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STRATIGRAPHY OF THE EARLY CRETACEOUS GIUMAL GROUP (ZANSKAR RANGE, NORTHERN INDIA)

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Key-words: Stratigraphy, Early Cretaceous, Tethys Himalaya, quartzo-feldspathic sandstones, volcanic arenites, glaucony, phosphates.

Riassunto. Le Arenarie di Giumal sono comprese tra le Argilliti di Spiti, di età Giurassico superiore - Cretaceo basale?, e i calcari pelagici delle Formazioni di Chikkim e Fatu La, di età medio-cretacea. La Formazione, istituita da Stoliczka (1866), è qui formalmente elevata al rango di Gruppo. Studi stratigrafici di dettaglio, durante quattro spedizioni geologiche nella Catena dello Zanskar, hanno infatti consentito di riconoscere al suo interno due nuove formazioni, entrambe ricoperte da successioni condensate; queste ultime sono considerate qui formalmente come orizzonti stratigrafici, riconoscibili e tracciabili in tutta l'area studiata.

La Formazione di Takh, che segue alle Argilliti di Spiti con contatto stratigrafico nell'Unità di Zumlung e spesso tettonizzato nell'Unità di Zangla, può essere a sua volta suddivisa in due parti. La parte inferiore (potente da 62 a 86 m nell' Unità di Zumlung) è caratterizzata da subarkose a grana fine e molto fine e da quarzareniti a grana da media a molto grossolana. Il detrito proveniva dal blocco continentale Indiano, sollevato durante una importante fase tettonica estensiva. Nella parte superiore (potente da 103 a 117 m), peliti scure localmente contenenti faune planctoniche mal preservate, di età probabilmente aptiana, diventano prevalenti, testimoniando una deposizione in una piattaforma aperta e più profonda. Al tetto della formazione, un orizzonte marker glauconitico (Arenite di Labar La) indica una marcata fase trasgressiva con apporti silicoclastici ridotti al termine dell'Aptiano o nell'Albiano inferiore.

La Formazione di Pingdon La (potente da 214 a 240 m nella parte sud-occidentale dell'Unità di Zangla, ma solo da 92 a 130 m nell'area di Nerak e nell'Unità di Zumlung) è caratterizzata dall'afflusso imponente e improvviso di frammenti di rocce vulcaniche alcaline. Le areniti vulcaniche alla base della formazione hanno grana fino a media, mentre nella parte centrale intervalli decametrici di subarkose e quarzareniti a grana anche molto grossolana si possono trovare nelle aree più prossimali. Le sezioni stratigrafiche più distali sono invece più monotone e contengono solo areniti vulcaniche a grana molto fine o fine inferiore. Nella parte superiore della formazione, alle areniti vulcaniche si intercalano areniti glauconitiche o localmente bioclastiche, contenenti rari Foraminiferi planctonici di età Albiano superiore.

La formazione è ricoperta da un orizzonte marker condensato (Glauco-fosforite di Nerak) di età Albiano superiore (Sottozona a *R. subticinensis*), che in aree distali è seguito dai fanghi pelagici della Formazione di Fatu La (Albiano sommitale). Nella parte occidentale dell'Unità di Zangla, un altro orizzonte marker condensato ricco in fosfati, glauconia e bioclasti (Glauco-fosforite dell'Oma Chu), che raggiunge il Cenomaniano superiore (Zona a *W. archaeocretacea)*, è seguito dai calcari pelagici della Formazione di Chik-

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kim (Turoniano inferiore). L'annegamento finale della piattaforma continentale indiana è stato determinato da una serie di episodi successivi di sottoalimentazione e approfondimento, legati a una complessa interazione tra processi tettonici, eustatici e paleo-oceanografici durante la fase finale dello smembramento del supercontinente di Gondwana.

Abstract. Detailed stratigraphic work in the course of four geologic expeditions has allowed refinement of the Early Cretaceous stratigraphy of the Zanskar Range. The Giumal Sandstone, which is comprised between the Late Jurassic to earliest Cretaceous? Spiti Shale and the mid-Cretaceous Chikkim and Fatu La pelagic limestones, is formally elevated to Group rank and subdivided into two new formations, both capped by laterally continuous condensed sections here considered as formal stratigraphic horizons.

The Takh Formation, overlying the Spiti Shale stratigraphically in the Zumlung Unit and commonly with tectonic contact in the Zangla Unit, is in turn subdivided into two parts. The lower part (62 to 86 m thick in the Zumlung Unit) is characterized by very fine to fine-grained subarkoses and medium to very coarse-grained quartzarenites derived from the rejuvenated Indian continental block. In the upper part (103 to 117 m thick), deeper-water dark pelites locally yielding ill-preserved faunas probably Aptian in age become more important. The formation is capped by a glauconitic marker horizon (Labar La Arenite), testifying to a major starved transgressive stage possibly close to the Aptian/Albian boundary.

The Pingdon La Formation (214 to 240 m thick in the southwestern part of the Zangla Unit and only 92 to 130 m thick in the Nerak area and Zumlung Unit) is characterized by the sudden appearance of up to medium-grained volcanic detritus. Decametric intervals of up to very coarse-grained quartzo-feldspathic sandstones characterize the middle part of the formation in proximal areas, whereas more monotonous distal sections contain only up to lower fine-grained volcanic arenites. In the upper part, volcanic arenite layers are interbedded with glaucony-rich or bioclastic sediments yielding sporadic foraminifers of Late Albian age.

The formation is capped by a condensed horizon (Nerak Glauco-phosphorite) of Late Albian age (*R. subticinensis* Subzone), which in distal areas is overlain by latest Albian multicolored pelagic limestones of the Fatu La Formation. In the western part of the Zangla Unit, another condensed horizon rich in phosphates, glaucony and bioclasts (Oma Chu Glauco-phosphorite), reaching up to the Late Cenomanian (*W.* archaeocretacea Zone), is followed by Early Turonian grey pelagic limestones of the Chikkim Formation. Final drowning of the Zanskar shelf occurred through successive episodes of starvation and deepening, related to a complex interplay of geodynamic, eustatic and paleoceanographic processes.

Introduction.

The Zanskar Range, comprised between the High Himalaya Crystalline to the southwest and the Indus-Yarlo suture to the northeast, is formed by a Late Precambrian to Early Eocene sedimentary succession belonging to the Tethys Himalaya Zone (Fig. 1). After initial opening of Neo-Tethys in the Permian, the Mesozoic succession was deposited on the northern passive continental margin of the Indian sub-continent. Stratigraphic observations on this Neo-tethyan sequence are contained in Fuchs (1982, 1986), Srikantia et al. (1980), Baud et al. (1982, 1984), Bassoullet et al. (1983), Kelemen & Sonnenfeld (1983), Gaetani et al. (1986), Garzanti et al. (1989), Jadoul et al. (1990), Gaetani & Garzanti (1991).

According to recent structural interpretations (Baud et al., 1982, 1984; Bassoullet et al., 1983; Gaetani et al., 1985; Searle et al., 1988; Garzanti & Brignoli, 1989; McElroy et al., 1990), several superimposed thrust sheets, tectonically transported to the SW and overlain by the Spongtang Oceanic Allochton can be recognized in the Zanskar Synclinorium (Fig. 1; for a different opinion see Fuchs, 1989). The Zangla thrust sheet, which is subdivided into a lower and an upper unit by a décollement surface following along the Oma Chu valley the incompetent Spiti Shale (Gaetani et al., 1985;

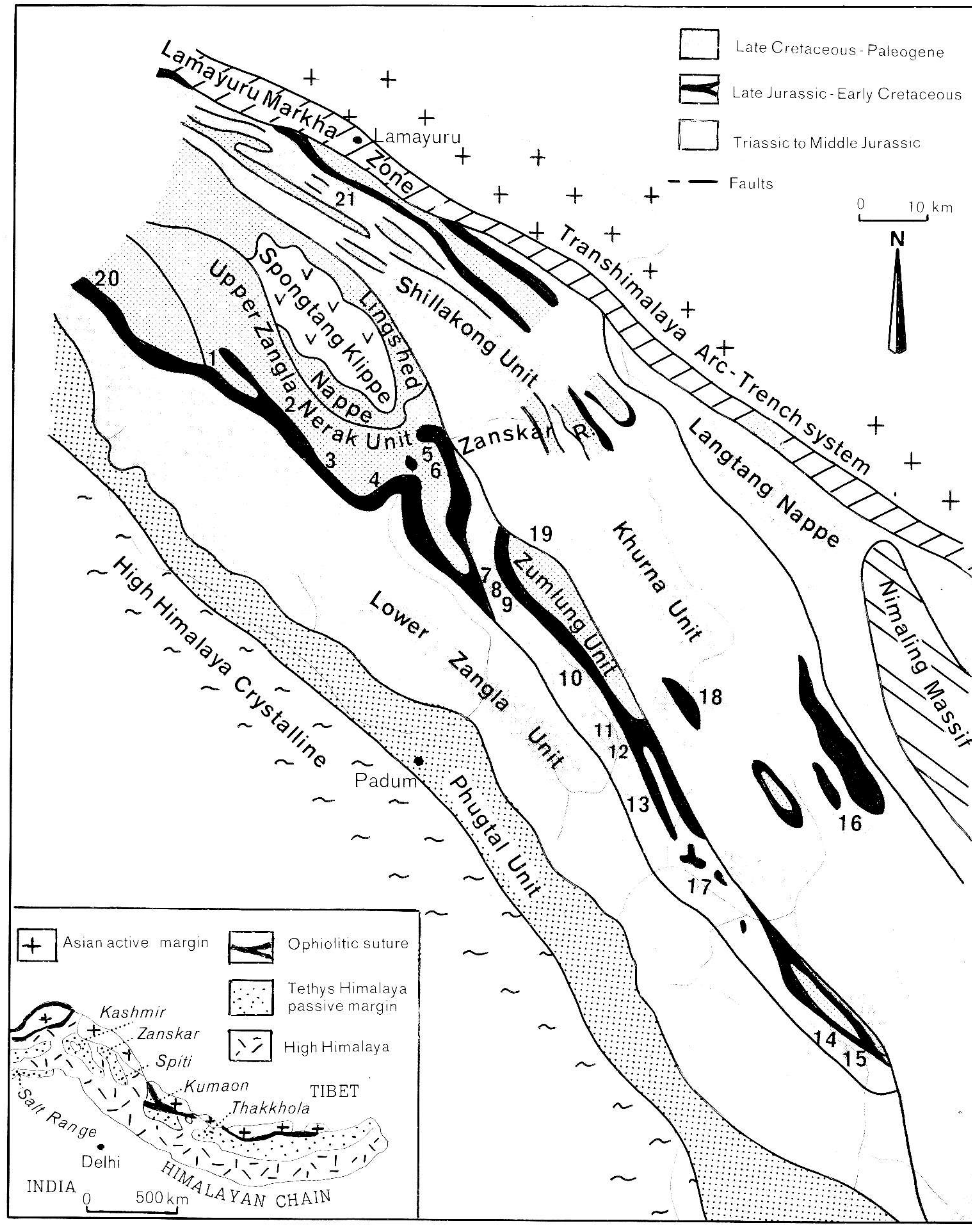


Fig. 1 - Geological sketch map of the Zanskar Range (compiled from several sources cited in the text), with location of the studied stratigraphic sections. Shown in inset is the areal distribution of Tethyan passive margin sediments in the Himalayan Chain. Numbers of measured sections from 1 to 15 as in Fig. 7 and 8. 16) Khurnak syncline; 17) Gotunda La; 18) Shapodakh La; 19) Chirche valley; 20) Spanboth valley; 21) Honupatta valley.

Garzanti & Brignoli, 1989), is the southernmost one containing Early Cretaceous sedimentary rocks. To the northeast, Cretaceous formations crop out in foot-wall synclines belonging to the Zumlung and Khurna Units. In the Nerak area, the Upper Zangla and Zumlung Units wedge out, and further to the north a very reduced Late Jurassic - Early Cretaceous section crops out in the Shillakong Unit.

Aim of the present paper, which is part of a continuing research program on the stratigraphic and paleogeographic evolution of the Tethys Himalaya carried out by members of the University of Milano, is to describe for the first time in detail the stratigraphy of the Early Cretaceous Giumal Sandstone in the various tectonic units of the Zanskar Range.

Analysis of sandstone petrography and sedimentologic features, with discussion of provenance and evolution of sedimentary environments are beyond the scope of the present work, and will be dealt with in separate forthcoming papers. For the detailed description of the Late Albian and Cenomanian condensed horizons the reader is referred to Garzanti et al. (1989). The causes of mid-Cretaceous drowning and subsequent evolution of the Zanskar passive margin are discussed at length in the companion paper by Premoli Silva et al. (1992). Sandstone classification adopted is after Folk (1980).

Stratigraphy

The Giumal Sandstone in the Zanskar Range is well exposed and comprised between Late Jurassic offshore pelites (Spiti Shale) and mid-Cretaceous pelagic limestones (Fatu La and Chikkim Formations). The unit, defined in the Spiti region by Stoliczka (1866), extends for over 250 km along strike through the Zanskar-Spiti Synclinorium, and possibly up to Kumaon (Heim & Gansser, 1939; Sinha, 1989). Correlative clastic wedges are called Lumshiwal Fm. in Pakistan (Shah, 1977; Khan et al., 1986) and Chukh Group in Nepal (Bassoullet & Mouterde, 1977; Garzanti & Pagni Frette, 1991).

In order to study the sedimentary evolution through time and across the Zanskar margin, 15 stratigraphic sections have been measured (see Fig. 1 for location), and over 300 samples collected during the course of four expeditions. After a preliminary survey in 1981, the sections of the Shillakong Unit and Nerak area were studied in 1983 (with A. Baud, Lausanne, and G. Mascle, Grenoble), while in 1984 (with R. Casnedi, Pavia) and 1987 (with F. Jadoul and A. Tintori, Milano) the attention was focused respectively on the Zangla and Zumlung Units.

The Giumal Group: a refined stratigraphic nomenclature.

The Giumal Sandstone is here raised to Group rank and subdivided into two new formations, capped by laterally continuous condensed horizons which are considered as formal stratigraphic horizons.

The *Takh Formation*, consisting of subarkoses and quartzarenites interbedded with burrowed siltstones and black shale tongues, directly overlies the Spiti Shale. Sandstones predominate in the lower part, whereas pelites become more important in the upper part. In northeastern Zanskar (Nerak area and Zumlung Unit), the formation is capped by a condensed horizon strongly enriched in glaucony (*Labar La Arenite*; Fig. 2).

The *Pingdon La Formation*, characterized by up to medium-grained volcanic arenites and dark pelites, comprises intervals of subarkoses and up to very coarse-grained quartzarenites (Fig. 3). In the western part of the Zangla Unit (Spanboth and upper Oma Chu valleys), the formation is capped by two superposed condensed intervals (*Nerak* and *Oma Chu Glauco-phosphorites*), paraconformably overlain by the grey pelagic limestones of the Chikkim Formation (Fig. 4). Further to the east, the Nerak Glauco-phosphorite is directly followed by the multicoloured pelagic limestones of the

Fig. 2 - The Giumal Group in the Takh section is 284 m thick (Zumlung Unit). Photo taken at 4700 m a.s.l. west of Takh. From bottom to top, note: arenaceous Lower Takh Fm. (T), stratigraphically overlying the Spiti Shale (S); back-stepping sequences at the top of the Lower Takh Fm.; first pelitic tongue (p_1) at the base of the Upper Takh Fm.; arenaceous sequences in the Upper Takh Fm.; second pelitic tongue (p_2); uppermost Takh Fm. fining-upward sequence (uT); Labar La Arenite (L); volcanic pelites and arenites at the base of the Pingdon La Fm. (v); volcanic pelites; coarsening-upward sublitharenite sequence and first quartzose sandstone bar (q_1); pelites and subarkoses (P); second quartzose sandstone bar (q_2); uppermost Pingdon La Fm. (uP); sharp contact with latest Albian Chikkim-like Fatu La pelagic limestones (F); tectonic contact (f) with the Kangi La Fm. (K).

Fatu La Formation (Fig. 5).

The type section for the Takh Formation was chosen in the Zumlung Unit (Fig. 2), where: a) thickness is maximum; b) all lithologic intervals are well represented; c) the lower boundary with the Spiti Shale is not tectonically disturbed. The type section for the Pingdon La Formation was instead chosen in the Zangla Unit (Fig. 3), where: a) thickness is double than in the Zumlung Unit; b) all lithologic intervals are well displayed; c) the transition to the overlying pelagic mudstones is most complete.

Takh Formation.

Zangla Unit.

The formation was cursorily observed in the Spanboth valley north of Ringdom (Lower Zangla Unit), where it was deformed in upper anchizonal conditions (Fig. 6). Two sections and five stratigraphic logs were studied in the area comprised between Pingdon La, Nerak and Zangla (Upper Zangla Unit), where a maximum thickness of 131 m was measured (Fig. 7). The original thickness was greater, since the lower part

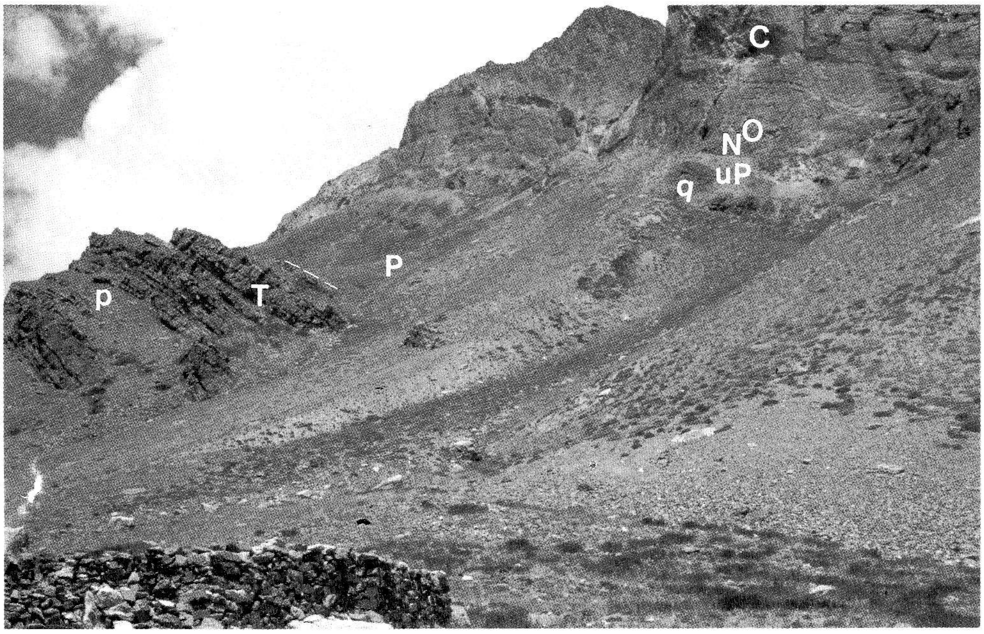


Fig. 3 - The Giumal Group in the Pingdon La section is over 330 m thick (Upper Zangla Unit). Photo taken on the left side of the valley connecting Pingdon La and Dibling, at 4150 m a.s.l. From bottom to top, note: Upper Takh Fm. (T), characterized by thickening-upward cycles separated by pelitic tongues yielding planktonic foraminifera (p); boundary between the Takh and Pingdon La Fm.; predominating pelites in the lower part of the Pingdon La Fm. (P); cross-bedded quartzarenite bar in the middle part of the Pingdon La Fm. (q); uppermost Pingdon La Fm. (uP); superposed Nerak (N) and Oma Chu (O) Glauco-phosphorites at the transition with the overlying Turonian Chikkim Fm. (C).

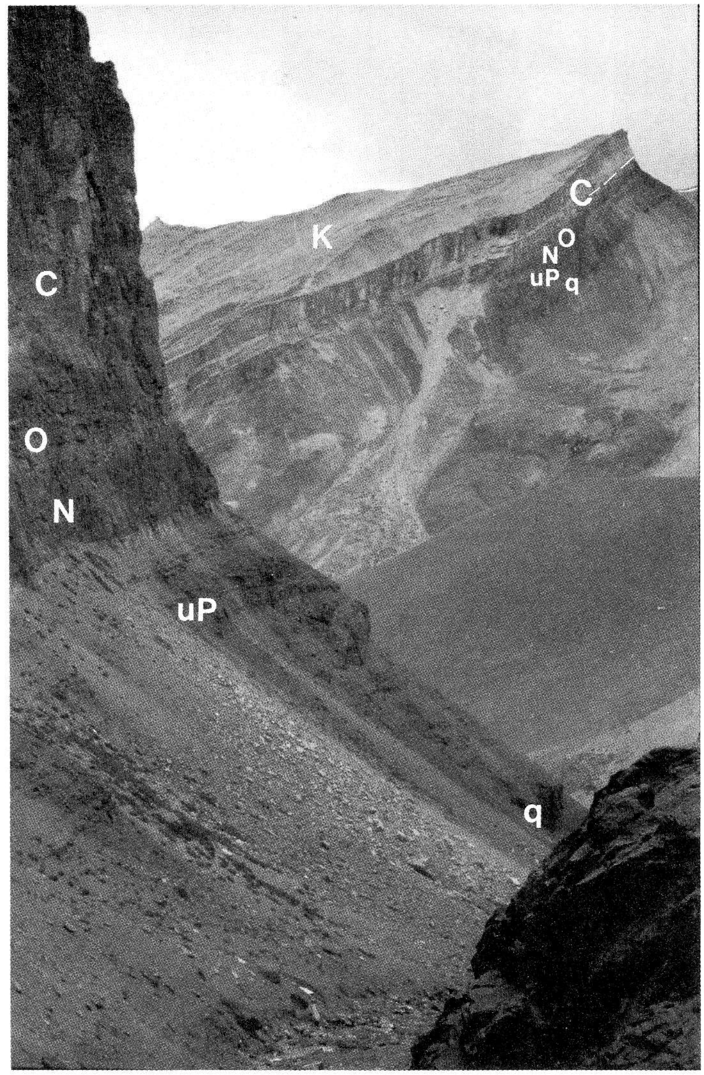


Fig. 4 - The transition between the Giumal Group and the Chikkim Formation in the Pingdon La section (photo taken just east of Pingdon La; Upper Zangla Unit). From bottom to top, note: quartzarenite bar in the middle Pingdon La Fm. (q); uppermost Pingdon La Fm. (uP), comprising volcanic arenites and pelites capped by bioclastic and glauconitic arenites of the *R. subticinensis* Subzone; Nerak Glauco-phosphorite (N); Oma Chu Glauco-phosphorite (O; *W. archaeocretacea* Zone in the upper part); Chikkim Fm. (C; *H. helvetica* Zone, with a lower well-bedded and an upper cliff-forming part); Kangi La Fm. (K). Also note lateral continuity both of sandstone bars in the upper Pingdon La Fm. and of the Nerak and Oma Chu Glauco-phosphorites, which can be all easily followed in the landscape.

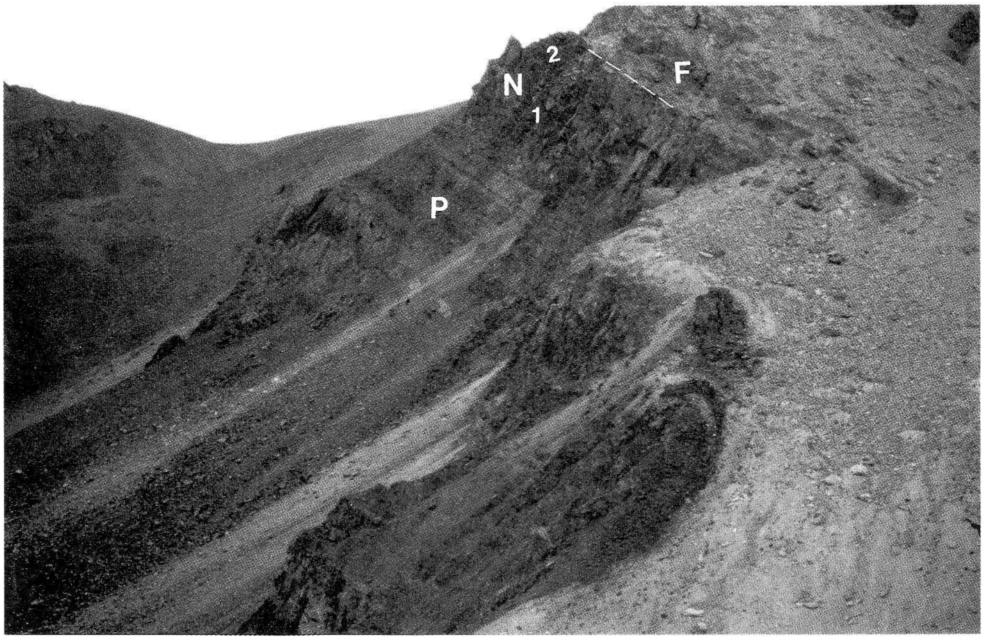


Fig. 5 - The transition between the Giumal Group and the Fatu La Formation in the Nerak section (photo taken above Nerak, looking towards the Labar La; Upper Zangla Unit). From bottom to top, note: volcanic arenites of the Pingdon La Fm. (P); Nerak Glauco-phosphorite (N; *R. subticinensis* Subzone), subdivided into a lower greensand part (1) and an upper part (2) richer in phosphates; sharp contact with the latest Albian Fatu La Fm. (F; *R. appenninica* Zone).

is tectonically cut out and uncoupled with respect to the underlying Spiti Shale at different incompetent stratigraphic horizons.

The lower 40 m of the Pingdon La section are made of up to coarse-grained, burrowed or cross-laminated quartzarenites locally showing scoured base, lateral accretion bedding and rip-up clasts. Sandstone beds are amalgamated and up to 1 m thick or separated by thin pelite layers. Next, a black shale tongue (10 m) contains radiolaria and silicified large planktonic foraminifera. The following 41 m are characterized by medium to very coarse quartzarenites displaying large to small scale cross-lamination and commonly arranged in coarsening and thickening-upward sequences up to 17 m thick (Fig. 3). Pelitic layers are subordinate. Rip-up clasts are frequent. Microconglomerates with quartzarenite lithoclasts (maximum diameter 0.5 cm) and large and numerous ferriferous nodules at the top are overlain by black shales (6 m) and cross-laminated quartzarenites (6 m). The following 11 m, consisting of black siltstones containing very fine-grained arenites still quartzose and glaucony-bearing at the base, mark the transition to the Pingdon La Formation.

At Sneatse, the top of the Takh Formation, tectonically overlying the Spiti Shale, is represented by very fine grained burrowed sandstones and rippled siltstones (18 m) followed by a medium-grained subarkose bar (4 m). The overlying black shales (20 m) mark the transition to the Pingdon La Formation.

In the Labar La section, the topmost 14 m of the Takh Formation, also lying tectonically over deformed Spiti shales, consist of very fine to fine-grained subarkoses. The transition to the Pingdon La Formation is marked by 6 m thick, quartz-rich and upper fine-grained greensands yielding sparse planktonic foraminifera and euhedral dolomite rhombs (type section of the Labar La Arenite).

A more continuous section is exposed in the Zangla area, where a thickening-upward cycle about 30 m thick, consisting of grey pelites and thin-bedded sandstones, locally calcareous or containing phosphatic

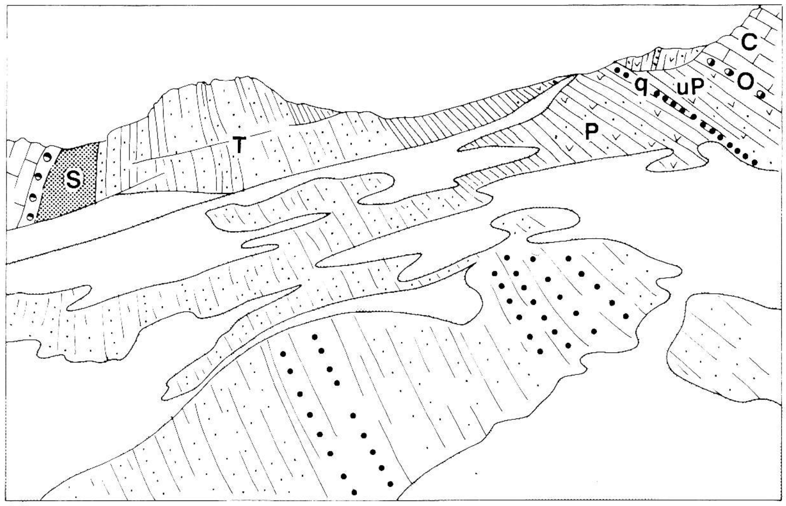


Fig. 6 - Sketch of the Giumal Group in the Spanboth valley (Lower Zangla Unit). This section was not measured (total thickness around 400 m). From bottom to top, note: reduced thickness of the Spiti Shale (S; only about 20 m); coarsening-upward trend in the Lower Takh Fm. (T; this part, mostly cut out tectonically in the Upper Zangla Unit, is similar to what observed in the Zumlung Unit); poorly-defined boundary between the Takh and Pingdon La Fms.; abundance of pelites in the lower part of the Pingdon La Fm. (P); occurrence of sandstone bars in the middle part (q); uppermost Pingdon La Fm. (uP); Nerak and Oma Chu (O) Glauco-phosphorites; Turonian Chikkim Fm. (C).

nodules and passing upward to cross-laminated fine-grained quartzarenites, directly overlies the Spiti Shale, probably with tectonic contact. Next, grey siltstones and subordinate very fine-grained burrowed sandstones (14 m) are followed by dark grey, thin to medium-bedded, very fine-grained and often burrowed subarkoses, locally calcareous and yielding belemnites or dark clay intraclasts up to 5 cm in size, interbedded with subordinate pelites (31.3 m). The overlying lower fine-grained burrowed subarkoses are mostly amalgamated or separated by thin pelitic interbeds (47 m). The topmost interval is characterized by upper fine-grained quartz-rich subarkoses with abundant silicate peloids and subordinate phosphates; burrowing is intense, with locally preserved cross-lamination (11 m).

Zumlung Unit.

The Takh Formation was studied in eight sections, from Sumdo to Takh (Fig. 8), where the lower boundary is marked by a rapid increase in sandstones, with sharp reduction in thickness of intercalated shales and disappearance of belemnite-bearing calcirudites. A total thickness of 193, 167 and 191 m was measured at Sumdo, Shade and Takh respectively, where the unit is exposed continuously from bottom to top (Fig. 9).

The formation may be subdivided into a lower arenaceous part (62 to 86 m), and an upper part. The latter is predominantly pelitic from Ningri La to Shade, whereas in the Sumdo and Takh areas mostly very fine-grained sandstones are common and contain pelitic tongues at the base, middle and top (105 to 117 m). The unit is capped by

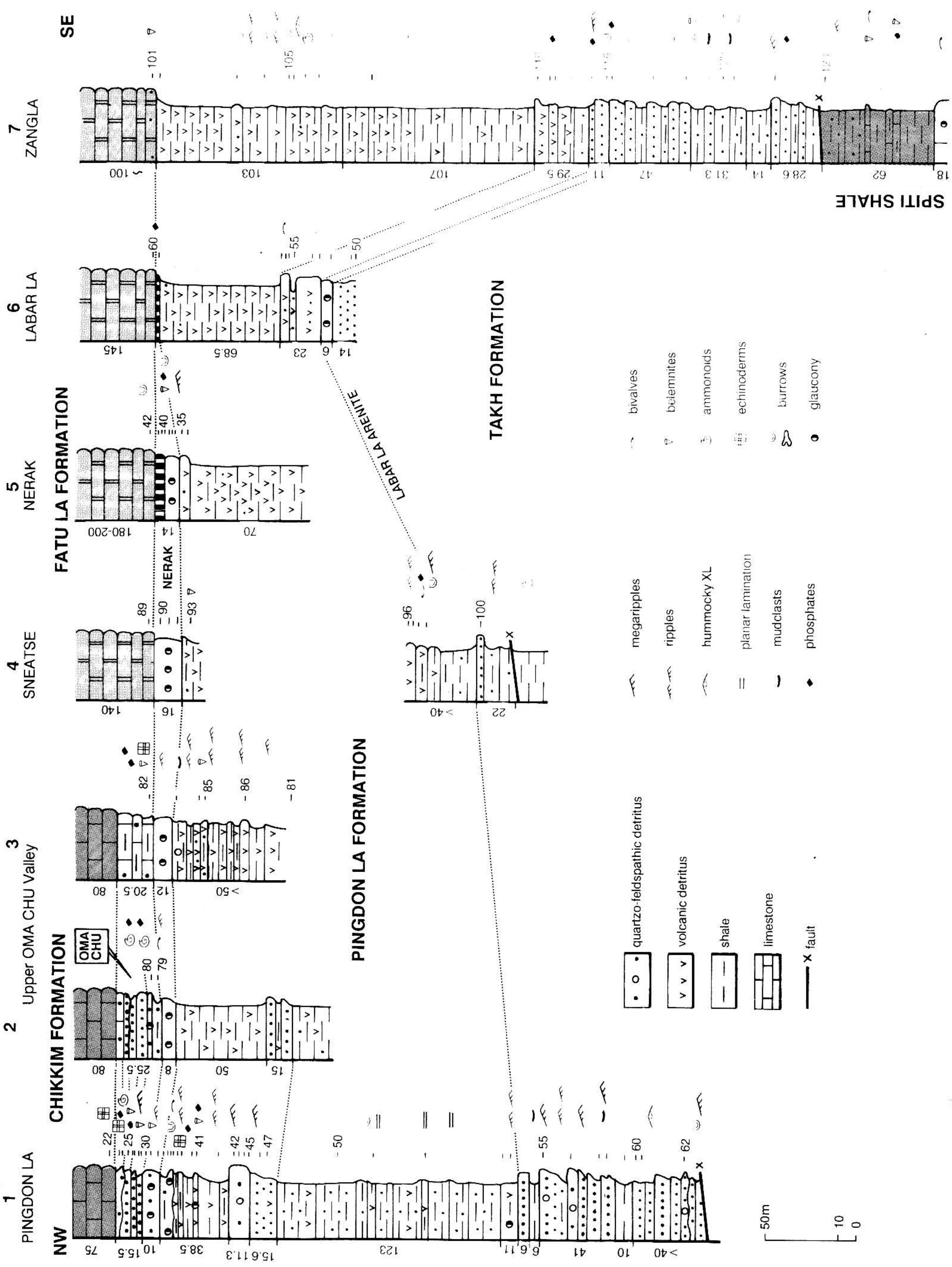


Fig. 7 - Measured stratigraphic sections in the Zangla-Nerak Unit. Thickness of each interval is given in metres. Dark shading) Spiti Shale at the base and Chikkim Fm. at the top; light shading) Fatu La Fm.

up to 5 m thick glauconitic greensands (Labar La Arenite).

In the two sections measured at Sumdo, the lower boundary may be transitional or sharp and marked by locally microconglomeratic quartzarenites (quartz pebbles up to 1 cm). The basal 20.5 m consist of amalgamated and locally cross-laminated, fine to lower medium-grained quartz-rich subarkose and quartzarenite bars up to 5 m thick, subordinate burrowed pelites and dark greenish arenites containing phosphates, silicate peloids, bivalves and belemnites. Next, a pelitic interval is capped by another quartzose sandstone bar (9.9 to 17.1 m), overlain by burrowed pelites and fine-grained subarkoses locally containing planktonic foraminifera (32.1 to 35.7 m). The top of the lower Takh Fm. is represented by burrowed pelites and quartz-rich sandstones, locally containing belemnite rostra and displaying small to large scale cross-lamination (8.9 to 9.8 m). The upper Takh Fm. begins with a pelitic tongue (14.5 m), overlain by very fine-grained, thin bedded burrowed subarkoses and subordinate siltstones (32,7 m). A strongly burrowed (?*Thalassinoides*) surface is followed by very fine-grained subarkoses, locally bioclastic or with low-angle cross-lamination, and subordinate burrowed siltstones (29 m). Another pelitic tongue (13.5 m) is overlain by burrowed siltstones and very fine-grained subarkoses with phosphatic and ferruginous nodules (27.3 m).

In the three measured sections from Ningri La to Lari La, where the boundary with the Spiti Shale is generally transitional, the lower Takh Fm. (62 to 64 m; Fig. 10) can be subdivided into three intervals. Very fine to fine-grained subarkoses, burrowed pelites and dark-greenish arenites containing phosphates, silicate peloids or belemnites (23.9 m) are followed by fine-grained cross-laminated subarkoses and interbedded pelites (9.1 to 10.8 m), and finally by prevalent thin-bedded or amalgamated subarkoses, commonly arranged in coarsening-upward cycles and displaying small to large scale cross-lamination (27 to 30.8 m). The upper Takh Fm. is made by several tens of m thick dark pelites, with intercalated thin-bedded and up to lower fine-grained subarkoses (Fig. 11). The latter are commonly bioclastic (bivalves, echinoderms) and display planar to ripple or hummocky cross-lamination.

At Shade the base of the formation is sharp and scoured. Fine grained subarkoses locally with mega-ripple cross-lamination prevail only in the basal interval (23.7 m), the top of which is abrupt. Next, black shales prevail for 32.1 m, while only the topmost 6.4 m contain very fine grained hummocky cross-laminated subarkoses yielding bivalves and phosphatic nodules. The upper Takh Fm. contains black shales, burrowed siltstones and rippled arenaceous layers a few cm thick at most in the lower 75.5 m, followed by lower fine-grained dark glauconitic subarkoses, amalgamated or rippled (16.8 m), and by burrowed siltstones (11 m). The unit is capped by very fine-grained, quartz-poor glauconitic greensands (1.6 m; Labar La Arenite).

At Takh, the base of the formation is marked by a fine-grained subarkose layer, followed by a massive interval of very fine grained arenites (38.3 m). Channelized beds up to over 1 m thick and a few m wide contain very fine-grained yellow-weathering cross-laminated bivalve-rich subarkoses, and thin out laterally into thin-bedded, locally glauconitic subarkoses and burrowed siltstones. Next, very fine to fine-grained subarkoses, still yielding bivalves and occasionally containing planktonic foraminifera, are arranged in well-developed thickening-upward cycles up to 18 m thick (28.5 m). The top of the lower Takh Fm. is represented by two other tickening-upward cycles of burrowed siltstones and up to lower very fine-grained bioclastic quartz-rich arkoses and subarkoses (19 m; Fig. 9). The upper Takh Fm. begins with a black pelitic tongue (9.5 m), followed by very fine to fine-grained burrowed subarkoses and siltstones arranged in poorly-developed thickening-upward cycles (44.7 m), and by another black shale tongue (13 m). Next, upper very fine-grained subarkoses with silicate peloids and glaucony (17.4 m) are followed by dark siltstones (15.5 m). The unit is capped by fine-grained and quartz-poor glauconitic greensands (4.8 m; Labar La Arenite; Fig. 2).

Pingdon La Formation.

Zangla Unit.

Three complete sections were measured at Pingdon La (214 m), Zangla (240 m) and Labar La (92 m), while partial sections were studied along the Oma Chu from Dibling to Sneatse and at Nerak (Fig. 7).

At Pingdon La, dark siltstones predominate in the lower 123 m over invariably very fine-grained volcanic arenites to subarkoses either burrowed or displaying planar to ripple lamination. Next, medium-bedded fine-grained cross-laminated subarkoses (15.6 m) are followed by a 11.3 m thick very coarse-grained and microconglomeratic quartzarenite bar showing spectacular multidirectional cross-lamination. The upper 38.5 m consist of dark siltstones and up to medium-grained volcanic arenites with ripple or megaripple cross-lamination, intercalated with up to 0.5 m thick graded layers with scoured base and yielding bioclasts and oversized rounded clay chips. Two superposed and laterally continuous condensed horizons follow, for a total thickness of 25.5 m (Fig. 4). Dark-coloured, pyritic, cross-laminated and coarse-grained, quartz-rich glauconitic greensands (Nerak Glauco-phosphorite), are overlain by cross-laminated, up to microconglomeratic quartzose arenites rich in glaucony, phosphates, echinoderms and belemnites, followed by channelized intraformational conglomerates with reworked phosphatic nodules commonly encasing ammonoid fragments (Oma Chu Glauco-phosphorite). In the topmost 3 m, starved ripples of phosphatic quartzarenite alternate with hybrid arenites yielding abundant echinoderms, followed by the grey Chikkim foraminiferal limestones. From Dibling down along the Oma Chu, the white quartzarenite bar in the middle part of the Pingdon La Formation rapidly thins out, and the whole unit consists of dark pelites and up to medium-grained volcanic arenites chiefly rippled or showing scoured base and planar to low-angle cross-lamination. The 32.5 to 33.5 m thick overlying condensed intervals comprise dark-coloured and finer-grained greensands showing small to large scale cross-lamination (Nerak Glauco-phosphorite), followed by up to microconglomeratic quartzose hybrid arenites, commonly channelized, cross-laminated and rich in phosphates, chert, belemnites, large bivalves and ammonoids; calcareous arenites with phosphatic nodules contain ammonoids and echinoderms in the upper part (Oma Chu Glauco-phosphorite).

At Sneatse, the Pingdon La Formation comprises up to medium-grained volcanic arenites showing graded-bedding, low-angle or small scale cross-lamination, and common lenses of oversized clay chips and phosphates. At its top, sublitharenites with echinoderm remains are capped by up to very coarse-grained hematitic glauconitic greensands (16 m; Nerak Glauco-phosphorite), directly overlain by the multicoloured foraminiferal mudstones of the Fatu La Formation.

At Nerak, 66 m thick dark volcanic siltstones gradually coarsen upward to lower fine-grained volcanic arenites with hematitic nodules (4 m). The unit is capped by glauconitic greensands (8 m; type section of the Nerak Glauco-phosphorite), containing sparse planktonic foraminifers and showing large scale cross-lamination spectacularly displayed by alignment of hematitic nodules. Another 6 m of intensely burrowed, very fine-grained phosphatic quartzose arenites with sparse planktonic foraminifers mark the transition to the Fatu La Formation (Fig. 5).

In the Labar La section, the basal upper fine to upper medium-grained volcanic arenites (23 m) are followed by limonitic siltstones capped by a few decimetric ferruginous arenite beds (68.5 m) and by thin cross-laminated quartzose glauconitic greensands (0.3 m; Nerak Glauco-phosphorite).

At Zangla, the basal 29.5 m consist of grey burrowed siltstones and volcanic arenites with silicate peloids or phosphatic nodules, followed by burrowed grey siltstones with intercalated very fine-grained volcanic arenites (107 m). The upper 103 m consist of very fine to lower fine-grained rippled or burrowed volcanic arenites showing low-angle and hummocky cross-lamination. Sporadic and badly-preserved ammonoids were found. At the top of the unit, tectonically disturbed black pelites pass directly to the multicoloured Fatu La limestones (Fig. 12).

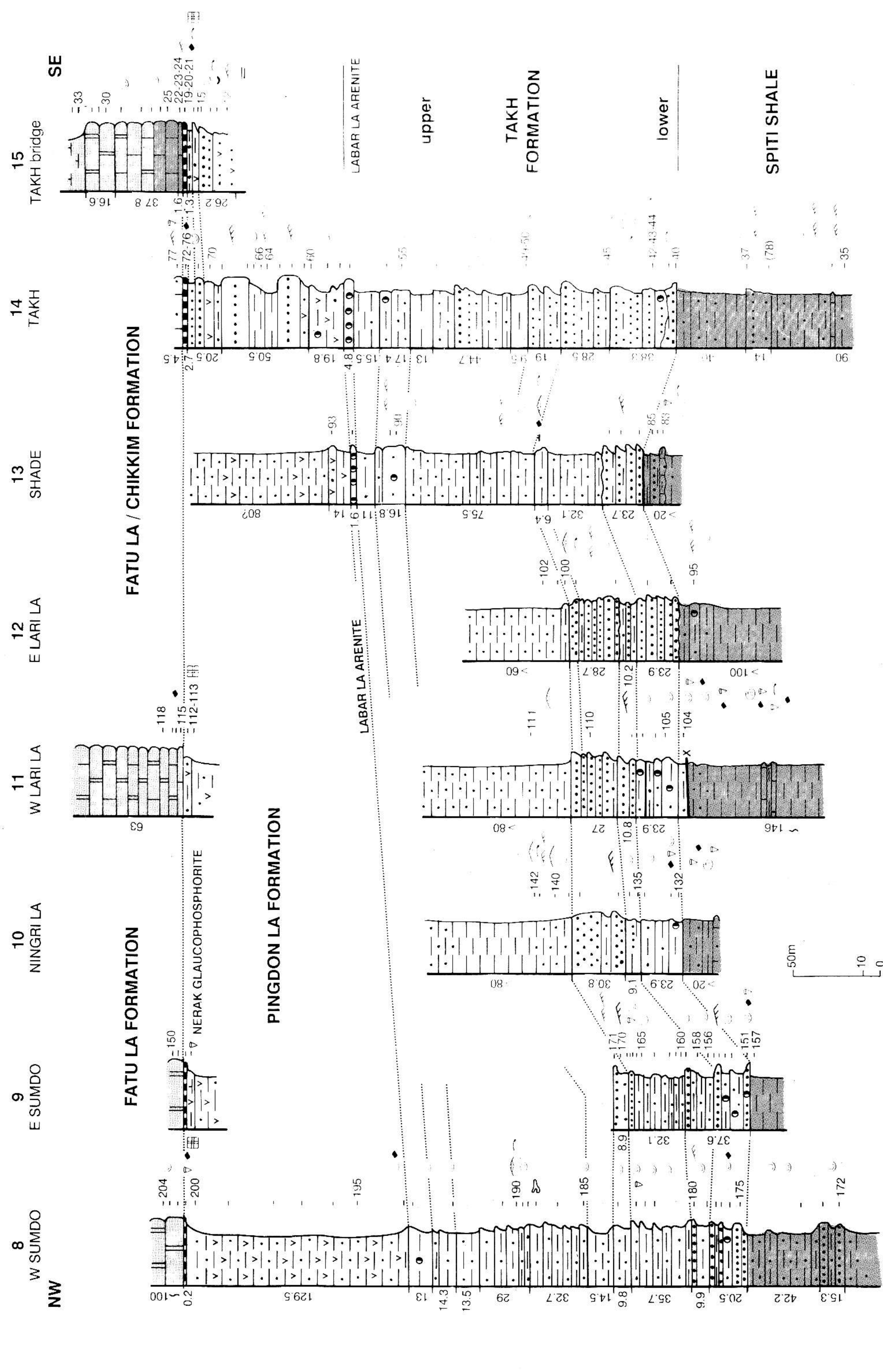
Zumlung Unit.

Two complete sections were measured at Sumdo (130 m) and Takh (94 m), while also three stratigraphic logs at the top and one at the base were studied (Fig. 8).

At Sumdo, the whole Pingdon La Formation consists of dark siltstones and lower very fine-grained feldspathic volcanic arenites (Fig. 13). The unit is capped by a thin condensed bed containing phosphates and belemnites (0.2 to 0.4 m; Nerak Glauco-phosphorite), overlain by the Fatu La Formation.

West of Lari La, the topmost metres of the unit consist of dark pelites and very fine-grained feldspathic volcanic arenites with phosphatic nodules, capped by a phosphatic marly layer (0.5 m; Nerak

Fig. 8 - Measured stratigraphic sections in the Zumlung Unit. Thickness of each interval is given in metres. Dark shading) Spiti Shale at the base and Chikkim-like facies of the Fatu La Fm. at the top; light shading) Fatu La Fm. Symbols as in Fig. 7.


NW
8 W SUMDO
9 E SUMDO
10 NINGRI LA
11 W LARI LA
12 E LARI LA
13 SHADE
14 TAKH
15 TAKH bridge
SE
FATU LA FORMATION
NERAK GLAUCOPHOSPHORITE
PINGDON LA FORMATION
LABAR LA ARENITE
FATU LA / CHIKKIM FORMATION
upper
TAKH FORMATION
lower
SPITI SHALE
50m
10
0

Glauco-phosphorite).

At Shade, the base of the unit consists of 10 m thick grey siltstones, overlain by fine-grained volcanic arenites (4 m), and followed by thick dark pelites.

At Takh, the lower 20 m consist of burrowed siltstones interbedded with up to fine-grained volcanic arenites, followed with sharp contact by amalgamated sublitharenites (5.5 m). Next, an up to medium-grained quartzarenite bar showing large-scale cross-lamination and burrowed stratal surfaces (12 m thick) is followed by black pelites and interbedded fine-grained sublitharenites (17 m), and then by another cross-laminated quartzarenite bar (16 m; Fig. 14). In the uppermost 20.5 m, subordinate burrowed siltstones are intercalated with up to medium-grained, thin to thick-bedded quartzose sandstones showing ripple, megaripple or planar lamination and containing glaucony or occasionally bivalves. The unit is capped by condensed arenites with reworked phosphatic nodules (0.3 to 2.7 m; Nerak Glauco-phosphorite).

In the Chirche valley section, described by Baud et al. (1982) in the northern Zumlung Unit, the Giumal Group is only about 50 m thick, suggesting that its thickness rapidly decreases towards the north.

Khurna Unit.

One section was cursorily observed in the Khurna Unit south of the Shapodak La, where Late Jurassic to Early Cretaceous pelites are over 100 m thick. Further to the north in the Khurnak syncline, only 30 to 50 m of ferruginous siltstones are reported to lie unconformably on top of lower Middle Jurassic limestones (Kioto Group). The abundance of volcanic detritus (Stutz, 1988, p. 51) suggests correlation with the Pingdon La Formation, while the quartzo-feldspathic Takh Formation and the Spiti Shale seems largely missing (Fuchs, 1986, p. 423; Stutz, 1988, p. 52). Conversely the following several hundred m thick pelites, which are overlain by Turonian multicoloured marlstones, would be much thicker than correlative intervals in all other tectonic units (Khurnak Fm. of Fuchs, 1984; Fuchs & Willems, 1990). Further investigations are required to clarify this point.

Shillakong Unit.

In the southern part of the Shillakong Unit (Photaksar - Honupatta area), only a few m of black ferruginous pelites are comprised between *Lithiotis*-bearing Early Jurassic limestones (Kioto Group) and the Late Cretaceous Fatu La Formation. In the northern Shillakong Unit (Fatu La area), the Fatu La Formation rests directly upon the Kioto Group (Bassoullet et al., 1983).

Age.

Search for microfossils and nannofossils was painstaking but largely unfruitful. Since age-diagnostic fossils occur only at the top of the Pingdon La Formation, correlation of stratigraphic intervals was largely based on petrographic composition and lithology alone, and age could only be inferred tentatively. Correlation with the global eustatic chart of Haq et al. (1988) is given only for the Pingdon La Formation; in the Takh Formation it represents little more than a mental exercise.

Biostratigraphic zonation for planktonic foraminifers is after Sliter (1989). Foraminifera were studied in thin section by I. Premoli Silva (Milano); nannofossils on

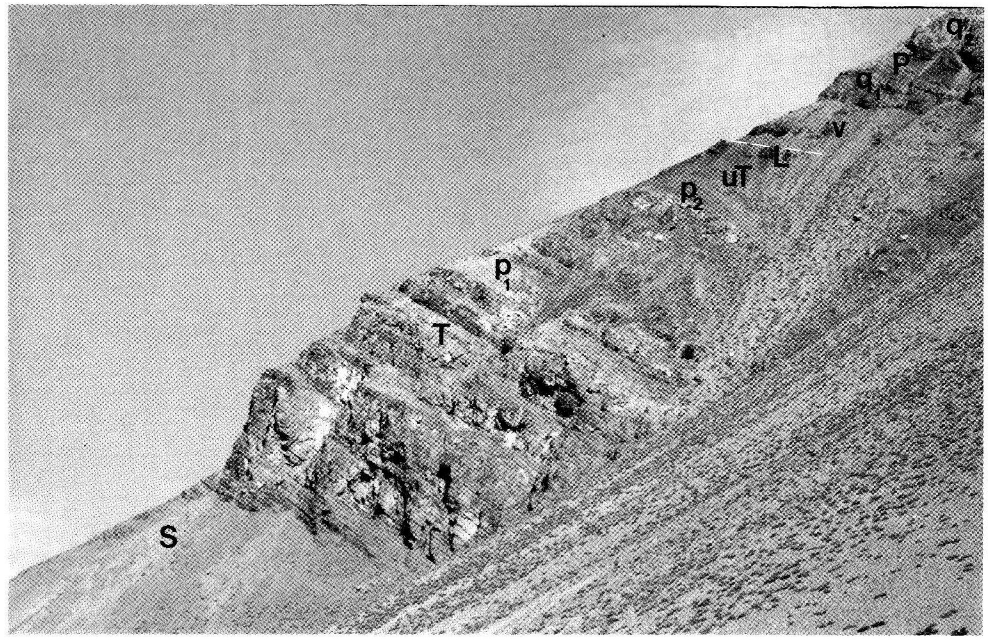


Fig. 9 - The Takh Formation in the type locality is 191 m thick (photo taken just west of Takh; Zumlung Unit). From bottom to top, note: rapid but transitional boundary between the Spiti Shale (S) and the Lower Takh Fm.; prograding and then back-stepping thickening-upward sequences in the commonly bioclastic sandstones of the Lower Takh Fm. (T); first pelitic tongue at the base of the Upper Takh Fm. (p_1); arenaceous sequences in the Upper Takh Fm.; second pelitic tongue (p_2); uppermost Takh Fm. (uT); Labar La Arenite (L), with seemingly unconformable lower boundary; volcanic arenites in the lower Pingdon La Fm. (v); quartzose sandstone bars (q_1, q_2) and interbedded finer-grained clastics in the middle part of the Pingdon La Fm. (P).

smear slides by E. Erba (Milano).

Takh Formation.

All attempts to date the Spiti Shale/Giumal Group transition were unsuccessful, and therefore is still unclear whether the section is stratigraphically continuous or a major gap exists between the two units.

In the Zangla Unit, where the Spiti/Giumal transition is tectonically truncated, the top of the Spiti Shale yielded a rich late Early Tithonian ammonite fauna (Oloriz & Tintori, 1991; Premoli Silva et al., 1992, fig. 6). In the Zumlung Unit the shale/sandstone transition is rapid but gradual, and the Spiti Shale probably ranges into the earliest Cretaceous. In the Spiti region in fact the Upper Spiti Shale (Lochambel Beds) contains Berriasian to Valanginian ammonoids (Uhlig, 1910; Krishna et al., 1982; Krishna, 1983), and also in the Shillakong Unit a possibly Valanginian ammonoid presumably derived from the uppermost Spiti Shale was found loose in a

Fig. 10 - The Lower Takh Fm. in the Ningri La section is 64 m thick (5100 m a.s.l., just east of Ningri La, Zumlung Unit; strata young from left to right). Note the overall coarsening and thickening-upward trend: transitional lower boundary with the Spiti Shale (S); grey-greenish siltstones and up to lower fine-grained subarkoses in the lower part of the Lower Takh Fm. (T_1); fine-grained, bedded to amalgamated, lighter subarkoses separated by thin pelitic intervals in the upper part of the Lower Takh Fm. (T_2); sharp boundary with the Upper Takh Fm. (p).

stream bed (Brookfield & Westermann, 1982).

The rapid increase of sand-sized siliciclastics is in general well recognizable across the Zanskar Range (Fig. 6, 9, 10), and is thought to represent a quasi-isochronous episode. A possible guess is that this event occurred at the close of the Valanginian, as reported not only in Kumaon, Nepal and South Tibet (Krishna, 1983), but also all around Neo-Tethys (Weissert, 1991).

The lowermost Takh Fm., where transgressive arenites rich in non-carbonate intrabasinal grains (Fig. 10; Garzanti, 1991) are common, might have been deposited at reduced sedimentation rates during the global tendency to eustatic rise around the Valanginian/Hauterivian boundary. Glauconitic ironstones at this time marked the transition from the Chichali shales to the Lumshiwal sandstones in the Trans-Indus Salt Range (Hallam & Maynard, 1987). The first appearance of unidentifiable planktonic foraminifera (Hedbergellids?) in the upper half of the lower Takh Fm. (ZD 181; ZD 45) confirm that these sediments are not older than the Late Hauterivian - Barremian.

The boundary between the lower and upper Takh Fm. appears to be slightly heterochronous. At Sumdo and Takh respectively one and two sandy thickening-upward cycles in the uppermost lower Takh Fm. already document a deepening trend (finer grain-size, occurrence of bivalves and belemnites; Fig. 2, 9, 13) and are thus probably time-equivalent with the lowermost upper Takh offshore pelites observed from Ningri La to Shade (Fig. 11). If this is correct, thickness of the underlying coastal sandstones is very homogeneous throughout the Zumlung Unit (62 to 70 m). Their top (Fig. 10, 11) might be tentatively correlated with the Barremian/Aptian boundary, since sharp sandstone/shale transitions are commonly recorded at this stage from western India to Nepal (Krishna, 1983).

The upper Takh Fm. is largely ascribed to the Aptian. At Pingdon La (Fig. 3; H 59), foraminifers resembling *Hedbergella delrioensis* (Carsey) associated with a few nannofossils (*Parhabdolithus* sp., *Rucinolithus terebrodentarius* Applegate, Bralower, Covington & Wise, 1987, *Braarudosphaera africana* Stradner, 1961) in fact suggest a mid-Aptian or younger age. Silicified planktonic foraminifera occur sporadically also in the uppermost Takh Fm. in the Sumdo section (Fig. 13; ZD 191, 193). These pelitic tongues yielding deep-water fauna may have been deposited during flooding episodes in the transgressive part of global Aptian to earliest Albian? eustatic cycles (LZB-4.1, 4.2 and UZA 1.1).

The Labar La Arenite, containing unidentifiable planktonic foraminifera and non-diagnostic nannofossils (*Watznaueria barnesae* Black in Black & Barnes, 1959,

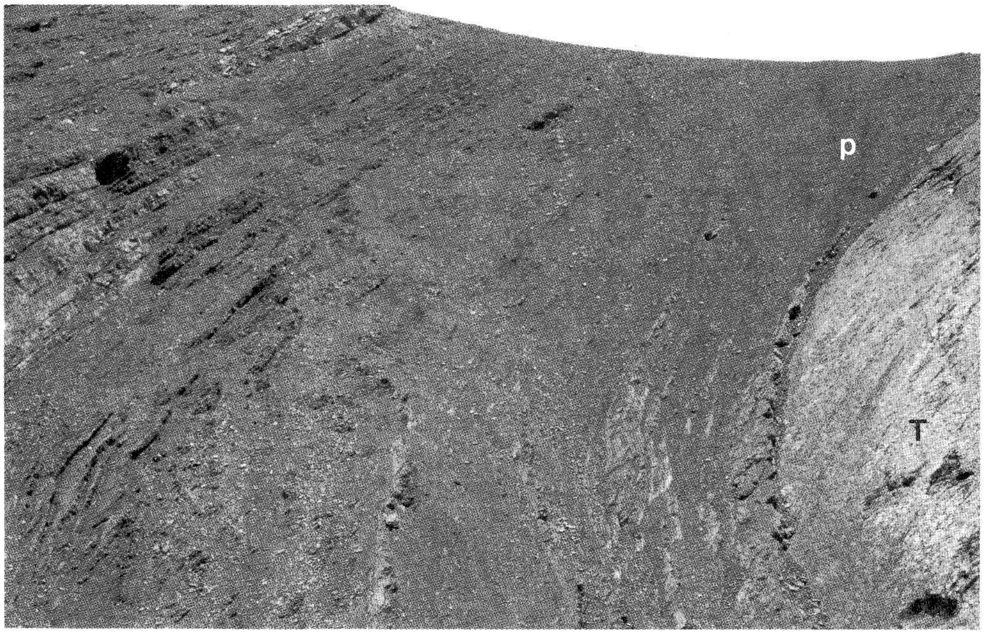


Fig. 11 - The Upper Takh Fm. in the Ningri La section is several tens of m thick (Zumlung Unit). From bottom to top, note: sharp boundary with the Lower Takh Fm. (T); prevailing dark pelites in the lower part of the Lower Takh Fm. (p), with thin-bedded, locally bioclastic and up to lower fine-grained subarkoses increasing upward in frequency.

Perch-Nielsen, 1968) represents a major stage of deepening and starvation, immediately followed by the sudden increase of volcaniclastic detritus everywhere in the Zanskar Range (Fig. 2). For its unique features this excellent petrographic marker is thought to be isochronous, and is tentatively correlated with the earliest Albian global flooding event (cycle UZA-1.1).

Pingdon La Formation.

The Pingdon La Formation is largely ascribed to the Albian (supercycle UZA-1), with the Oma Chu Glauco-phosphorite reaching up to the Late Cenomanian (part of supercycle UZA-2). In the central part of the studied area, sediment influx was insufficient to keep up with strong subsidence, and a monotonous deepening section of volcanic arenites and pelites was deposited (Fig. 12, 13). A few, unidentifiable Nannoconids were found locally. Only in the easternmost (Pingdon La) and westernmost (Takh) studied sections, coarser-grained quartzose sandstones deposited in valley fills incised at lowstand stages are intercalated in the middle part of the formation (Fig. 2, 3 , 4, 14). The uppermost Pingdon La Fm., frequently containing arenites enriched in carbonate and non-carbonate intrabasinal grains (Fig. 14), also yielded a few recogniz-

Fig. 12 - The Pingdon La Fm. west of Zangla, along the trail to Namche La (Upper Zangla Unit; total thickness of the formation about 240 m; this section was not measured). Note that the unit in this area is formed entirely by volcanic arenites, which are coarser-grained in the basal few tens of metres, displaying an aggrading to back-stepping trend (v). The upper part is largely pelitic, slightly coarsening-upward in the middle-upper part (P). Dark pelites at the top are sharply followed by the latest Albian Fatu La Fm. (F).

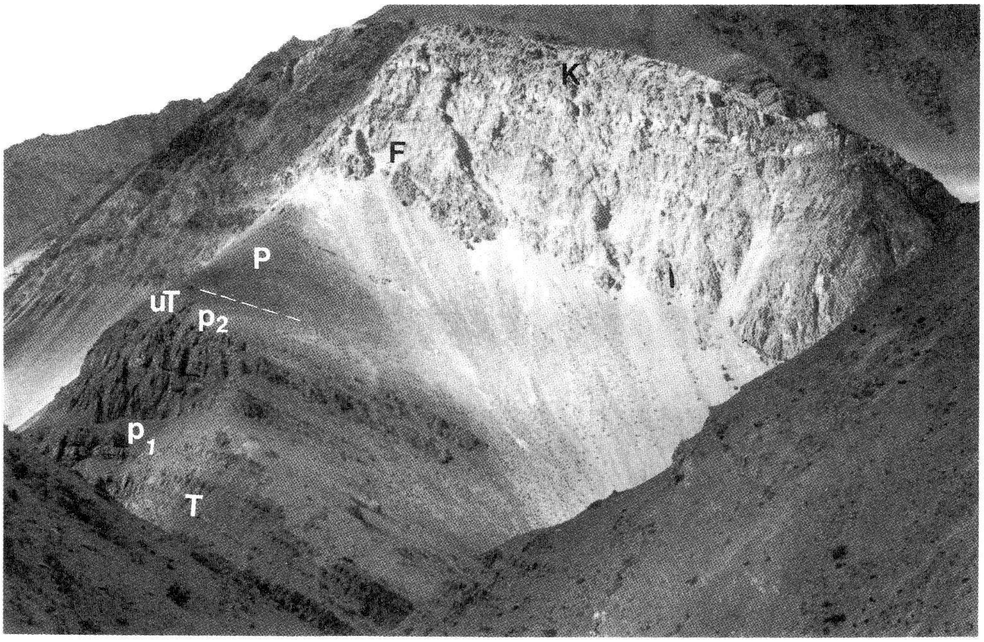


Fig. 13 - The Pingdon La Fm. at Sumdo is reduced to a thickness of only 130 m (Zumlung Unit). From bottom to top, note: arenaceous Lower Takh Fm. (T); first pelitic tongue at the base of the Upper Takh Fm. (p_1); arenaceous sequences separated by a strongly burrowed surface; second pelitic tongue (p_2); uppermost Takh Fm. (uT); Pingdon La Fm. (P); sharp boundary with the latest Albian Fatu La Fm. (F); sharp boundary with the Kangi La Fm. (K).

able specimens of planktonic foraminifera, pointing to a Late Albian age (Fig. 4; H 36; *R. subticinensis* Subzone; Premoli Silva et al., 1992).

Nerak Glauco-phosphorite.

Due to still relatively shallow water depth, only sparse foraminifers were found in the Nerak greensands at Nerak (Fig. 5; G 38, 39, 40) and in thin condensed glauco-phosphorites at Sumdo (Fig. 13; ZD 201), indicating a Late Albian age both in the Zangla and Zumlung Units (*R. subticinensis* Subzone; cycle UZA-1.5; Premoli Silva et al., 1992).

The base of the Fatu La Formation contains latest Albian foraminiferal assemblages (lower *R. appenninica* Zone) both in the Zangla (H 89, G 42, G 60, H 101) and in the Zumlung Unit (ZD 115, ZD 77, 23; with the *R. ticinensis* Zone found only in sample ZD 22; Premoli Silva et al., 1992). The unconformable base of the Fatu La Formation (Fig. 5, 12, 13, 14; see also Premoli Silva et al., 1992, fig. 7, 8 and 9), is thus bracketed between the global type I sequence boundary at 98 my and the flooding event at 97 my of the Haq et al. (1988) chart.

Oma Chu Glauco-phosphorite.

In the western part of the Zangla Unit, the interval comprised between the Nerak Glauco-phosphorite and the Chikkim Formation includes several sequences, commonly showing scoured base and displaying evidence of repeated reworking (Garzanti et al., 1989). The lower ones are still Late Albian in age, as indicated by the occurrence of *Biticinella breggiensis* (Gandolfi) 7.5 m above the top of the greensands in the upper Oma Chu drainage (H 80). Non-diagnostic foraminifera (Hedbergellids, *Globigerinelloides*) occur in the lower and middle sequences (H 26, H 82). In the upper part of the interval (Oma Chu Glauco-phosphorite s.s.), Late Cenomanian ammonoids encased in redeposited phosphatic nodules (*Protachantoceras*; A. Tintori, pers. comm., 1985) occur associated with planktonic foraminifers of the *W. archaeocretacea* Zone (H 24; lower transgressive part of cycle UZA-2.5).

The base of the Chikkim Formation (Fig. 3, 4, 6) contains planktonic foraminifers of Early Turonian age, mixed with older reworked foraminifers and abundant bioclasts (*H. helvetica* Zone; Premoli Silva et al., 1992). It can thus be correlated with the global flooding event at 91.5 my of the Haq et al. (1988) chart.

Conclusions

The Early Cretaceous Giumal Group is here subdivided into two formations, both capped by laterally continuous condensed horizons.

In the lower part of the Takh Formation, which is 62 to 86 m thick in the Zumlung Unit whereas in the Zangla Unit it is largely missing, very fine to fine-grained subarkoses and medium to very coarse-grained quartzarenites prevail over burrowed siltstones. Abundance of non-carbonate intrabasinal grains in the basal 16 m points to a starved transgressive stage.

The transition to deeper-water dark pelites in the upper part of the Takh Formation (103 to 117 m thick) suggests higher tectonic subsidence rates. In the Zumlung Unit, the uppermost 27 to 33 m of the formation are characterized by sandstones commonly bearing non-carbonate intrabasinal grains, followed by pelites.

The Takh Formation is capped by subarkoses strongly enriched in silicate peloids (up to 11 m at Zangla) or glauconitic greensands (up to 6 m at Labar La). This condensed marker interval (Labar La Arenite) characterizes all of the more distal northeastern Zanskar sections, and testifies to a major starved transgressive stage.

The Pingdon La Formation (214 to 240 m thick in the southwestern part of the Zangla Unit and only 92 to 130 m thick in the Nerak area and Zumlung Unit) is characterized by the sudden appearance of up to medium-grained volcanic detritus (basal 14 to 30 m). Intervals of fine-grained subarkoses and medium to very coarse-grained quartzarenites characterize the middle part of the formation in proximal areas

(27 m at Pingdon La; 51 m at Takh). These bars thin out seaward, where thick monotonous sections contain only up to lower fine-grained volcanic arenites. The upper part (39 m at Pingdon La, 21 m at Takh) comprises few volcanic-rich layers, interbedded with dark pelites and arenites bearing sporadic Late Albian planktonic foraminifera.

In the western part of the Zangla Unit (Spanboth and upper Oma Chu valleys), Late Albian quartz-rich glauconitic greensands (Nerak Glauco-phosphorite) are followed by quartzarenites rich in phosphates, glaucony and bioclasts reaching up to the Late Cenomanian (Oma Chu Glauco-phosphorite). These condensed intervals at the top of the Giumal Group (26 to 33 m thick) are sharply overlain by Early Turonian grey pelagic limestones of the Chikkim Formation.

In the more distal northeastern parts of the studied area, the Nerak Glauco-phosphorite, still 14 to 16 m thick between Sneatse and Nerak but abruptly reduced to a single thin condensed bed at Labar La and in the Zumlung Unit, is unconformably overlain by latest Albian multicoloured pelagic limestones of the Fatu La Formation.

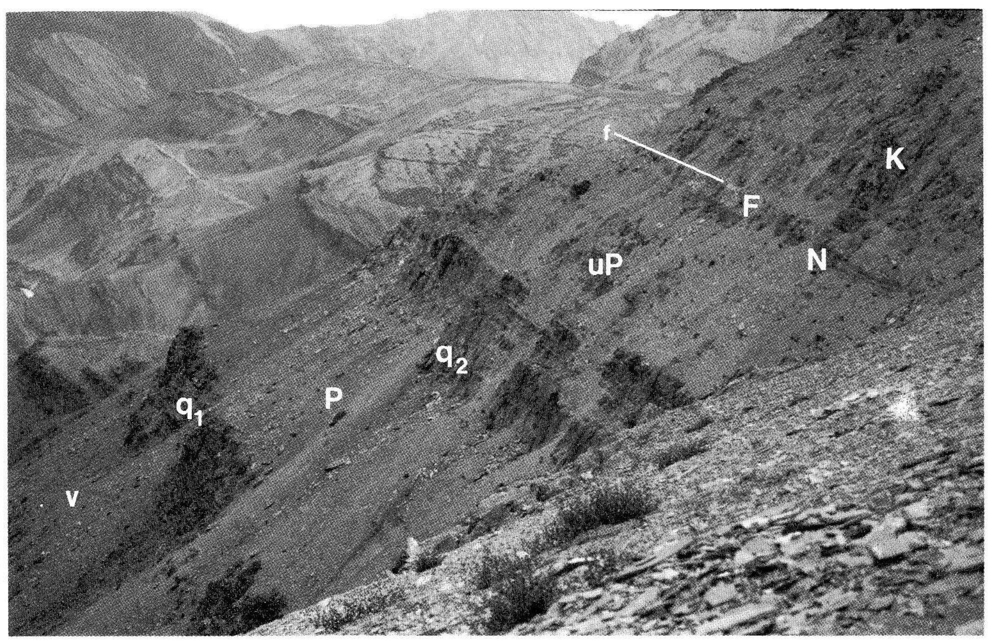


Fig. 14 - The Pingdon La Fm. at Takh is 94 m thick (Zumlung Unit). From bottom to top, note: volcanic pelites and arenites in the lower Pingdon La Fm. (v); first quartzose sandstone bar (q_1); pelites and subarkoses (P); second quartzose sandstone bar (q_2); uppermost Pingdon La Fm. (uP); Nerak Glauco-phosphorite (N); sharp stratigraphic contact with latest Albian Chikkim-like Fatu La pelagic limestones (F); tectonic contact (f) with the Late Campanian to Maastrichtian Kangi La Fm. (K).

The Early Cretaceous evolution of the Indian margin.

The refined stratigraphy presented in this paper sheds new light on the Tethys Himalaya sedimentary history, even though poor biostratigraphic information leaves open a number of questions, particularly as regards the lower part of the Giumal Group.

The rapid increase in sand-sized quartzo-feldspathic detritus at the base of the Takh Formation suggests erosion of the tectonically rejuvenated Indian continental block during rifting between the Indian sub-continent and the rest of Gondwana-Land. If this event was indeed Late Valanginian in age, as possibly indicated by circumstantial evidence, also a global climatic change towards more humid "greenhouse" conditions may be suggested as a minor contributing factor to increased sand supply to the Zanskar shores of Neo-Tethys (Weissert, 1991).

The sharp change in mineralogy recorded at the base of the Pingdon La Formation testifies to a major alkaline volcanic event which affected the Zanskar passive margin at Albian times. Several short-lived pulses of volcanism alternated with minor stages of renewed uplift of southern continental blocks, until both volcaniclastic and quartzo-feldspathic detritus was sharply reduced in the Late Albian. Intraplate alkaline magmatism was also recorded about 1000 km to the east in central Nepal (Bordet et al., 1971; Sakai, 1983; Arita et al., 1991). This episode occurred during the climax of extensional tectonism, when deep-seated faults propagated through the continental crust and tapped magma sources in the upper mantle (Garzanti & Jansa, 1990), and was ended by drowning of the whole Tethys Himalayan passive margin in the latest Albian (Garzanti & Pagni Frette, 1991; Premoli Silva et al., 1992).

Final drowning in Zanskar occurred through successive episodes of starvation and deepening, related to a complex interplay of tectonic, eustatic and oceanographic processes (Garzanti, 1991; see full discussion in Premoli Silva et al., 1992). Multiple tectono-eustatic pulses occurred during the greatest sea-level rise of the Mesozoic (Haq et al., 1988), in a period of reduced climatic gradients and expanded oxygen-minimum layer in the world oceans (Arthur et al., 1990), but also accompanied the final detachment of India from Gondwana-Land and the onset of northward subduction of Neotethyan oceanic crust underneath the Asian active margin (Garzanti et al., 1987; Garzanti & Van Haver, 1988).

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