stromatolites.

Locally (Zangla) dolomitized oolitic grainstones dominate. Intrabioclastic packstone/grainstones become locally abundant in the upper part of the unit. In Zangla the topmost layer yields a rich fauna of megalodontids. Thickness 70–150 m.

The unit represents a large scale regressive sequence. A transition from subtidal inner shelf with channels, oolitic bars and storm layers to interior platform/tidal flat has been detected. In the Phugtal/Tanze area more restricted environments (sabkha) are inferred. Dip of cross laminae points to E–SEward paleocurrents.

A Norian age may be suggested for the top of the unit where abundant megalodontids occur.

Quartzite Series. (EF, FJ, EG).

The unit sharply overlies the Zozar Fm. from Ringdom to Tanze and it is generally 120–130 m thick. Two new sections (Zangla and Phugtal) have been measured (Fig. 12). The following description refers mainly to the interesting Zangla section, which is the most complete and thickest (300 m). Six main lithofacies have been recognized:

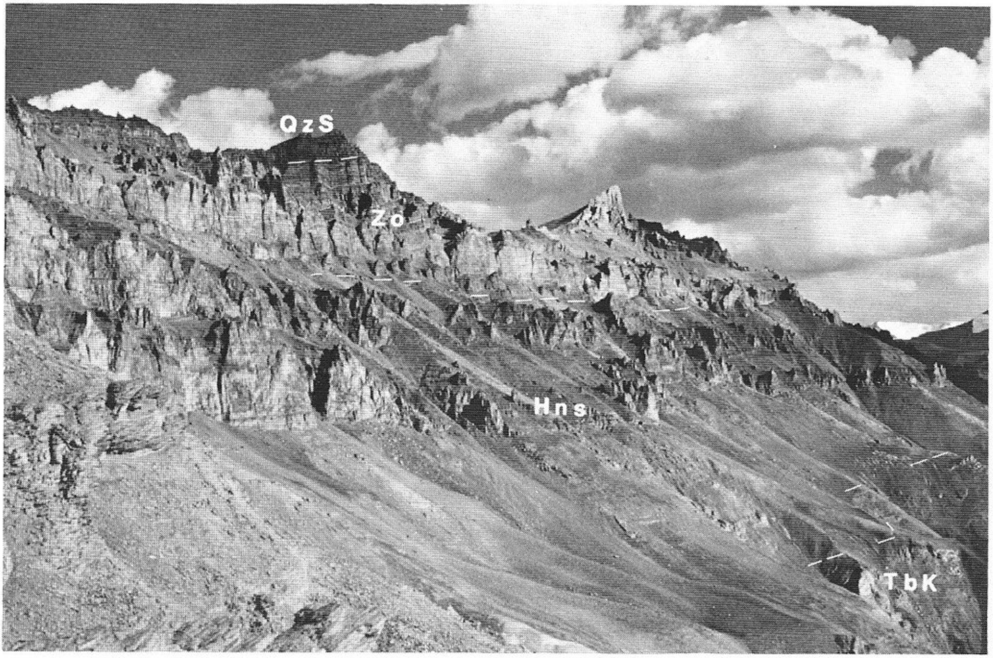


Fig. 11 – Upper Hanse Fm., Zozar Fm., and lower Quartzite Series cropping out on the southern slope of the ridge north of Tanze, where a section was measured. TbK = Tamba Kurkur Fm.; Hns = Hanse Fm.; Zo = Zozar Fm.; QzS = Quartzite Series.

a) well–bedded, dark green–grey bioturbated sandstones with parallel or cross–lamination;

b) well–bedded to amalgamated white sandstones with high–angle cross–lamination and minor burrowing;

c) bioclastic packstone/grainstones (benthic foraminifera, brachiopods, crinoids, bryozoans, pelecypods);

d) small coral boundstones, occasionally reaching plurimetric size;

e) fossiliferous mudstone/wackestones with large pelecypods (megalodontids, alatoconchids?) and extensive bioturbation;

f) grey micaceous siltstones.

The formation contains mostly very fine to fine–grained, very well to moderately sorted and subangular subarkoses. Below the boundary with the Kioto Lst., medium grained quartzarenites with subrounded but moderately sorted grains occur. Quartz is mostly monocrystalline and K–spar (orthoclase and common cross–hatched microcline) dominates among the feldspars, which are distinctly concentrated in the very fine sand fraction. Ultrastable heavy minerals and particularly white micas are abundant in the finer samples. Calcareous

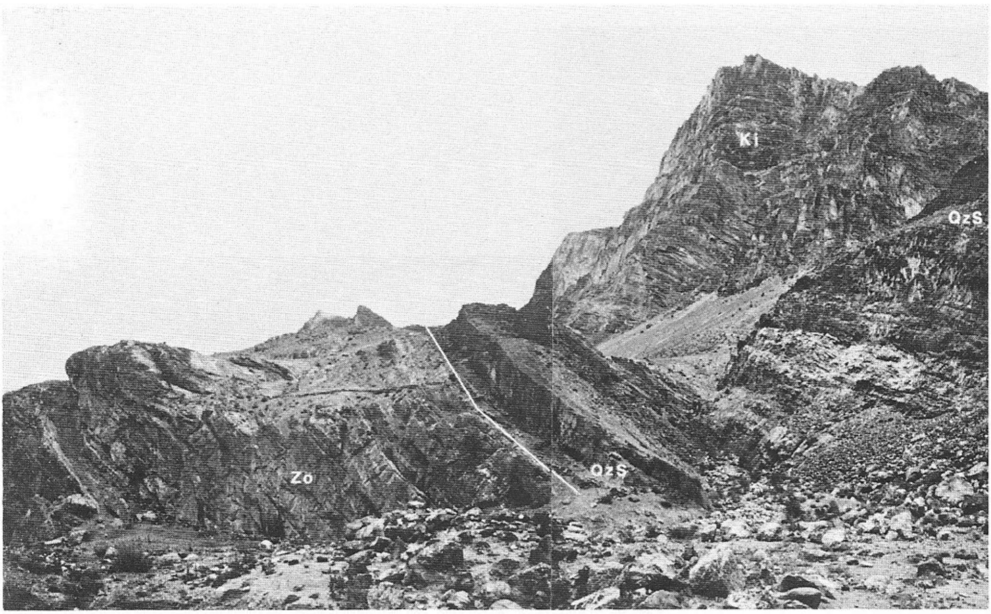


Fig. 12 – Close up view of section 1 of Fig. 13, showing the upper lithozone of the Zozar Fm. (Zo) and the lower part of the Quartzite Series (QzS). The stratigraphic boundary crops out along the trail to the Namche La. The topmost layer of the Zozar Fm. is rich in *Neomegalodon* sp.; the basal layer of the Quartzite Series is a bioclastic horizon rich in crinoids and brachiopods (*Fissirhynchia fissicostata*, *Rhaetina* sp.).

allochems are generally absent in the sandstone beds, but hybrid arenites and arenaceous limestones are widespread.

Two main lithozones are recognized from bottom to top:

A) grey sandstones (a) dominate. Thick intercalations of white sandstones (b) are subordinate, whereas biocalcarenites (c) characterize the lower portion (more abundant in the Phugtal than in the Zangla area). At Zangla, a basal bioclastic layer yielded brachiopods of Norian/Rhaetian age (*Fissirhynchia fissicostata* (Suess), *Rhaetina* sp.), while a coral horizon (d) was found in the upper portion of lithozone A. Thickness about 150 m at Zangla.

B) Biocalcarenites (c) are common and tend to be replaced upward by sandstones (a, b). A pelitic interval (f) is present at the base of lithozone B, while micrites with large pelecypods (e) at the top of the sequence mark the transition to the Kioto Limestone. This lithozone is about 150 m thick at Zangla, where the anomalous thickening of the sandstones, which corresponds to a reduced thickness of the Kioto limestones, may suggest interfingering relationships between the upper Quartzite Series and the lower Kioto Lst.

A specimen of the *Juvavites* group was found east of Tongde La. Fossil content indicates a Norian/Rhaetian age for the unit.

The formation represents a marked increase in terrigenous detritus brought by deltaic systems into an inner shelf becoming more diversified upward (channels, bars). Paleocurrents point to polymodal transport direction (NE–ward, subordinate WNW–ward). A «continental block, craton interior» provenance (Dickinson & Suczek, 1979) is indicated by sandstone composition, which is typical of post–break up passive margin sands. Phyllosilicate and quartz recrystallization is widespread, indicating anchimetamorphic (central–eastern Zanskar) to lower greenschist facies (Ringdom area) Himalayan deformation.

Kioto Limestone. (EF, FJ).

The unit crops out from Ringdom Gompa to the Tanze area. Five sections have been studied in the Zangla Nappe (Ringdom, Zangla area, Zozar area) as well as partial sections in the Zumlung nappe (Tantak area). A similar thickness has been evaluated for the Kioto Lst. of the Zangla (450–500 m) and Zumlung (500–600 m) nappes (Fig. 13).

The boundary with the underlying Quartzite Series is transitional. In the Zangla unit five lithofacies have been distinguished that occur in cycles of several tens of metres.

a) Amalgamated beds, frequently dolomitized, of dark grey biointraclastic packstones (brachiopods, pelecypods, corals, benthic foraminifers) intercalated with dark bioturbated fossiliferous (megalodontids, ?alatoconchids) wackestones. The lithofacies is typical of the basal portion of the Kioto Lst., where sandy layers still occur;

b) well bedded, planar to nodular, dark grey fine intrabioclastic packstones, locally rich in ooids;

c) well bedded, planar to nodular, dark grey bioturbated mudstones to bioclastic wackestones with scanty whole fossils (corals) intercalate to fine intrabioclastic packstones with ?alatoconchids;

d) well bedded, planar, dark grey marly mudstone/wackestones intercalated with marls, locally bioturbated.

Packstones (lithofacies b and c) and subordinate marly mudstones (d), more frequent at Ringdom, form the central part of the unit;

e) planar to nodular, dark grey bioclastic packstones and wackestones with intercalations of well sorted and very fine grained calcareous quartzarenites. The lithofacies characterizes the upper Kioto Lst. in the Zangla area and might be correlated to the Laptal Beds Auct. (Heim & Gansser, 1939).

The top surface of the Kioto Lst. is often characterized by small borings and minor dolomitization.

The unit represents a large scale transgressive–regressive sequence starting with medium to high energy inner shelf environment characterized by bars,

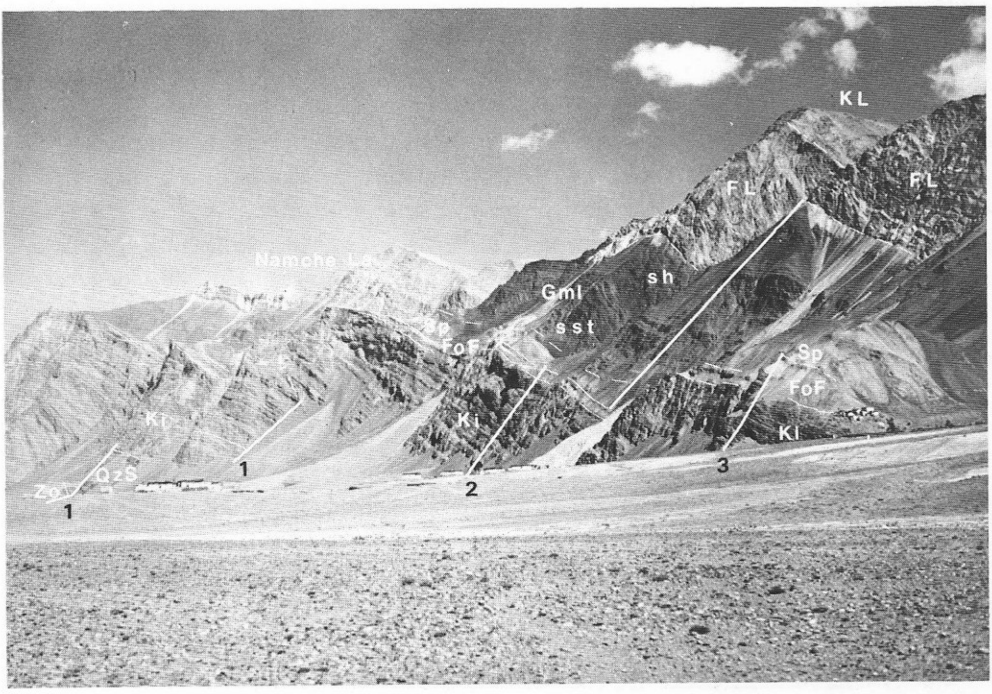


Fig. 13 – The Upper Triassic/Upper Cretaceous sequence between Zangla and the valley to the Namche La northward. Several sections have been studied from the Zozar Fm. to the Giumal Sdst. Zo = Zozar Fm.; QzS = Quartzite Series; Ki = Kioto Lst.; FoF = Ferruginous Oolite Fm.; Sp = Spiti Shales; Gml = Giumal Sdts, sst = sandstones, sh = shales; FL = Fatu La Fm.; KL = Kangi La Fm.

channels and small patch reefs (a). Low to medium energy subtidal inner shelf conditions with poor but differentiated fauna and extensive bioturbation follow (b, c). In the middle part of the unit low energy, interior platform conditions are documented (d). The upper Kioto Lst. is interpreted as medium energy inner shelf with terrigenous supply possibly connected to short term base level fluctuations (e).

At the base of the unit few layers with very abundant large megalodontids and ?alatoconchids are present. In the Zumlung unit, basal arenaceous facies (a) seem lacking. Beds rich in *Lithiotis* sp. and rhynchonelloids are peculiar to the Zumlung unit, and are probably located in the middle portion of the Kioto Lst.

On the base of preliminary studies on the faunal content (benthic foraminifera, large pelecypods, brachiopods) a latest Triassic age is inferred for the lower–middle Kioto Lst. Scanty benthic foraminifera in the upper portion suggest a Late Liassic–?Early Dogger age for the top of the unit.

Ferruginous Oolite (F.O.) Formation. (FJ, EF, EG, AT).

Several sections have been measured along a 100 km–long NW–SE profile from Ringdom Gompa to Tantak (Jadoul et al., 1985). The contact with the underlying Kioto Limestone is sharp and unconformable. The F.O. Fm. (Krishna, 1983) consists of four lithozones, from bottom to top: A) fossiliferous ironstone (belemnites, trigonids, ostreids, gastropods, crinoids and ammonites –*Reineckeia* cf. *stuebeli* Steinmann, *Macrocephalites* sp. ind.) rich in chamosite/goethite ooids. Thickness 0.5–10 m; B) varicoloured shales with scattered belemnites, ammonites (*Indosphinctes* cf. *peregrinus* Spath) and ferruginous ooids. Thickness 2–20 m; C) cross–bedded bioclastic quartzarenites locally with graded bedding and hummocky cross–stratification. Thickness up to 20 m; D) fossiliferous oolitic arenites (ostreids, trigonids, isognomids, belemnites, gastropods, crinoids and ammonoids – ?*Choffatia (Grossouvria)* sp. ind.). Thickness 2–5 m.

The F.O. Fm. is overlaid with sharp contact by the Spiti Shale. The ammonite fauna suggests a Callovian age for the F.O. Fm. and shows that its base is heterochronous, becoming slightly younger from the west (?Bathonian–Early Callovian) to the east (Middle–Late Callovian).

The unconformity between the Kioto Lst. and the F.O. Fm. corresponds to a time gap of several MY, which may be ascribed to non–deposition due to limited drowning and marked changes in chemistry and circulation patterns. The alternative hypothesis of generalized erosion of the shelf during a pre–Callovian low–stand is favoured by one of us (EG) (1). Sedimentation resumed

(1) In this case, the spectacular slope–instability phenomena documented in the northern Lamayuru Nappe, which contains carbonate olistoliths of Norian to Early Dogger age (Bassoullet et al., 1981), may be correlatable to the Kioto/F.O. gap.

with ferruginous oolites (lithozone A), progressively onlapping the underlying unconformity. Next, the F.O. Fm. shows a coarsening–upward sequence, attesting the progradation of terrigenous deposits on a storm–dominated shelf (lithozones B and C), capped by an iron oolitic «roof bed» (lithozone D; Bayer et al., 1984). The quartzarenites of lithozone C suggest a partly multicyclic provenance from craton interiors. Paleocurrents and facies changes indicate dispersal of the detritus from SW to NE.

Spiti Shale. (AT, EG).

The unit consists of dark shales with locally intercalated marls and calcareous quartzose siltstones. Rare very fine–grained sandstones and thick beds of graded biocalcirudites or lags rich in big belemnites and ammonite fragments are also observed.

In the Ringdom area, the thickness of the Spiti Shale is about 20 m and no fossils were found. Thickness increases eastward, reaching 62 m west of Zangla. Usually, only the Lower Member is present, with rare and poorly preserved ammonites. In Spiti, this unit (*Belemnopsis Gerardi* Beds) is dated as Late Oxfordian and unconformably overlies the F.O. Fm. (Arkell, 1956). Only near Sneatze, a thin interval rich in ammonites may be ascribed to the Middle Member (Chidamu Beds). A few *Ataxioceratidae*, collected just below the tectonic contact with the Giumal Sandstone, indicate an Early Tithonian age (Oloriz, pers. comm.), in accord with previous Authors (Arkell, 1956). In the Zangla area, the boundary with the Giumal Fm. is transitional over several meters, but no identifiable ammonites were found. Further west, in the Tantak area, the Spiti Shale is strongly deformed and forms the core of the Sumdo isoclinal synclines and of the Shade synform, respectively in front and behind the Zumlung Nappe front.

The unit was deposited on an undisturbed mid–outer shelf only episodically affected by major storm events (Fig. 14). This conclusion is suggested also by the ammonite association, which is interpreted as sublittoral (Oloriz, pers. comm.). For the lack of biostratigraphic control, we cannot assess whether the upper part of the Spiti Shale and the overlying Giumal Fm. have interfingering or unconformable relationships and how much of the earliest Cretaceous is represented in the studied area.

Giumal Sandstone. (EG, RC).

Two complete sections (Dibling, Zangla) and several logs at the top of the unit have been measured from Ringdom to Tantak (Fig. 13). The formation can be subdivided into three parts.

The Lower Giumal (160–200 m in the Zangla Nappe) contains dark grey sandstones in laterally continuous decimetric layers separated by pelitic interbeds or amalgamated. Bioturbation is very extensive, and parallel or cross-lamination is rarely observed. Pockets of black mudclasts occur. In western Zanskar the sequence is sandy and displays several thickening-upward cycles up to a few tens of m thick, separated by pelitic intervals. The sandstones interfinger laterally with pelites along a palinspastic distance of several tens of

Fig. 14 – Storm layer in the Spiti Shale between Oma Chu and Sneatze. The coarse fraction is made of belemnite rostra and few fragmentary ammonites.

km, and in the Tantak area (Zumlung Nappe) only one thickening–upward sandstone body (25 m thick), locally displaying hummocky cross–stratification, is enclosed in thick pelites. Poorly preserved and silicified planktonic foraminifera resembling *Hedbergella delrioensis* (Carsey) found in a 10 m thick black shale tongue, 50 m below the top of the Lower Giumal at Dibling, point to a Late Aptian, possibly Albian age (I. Premoli Silva, pers. comm.).

The Middle Giumal (110–130 m in the Zangla Nappe) consists of dark grey pelites with intercalated parallel–laminated sandstone beds (10–30 cm thick).

The Upper Giumal (90–100 m in the Zangla Nappe) contains at its base a several m thick stack of up to very coarse–grained cross–bedded quartzarenites with herringbones and mud partings between cross–sets. Next, dark pelites with intercalated volcanic arenites and biocalciruditic lags with belemnites are followed by a widespread interval (several m thick) of black glaucónitic sandstones with ferriferous nodules. These arenaceous bodies were traced laterally toward the east (along the Oma Chu) into interbedded very fine–grained sands and muds, and at Zangla the Middle and Upper Giumal are difficult to separate in the field. Here the contact with the overlying Fatu La Limestone is sharp, whereas in the more proximal zone (Ringdom to upper Oma Chu) alternating quartzose and calcareous arenites mark the transition with the grey Chikkim Limestone. These sandstones are locally very coarse–grained and rich in phosphatic nodules containing small ammonites of Late Cenomanian age (*Protachantoceras*).

The Giumal Sandstone reflects the multiple progradation of clastic detritus brought by deltaic systems onto a shelf influenced by storm–wave action (Lower Giumal at Tantak) or tidal currents (base of the Upper Giumal at Dibling). The lateral transition to offshore pelites can be followed over the whole extension of the continental shelf, and transgressive pelagic shales may sharply overlay sandstone bars in the proximal zone. Deposition in the outer zone was mostly from suspension below storm–wave base. The disconformable transition to the overlying Fatu La Limestone corresponds to a depositional sequence boundary. Depositional episodes separated by transgressive condensed sections with reworked phosphatic horizons or glauconitic and ferriferous hardgrounds (Vail et al., 1984) can be recognized within the unit, whereas the base of the Upper Giumal marks a prominent downward shift of coastal onlap.

Sandstone mineralogy suggests a continental block provenance for the subarkoses to quartzarenites of the Lower and uppermost Giumal Formation, whereas the quartzose volcanic arenites dominating the middle–upper part of the unit do not fit any of the first order provenance groups of Dickinson & Suczeck (1979) and Valloni (1985). Mixing in different proportions of quartzose detritus from the Indian craton and mafic volcanic rock fragments points to a «basaltic» volcanic event affecting the whole Tethys Himalayan margin in the Early Cretaceous. In fact, analogous clastic units are associated with basaltic lavas in Nepal (Bordet et al., 1971; Sakai, 1983). This extensional magmatism is coeval with the initial spreading between India and Australia–Antarctica (Markl, 1974; Johnson et al., 1976). The occurrence of abundant volcanic detritus in Albian shelf sediments of the northwestern Himalaya sheds new light on the Late Mesozoic spreading history of Gondwanaland fragments.

Chikkim Formation. (MG, AT).

This unit has been followed in its outcropping area from the Spanboth River to the middle Oma Chu, where it interfingers with the time equivalent Fatu La Fm. Usually it forms a step in the slope below the recessive profile of the overlying Kangi La Fm. (Fig. 15).

The basic lithology is made by grey, slightly nodular, well bedded limestone. The succession is rather monotonous, with thinner and more nodular beds in the lower 30–35 m, followed by thin to medium amalgamated beds in the upper 40–45 m. Wackestones dominate with at least half of the sediment made by foraminifera, mainly planktic. At the base small quartz clasts pollute the limestone as heritage of the underlying Giumal Sandstone. Local bottom winnowing may result in sorting of the foram tests and mud removal. In this case packstones and rarely grainstones occur. Mudstones are rare and are present especially in the lower part. Burrowing is extensive and causes lumps of globotruncanids.

Microfacies are dominated by planktic foraminifera, with radiolaria and calcisphaerae, sometimes significant (identifications by I.Premoli Silva, Milano). In the lower part small *Whiteinella* and *Globigerinelloides* represent the most common fauna, then globotruncanids spread over. The base of the unit falls into the *Praeglobotruncana helvetica* zone. *Whiteinella, Globigerinelloides, Hedbergella* and rare specimens of *P. helvetica* (Bolli) are present (1). Age: Early Turonian.

At the top of the formation two situations have been detected:

1) in the section measured at the base of the Pingdon La, a hyatus occurs between the Chikkim Fm. and the Kangi La Fm. One m below the top of the formation the faunal content belongs to the *D. asymetrica* zone (*Dicarinella asymetrica* (Sigal) is associated with *D. concavata* (Brotzen), *Globotruncana bulloides* Vogler, *Marginotruncana pseudolinneiana* Pessagno). Age: top of the Santonian. The age of the overlying Kangi La Fm. falls into the Campanian;

2) in other places, below the Barmi La and above Sneatze, where the Chik-

kim Fm. interfingers with the Fatu La Fm., the transition to the Kangi La Fm. is more gradual. The topmost microfacies is here dominated by globotruncanids and *Inoceramus* fragments. The presence of *Globotruncana arca* (Cushman), *Gl. bulloides* Vogler, *Gl. ventricosa* White, *Gl. rosetta* (Carsey), *Globotruncanita stuartiformis* (Dalbiez) points to the *Gl. ventricosa* zone of the Campanian.

The Chikkim Fm. is interpreted as deposited under pelagic, upper bathyal, low rate sedimentation conditions, with no or very limited terrigenous supply.

Fatu La Formation. (MG, EG, AT).

This unit widely crops out in the western part of the Zangla Nappe and in the Zumlung Nappe. It consists of multicoloured marly limestones (grey, red, green) in amalgamated and burrowed beds. Limestones may also occur, especially westwards and in the uppermost part, which locally contains abundant pyrite and *Inoceramus* remains. The upper boundary with the Kangi La Fm. is sharp, marked by a great increase of clay content and by the change to a dark–grey colour. West of the river Zanskar, the age of the Fatu La Fm. is bracketed between the Turonian and the Early Campanian, with diagnostic assemblages of foraminifera similar to those previously described in the Chikkim Lst. The two units are thus time equivalent and their interfingering area lies between the Barmi La and Sneatze, as already shown by Kelemen & Sonnenfeld (1983). In the Zangla area instead, the Fatu La Fm. has a wider age range. The very base at Zangla yielded a rich planktic assemblage of the latest Albian, with abundant *Planomalina buxtorfi* (Gandolfi). Between Zangla and the Namche La, the topmost part of the unit is probably still Santonian, but heavy recrystallization prevents good fossil identification.

The Fatu La Fm. was deposited on an open shelf/slope with persistent mud supply and better oxygenation with respect to the Chikkim Lst.

Kangi La Formation. (MG, AT, EG).

This unit widely crops out from the Spanboth Valley through the Oma Chu drainage system till the area of Lingshed and Zanskar river. The thickness is relevant, increasing from SW to E and NE. In the upper Oma Chu area it reaches at least 500–600 m, and in the Barmi La–Haluma La ridge all the mountain is made by this formation. However, deformation prevents accurate measurements and part of the increase in thickness is probably due to the «décollement» tectonics.

Two members may be recognized. The lower one is made by fissile dark marls and marly clays, with sparse phosphatic nodules. Bedding is faint, with sparse more calcareous thin beds. Approximate thickness in the upper Oma

Fig. 15 – The Cretaceous – Paleogene sequence W of Dibling, upper Oma Chu drainage system. Bottom to top: Gml = Giumal Sdts.; Ck = Chikkim Fm.; LKL = lower member of the Kangi La Fm.; UKL = upper member of the Kangi La Fm.; Sb = Spanboth Fm. with its three members, the middle one made of quartzarenites (qrtz).

Chu is at least 350 m. The upper member is more calcareous and arenaceous, with better defined bedding and more prominent rugged outcrops. At Dibling village we measured 181 m for this member. Common feature to the Kangi La Fm., especially in the upper member, is the abundance of trace fossils: *Zoophycus, Rhizocorallium,* U tubes and other small dense burrowings. Microfacies is mostly poor. In the lower member mudstones or wackestones dominate. Rarely, probably connected with burrowing, globotruncanid packing may occur. The base of the unit falls into the *Gl. ventricosa* zone, due to the presence of *Globotruncana ventricosa* White, *Gl. rosetta* (Carsey), *Rugoglobigerina rugosa* (Plummer), *Globotruncanita stuartiformis* (Dalbiez), *Marginotruncana coronata* (Bolli). Age: Campanian. (Foraminifera identifications by I. Premoli Silva, Milano).

The upper member contains also very fine and calcareous arenites. Its foraminiferal content is scarse. At the top *Heterohelix, Gumbelitria, Omphalocyclus macroporus* (Lamarck) and *Goupillaudina* sp. have been found. Coral, gastropod and bryozoan fragments are also present. Age: in the topmost part of the formation the Maastrichtian is documented.

The Kangi La Fm. indicates an abrupt change in the sedimentation, with abundant terrigenous supply, which progressively increases in grain–size. The lithofacies, fauna and trace fossil assemblage point to an upper bathyal to outer shelf depositional environment with overall shallowing trend. Sedimentation rate exceeds several times the rate of the Chikkim Fm. and our data indicate a Campanian age for this turning point of the passive margin history.

Spanboth Formation. (AN, EF, EG).

The unit widely crops out in several folds in West Zanskar, from the Kanji La to the Kesi La.

The formation is subdivided in three members (Gaetani et al., 1983). Two sections (Fig. 16) have been measured in the Spanboth Valley (Marpo section) and to the east of Dibling village.

Lower Member: measured only in the Dibling section (45 m thick). Nodular to planar, dark, burrowed (*Zoophycus*) mudstones to bioclastic wackestones (*Omphalocyclus macroporus* (Lamarck)) followed by dark marly clays interbedded with bioclastic packstones. On the whole from west to east a reduction in thickness (140 m, Spanboth Chu sections, to 45 m, Dibling section) and a decrease of the carbonate content have been detected. These data suggest a transition from inner (Spanboth area) to outer shelf environment (Dibling area).

Middle Member: it consists of white, brown–weathered quartzarenites increasing in thickness toward the east (13 m Spanboth Chu section – Gaetani et al., 1983 – to 59 m Dibling section). In the Kanji area, large–scale (several meters) crossbeds were formed by lateral accretion in sinuous distributary

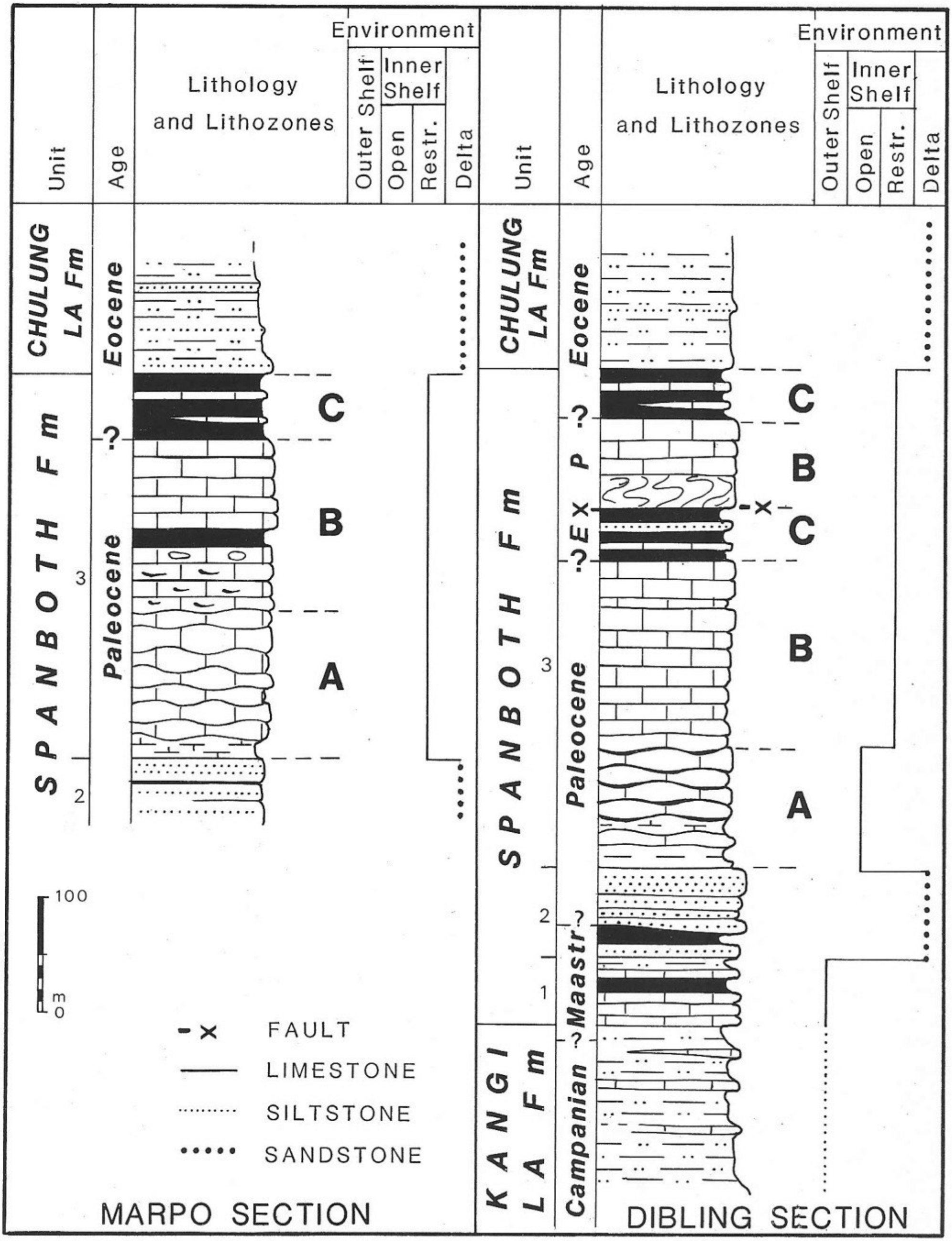


Fig. 16 – Sections of the Spanboth Fm. at Marpo in the Spanboth Valley and north of the village of Dibling. In the last one the Spanboth Fm. is tectonically repeated in the upper part. Capital letters A, B, C refer to the lithozones of the third member of the Spanboth Formation.

channels. In the Dibling area, pelites and cross–laminated sandstones arranged in thickening upward sequences are interpreted as the mouth bar deposits of a fluvial dominated delta. In the topmost part of this member (Dibling section) rotaliids and *Lockhartia* sp. are present.

Upper Member: about 200 m thick. Three lithozones have been distinguished from bottom to top:

a) nodular dark grey marly bioclastic wackestones with locally thicker marly horizons at the base (about 70 m thick). Rotaliids, *Lockhartia* sp., miliolids, chrysalidinae, very abundant, characterize the lower part of this member. In the middle/upper part *Daviesina danieli* Smout, *Operculina* sp. and *Ranikothalia* sp. appear (Marpo section). Few dasyclads (*Furcoporella diplopora* Pia, *Clypeina* cf. *merienda* Elliott, *Cymopolia* sp.) and udoteaceae algae (*Ovulites* sp. aff. *O. kangpensis* Yu–Jing) are also present;

b) dark grey, planar bedded, locally bioturbated, bioclastic wackestone/packstones. In the Marpo section an intercalation of grey greenish clays with interbedded bioclastic packstones (13 m) is present (about 110 m thick). *Daviesina langhami* Smout, *D. khatiyhai* Smout, *Operculina* sp., rotaliids and *Lockhartia* sp. have been found in the middle part. In the upper part of this lithozone b) the *Fasciolites (Glomalveolina) primaeva, F. (G.) levis* and *F. cucumiformis* biozones were identified;

c) grey greenish clays and marly clays with thin intercalations of bioclastic packstones and very fine cross–laminated, locally graded, calcareous siltstones (about 25 m thick). This lithozone is characterized by the presence of *Fasciolites ellipsoidalis* (Hottinger), particularly abundant in the upper part. Abundant udoteaceae algae are present (*Ovulites margaritula* (Lamarck), *O.* aff. *elongata* Lamarck, *Halymeda* aff. *lingulata* Yu–Jing).

The Spanboth Formation ranges from Maastrichtian to earliest Eocene.

Concerning the age of the upper limit of the Spanboth Fm., some remarks have to be done. According to Hottinger (1960 a, b), the *primaeva* and the *levis* biozones are characteristic of the Thanetian p.p., while the *cucumiformis* and the *ellipsoidalis* define the Lower Ilerdian. On the basis of the most recent views in chronostratigraphic correlations (Schaub, 1981; Berggren et al., 1984) two hypothesis can be proposed: 1) the two lower alveolinid assemblages are Upper Paleocene while the boundary Paleocene/Eocene can be placed or at the base of the *cucumiformis* biozone or at the base of the *oblonga*, that points to the Lower Cuisian (Schaub, 1981); 2) following Berggren et al. (1984), the Paleocene/Eocene boundary (corresponding to the *Discoaster multiradiatus/Marthasterites contortus* boundary) is contained in the *ellipsoidalis* biozone.

The dasyclad and udoteacean flora, found in lithozone a, points to a Paleocene–Early/Middle Eocene age (Bassoullet et al., 1983). The udoteacean flora which characterizes lithozone c is normally referred to the Middle Eocene (Bassoullet et al., 1983). However, the algae are associated with large foraminifera indicating an older age (Late Paleocene/earliest Eocene). Then further study is needed to clarify the true range of those algae.

Chulung La Formation. (EG, RC).

The unit (at least 160 m thick) crops out at the core of tight synclines in the Spanboth Valley and on the mountains above Dibling. The transition to the Spanboth Fm. is characterized by a few metres (Dibling) to a few tens of metres (Marpo) of grey marls with locally interbedded calcareous siltstones with parallel– or cross–lamination and lenses of rip–up clasts or bioclasts. The marls are overlaid by greenish siltstones (56 m in the Spanboth Valley to 10 m at Dibling) showing poorly–developed fining– upward sequences capped by thin and vuggy carbonate beds. The main body of the Chulung La Fm. (at least 100 m– thick in the Spanboth Valley) consists of red beds arranged in fining–upward sequences. A scoured base is locally overlaid by thin intraformational conglomerates or directly by fine–grained sandstones with trough cross–lamination followed by coarse siltstones with climbing ripples and finally by red muds. The latter locally contain small calcareous nodules («paleocaliches»). Channel–fill deposits are generally 2–3 m thick and are encased in largely prevailing overbank muds.

Paleochannels had low width / depth ratio and were of suspended load, sinuous or anastomosing type. The sequence testifies to the progradation of a fluvial–dominated deltaic system in a shallow lagoon. Green siltstones with interbedded lagoonal to sabkha carbonates overlying prodelta pelites were laid down in a lower delta plain environment, while fine–grained red beds represent upper delta plain subaerial sediments. Sedimentary features indicate tropical climate and high sedimentation rates.

As to sandstone petrography, the Chulung La Fm. consists of moderately sorted volcanic arenites rich in albitized plagioclase grains, volcanic quartz and hematitic rip–up clasts. Ophiolitic detritus is minor. Coarse sand–sized reworked caliche arenites often with a fine–grained siliciclastic matrix are common in the Dibling section. Among the carbonate extrabasinal fraction, rare globotruncanids occur. Mineralogy points to provenance from a magmatic arc. A slight excess of quartz may indicate recycling from the advancing thrust sheets of the subduction complex of the Eurasian active margin.

Diagenetic processes include early formation of tectosilicate cements (quartz, albite) and late replacements by authigenic calcite, chlorite and epidote. Deformation and recrystallization of silicates along with epidote growth are more extensive in the Spanboth section, implying deformation at rather high diagenetic temperatures beneath a tectonic overburden of at least some km during the Himalayan Orogeny.

Acknowledgements.

We are mostly grateful to our sherpas, Danu (sirdar), Sonam, and Dawa, who perfectly performed the caravan duties. Giulio and Paolo Gaetani worked as field assistants. General organization through ARTOU, Genève.

We received assistance and help by several colleagues. In Italy by: I. Premoli Siva (Milano) for foraminifera identification, G. Pavia (Torino) for checking the Dogger ammonite identification, F. Fonnesu (AGIP, Milano) and M. Gnaccolini (Milano) for discussion on sedimentological aspects, D. Fontana (Modena) for guidance at the SEM, E. Erba (Milano) for search of nannofossils, L. De Capitani (Milano) for analysis of volcanic rocks. Abroad by: H. Whittington (Cambridge, U.K.) for Cambrian trilobite identification, H.H. Brunton (London, U.K.) for Carboniferous brachiopod identification, F. Oloriz (Granada, Spain) for preliminary Tithonian ammonite identification, K. Honegger (Zürich, Switzerland) for analysis of Panjal Traps dykes. To all friends and colleagues our warm thanks.

REFERENCES

Arkell W.J. (1956) - The ranges of southeast Asia - Spiti and Niti. In Jurassic geology of the world, pp. 406–409, Oliver & Boyd, Edinburgh.

Banerjee D.M. (1974) - Stratigraphy and depositional characteristics of Tethyan sediments in Kuti–Kalapani area, Kumaun, India. *Himalayan Geol.*, v. 4, pp. 296–322, 4 fig., Dehra Dun.

Bassoullet J.P., Colchen M., Marcoux J. & Mascle G. (1981) - Les masses calcaires du flysch triasico–jurassique de Lamayuru (zone de la suture de l'Indus, Himalaya du Ladakh): klippes sédimentaires et éléments de plate–forme remanies. *Riv. It. Paleont. Strat.*, v. 86 (1980), n. 4, pp. 825–844, 2 pl., 5 fig., Milano.

Bassoullet J.P., Bernier P., Deloffre R., Genot P., Poncet J. & Roux A. (1983) - Les Algues Udoteacées du Paléozoique au Cénozoique. *Bull. Centr. Rech. Explor. Prod. Elf. – Aquitaine*, v. 7, n. 2, pp. 449–621, 16 pl., 13 fig., 16 tab., Pau.

Baud A., Gaetani M., Garzanti E., Fois E., Nicora A. & Tintori A. (1984) - Geological observations in southeastern Zanskar and adjacent Lahul area (northwestern Himalaya). *Ecl. Geol. Helv.*, v. 77, n. 1, pp. 171–197, 11 fig., Basel.

Bayer U., Altheimer E. & Deutschle W. (1984) - Environmental evolution in shallow epicontinental seas: sedimentary cycles and bed formation. In Bayer U. & Seilacher A. (Eds.) - Sedimentary and evolutionary cycles. Lectures Notes in Earth Sciences, pp. 347–381, 18 fig., Springer Verlag, Heidelberg.

Berggren W. A., Kent D. V. & Flynn J. J. (1984) - Paleogene Geochronology and Chronostratigraphy. In Snelling N. J. (Ed.) - Geochronology and the Geologic Time Scale. *Geol. Soc. London, Sp. Paper*, 138 pp., 4 app., 6 fig. (Preprint: Woods Hole Oceanographic Institution, Woods Hole, Massachusetts).

Bordet P., Colchen M., Krummenacher D., Le Fort P., Mouterde R. & Remy M. (1971) - Recherches Géologiques dans l'Himalaya du Nepal, région de la Thakkola. Centr. Nat. Rech. Sc., 279 pp., Paris.

Casnedi R., Garzanti E. & Jadoul F. (1985) - Lower Paleozoic sedimentary evolution in Zanskar (NW Himalaya). 6 European Reg. Meet. Sedim. I.A.S. Lleida '85, Abstracts, pp. 79–82, 1 fig., Lleida.

Dickinson W.R. & Suczek C.A. (1979) - Plate tectonics and sandstone composition. *Am. Ass. Petr. Geol. Bull.*, v. 63, pp. 2164–2172, Tulsa.

Gaetani M., Nicora A., Premoli Silva I., Fois E., Garzanti E. & Tintori A. (1983) - Upper Cretaceous and Paleocene in Zanskar Range (NW Himalaya). *Riv. It. Paleont. Strat.*, v. 89, n. 1, pp. 81–118, 4 pl., 7 fig., Milano.

Gaetani M., Garzanti E. & Jadoul F. (1985) - Main structural elements of Zanskar, NW Himalaya (India). *Rend. Soc. Geol. It.*, v. 8, pp. 3–8, Roma.

Garzanti E., Casnedi R. & Jadoul F. (1985) - Sedimentary evidence of a Cambro–Ordovician orogenic event in the NW Himalaya. *Sedim. Geol.*, in press, Amsterdam.

Gupta V.J. (1977) - A note on the Paleozoic stratigraphy of the Luneak valley with a description of a new species of *Retichonetes* from Surichun La, Ladakh. *Rec. Res. in Geol.*, v. 4, pp. 37–45, Delhi.

Gupta V.J. (1981) Lower Paleozoic Cystoids and Crinoids from Ladakh. *Himalayan Geol.*, v. 9/1 (1979), pp. 348–351, Dehra Dun.

Gupta V.J. & Shaw F.C. (1982) - Lower Paleozoic Trilobites from Ladakh. In Gupta V.J. (Ed.) - Recent Researches in Geology, v. 8, pp. 55–64, Hindustani Press, Delhi.

Harland W.H., Cox A.V., Llewellyn P.G., Pickton C.A.G., Smith A.G. & Walters R. (1982) - A geological time scale. Cambridge Earth Sc. Ser., Cambridge.

Hayden H.H. (1904) - The geology of Spiti, with part of Bashahr and Rupshu. *Mem. Geol. Surv. India,* v. 26, pp. 1–129, Calcutta.

Heim A. & Gansser A. (1939) - Central Himalaya. Geological observations of the Swiss expedition 1936. *Mém. Soc. Helv. Sc. Nat.*, v. 73, n. 1, 246 pp., Zürich.

Hottinger L. (1960 a) - Recherches sur les Alvéolines du Paléocène et de l'Eocène. *Schw. Palaeont. Abhandl.*, v. 75/76, Texte (I): 144 pp., 117 fig., 1 tab.; Atlas (II): 18 pl., Basel.

Hottinger L. (1960 b) - Über paleocaene und eocaene Alveolinen. *Ecl. Geol. Helv.*, v. 53, n. 1, pp. 265–284, 21 pl., 1 tab., 3 fig., Basel.

Kelemen P.B. & Sonnenfeld M.D. (1983) - Stratigraphy, structure, petrology and local tectonics, Central Ladakh, NW Himalaya. *Schw. Min. Petr. Mitt.*, v. 63, pp. 267–287, Zürich.

Krishna J. (1983) - Callovian–Albian ammonoid stratigraphy and paleobiogeography in the Indian subcontinent with special reference to the Tethys Himalaya. *Himalayan Geol.*, v. 11 (1981), pp. 43–72, Dehra Dun.

Jadoul F., Fois E., Tintori A. & Garzanti E. (1985) - Preliminary results on Jurassic stratigraphy in Zanskar (NW Himalaya). *Rend. Soc. Geol. It.*, v. 8, pp. 9–13, Roma.

Johnson B.D., Powell C.M. & Veevers J.J. (1976) - Spreading history of the eastern Indian ocean and Greater India's northward flight from Antarctica and Australia. *Geol. Soc. Am. Bull.*, v. 87, pp. 1560–1566, 4 fig., Boulder.

Markl R.G. (1974) - Evidence for the breakup of eastern Gondwanaland by the Early Cretaceous. *Nature*, v. 251, pp. 196–200, 5 fig., London.

Mukherjee B. & Dasgupta P.K. (1972) - Depositional environment of the Upper Member of "Muth Quartzite" from Spiti and Kuti Regions, Central Himalayas, India. 24th IGC, Sect. 6, pp. 424–431, Montreal.

Nanda M.M. & Singh M.P. (1977) - Stratigraphy and sedimentation of the Zanskar area, Ladakh and adjoining parts the Lahaul region of Himachal Pradesh. *Himalayan Geol.*, v. 6, pp. 367–388, Dehra Dun.

Nicora A., Gaetani M. & Garzanti E. (1985) - Late Permian to Anisian in Zanskar (Ladakh, Himalaya). *Rend. Soc. Geol. It.*, v. 7 (1984), pp. 27–30, 1 fig., Roma.

Odin G.S. (1982) - Numerical dating in stratigraphy (Part 1) 630 pp., Wiley, New York.

Pearce J.A. & Cann J.R. (1973) - Tectonic setting of basic volcanic rocks determined using trace elements analyses. *Earth Pl. Sci. Lett.*, v. 19, pp. 290–300, Amsterdam.

Pegasus Ed. (1983) - Ladakh – Zanskar map, scale 1:350.000, Zürich.

Robaszynski F. & Caron M., coord. and Eur. Work. Group Plankt. (1979) - Atlas de Foraminifères planctoniques du Crétacé Moyen (Mer Boréale et Téthys). *Cah. Micropaléont.*, C.N.R.S., 1979–1, 185 pp., 39 pl., 9 fig.; 1979–2, 181 pp., 41 pl., Paris.

Robaszynski F., Caron M., Gonzales Donoso J.M. & Wonders A.H., Eds. and Eur. Work. Group Plankt. (1984) - Atlas of Late Cretaceous Globotruncanids. *Rev. Micropaléont.*, v. 26, n. 3–4, pp. 145–305, 54 pl., 12 fig., Paris.

Sakai H. (1983) - Geology of the Tansen Group of the Lesser Himalaya in Nepal. *Mem. Fac. Sci. Kyushu Univ.*, Ser. D, v. 25, pp. 27–74, 6 pl., 23 fig., Kyushu.

Schaub H. (1981) - Nummulites et Assilines de la Téthys paléogène. Taxinomie, phylogénèse et biostratigraphie. *Schw. Palaeont. Abhandl.*, v. 104, 238 pp., 18 pl., 116 fig., Basel.

Srikantia S.V., Ganesan T.M., Rao R.N., Sinha P.H. & Tirkey B. (1980) - Geology of the Zanskar area, Ladakh Himalaya. *Himalayan Geol.*, v. 8, n. 2 (1978), pp. 1009–1033, 2 fig., Dehra Dun.

Suttner L.J., Basu A. & Mack G.H. (1981) - Climate and origin of quartzarenites. *Jour. Sedim. Petr.*, v. 51, pp. 1235–1246, Tulsa.

Trommsdorff V., Dietrich V. & Honegger K. (1982) - The Indus suture zone: paleotectonic and igneous evolution in the Ladakh Himalayas. In Hsü K. (Ed.) - Mountain building processes, pp. 213–228, Academic Press, London.

Vail P.R., Hardenbol J. & Todd R.G. (1984) - Jurassic unconformities, chronostratigraphy and sea level changes from seismic stratigraphy and biostratigraphy. In Schlee J. (Ed.) Interregional unconformities and hydrocarbon accumulation. *Am. Ass. Petr. Geol. Mem.*, n. 36, pp. 129–144, 12 fig., Tulsa.

Valloni R. (1985) - Reading provenance from modern marine sands. In Zuffa G.C. (Ed.) - Provenance of arenites. *Nato ASI Series*, n. 148, pp. 309–332, 6 fig., Reidel, Dordrecht.

Wilson M.D. & Pittman E.D. (1977) - Authigenic clays in sandstones: recognition and influence on reservoir properties and paleoenvironmental analysis. *Jour. Sedim. Petr.*, v. 47, pp. 3–31, Tulsa.