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# STRATIGRAPHY OF THE CHIKKIM AND FATU LA FORMATIONS IN THE ZANGLA AND ZUMLUNG UNITS (ZANSKAR RANGE, INDIA) WITH COMPARISONS TO THE THAKKHOLA REGION (CENTRAL NEPAL) : MID-CRETACEOUS EVOLUTION OF THE INDIAN PASSIVE MARGIN

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*Key-words:* Stratigraphy, Cretaceous, Tethys Himalaya, Planktonic foraminifera.

*Riassunto.* L'analisi biostratigrafica di dettaglio delle unità pelagiche medio-cretacee del Tethys Himalaya ha fornito nuovi importanti elementi per ricostruire l'evoluzione del margine continentale passivo indiano. Dopo una attività magmatica alcalina registrata durante il Cretaceo inferiore dallo Zanskar fino al Nepal, sedimenti glauco-fosforitici condensati si depositarono durante la Sottozona a *Rotalipora subticinensis*, seguiti in discordanza da calcari pelagici durante le Zone a *Rotalipora ticinensis* e a *Rotalipora appenninica* (Formazione di Fatu La in Zanskar e Formazione di Muding in Nepal). In tutta la zona sedimentaria del Tethys Himalaya l'annegamento delle piattaforme clastiche è dunque avvenuto con le stesse modalità e in modo sincrono a partire dall'Albiano superiore. La base della Formazione di Chikkim in Zanskar è più recente, e segue ad areniti "palinseste" e glauco-fosforiti risedimentate durante il Cenomaniano superiore (Zona a *Whiteinella archaeocretacea*).

Per diversi milioni di anni, nel Cenomaniano e dal Turoniano superiore al Campaniano, iati di simile età ed estensione caratterizzano in Zanskar le Formazioni di Chikkim e Fatu La. Queste lacune sono attribuite alla risospensione continua dei fanghi pelagici, dovuta alla azione di forti correnti oceaniche sulla parte superiore della scarpata. Tassi di accumulo fino a 100 volte più elevati si registrarono nel Turoniano inferiore-medio quando, a maggiori profondità, la sedimentazione risentì in misura minore della azione delle correnti. I tassi di accumulo aumentarono ancora nel Maastrichtiano, quando marne e areniti di mare sempre meno profondo furono infine sostituite da carbonati di piattaforma interna (Formazione di Kangi La e Calcari di Marpo).

La successione studiata mostra una ripetizione quasi speculare delle facies sedimentarie, che è parte di una supersequenza tettono-eustatica durata per gran parte del Cretaceo. L'evoluzione sedimentaria riflette una complessa inter-relazione tra fenomeni regionali e globali, tra cui la fase tettonica estensiva e il magmatismo che hanno accompagnato lo smembramento finale del supercontinente di Gondwana e l'apertura dell'Oceano Indiano, una tendenza eustatica trasgressiva di lungo termine, una mutata circolazione paleo-oceanografica, ed eventi anossici nella Neotetide.

*Abstract.* Detailed biostratigraphic study of mid-Cretaceous Tethys Himalayan pelagic units shed new light on the evolution of the northern India passive continental margin. After a major episode of alkaline

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magmatism recorded from Zanskar to Nepal in the Early Cretaceous, condensed glauco-phosphorites were deposited during the *Rotalipora subticinensis* Subzone, and were overlain unconformably by pelagic mudstones during the *Rotalipora ticinensis* to *Rotalipora appenninica* Zones (Fatu La Formation in Zanskar and Muding Formation in Nepal). Throughout the Tethys Himalaya drowning of clastic shelves thus occurred with the same modalities and synchronously in Late Albian time. The base of the Chikkim Formation in Zanskar is younger, and overlies palimpsest arenites and reworked glauco-phosphorites deposited during the latest Cenomanian *Whiteinella archaeocretacea* Zone.

Hiatuses several million years long, mainly coeval and similar in duration in the Chikkim and Fatu La Formations, characterize the Cenomanian and the Late Turonian to Campanian sections throughout the Zanskar Range. These hiatuses are ascribed to continuous resuspension of pelagic sediments on the upper slope, caused by the action of strong eastbound oceanic currents. Much higher accumulation rates were recorded in the early-middle Turonian, when deposition occurred at greater depths below the mudline. Accumulation rates increased greatly in the Maastrichtian, when offshore marls with sparse phosphate nodules were gradually replaced by inner shelf carbonate facies at the close of the Cretaceous.

The studied succession shows a mirror-like repetition of sedimentary facies, interpreted as part of a 65 to 70 my long Cretaceous supersequence. Sedimentary evolution reflected a complex interplay of global and regional phenomena, including the extensional and magmatic episodes leading to the final fragmentation of Gondwana-Land and opening of the Indian Ocean, a long-term tendency to eustatic rise, changing paleo-oceanographic circulation, and oceanic anoxic events.

## Introduction.

The Mesozoic sedimentary succession of the Zanskar Range (Fig. 1) was deposited on the northern passive continental margin of the Indian sub-continent, facing the Neo-Tethys Ocean. Reconnaissance stratigraphic study of the Cretaceous units cropping out in this area was carried out in the late seventies and eighties by several scientific parties (Fuchs, 1982, 1984, 1986, 1987; Baud et al., 1982, 1984, 1987; Bassoullet et al., 1983, 1984; Kelemen & Sonnenfeld, 1983; Gaetani et al., 1980, 1983, 1986; Garzanti et al., 1987; Fuchs & Willems, 1990).

The Cretaceous succession, overlying the Late Jurassic Spiti Shale, begins with the coastal to shelfal clastics of the Giumal Sandstone Group, which is capped by two distinct and laterally-continuous condensed horizons (Nerak and Oma Chu Glauco-phosphorites; Garzanti et al., 1989; Garzanti, 1992). The Giumal Group is sharply followed by pelagic Scaglia-like foraminiferal mudstones and wackestones (Chikkim and Fatu La Formations), overlain in turn by very fine-grained hybrid arenites and marls (Kangi La Formation) passing distally to black shales (Goma Formation). Finally, shallow-water carbonate ramps (Marpo Limestone) prograded onto proximal areas at the close of the Cretaceous (Nicora et al., 1987).

Scaglia-like pelagic limestones are a characteristic mid-Cretaceous facies occurring all along the Indian margin of Neo-Tethys, and are found also in the Kumaon region ("upper flysch" of Heim & Gansser, 1939; Sangchamalla Formation of Sinha, 1989) and in the Thakkhola Graben (central Nepal), some 1000 km to the east of the Zanskar Range.

In the latter area, the only one in Nepal where Cretaceous sediments are preserved, the foraminiferal marly limestones of the Muding Formation sharply overlie the Chukh Group, a deltaic to shelfal clastic complex of Early Cretaceous age (Bas-

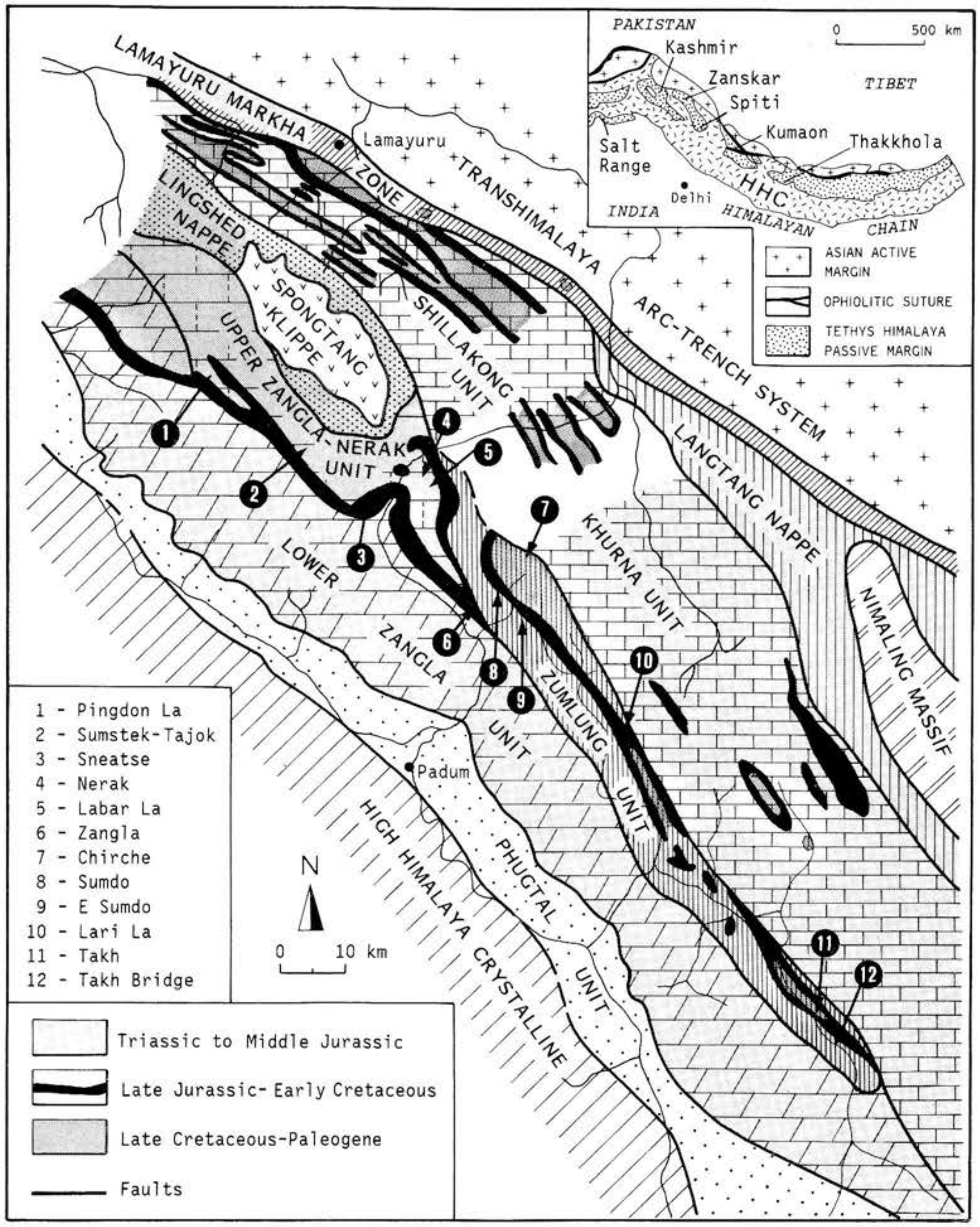


Fig. 1 - Geologic sketch map of the Zanskar Range (compiled after several sources cited in text) with location of stratigraphic sections. Sections 1 to 6 are in the Upper Zangla-Nerak Unit; sections 8 to 12 in the Zumlung Unit, as well as section 7 (studied by Baud et al., 1982). The Honupatta section is in the Shillakong Unit south of Lamayuru. Photo in Fig. 21 and sample ZD 143 were taken west of Ningri La between sections 9 and 10.
Inset shows distribution of Tethys Himalayan sediments and location of study areas in the Himalayan Chain (Zanskar lies 600 km north of Delhi, India; Thakkhola lies 200 km northwest of Katmandu, Nepal). HHC) High Himalayan Crystalline.

soullet & Mouterde, 1977; Garzanti & Pagni Frette, 1991).

The aim of the present paper, which is part of a continuing research program on the stratigraphic and paleogeographic evolution of the Tethys Himalaya zone carried out by members of the University of Milano, is to provide new biostratigraphic data and to describe for the first time in detail the stratigraphy of the mid-Cretaceous Chikkim and Fatu La Formations in the Zangla and Zumlung tectonic units of the Zanskar Range (Gaetani & Garzanti, 1991). New information is also provided from a detailed section of the central Nepal Muding Formation, which substantially modifies previous beliefs and indicates close parallelism in the sedimentary evolution of the whole Indian continental margin.

## Stratigraphy

### **Chikkim Formation** (Zanskar Range).

The term Chikkim was introduced by Stoliczka (1866), to designate the calcareous unit overlying the Giumal Sandstone in Spiti. The formation was assigned an either Early or Late Cretaceous age (Gansser, 1964). In Spiti, the Chikkin Formation is the youngest unit exposed, whereas towards the Indus Valley it is overlain by a "flysch-like" unit according to Gansser (1964).

In the Zanskar Range, the unit is exposed both in the Lower and Upper Zangla Units (Gaetani et al., 1985; Garzanti & Brignoli, 1989), in the SW part of the investigated area (upper Oma Chu drainage), whereas it gradually interfingers with the marly and multicoloured Fatu La Formation towards the east and the north (Fig. 2). Lithofacies more and more akin with the Chikkim Formation reappear in the eastern Zumlung Unit, towards Spiti.

The Chikkim Formation consists mainly of grey, well-bedded, partly nodular limestones, locally thin-bedded and with rare marly interbeds. The lower boundary is fairly sharp, with quartzose siliciclastic detritus up to upper medium sand-sized rapidly vanishing within the basal metre. The very base of the unit may contain frequent belemnite rostra and abundance of echinoderm remains at Pingdon La. The nodular calcareous beds tend to be increasingly amalgamated upwards, giving a cliff-forming aspect to the unit. The presence of globotruncanids, commonly packed within cm-sized burrows, can be easily observed in the field with a hand-lens. More hardened surfaces were detected in the upper part, where the sequence becomes somewhat condensed.

The unit may be capped either by sharp and undulating, hardened and burrowed surfaces or by a few beds, usually dense with inoceramid prismatic shell particles and even larger fragments, marking the more gradual transition to the overlying Kangi La Formation.

The total thickness is between 76 and 89 m. In the lower Oma Chu drainage, the unit gradually passes laterally to the Fatu La Formation, maintaining its most

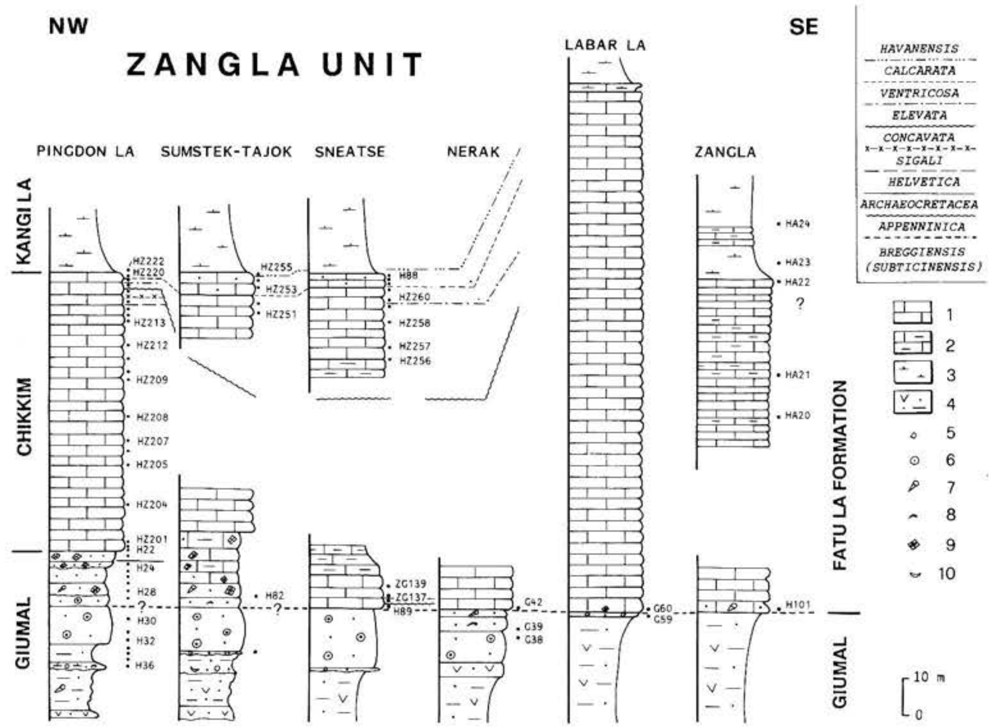


Fig. 2 - Lithologic logs of the studied sections (Zangla Unit), showing sample distribution and correlations based on recognized planktonic foraminiferal biozones (see Fig. 10 to 20 for zonal succession and ages). Dots show all samples examined, but due to space limitation only selected samples are identified. 1) mudstones/wackestones; 2) marly limestones; 3) marls; 4) siltstones/sandstones with volcanic detritus; 5) reworked phosphate nodules; 6) glaucony peloids; 7) belemnites; 8) bivalves; 9) echinoderms; 10) mudclasts.

typical, more calcareous condensed facies in the basal and topmost parts, while the middle part is characterized by marly Scaglia-like sediments.

### **Fatu La Formation** (Zanskar Range).

The term Fatu La Limestone was first introduced by French Authors (Bassoullet et al., 1978), who recognized a Late Campanian microfauna in the "multicoloured limestones" of the northern Shillakong Unit, erroneously ascribed at first to the Triassic (Fuchs, 1977, 1979). The formation has been given several other names,which are considered as younger synonyms ("calcaires multicolorés" of Baud et al., 1982; "Shillakong Formation" of Fuchs, 1982; "Multicoloured formation" of Kelemen & Sonnenfeld, 1983). The Late Aptian/Early Albian age assigned to the base of the formation in the southern Shillakong Unit (Bassoullet et al., 1983, 1984) has not been confirmed by later work (Gaetani et al., 1986; Baud et al., 1987), and in the Zanskar Range the unit ranges in age from latest Albian to Campanian or even as young as Middle Maastrichtian (Khurmafu section south of Labar La and just below the Lingshed-Spongtang Klippe close to Yelchung: Baud et al., 1987; Markha region: Stutz, 1988, p. 70). Only sparse biostratigraphic data collected on partial stratigraphic sections have been published so far (Baud et al., 1982: Fuchs, 1984, 1987; Gaetani et al., 1986; compilation by Fuchs & Willems, 1990).

The Fatu La Formation crops out in the Upper Zangla-Nerak Unit (Sneatse-Nerak-Zangla area), where typical multicoloured marly facies occur in the middle part of the unit, whilst the base and top still recall the grey Chikkim limestones (Fig. 2). In the Zumlung Unit, typical reddish intervals occur only west of Ningri La, whereas to the east thickness and facies compare more and more closely with the Chikkim Formation, particularly in the lower part where burrowing is more intense (Fig. 3). Exclusively grey-greenish colours were observed at Lari La, Shade and Gotunda La; at Takh greenish colours occur only in the upper part, and the grey burrowed limestones of the lower part strongly resemble the Chikkim limestones.

The lower boundary with the Giumal Sandstone is invariably sharp. Sparse reworked phosphate nodules and belemnite rostra may occur only in the basal metre


Fig. 3 - Lithologic logs of the studied sections (Zumlung Unit), showing sample distribution and correlations based on recognized planktonic foraminiferal biozones (see Fig. 10 to 20 for zonal succession and ages). The Chirche section is drawn after Baud et al. (1982, pp. 355-356). Symbols as in Fig. 2.

along with fine to lower medium sand-sized quartzose siliciclastic detritus. The latter makes up 0 to 10% of the rock in the basal centimetres of the unit at Labar La, Nerak, Sumdo and Takh, reaching up to 40% and upper medium sand-size at Lari La, where it is still present 2.5 metres above the base.

Silt- to sand-sized siliciclasts are completely absent throughout the rest of the unit, which consists of medium-bedded multicoloured argillaceous mudstones and wackestones rich in planktonic foraminifera. Reddish marlstone bands typically occur in the middle part of the formation, and become more numerous towards the north. Grey colours are frequent at the base of the unit, but locally pyritic grey limestones yielding inoceramid, echinoderm or fish remains also characterize the topmost metres. The boundary with the Kangi La Formation is mostly sharp.

Straight-crested wave ripples with height up to 10 cm and wave-length of 20-30 cm were observed and sampled just west of Nigri La, in greyish foraminiferal wackestones of Coniacian/Santonian? age. Starved ripples, which are common at the transition with the underlying Giumal Group, were also observed 15 m below the top of the unit at Takh.

The thickness of the Fatu La Formation tends to increase northwards from about 100 m in the Namche La-Zangla area, to 130-150 m at Sneatse and Labar La and to 200 m or even more in the Nerak area and in the Shillakong Unit. Fuchs & Willems (1990, pl. 2) reported very thick Fatu La facies also north of the Kangi La. In the Zumlung Unit, the thickness decreases southeastwards from 100-120 m at Sumdo, to 65 m at Lari La and 56 m at Takh. According to Baud et al. (1982), the total thickness rapidly increases northwards, to over 200 m in the upper Chirche Valley. Further to the north, Fatu La facies are less widespread. In the Khurnak Syncline, a few to several tens of m-thick greyish to multicoloured limestones of Turonian to Late Campanian-Maastrichtian age (Fuchs, 1986) are found resedimented as olistostromes within sediments of Tertiary age (H. Masson in Stutz, 1988, p. 71).

Multicoloured marly foraminiferal limestones are reported even in the continental rise succession of the Markha Unit, just south of the Indus ophiolitic suture. Here, the upper part of the nearly 85 m-thick Omlung Formation contains resedimented Fatu La facies yielding abundant reworked faunas of Coniacian, Santonian and Campanian age, associated with Middle Maastrichtian species (M. Caron in Stutz, 1988, p. 70; see also Fuchs, 1984). Similar multicoloured limestones pinched in tight synclines within the Lamayuru Unit were observed by one of us (EG) in the same tectonic position southeast of Lamayuru near Urtsi during the 1983 expedition.

**Muding Formation** (Central Nepal).

The mid-Cretaceous "calcaires de teinte claire" cropping out in the Thakkhola Graben (Central Nepal; Bordet et al., 1971) were later called formally Muding Formation (Bassoullet & Mouterde, 1977; Garzanti & Pagni Frette, 1991). The term "Dzong

Formation" (Gradstein et al., 1989) cannot be even considered as a younger synonym, since it was introduced much earlier to designate the underlying sandstone/shale stratigraphic unit (Colchen, 1971, in Bassoullet & Mouterde, 1977). The Aptian age previously assigned to the unit (early-middle Gargasian; Bordet et al., 1967, 1971) needs revision, as indicated by the Albian fauna found in the underlying strata.

The unit is exposed only at the core of complex synclines in the upper Thakkhola Valley north of Kagbeni towards the restricted area of Mustang. Only one continuous stratigraphic section could be measured by one of us (EG) on the Dzong ridge at 3500 m a.s.l., during the Ev-K$^2$-CNR expedition of October 1989. The section, to our knowledge the first published so far, displays the transition between the 25.4 m-thick major Glauconitic Horizon capping the Chukh Group, and the 40 basal metres of the Muding Formation, comprising light-grey fucoid-bearing pelagic limestones and marls of Late Albian age (Fig. 4). The Glauconitic Horizon is characterized by common inoceramids, planktonic foraminifera and rare echinoderms, whereas sparse ostracods and siliceous sponge spicules also occur in the Muding Formation. In the lower 20 m of the latter, glaucony and siliciclasts (quartz, minor feldspars, granophyric and "trachytic" igneous rock fragments) still occur; phosphate grains are found throughout the section. Bioturbation is intense in the Glauconitic Horizon and

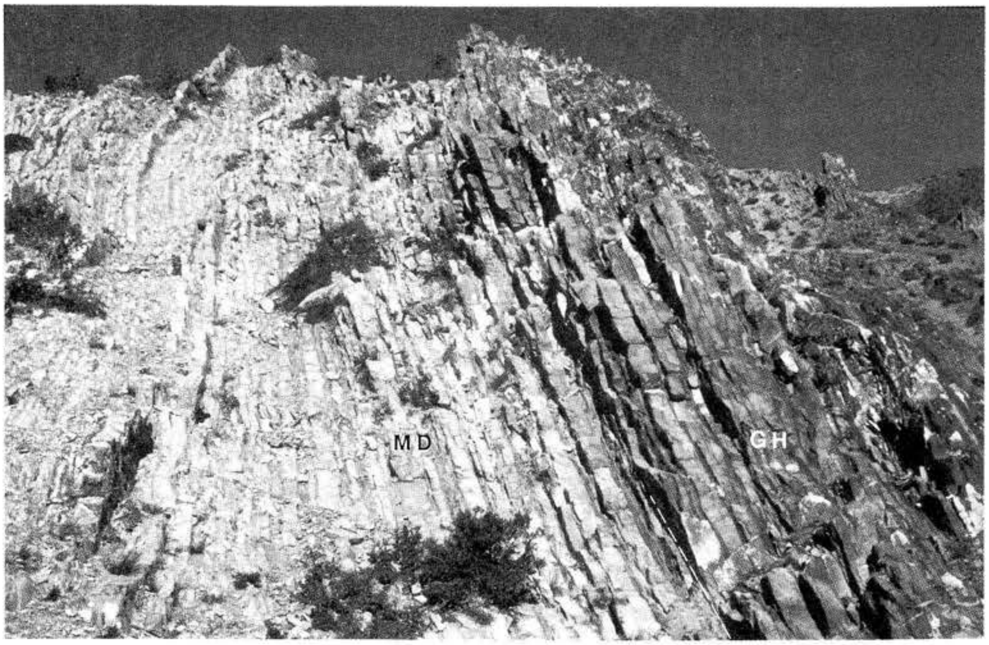


Fig. 4 - Transitional boundary between the Glauconitic Horizon (GH) and the Muding Formation (MD) in the Dzong ridge section (central Nepal).

tends to decrease upward in the Muding Formation. The upper part of the latter unit is covered in the studied area, and Late Cretaceous sediments have not been found.

## Stratigraphic sections

### Thakkhola Graben (Central Nepal).

#### Dzong ridge section.

Bottom to top:

*Glauconitic Horizon.*

1) Green glauconitic arenites with hematitic nodules and burrowed greenish-grey siltites in beds 20-40 cm thick or amalgamated up to 2 m. Samples HN 76, 77. Thickness 13.8 m;
2) grey burrowed siltites intercalated with a few glauconitic marly limestones in beds up to 20 cm thick. Samples HN 78, 79. Thickness 4.55 m;
3) glauconitic arenites with hematitic nodules; light-grey marly limestones become common at the top. Sample HN 80. Thickness 4.3 m;
4) greenish-grey glauconitic marly limestones in beds 5 to 20 cm thick, containing arenite laminae and ripples; glauconitic arenites are subordinate. Sample HN 81. Thickness 2.7 m.

*Muding Formation.*

5) Light-grey marly limestones in 5 to 20 cm thick beds separated by subordinate greenish-grey marls; glaucony, still abundant at the base, progressively diminishes upward. Thickness 3.1 m;
6) grey marls interbedded with subordinate light-grey marly limestones in beds up to 15 cm thick. Sample HN 82. Thickness 2.65 m;
7) light grey thin-bedded marly limestones and greenish-grey marls.Thickness 6.1 m;
8) reddish marls and subordinate marly limestones. Thickness 0.7 m;
9) light-grey marly limestones in up to 15 cm thick beds and greenish-grey marls. Sample HN 83. Thickness 3.15 m;
10) monotonously alternating marly limestones and marls; the latter become more and more common upwards. Thickness 15 m;
11) grey marls with subordinate marly limestones. Sample HN 84. Thickness 4.5 m;
12) poorly exposed grey marlstones. Thickness 5 m.

### Zangla Unit - Spanboth-Oma Chu area (W Zanskar, India).

Two complete stratigraphic sections in the Chikkim Formation (Spanboth Valley and Pingdon La) and logs at the Giumal/Chikkim and Chikkim/Kangi La transitions (Sumstek-Tajok) were measured (Fig. 2). In this area, two superposed condensed intervals, the Nerak Glauco-phosphorite and the Oma Chu Glauco-phosphorite, mark the Giumal/Chikkim transition.

#### Spanboth section.

The section was measured in 1981 on the right bank and cliff of the Spanboth Chu, a few km north of Ringdom Gompa. Due to epizonal metamorphism and intense calcite recrystallization, microfossils are no longer recognizable.


Fig. 5 - In the Pingdon La section, the Chikkim Formation (CF) overlies the Oma Chu Glauco-phosphorite (OGF) and comprises a lower less resistant part, followed by cliff-forming limestones.

Bottom to top:

*Chikkim Formation.*

1) Nodular to mottled thin-bedded grey mudstones/wackestones, with enrichment of belemnite rostra about 5 m above the base; marly interbeds are strongly schistose; pyrite framboids occur. Thickness about 31 m;
2) dark grey limestones; schistosity simulates thin parallel lamination. Thickness 17 m;
3) cliff-forming, amalgamated and strongly recrystallized limestones, with only a few marly interbeds. Thickness 18 m;
4) grey nodular limestones alternating with slaty marlstones. Thickness 13 m;
5) cliff-forming grey nodular limestones and subordinate marlstones. Thickness 10 m.

## Pingdon La section.

One stratigraphic log at the Giumal/Chikkim transition was measured in 1984 east of Pingdon La at 4250 m. a.s.l. on the left side of the valley leading to Dibling (Fig. 5).

Bottom to top:

*Topmost Giumal Sandstone.*

1) Quartzose bio-intraclastic, up to microconglomeratic arenites yielding bivalves, gastropods, echinoderms, foraminifera, glaucony, lithoclasts and "trachytic" volcanic rock fragments. Samples H 34, 35, 36. Thickness 2 m;
2) grey burrowed siltstones. Sample H 33. Thickness 5 m.

*Nerak and Oma Chu Glauco-phosphorites.*

3) Dark quartzose glauconitic greensands with phosphates; pyrite and cross-lamination. Samples H 30, 31, 32. Thickness 10 m;

4) coarse-grained, medium to thick-bedded glauconitic quartzarenites; dolomite occurs. Samples H 28, 29. Thickness 3.1 m;
5) coarse-grained hybrid arenite lenses full of poorly-oriented belemnites and rich in glaucony; pyrite nodules occur. Sample H 27. Thickness 0 to 0.2 m;
6) medium-grained quartzarenites with echinoderms and black grains, alternating with medium-bedded quartzose hybrid arenites rich in belemnites, echinoderms and planktonic foraminifera; large scale cross lamination points to unidirectional ESE-ward paleocurrents. Sample H 26. Thickness 3.5 m;
7) massive fine-grained quartzarenites yielding sparse echinoderms, belemnites and phosphates. Sample H 25. Thickness 4 m;
8) channelized medium-grained quatzarenites full of reworked phosphatic nodules commonly encasing ammonoids (Acanthoceratid sp. juv., det. A. Tintori, Milano) and yielding foraminifera and glaucony. Sample H 24. Thickness 0.5 to 2 m;
9) medium-grained bioclastic quartzarenites yielding echinoderms and bivalves, alternating with limestones containing irregular sand layers or lenses 1 to 20 cm thick and sparse phosphate nodules. Sample H 23. Thickness 3 m.

*Chikkim Formation.*

10) Grey-bluish biocalcarenites yielding echinoderms, foraminifera and calcispheres. Sample H 22 at the base. Thickness 1 m.

The section continues on the left slope of the creek flowing from the Pingdon La, about 1 km before the confluence with the Oma Chu, where the measured total thickness of the Chikkim Formation is 76.1 m;

11) thin-bedded grey nodular wackestones, containing sparse belemnite rostra and fish teeth in the basal metres; occasional thicker beds are present. Samples HZ 201 to 205. Thickness 26 m;
12) very thin-bedded mudstones/wackestones with marly interbeds. Sample HZ 206. Thickness 6.5 m;
13) monotonous sequence of thin to medium-bedded grey mottled wackestones, sometimes in thicker amalgamated beds; they may be locally packed with globotruncanids, especially within burrow-fills; marls are scarce. In the upper part thin calcarenitic layers and hardened surfaces were observed; sparse echinoid tests are preserved in life position. The topmost surface layer is irregular and shows vertical burrows. Contact with the overlying unit is sharp. Samples HZ 207 to 220. Thickness 42.6 m.

*Kangi La Formation.*

14) Monotonous, mottled, poorly-bedded, dark grey splintery marls, with sparse small calcareous nodules. Samples HZ 220 to 222 in the basal beds.

### Sumstek-Tajok section.

Two stratigraphic logs were measured in 1984 north of the Barmi creek-Oma Chu confluence, on the trail to the Barmi La. The Giumal/Chikkim transition crops out at 3750 m a.s.l.

Bottom to top:

*Topmost Giumal Sandstone.*

1) Dark siltstones to up to very coarse-grained volcanic sublitharenites with biotite, acid tuff and "trachytic" rock fragments; dark clay chips and scoured base occur locally. Sample H 83. Thickness 3.9 m.

*Nerak and Oma Chu Glauco-phosphorites.*

2) Dark ferruginous arenites with ripple cross-lamination. Thickness 12 m;
3) bioclastic quartzarenites yielding belemnites, echinoderms and bivalves. Sample H 82. Thickness 6.5 m;
4) grey arenaceous mudstones with phosphatic nodules. Thickness 14 m.

*Chikkim Formation*

5) Grey bedded limestones.

The section continues upwards for several tens of metres.

At the narrow bend of the Barmi creek, the topmost part of the Chikkim Formation was studied. Note that in this section the boundary with the Kangi La Formation, exposed at 4050 m a.s.l., is transitional in nature.

1) Grey wackestones, loosely nodular and mottled. Sample HZ 251. Thickness over 10 m;
2) very thin-bedded grey nodular wackestones. Sample HZ 252. Thickness 2.8 m;
3) grey, thin-bedded and platy wackestones/packstones, with fine-grained siliciclastic detritus, including muscovite. Samples HZ 253, 254, 255. Thickness over 5 m.
*Kangi La Formation.*
4) Dark grey thin-bedded marly limestones, with marly interbeds increasing upwards, grading after some 2 m to splintery dark grey marls, then monotonously developed for at least 200 m.

### Zangla Unit - Zangla-Nerak area.

One complete stratigraphic section of the Fatu La Formation (Labar La) and logs at the Giumal/Fatu La and Fatu La/Kangi La transitions (Sneatse, Nerak, Zangla) were studied (Fig. 2). In this area the Giumal/Fatu La transition is marked by the Nerak Glauco-phosphorite.

#### Sneatse section.

The section was measured (August 1984, September 1987) along the gully north of Sneatse starting at 4150 m a.s.l., along the main trail Padum - Lingshed (Fig. 6).

Bottom to top:
*Topmost Giumal Sandstone.*
1) Dark grey siltstones and very fine-grained calcareous volcanic arenites yielding biotite, "trachytic" volcanic rock fragments and belemnites. Sample H 93. Thickness 2.5 m.
*Nerak Glauco-phosphorite.*
2) Fine to coarse-grained cross-laminated quartzose glauconitic greensands with hematitic nodules. Samples H 90 to 92. Thickness 16 m.
*Fatu La Formation.*
3) Grey thin-bedded wackestones affected by strong deformation. Samples H 89 at the very base (Fig. 7), ZG 137, 138. Thickness about 20 m;
4) greenish grey marly limestones grading upwards to red marls and marly limestones. Sample ZG 139. Thickness about 15 m;
5) red marls and well-bedded reddish marly limestones. Estimated total thickness of the Fatu La Fm. is about 140 m.

Continuing on the right orographical side, above the main step of the trail:

6) red marly limestones in thin amalgamated beds. Sample HZ 256. Thickness several m;
7) mottled and nodular, thin-bedded or amalgamated grey or greenish wackestones. Sample HZ 257. Thickness 3 m;
8) thin-bedded and platy, grey packstones/wackestones with inoceramid fragments. The clay content gradually increases towards the top. Samples HZ 258 to 261. Thickness 16 m;
9) platy medium-bedded grey packstone/wackestone with large fragments of inoceramids and fish scales; pyrite framboids. Samples HZ 262 to 264; H 88 at the top. Thickness 3.4 m.
*Kangi La Formation.*
10) Dark grey mottled splintery marls, monotonously developed for more than 300 m.

#### Nerak section.

One stratigraphic log at the Giumal/Fatu La transition was measured in 1983 between Nerak and Labar La.


Fig. 6 - The Cretaceous succession at Sneatse, where the upper part of the Giumal Group (Pingdon La Fm. of Garzanti, 1992) lies tectonically on top of ammonoid-bearing late Early Tithonian Spiti Shale (SS; Oloriz & Tintori, 1991; Oma Chu flat of Gaetani et al., 1985; Garzanti & Brignoli, 1989). The Giumal Group (GG) is sharply overlain by multicoloured limestones of the Fatu La Formation (FL), followed in turn by the Kangi La Formation (KL). KT) Jurassic strata of the Kioto Limestone.

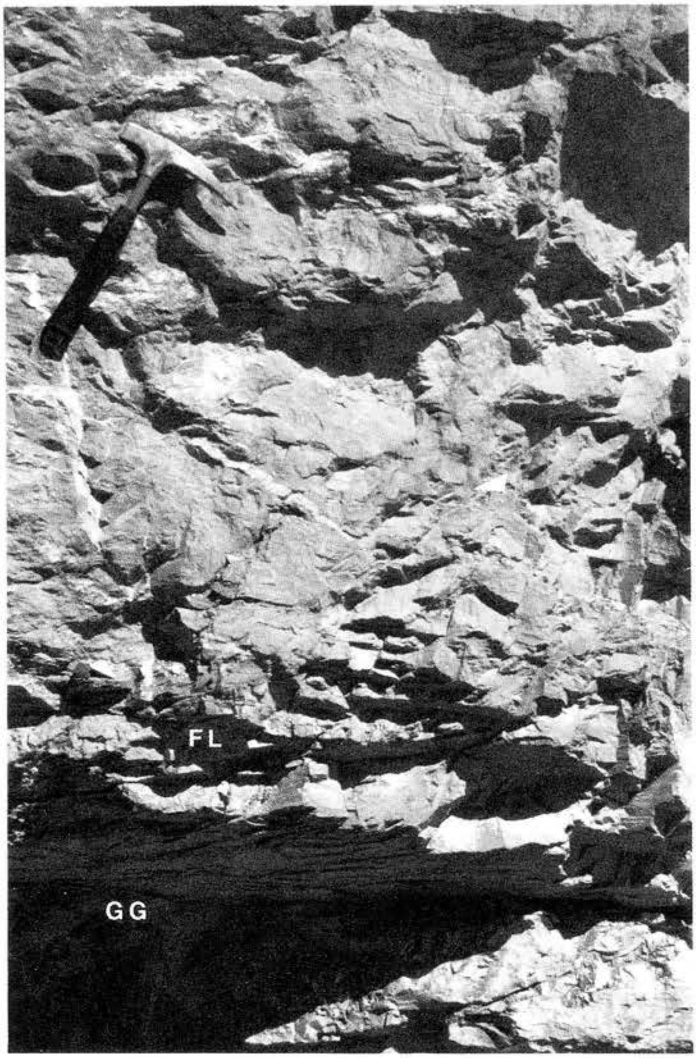


Fig. 7 - Sharp basal contact in the Sneatse section between the top of the Giumal Group (GG) and grey condensed limestones of latest Albian to Late Cenomanian age (Fatu La Fm.; FL).

Bottom to top:

*Topmost Giumal Sandstone.*

1) Dark grey ferruginous siltstones and very fine-grained volcanic arenites several tens of m-thick. Arenites are slightly coarser-grained in the topmost 4 m.

*Nerak Glauco-phosphorite.*

2) Fine-grained quartzose glauconitic greensands with large-scale cross-bedding, hematitic nodules and sporadic planktonic foraminifera; partly glauconized "trachytic" and hypabissal rock fragments occur; authigenic stilpnomelane and tourmaline are common. Samples G 35, 36, 37, 38. Thickness 8 m;
3) very fine-grained burrowed quartzose arenites with volcanic rock fragments, sparse glaucony and foraminifera. Samples G 39, 40. Thickness 5 m;

4) burrowed reddish calcareous arenites with belemnites. Sample G 41. Thickness 1 m.
*Fatu La Formation.*
5) Burrowed reddish to light grey and greenish-grey marly limestones. Sample G 42. Thickness over 100 m.

## Labar La section.

One complete section was measured in 1983 on the eastern slope of the creek flowing south of Labar La by Aymon Baud (Lausanne) and one of the writers (EG; Fig. 8).

Bottom to top:
*Topmost Giumal Sandstone.*
1) Dark grey ferruginous siltstones several tens of m-thick.
*Nerak Glauco-phosphorite.*
2) Thin-bedded very fine-grained quartzose glauconitic greensands with hematitic nodules. Sample G 59. Thickness 0.3 to 0.5 m.
*Fatu La Formation.*
3) Grey arenaceous limestones with reworked phosphatic nodules. Sample G 60. Thickness 0.3 m;
4) light grey, greenish-grey and reddish marly limestones; measured thickness is 140 m, but the rocks show significant deformation, with incipient development of cleavage and transposed bedding;
5) grey marly limestones and marls. Thickness 4 m.
*Kangi La Formation.*
6) Dark grey burrowed marls with sharp basal contact. Thickness over 300 m.


Fig. 8 - The Cretaceous succession at Labar La, where the upper part of the Giumal Group (GG; Pingdon La Formation of Garzanti, 1992) is sharply overlain by the multicoloured limestones of the Fatu La Formation (FL). The top of the Fatu La Fm. consists of a grey mudstone band abruptly followed by the Kangi La Fm. marls (KL).

### Zangla section.

One log at the transition between the Giumal and Fatu La Formations was sampled in 1984 just west of Zangla at 4190 m a.s.l.

Bottom to top:

*Topmost Giumal Sandstone.*

1) Dark grey, several tens of m-thick siltstones with sporadic very fine-grained volcanic arenites.

*Fatu La Formation.*

2) Grey cleaved arenaceous limestones yielding belemnites with sharp basal contact. Sample H 101. Thickness about 1.5 m.

Just above Zangla, a stratigraphic log within the Fatu La Formation was measured in 1984 by Andrea Tintori (Milano):

3) reddish to greenish marlstones. Sample HA 20. Thickness 3.6 m;
4) greenish to grey well-bedded marly limestones. Thickness 6 m;
5) grey medium-bedded marly limestones. Sample HA 21. Thickness 4.8 m;
6) greenish marlstones, reddish at the top. Thickness 17 m;
7) grey mudstones with echinoid remains and pyrite nodules at the top. Sample HA 22. Thickness 9.5 m;
8) grey burrowed marlstones. Samples HA 23, 24. Thickness over 14 m.

### **Zumlung Unit** (E Zanskar, India).

Two complete stratigraphic sections of the Fatu La Formation (Lari La and Takh bridge) and logs at the transition between the Giumal and Fatu La Formations (Sumdo, E Sumdo, Takh) were measured in 1987 (Fig. 3). In this area, the top of the Giumal Sandstone Group is marked by thin condensed beds which are correlated with the Nerak Glauco-phosphorite.

### Sumdo and E Sumdo sections.

Two stratigraphic logs at the Giumal/Fatu La transition were measured at Zangla-Sumdo along the Zumlung Chu at 4000 m a.s.l., and south of Charcha La at 4350 m a.s.l. respectively.

Bottom to top:

*Topmost Giumal Sandstone.*

1) Dark grey burrowed siltstones and sporadic very fine-grained quartz-rich volcanic arenites; discontinuous lenses up to 0.3 m thick of silty marls yield bivalves and calcispheres. Samples ZD 144 to 146, 200. Thickness 5 m.

*Nerak Glauco-phosphorite.*

2) Hybrid arenites particularly rich in reworked phoshatic nodules up to 5 cm in size at the base and top, passing laterally to lenticular belemnite lags and quartzose mudstones. Samples ZD 147, 148, 201. Thickness 0.2 to 0.35 m.

*Fatu La Formation.*

3) Grey burrowed limestones, packed with planktonic foraminifera and locally slightly arenaceous at the very base, follow with sharp contact. Samples ZD 149, 150, 202. Thickness 1.5 m;
4) grey marly limestones and marlstones. Sample ZD 203. Thickness 8 m;
5) light grey marly limestones with one reddish layer at the top. Sample ZD 204. Thickness about 20 m.

A more complete, over 200 m-thick section was measured in the nearby upper Chirche Valley by Baud et al. (1982).

### Lari La section.

One complete stratigraphic section of the Fatu La Formation was measured along the valley of the first left tributary of the Niri Chu just west of Lari La.

Bottom to top:

*Topmost Giumal Sandstone.*

1) Dark grey burrowed ferruginous siltstones and subordinate very fine-grained quartz-rich volcanic arenites. Samples ZD 112, 113. Thickness 4 m;

*Nerak Glauco-phosphorite.*

2) Very fine-grained quartz-rich volcanic arenite. Sample ZD 114. Thickness 0.45 m;

*Fatu La Formation.*

3) Quartzose micritic wackestone with phosphatic nodules at the base. Sample ZD 115. Thickness 0.45 m;
4) grey foraminiferal marly wackestones. Sample ZD 116. Thickness 2 m;
5) grey marly limestones and burrowed marlstones. Samples ZD 117, 118. Thickness 8 m;
6) light grey or greenish-grey, well-bedded, burrowed marly limestones and marlstones. Thickness 30 m;
7) light grey wackestones. Sample ZD 119. Thickness 2 m;
8) light grey bedded marly limestones and marlstones. Sample ZD 120. Thickness 10 m;
9) light grey bedded mudstones/wackestones. Sample ZD 121. Thickness 3 m;
10) grey marly limestones and marlstones. Thickness 4.5 m;
11) grey wackestones. Samples ZD 122, 123. Thickness 5.2 m.

*Kangi La Formation.*

12) Dark grey burrowed cleaved marls with sharp basal contact. Samples ZD 124, 125. Thickness over 300 m.

### Takh and Takh bridge sections.

One complete stratigraphic section of the Fatu La Formation on the northern bank of the Tarap Chu close to Takh bridge, and one log at the transition between the Giumal and Fatu La Formations just west of Takh at 4700 a.s.l. were measured (Fig. 9).

Bottom to top:

*Topmost Giumal Sandstone.*

1) Dark grey siltstones and burrowed quartzose sandstones in beds up to 0.8 m thick. Sample ZD 18. Thickness 5.2 m.

*Nerak Glauco-phosphorite.*

2) Medium to very coarse-grained quartzose arenites with common phosphates, chert, ferruginous ooids, chamosite peloids and clay chips. Microconglomeratic beds with scoured base and reworked phosphatic nodules are laterally discontinuous. Samples ZD 19, 20, 72, 73, 74. Thickness 1 to 2.2 m;
3) reworked glauco-phosphorites, with phosphatic nodules up to 3 cm in size concentrated at the base and top, passing laterally to medium-grained quartzarenites and quartzose micritic wackestones. Samples ZD 21, 75, 76. Thickness 0.3 to 0.5 m.

*Fatu La Formation.*

4) Three 0.5 to 0.6 m-thick beds of grey burrowed wackestones with discontinuous sandy lenses and belemnites. Samples ZD 22 and 77 (first bed), ZD 23 (second bed), ZD 24 (third bed). Thickness 1.6 m;
5) light grey thin-bedded burrowed limestones. Samples ZD 25, 26, 27. Thickness 14.6 m;
6) light grey well-bedded limestones with thin marly interbeds at the top. Samples ZD 28, 29. Thickness 23.2 m;
7) grey marlstones with sparse silty lenses. Sample ZD 30. Thickness 3 m;
8) grey-greenish marly limestones with greenish marly interbeds. Sample ZD 31. Thickness 8 m;
9) grey bedded wackestones. Sample ZD 32. Thickness 5.6 m.

*Kangi La Formation.*

10) Grey bioclastic marly wackestones and dark grey burrowed marls with sharp unconformable basal contact and upward-increasing silt content. Sample ZD 33 at the base. Thickness over 200 m.

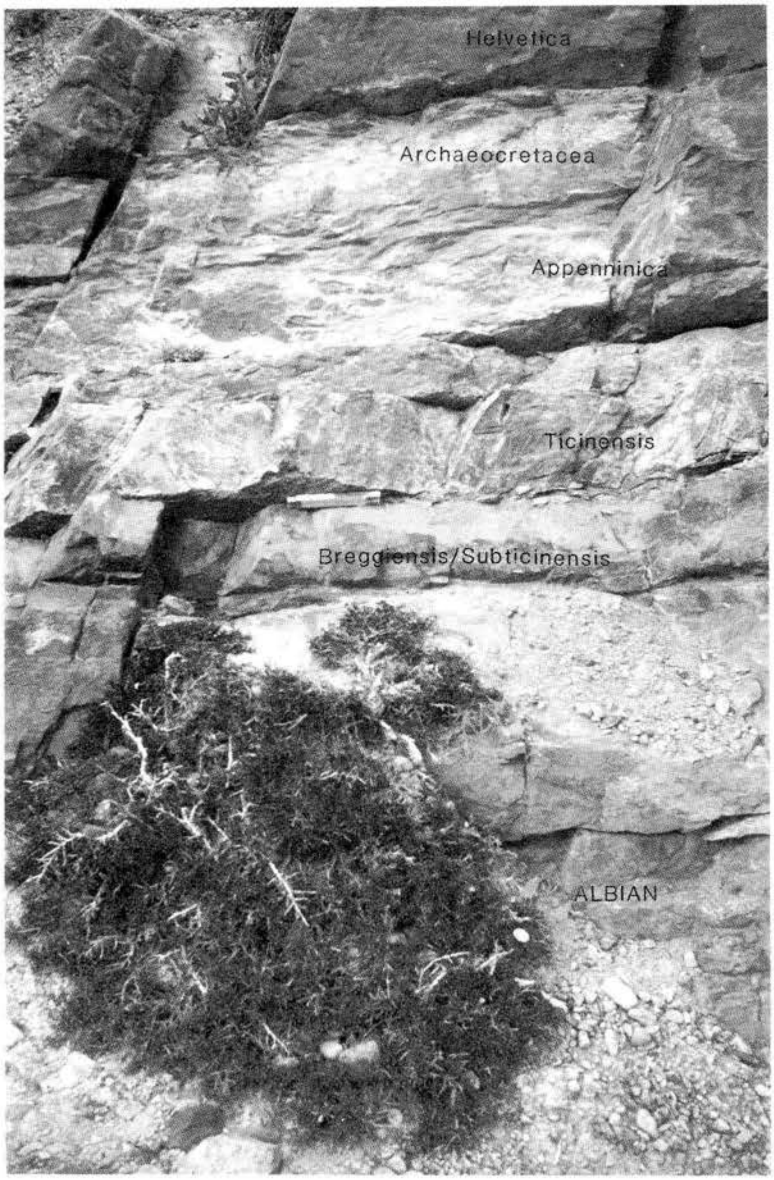


Fig. 9 - Boundary between the Albian upper part of the Giumal Group and the latest Albian to Late Cenomanian base of the Fatu La Formation in the Takh Bridge section. The thin Nerak Glauco-phosphorite (*R. subticinensis* Subzone; ZD 21) is overlain by three condensed limestone beds dated at the *R. ticinensis* (ZD 22), *R. appenninica* (ZD 23) and *W. archaeocretacea* (ZD 24) foraminiferal zones, followed in turn by an expanded Turonian section of mudstones/wackestones (*H. helvetica*; ZD 25; see Fig. 17 for full biostratigraphic information). Scale bar is 20 cm.

**Shillakong Unit** (N Zanskar, India).

Honupatta section.

One partial log in anchimetamorphic limestones of the middle Fatu La Formation was sampled in 1983, in the Honupatta gorge north of Honupatta.

Bottom to top:

*Fatu La Formation.*

1) Grey-green deformed marly limestones. Sample FL 1 at the very top. Thickness over 10 m;
2) reddish recrystallized marly limestones. Thickness 3 m.
3) metamorphosed silvery marlstones, greenish-grey at the base. Thickness 35 to 40 m.

*Goma Formation.*

4) Black pelites at the core of a narrow syncline. Thickness some tens of metres.

## Biostratigraphy

The biostratigraphy for the sections studied from Zanskar and Nepal is based on planktonic foraminifera, which although often poorly preserved could be identified from most levels without major uncertainties. The study was carried out in thin section as all the lithologies were indurated. Identification of planktonic foraminifera in thin section is somewhat more difficult than on isolated specimens, as it is based on bidimentional observation rather than tridimensional. Reliable observations, however, can be obtained because most of the Cretaceous planktonic foraminifera display a characteristic profile. Moreover, in identiying an individual species the shape of the inner whorls, the size ratio between the inner and outer whorls, the thickness of the wall, and ornamentation are also taken into account. Most of these features can be observed even in poorly preserved specimens.

Calcareous nannofossils could not be studied in order to confirm or implement the foraminiferal data, since all samples from the Zanskar Range were barren, due to diagenetic recrystallization, which strongly affected the original micrite now replaced by microsparite. Only in the Thakkhola Graben (Nepal) are nannofossils preserved due to the much lower temperatures reached during the Himalayan metamorphism.

Common to abundant planktonic foraminifera were encountered in the mid to Late Cretaceous Chikkim, Fatu La, and Kangi La Formations of Zanskar and in the Muding Formation of Nepal, whereas only rare to few specimens occur in the uppermost part of the Early Cretaceous Giumal and Chuck sandstone Groups. Preliminary investigations dated the limestone units of the Tethys Himalaya as ranging from Late Albian to about the Campanian/Maastrichtian boundary (Gaetani et al., 1986). The present detailed study revealed that: 1) most planktonic foraminifera are strongly recrystallized, in some layers severely deformed, and sometimes cut by solution seams; 2) the planktonic faunas are accumulated and mixed in age. Because of such a bias, zonal boundaries were difficult to place precisely. Although most zonal attributions should be considered as a minimum age, the biostratigraphic scheme presented herein

| SPECIES / SAMPLES | H 36 | H 26 | H 24 | H 22 | HZ201 | HZ202 | HZ204 | HZ205 | HZ206 | HZ207 | HZ208 | HZ209 | HZ210 | HZ211 | HZ212 | HZ213 | HZ214 | HZ215 | HZ216 | HZ217 | HZ218 | HZ219 | HZ220 | HZ222 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Globigerinelloides alvarezi* | | | | | | | | | | | | | | | | | | | | | | | | r |
| *Heterohelix striata* | | | | | | | | | | | | | | | | | | | | | | | | r |
| *Heterohelix globulosa* | | | | | | | | | | | | | | | | | | | | | | | | r |
| *Globigerinelloides messinae* | | | | | | | | | | | | | | | | | | | | | | | | r |
| *Globotruncanita stuarti* | | | | | | | | | | | | | | | | | | | | | | | r | r/f |
| *Heterohelix glabrans* | | | | | | | | | | | | | | | | | | | | | | | r | |
| *Rugoglobigerina rugosa* | | | | | | | | | | | | | | | | | | | | | | | r | cf |
| *Hedbergella monmouthensis* | | | | | | | | | | | | | | | | | | | | | | | r | |
| *Hedbergella holmdelensis* | | | | | | | | | | | | | | | | | | | | | | | r | r |
| *Globotruncana rosetta gr.* | | | | | | | | | | | | | | | | | | | | | | | r | r |
| *Globotruncana hilli* | | | | | | | | | | | | | | | | | | | | | | r | | |
| *Globotruncana bulloides* | | | | | | | | | | | | | | | | | | | | | | r | r | r |
| *Globotruncana ventricosa* | | | | | | | | | | | | | | | | | | | | | | cf | r | r |
| *Pseudotextularia elegans* | | | | | | | | | | | | | | | | | | | | | cf | cf | | f |
| *Pseudoguembelina costulata* | | | | | | | | | | | | | | | | | | | | | r | | | |
| *Ventilabrella browni* | | | | | | | | | | | | | | | | | | | | | r | r | | f |
| *Ventilabrella glabrata* | | | | | | | | | | | | | | | | | | | | | r | r | f | r |
| *Ventilabrella eggeri* | | | | | | | | | | | | | | | | | | | | | C | | | |
| *Globigerinelloides prairiehillensis* | | | | | | | | | | | | | | | | | | | | | r | r | | |
| *Globigerinelloides bollii* | | | | | | | | | | | | | | | | | | | | | r | r | | |
| *Globotruncanita stuartiformis* | | | | | | | | | | | | | | | | | | | | | r | f | f | C |
| *Globotruncanita elevata* | | | | | | | | | | | | | | | | | | | | | r | r | r | |
| *Globotruncana linneiana* | | | | | | | | | | | | | | | | | | | | | r | r | | |
| *Globotruncana arca* | | | | | | | | | | | | | | | | | | | | | ? | f | f | f |
| *Globotruncana lapparenti* | | | | | | | | | | | | | | | | | | | | | r | r | r | r |
| *Contusotruncana fornicata* | | | | | | | | | | | | | | | | | | | | | r | r | f | f |
| *Dicarinella asymetrica* | | | | | | | | | | | | | | | | | | | | | r | r/f | r | |
| *Marginotruncana paraconcavata* | | | | | | | | | | | | | | | | | | | | cf | | | | |
| *Dicarinella concavata* | | | | | | | | | | | | | | | | | | | | f | r | r/f | | |
| *Marginotruncana undulata* | | | | | | | | | | | | | | | | | | | | vr | | | | |
| *Archaeoglobigerina cretacea* | | | | | | | | | | | | | | | | | | | r | r | | r | r | r |
| *Dicarinella primitiva* | | | | | | | | | | | | | | | | | | | r | r | | | | |
| *Hedbergella flandrini* | | | | | | | | | | | | | | | | | | | r | r | | | | |
| *Marginotruncana marginata* | | | | | | | | | | | | | | | | | | | r | C | r | r | | |
| *Marginotruncana marianosi* | | | | | | | | | | | | | | | | | | | ? | | | | | |
| *Marginotruncana coronata* | | | | | | | | | | | | | | | | | vr | | f/C | C | r | f | | |
| *Whiteinella aumalensis* | | | | | | | | | | | | r | vr | | r | ? | r | | | | | | | |
| *Heterohelix reussi* | | | | | | | | | | | | cf | | | r | | f | C | C | A | A | f | | |
| *Marginotruncana pseudolinneiana* | | | | | | | | | | | r | | | | | cf | | r | f/C | C | r | f | | |
| *Globigerinelloides caseyi* | | | | | | | | | r | | | | | | | | | | | | | | | |
| *Globigerinelloides ultramicrus* | | | | | | | | | r | r | r | r | | | | | | | | | | | | |
| *Marginotruncana renzi* | | | | | | | | cf | | r | r | r | | | | | | r | r | C | r | | | |
| *Marginotruncana schneegansi* | | | | | | | | cf | | cf | | | | | | | | r | r | C | r | | | |
| *Marginotruncana sigali* | | | | | | | | cf | | | | r | | cf | | | cf | r | r | C | r | f | | |
| *Marginotruncana spp.* | | | | | | | | f | r | | | f | | | ? | r | r | | A | AA | | C | C | |
| *Schackoina sp.* | | | | | | | | r | r | | | | vr | | | r | | | | | | | | |
| *Heterohelix moremani* | | | | | | | vr | ? | r | r | r | f/C | f | r/f | C | f | C | C | f | | | | | |
| *Dicarinella ? oraviensis* | | | | | | | r | r | r | | | r | cf | r | cf | r | cf | r | r | r | | | | |
| *Dicarinella imbricata* | | | | | | cf | | r | | | | | | | | | | r | r | | | | | |
| *Dicarinella algeriana* | | | | | | r | r | r | | | r | r | | vr | r | r | r | r | | | | | | |
| *Dicarinella canaliculata* | | | | | cf | | cf | r | cf | | r | cf | | | | | | | | | | | | |
| *Dicarinella hagni* | | | | | cf | r | cf | r | r | r | | | | | | | | r | cf? | | | | | |
| *Helvetoglobotruncana helvetica* | | | | cf | cf | ? | cf | ? | vr | | r | cf | vr | | | cf | | C | cf | | | | | |
| *Whiteinella kingi* | | | | r | cf | cf | | | | | | | | | r | cf | | | | | | | | |
| *Whiteinella brittonensis* | | | | r | | | cf | | | | r | r | cf | cf | | r | | r | | | | | | |
| *Whiteinella archaeocretacea* | | | | r | r | r | ? | cf | r | | | r | | | cf | r | vr | r | cf | | | | | |
| *Favusella sp.* | | | | vr | f | | | | | | ? | | | | | | | | | | | | | |
| *Whiteinella inornata* | | | cf | | cf | | r | r | r | | | | | | | r | | | | | | | | |
| *Whiteinella praehelvetica* | | | cf | cf | r | r | vr | | | | | ? | | | vr | | | | | | | | | |
| *Whiteinella baltica* | | | vr | f | C | C | | | cf | r | f | r | | cf | f/C | f | r/f | r | r | vr | | f | | |
| *Whiteinella aprica* | | | vr | r/f | f | r | r | r | r | r | | r | | | f/C | f | f | r | | | | | | |
| *Praeglobotruncana gibba* | | | vr | | r | | | r | | r | | r | r | | | r | r | r | | | | | | |
| *Praeglobotruncana stephani* | | | vr | | r | | r | r | r | r | r | r | C | r | r | r | r/f | f | | | | | | |
| *Rotalipora deeckei* | | | vr | | | | | | | | | ? | vr | | | | | | | | | | | |
| *Rotalipora greenhornensis* | | | vr | | r | r | r | vr | r | r | r | r | f | vr | r | r | f | r | | | | | | |
| *Rotalipora cushmani* | | | vr | | | | | | cf | r | ? | r | r | | cf | cf | f/C | r | | | | | | |
| *Hedbergella planispira* | | | vr | C | r | r | f | r | r | r | f | r | f | r | f | f | r | r | | | | | | |
| *Globigerinelloides bentonensis* | | cf | vr | C | vr | r | f | r | r | r | r | r | f/C | r | f | r | | | r | | | | | |
| *Hedbergella simplex* | | | vr | r | r | r | vr | r | r | r | r | r | r | r | r | r | r | r | | | | | | |
| *Hedbergella delrioensis* | r | cf | vr | f | r | r | f | r | r | | r | | | | | | | | | | | | | |
| *Ticinella primula* | vr | | | | | | | | | | | | | | | | | | | | | | | |
| *Ticinella roberti* | vr | | | | | | | | | | | | | | | | | | | | | | | |
| *Rotalipora subticinensis* | vr | | | | | | | | | | | | | | | | | | | | | | | |
| *Ticinella praeticinensis* | vr | | | | | | | | | | | | | | | | | | | | | | | |
| *Ticinella madecassiana* | vr | | | | | | | | | | | | | | | | | | | | | | | |
| *Hedbergella rischi* | vr | | | | | | | | | | | | | | | | | | | | | | | |
| PLANKTONIC FORAMINIFERA – ABUNDANCE | vr | r/f | r/f | A | A | C | f | f/C | A | f | C | A | C | f | AAA | A | AA | AAA | AAA | AAA | AAA | AAA | AAA | A |
| PLANKTONIC FORAMINIFERA – PRESERVATION | vp | vp | p | p | p | p | vp | vp | p | vp | p | p | vp | vp | vp | vp | p/m | vp/p | p | m | m | m | p | p |
| PLANKTONIC FORAMINIFERA – DEFORMATION | | | | | | | | m | | | | | m | h | h | l | | l/h | | | | | | |
| BENTHIC FORAMINIFERA | fsh | fsh | vr | fsh | Csh | Csh | f | rsh | r/f | f | fsh | r/f | rsh | r | f | Csh | f/C | f | r | f | r | r | r | f |
| RADIOLARIANS | | | r | | A | C | C/A | f/C | | | | | | | | | f/C | r | | | | | | |
| CALCISPHERES | | | r | A | C | C | C/A | C | | C | r | f | | | | C/A | C | | | | | | | |
| ECHINOIDS | f | C | | AAA | C | C | | | | | | | | | | | f | | | | | | | |
| MOLLUSKS | AAA | | | C | | | | | | vr | Apl | | | | | | | | ? | | | | | |
| QUARTZ | | AAA | AAA | f | | | | | | | | | | | | | | | | | | | | |
| GLAUCONY | | | f | | | | | | | | | | | | | | | | | | | | | |
| PHOSPHATES | | | r | f | | | | | | | | | | | | | | r | | | | | | |
| PYRITE | | | f | | | | C | | f | | | | | f | r/f | | | | | | | | | r |
| RESEDIMENTATION | | | | | | m | | m | m | | | m | | | h | h | m | h | h | h | h | h | h | m |
| TECTONIC DEFORMATION | | | | | | | | m | m | | | | | | h | | | m/h | | | | | | |
| LAMINATION | | | | | | | | m | m | | | | h | h | h | | | | | | | | | |
| ZONES | R. subticin | | Warc | | | | | | | Helvetoglobotruncana helvetica | | | | | | | | | Msig | Dcon | Gele | Gven | Gcal | Ghav |
| AGE | ALBIAN | | | | | | | | | | TURONIAN | | | | | | | | | | | CAMPANIAN | | M |

is considered reliable (see Fig. 10 to 20).

The zonal scheme which applies best to the Himalayan faunas is that of Sliter (1989), which is specifically based on taxa identified in thin section. It is worth mentioning that Sliter's zonation is very similar to others based on whole specimens that are well known and of common use in the literature (e.g. Caron, 1985; Sigal, 1987). The zonal scheme used is shown in Fig. 20, plotted against the age according to recent correlation between planktonic foraminiferal assemblages and ammonites (Robaszynsky et al., 1990).

The distribution and estimated abundance of planktonic foraminifera in each section and locality are plotted in Fig. 10 to 19 along with those of other fossil and mineral components.

The biozones identified are (from bottom to top):

*Rotalipora subticinensis* Subzone (*Biticinella breggiensis* Zone).

Rare to few planktonic foraminifera occur in the Nerak Glauco-phosphorite at the top of the Giumal Group (Pl. 37, fig. 1). This zone was identified on the presence of the zonal and subzonal markers associated with few hedbergellids, *Globigerinelloides*, *Ticinella roberti*, *T. raynaudi*, *T. madecassiana*, and *T. primula*.

Very sparse planktonic specimens also occur in some underlying layers, that belong to the upper part of the Giumal Group. Their scarcity prevented any zonal attribution.

*Occurrence*. Nerak section, G 38 to G 40; Pingdon La section, H 36; Sumdo section, ZD 201; possibly Sumstek section, H 82 unzoned, and Lari La section, ZD 114 unzoned. Dzong ridge section, HN 76 to HN 81.

*Rotalipora ticinensis* Zone.

In the Takh Bridge section abundant planktonic foraminifera occur at the very base of the Fatu La Formation, where the zonal marker is associated with *Rotalipora subticinensis*, *T. primula*, *T. raynaudi*, *Favusella washitensis*, *Biticinella breggiensis*, *Globigerinelloides bentonensis*, and some hedbergellids.

*Occurrence*. Takh Bridge section, ZD 22.

*Rotalipora appenninica* Zone.

This zone was identified on the basis of the occurrence of the zonal marker associated with *Planomalina buxtorfi* (Pl. 37, fig. 4), *Praeglobotruncana stephani*, *P.*

Fig. 10 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Pingdon La section, Zangla Unit. Plain line) normal zonal boundary; dashed line) hiatus. R. subticin.) *Rotalipora subticinensis*; Warc) *Whiteinella archaeocretacea*; Msig) *Marginotruncana sigali*; Dcon) *Dicarinella concavata*; Gele) *Globotruncanita elevata*; Gven) *Globotruncana ventricosa*; Gcal) *Globotruncanita calcarata*; Ghav) *Globotruncanella havanensis*. Abundance) vr, very rare; r, rare; f, few; C, common; A, abundant; AA to AAA, very to extremely abundant. Preservation) vp, very poor; p, poor; m, fair. Deformation, Resedimentation, Tectonic deformation, and Lamination) l, low; m, medium; h, high. Other symbols) sh, occurrence of shallow-water forms; pl, pelagic pelecypods. Reworked forms in bold letters.

| SPECIES / SAMPLES | H 82 | HZ251 | HZ252 | HZ253 | HZ254 | HZ255 |
|---|---|---|---|---|---|---|
| *Globotruncanella havanensis* | | | | | | r |
| *Globotruncanita subspinosa* | | | | | | cf |
| *Globotruncanita calcarata* | | | | vr | ? | |
| *Globotruncanita stuarti* | | | | r | r/f | r/f |
| *Globotruncana ventricosa* | | | | r | r/f | r/f |
| *Globotruncana lapparenti* | | | | r | r | r |
| *Contusotruncana patelliformis* | | | | r | f | r |
| *Globotruncana orientalis* | | | | r | r | r |
| *Globotruncana rosetta* | | | | C | f | f |
| *Hedbergella holmdelensis* | | r | r | r | r | r |
| *Globigerinelloides alvarezi* | | r | r | r | r | r |
| *Globigerinelloides prairiehillensis* | | f | r | f | f | f |
| *Pseudoguembelina palpebra* | | vr | vr | | | |
| *Pseudoguembelina costulata* | | r | r | vr | r | r |
| *Heterohelix globulosa* | | f | f | f | f | f |
| *Pseudotextularia elegans* | | r | r | C | C | C |
| *Heterohelix reussi* | | f | f | | | |
| *Ventilabrella browni* | | r | r | | | |
| *Ventilabrella glabrata* | | r | r | | | |
| *Globotruncana bulloides* | | r | r/f | r/f | r | r |
| *Archaeoglobigerina cretacea* | | r | r | r | r | r |
| *Contusotruncana fornicata* | | f | f | f | f | f |
| *Globotruncanita stuartiformis* | | f | f | C | f | f |
| *Globotruncanita elevata* | | r | r | r | r | ? |
| *Globotruncana arca* | | f | f | f | f | f |
| *Globotruncana linneiana* | | f | f | r/f | f | f |
| *Marginotruncana coronata* | | f | f | | | |
| *Marginotruncana pseudolinneiana* | | f | f | | | |
| *Marginotruncana* spp. | | f | f | | | |
| *Dicarinella asymetrica* | | r | r | | | |
| *Globigerinelloides* spp. | r | | | | | |
| *Hedbergella* spp. | r | | | | | |
| PLANKTONIC FORAMINIFERA – ABUNDANCE | r | AA | AA | AAA | AAA | AA |
| PLANKTONIC FORAMINIFERA – PRESERVATION | | m | m | p/m | vp | vp |
| PLANKTONIC FORAMINIFERA – DEFORMATION | | | | | h | |
| BENTHIC FORAMINIFERA | C-sh | | | r | | |
| ECHINOIDS | AAA | | | | | |
| INOCERAMIDS | | | | | | f/C |
| OTHER MOLLUSKS | C | | | | | |
| QUARTZ | AA | | | | | |
| PHOSPHATES | f | | | | | |
| GLAUCONY | f | | | | | |
| PYRITE | | r | | | | |
| RESEDIMENTATION | | h | h | h | h | h |
| TECTONIC DEFORMATION | | | | | h | |
| ZONES | unzon. | G.ele /G.ven. | | G. calcarata | | G.hav. |
| AGE | ALB ? | CAMPANIAN | | | | MAA |

Fig. 11 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Sumstek-Tajok section, Zangla Unit. Plain line) normal zonal boundary; heavy line) no continuous sampling. G.ele) *Globotruncanita elevata*; G.ven.) *Globotruncana ventricosa*; G.hav.) *Globotruncanella havanensis*. For other symbols see caption of Fig. 10.

| SPECIES \ SAMPLES | H89 | ZG137 | ZG138 | ZG139 | HZ256 | HZ257 | HZ258 | HZ259 | HZ260 | HZ261 | HZ262 | HZ263 | HZ264 | H 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Globotruncana lapparenti* | | | | | | | | | | | | | | r |
| *Globotruncanita stuarti* | | | | | | | | | | | r/f | | | r |
| *Pseudoguembelina costulata* | | | | | | | | | r | r | | | | r |
| *Globotruncana rosetta* | | | | | | | | | cf | | | | r | r |
| *Globotruncana ventricosa* | | | | | | | | | cf | r/f | | | | r |
| *Globigerinelloides subcarinatus* | | | | | | | r | r | | | | | | |
| *Globigerinelloides messinae* | | | | | | | r | r | r | r | | | | |
| *Contusotruncana patelliformis* | | | | | | | cf | cf | cf | | | | | r |
| *Hedbergella holmdelensis* | | | | | | | cf | r | r | | | | | r |
| *Globigerinelloides alvarezi* | | | | | | cf | f | | | r | | | | r |
| *Globigerinelloides prairiehillensis* | | | | | r | | f | f | f | r | f | | r | r |
| *Heterohelix globulosa* | | | | | f | | f | f | f | f | f | | | f |
| *Pseudotextularia elegans* | | | | | cf | cf | cf | cf | C | f | C | r/f | r/f | f |
| *Ventilabrella browni* | | | | | f | r | r | | | r | r | | | r |
| *Ventilabrella glabrata* | | | | | f | r | r | | | r | r | | | |
| *Globotruncana hilli* | | | | | r | | | | | | | | | |
| *Globotruncanita stuartiformis* | | | | | r/f | f | f | r/f | f | f | f | r | r | f |
| *Globotruncanita elevata* | | | | | r/f | f | r/f | r | r | r | r | | r | |
| *Archaeoglobigerina cretacea* | | | | | vr | r | r | r | r | r | | | | |
| *Contusotruncana fornicata* | | | | | r | r | f | f | f | f | f | | | f |
| *Globotruncana linneiana* | | | | | r/f | r | r | C | C | f | f/C | r | r | f |
| *Globotruncana bulloides* | | | | | r | r | r | r | r | f | vr | r | | |
| *Globotruncana arca* | | | | | r | f | f | f | f | f | r | | r | f |
| *Dicarinella asymetrica* | | | | | f | r | | r | r | r | r | r | r | f |
| *Marginotruncana coronata* | | | | r | | f | | | | | | | | |
| *Marginotruncana pseudolinneiana* | | | | r | | f | | | | | | | | |
| *Marginotruncana sigali* gr. | | | r | r | | f | | | | | | | | |
| *Marginotruncana* spp. | | | | | | AA | A | f | f | r | r | | r | f |
| *Dicarinella ? oraviensis* | | | r | | | | | | | | | | | |
| *Whiteinella kingi* | | | r | | | | | | | | | | | |
| *Helvetoglobotruncana helvetica* | | | vr | r | | | | | | | | | | |
| *Heterohelix reussi* | | | C | r | f/C | f | | | | | | | | |
| *Whiteinella inornata* | | | r | | | | | | | | | | | |
| *Dicarinella imbricata* | | | r | | | | | | | | | | | |
| *Dicarinella canaliculata* | | r | r | r | | | | | | | | | | |
| *Whiteinella brittonensis* | | r | | | | | | | | | | | | |
| *Whiteinella archaeocretacea* | | r | cf | ? | | | | | | | | | | |
| *Whiteinella baltica* | | r | r | | | | | | | | | | | |
| *Whiteinella aprica* | | r | cf | r | | | | | | | | | | |
| *Heterohelix moremani* | | f/C | C | C | | | | | | | | | | |
| *Dicarinella algeriana* | | r | | | | | | | | | | | | |
| *Praeglobotruncana gibba* | | r | r | | | | | | | | | | | |
| *Rotalipora deeckei* | | r | ? | | | | | | | | | | | |
| *Rotalipora cushmani* | | r | r | r | | | | | | | | | | |
| *Rotalipora greenhornensis* | | r | r | r | | | | | | | | | | |
| *Globigerinelloides bentonensis* | | r | r | | | | | | | | | | | |
| *Praeglobotruncana stephani* | f | f | r | | | | | | | | | | | |
| *Hedbergella planispira* | f | f | r | | | | | | | | | | | |
| *Hedbergella simplex* | f | f | r | | | | | | | | | | | |
| *Rotalipora gandolfii* | cf | | | | | | | | | | | | | |
| *Planomalina buxtorfi* | cf | | | | | | | | | | | | | |
| *Rotalipora balernaensis* | r | | | | | | | | | | | | | |
| *Rotalipora appenninica* | C | | | | | | | | | | | | | |
| *Favusella* sp. | cf | | | | | | | | | | | | | |
| PLANKTONIC FORAMINIFERA — ABUNDANCE | f | AAA | AAA | C | AAA | AAA | AAA | AAA | AAA | AAA | AA | f | f | AAA |
| PLANKTONIC FORAMINIFERA — PRESERVATION | vp | p | vp | vp | vp | p | m | m | p | p/m | p | vp | vp | vp |
| PLANKTONIC FORAMINIFERA — DEFORMATION | h | | h | h | | | | | | | | | | |
| BENTHIC FORAMINIFERA | vr | r | | | | | | | | f | C-sh | C-sh | C-sh | |
| RADIOLARIANS | | r/f | | | | | | | | | | | | |
| CALCISPHERES | | C | A | | | | | | | | | | | |
| ECHINOIDS | | | | | | | | | | | r | | | |
| INOCERAMIDS | | f | | | | | | | | C | | AA | AA | |
| OTHER MOLLUSKS | | | | | | | | | | C | | | | |
| PYRITE | | | | | | | | r | r | | | | | |
| RESEDIMENTATION | | h | h | ? | h | h | h | h | h | h | h | h | h | h |
| TECTONIC DEFORMATION | h | | h | h | | | | | | | | | | |
| LAMINATION | | | h | h | h | | | | | | h | h | h | |
| ZONES | Rapp | Warch | H. helvetica | | Globotruncanita elevata | | | | G. ventricosa | | Gcal | G.havanensis | | |
| AGE | ALB | TURONIAN | | | CAMPANIAN | | | | | | | MAASTRICHTIAN | | |

Fig. 12 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Sneatse section, Zangla Unit. Plain line) normal zonal boundary; heavy line) no continuous sampling; dashed line) hiatus. Rapp) *Rotalipora appenninica*; Warch) *Whiteinella archaeocretacea*; Gcal) *Globotruncanita calcarata*. For other symbols see caption of Fig. 10.

| SPECIES \ SAMPLES | NERAK | | | | LABAR LA | |
|---|---|---|---|---|---|---|
| | G 38 | G 39 | G 40 | G 42 | G 59 | G 60 |
| *Ticinella praeticinensis* | | | | | | ? |
| *Ticinella primula* | | | | | | r |
| *Hedbergella simplex* | | | | r | | |
| *Planomalina buxtorfi* | | | | ? | | |
| *Rotalipora appenninica* | | | | cf | | |
| *Rotalipora balernaensis* | | | | r | | |
| *Rotalipora ticinensis* | | | | r | | |
| *Rotalipora subticinensis* | | | | r | | |
| *Ticinella raynaudi* | | | | r | | |
| *Praeglobotruncana stephani* | | | | r | | |
| *Globigerinelloides caseyi* | | | | r | | |
| *Biticinella breggiensis* | vr | vr | | r | | r |
| *Globigerinelloides bentonensis* | r | | | r | | |
| *Hedbergella delrioensis* | r | | | r | | r |
| *Hedbergella planispira* | r | | | r | | r |
| *Hedbergella* spp. | r | vr | | | vr | |
| PLANKTONIC FORAMINIFERA – ABUNDANCE | f | r | r | r-C | vr | r/f |
| PLANKTONIC FORAMINIFERA – PRESERVATION | vp | vp | vp | p | vp | vp |
| PLANKTONIC FORAMINIFERA – DEFORMATION | | | h | | | |
| BENTHIC FORAMINIFERA | vr | r | r | vr | | f |
| ECHINOIDS | | | | r | | f |
| INOCERAMIDS | | | | f | | |
| QUARTZ | AAA | AA | AA | A | AA | C |
| PHOSPHATES | C | C | f | ? | C | C |
| GLAUCONY | AAA | f | r | f | AAA | |
| PYRITE | | | | r | | |
| RESEDIMENTATION | | | | m/h | | |
| TECTONIC DEFORMATION | | | | h | | |
| ZONES | B. breggiensis | | | R.app. | ? | br ? ap |
| AGES | LATE ALBIAN | | | | L. ALBIAN | |

Fig. 13 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Nerak and Labar La sections, Zangla Unit. Plain line) normal zonal boundary; dashed line) uncertain boundary. br) *Biticinella breggiensis*. *Ticinella praeticinensis* and *Rotalipora subticinensis* Subzones could not be identified; R. app. and ap) *Rotalipora appenninica*. For other symbols see caption of Fig. 10.

*delrioensis*, *Rotalipora balernaensis*, and *R. ticinensis*. In most sections *Biticinella breggiensis*, *Ticinella roberti*, *T. raynaudi*, *T. primula* are still present and occasionally together with *Planomalina praebuxtorfi*. This suggests that only the lower part of the *R. appenninica* Zone is represented in the Zanskar Range as also corroborated by the absence of *Rotalipora gandolfii* and *R. micheli*. Planktonic foraminifera are recrystallized but rarely deformed or compressed.

*Occurrence*. Lari La section, ZD 115; Nerak section, G 42; Labar La section, G 60; Zangla section, H 101; Takh Bridge section, ZD 23; Takh section, ZD 77; Sneatse section, H 89; Dzong ridge section, HN 82 to HN 84.

| SPECIES / SAMPLES | H 101 | HA 20 | HA 21 | HA 22 | HA 23 | HA 24 |
|---|---|---|---|---|---|---|
| *Marginotruncana pseudolinneiana* | | | | | | cf |
| *Marginotruncana sigali* | | | | | | cf |
| *Marginotruncana* spp. | | | r | ? | | r |
| *Whiteinella* spp. | | | ? | | | ? |
| *Dicarinella hagni* | | | ? | | | |
| *Heterohelix reussi* | | | r | r/f | ? | r |
| Double keeled forms | | ? | | | | |
| *Heterohelix moremani* | | r | r | C | | |
| *Whiteinella inornata* | | r | | | | |
| *Rotalipora greenhornensis* | | ? | r | r | | |
| *Rotalipora cushmani* | | ? | r | | | |
| *Rotalipora reicheli* | | ? | | | | |
| *Hedbergella planispira* | r | | | | | |
| *Hedbergella simplex* | r | | | | | |
| *Hedbergella delrioensis* | r | | | | | |
| *Globigerinelloides ultramicrus* | r | | | | | |
| *Globigerinelloides bentonensis* | r | r | r | r | | |
| *Globigerinelloides caseyi* | r | | | | | |
| *Praeglobotruncana stephani* | r | r | r | | | |
| *Praeglobotruncana delrioensis* | r | | | | | |
| *Planomalina buxtorfi* | r | | | | | |
| *Rotalipora appenninica* | r | cf | ? | ? | | |
| *Rotalipora ticinensis* | r | | | | | |
| *Rotalipora subticinensis* | r | | | | | |
| *Rotalipora balernaensis* | r | | | | | |
| *Biticinella breggiensis* | vr | | | | | |
| PLANKTONIC FORAMINIFERA – ABUNDANCE | C/A | AA | C | A | C | C |
| PLANKTONIC FORAMINIFERA – PRESERVATION | vp | vp | vp | vp | vp | vp |
| PLANKTONIC FORAMINIFERA – DEFORMATION | h | h | | | h | m/h |
| BENTHIC FORAMINIFERA | r/f | | | | | |
| RADIOLARIANS | r/f | | | | | |
| ECHINOIDS | | | | r | | |
| INOCERAMIDS | | | | r | | |
| PYRITE | | | | r | r | r |
| RESEDIMENTATION | | h | ? | m? | ? | h |
| TECTONIC DEFORMATION | ? | h | | | h | m |
| LAMINATION | | h | | | h | h |
| ZONES | R.app | Helv. helvetica or younger | | | | |
| AGE | ALB | TURONIAN or younger | | | | |

Fig. 14 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Zangla section, Zangla Unit. Plain line) normal zonal boundary; dashed line) hiatus. R. app) *Rotalipora appenninica*. For other symbols see caption of Fig. 10.

| SPECIES / SAMPLES | SUMDO | | | | E SUMDO | |
|---|---|---|---|---|---|---|
| | ZD201 | ZD202 | ZD203 | ZD204 | ZD149 | ZD150 |
| *Marginotruncana coronata* | | | | | vr | |
| *Marginotruncana sigali* | | | | | vr | |
| *Marginotruncana* spp. | | | | | r | ? |
| *Whiteinella inornata* | | | | r | r | r |
| *Whiteinella kingi* | | | | r | cf | r |
| *Whiteinella gigantea* | | | | r | | ? |
| *Whiteinella* spp. | | | | A | r/f | C |
| *Helvetoglobotruncana helvetica* | | | cf | cf | ? | cf |
| *Schackoina* spp. | | | r | r | | |
| *Dicarinella ?oraviensis* | | | r | r | vr | ? |
| *Heterohelix reussi* | | | r | r | f/C | r/f |
| *Heterohelix moremani* | | | AA | r | f/C | r |
| *Praeglobotruncana gibba* | | | r | r | vr | |
| *Whiteinella archaeocretacea* | | | r | f/C | cf | ? |
| *Rotalipora cushmani* | | | r | | r | f |
| *Whiteinella brittonensis* | | r | r | | | r |
| *Whiteinella aprica* | | r | r | r | | vr |
| *Whiteinella baltica* | | r | r | f | r | r/f |
| *Marginotruncana renzi* | | cf | | r | | |
| *Dicarinella hagni* | | r | r | cf | r | r |
| *Dicarinella canaliculata* | | r | | | r | r |
| *Dicarinella imbricata* | | r | r | | | f |
| *Praeglobotruncana stephani* | | r | | r | vr | r |
| *Dicarinella algeriana* | | r | r | | r/f | ? |
| *Whiteinella aumalensis* | | r | r | r | | |
| *Rotalipora greenhornensis* | | r/f | r | | r | r |
| *Rotalipora appenninica* | | r | cf | | r | ? |
| *Globigerinelloides bentonensis* | f | r | r/f | r | r | r |
| *Hedbergella delrioensis* | r | r | r | r | r | r |
| *Hedbergella planispira* | r | r | r | r | r | r |
| *Hedbergella simplex* | r | r | r | r | r | r |
| *Rotalipora subticinensis* | r | | | | | |
| *Biticinella breggiensis* | r | | | | | |
| *Ticinella roberti* | cf | | | | | |
| *Praeglobotruncana delrioensis* | r | | | | | |
| *Ticinella praeticinensis* | r | | | | | |
| *Favusella* sp. | ? | | | | | |
| PLANKTONIC FORAMINIFERA — ABUNDANCE | r | AAA | AAA | C | A | AAA |
| PLANKTONIC FORAMINIFERA — PRESERVATION | vp | p | vp | vp | vp/p | vp |
| PLANKTONIC FORAMINIFERA — DEFORMATION | h | h | | m/h | h | h |
| BENTHIC FORAMINIFERA | f | f | r | vr | f | f |
| RADIOLARIANS | C | | | | | |
| CALCISPHERES | | | | | f | A |
| ECHINOIDS | f | | | | | |
| OSTRACODS | | | | | | vr |
| INOCERAMIDS | | | | | | r |
| QUARTZ | A | | | | f | r |
| RESEDIMENTATION | | h | h | | h | h |
| TECTONIC DEFORMATION | h | m | | m | | h |
| LAMINATION | | | | h | | |
| ZONES | Rsubt | Warch | H. helvetica | | H. helvetica | |
| AGE | ALB | TURONIAN | | | TURONIAN | |

Fig. 15 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Sumdo and E Sumdo sections, Zumlung Unit. Plain line) normal zonal boundary; dashed line) hiatus. Rsubt) *Rotalipora subticinensis*; Warch) *Whiteinella archaeocretacea*. For other symbols see caption of Fig. 10.

*Whiteinella archaeocretacea* Zone.

The Chikkim Formation starts with heavily resedimented layers in which planktonic foraminifera are litterally packed almost without micrite. Planktonic foraminiferal faunas are strongly recrystallized and specimens are also frequently cut at one edge by solution seams.

Planktonic assemblages contain common whiteinellids including the zonal marker, *W. aprica*, *W. baltica* and rarer *W. brittonensis* associated with common to frequent *Heterohelix moremani* and *H. reussi*, few *Dicarinella canaliculata* (Pl. 38, fig. 1), *D. algeriana*, and rare *Whiteinella praehelvetica*. This assemblage is attributed to the named zone, as *Helvetoglobotruncana helvetica*, the index species of the following zone, is apparently not yet present. The possibility of *H. helvetica* being masked by the strong mixing cannot, however, be ruled out. The assemblages are also rich in rotaliporids including not only *R. cushmani*, *R. greenhornensis*, and occasionally *R. deeckei*, but also *R. appenninica* and *R. brotzeni*. All the rotaliporids are considered reworked. The fine fraction is occasionally rich in calcispherulids.

*Occurrence*. Pingdon La section, H 24; Takh Bridge section, ZD 24; Sneatse section, ZG 137; Sumdo section, ZD 202.

*Helvetoglobotruncana helvetica* Zone.

This zone is the best represented in the entire sequence studied. Most layers display a resedimented character. Reworking may be important especially at the base, but decreases upwards although it is never absent. Preservation of planktonic foraminifera varies from fair to very poor and recrystallization often is very strong. Their abundance varies according to the redeposited character of the sediments and ranges from layers packed with specimens to almost barren. Several layers in this intervals yield severely deformed and compressed planktonic specimens.

Planktonic foraminiferal faunas contain few to rarely common *Helvetoglobotruncana helvetica* (Pl. 38, fig. 2) along with common whiteinellids and *Heterohelix* and much rarer dicarinellids, praeglobotruncanids and *Globigerinelloides*. The marginotruncanids appear at about half way through this interval, and are rare at the beginning and then gradually become more common. Reworked Cenomanian rotaliporids continue to occur throughout, although their abundance decreases upwards. In the lower portion of the zone the fine fraction is very rich in calcispherulids including *Pithonella*, which are visible even in the most cleaved layers.

*Occurrence*. Sumdo section, ZD 203, ZD 204; E Sumdo section, ZD 149, ZD 150; Sneatse section, ZG 138, ZD 139; Pingdon La section, H 22, HZ 201 to HZ 215; Lari La section, ZD 116 to ZD 120; Takh Bridge section, ZD 25 to ZD 30; Honupatta section, FL 1. Possibly part of the Zangla section.

*Marginotruncana sigali* Zone.

In several sections, a few meters are attributable to a portion of this zone followed by the second important stratigraphic gap. Planktonic foraminifera are abun-

| SPECIES / SAMPLES | ZD114 | ZD115 | ZD116 | ZD117 | ZD118 | ZD119 | ZD120 | ZD121 | ZD122 | ZD123 | ZD124 | ZD125 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Globotruncanita calcarata* | | | | | | | | | | | | r |
| *Hedbergella holmdelensis* | | | | | | | | | | | | r |
| *Globigerinelloides prairiehillensis* | | | | | | | | | | | | f |
| *Globotruncana bulloides* | | | | | | | | | | | | r |
| *Globotruncanita stuarti* | | | | | | | | | | | cf | r |
| *Globigerinelloides messinae* | | | | | | | | | | | r | r |
| *Heterohelix globulosa* | | | | | | | | | | | f | f |
| *Heterohelix glabrans* | | | | | | | | | | | r | r |
| *Globotruncana ventricosa* | | | | | | | | | | | r | r/f |
| *Globotruncana lapparenti* | | | | | | | | | | | r | r |
| *Globotruncana linneiana* | | | | | | | | | | | r | r |
| *Globotruncana arca* | | | | | | | | | | | r | f |
| *Ventilabrella glabrata* | | | | | | | | | | f | r/f | r |
| *Ventilabrella browni* | | | | | | | | | | f | r/f | r |
| *Contusotruncana fornicata* | | | | | | | | | | r | r | f |
| *Pseudotextularia elegans* | | | | | | | | | | cf | f | f |
| *Globotruncanita stuartiformis* | | | | | | | | | | r | f | f |
| *Globotruncanita elevata* | | | | | | | | | | r | ? | cf |
| *Dicarinella asymetrica* | | | | | | | | | | f/C | | |
| *Dicarinella concavata* | | | | | | | | | | f/C | | |
| *Dicarinella primitiva* | | | | | | | | | cf | | | |
| *Whiteinella inornata* | | | | | | | | | ? | | | |
| *Marginotruncana marginata* | | | | | | | | | cf | r | | |
| *Marginotruncana tarfayaensis* | | | | | | | | cf | ? | | | |
| *Marginotruncana sinuosa* | | | | | | | | vr | | | | |
| *Marginotruncana undulata* | | | | | | | | ? | | | | |
| *Archaeoglobigerina cretacea* | | | | | | ? | | | | | | |
| *Hedbergella flandrini* | | | | | | ? | | | r | | | |
| *Globigerinelloides caseyi* | | | | | | r | | | | | | |
| *Marginotruncana coronata* | | | | | | r | | r | r | f | r | |
| *Marginotruncana pseudolinneiana* | | | | | | r | | | r | r | f | |
| *Heterohelix moremani* | | | | | | r | | | | | | |
| *Marginotruncana sigali* | | | | cf | | r | cf | r | C | r | | |
| *Marginotruncana schneegansi* | | | | ? | r | r | cf | r | r | r | | |
| *Marginotruncana renzi* | | | | cf | | r | | | | r | | |
| *Marginotruncana* spp. | | | | r | r | | r | | | | f | f |
| *Schackoina* sp. | | | | r | | | r | r | r | | | |
| *Dicarinella hagni* | | | | r | | | | | | | | |
| *Whiteinella archaeocretacea* | | | | r | r | | | | | | | |
| *Whiteinella paradubia* | | | | r | cf | | | | | | | |
| *Whiteinella brittonensis* | | | | r | | | | | | | | |
| *Whiteinella aprica* | | | | C | f | | | | | | | |
| *Dicarinella ? oraviensis* | | | r | r | | | | r | f/C | | | |
| *Heterohelix reussi* | | | r | f | f | f | | f | f | C | | f |
| *Helvetoglobotruncana helvetica* | | | ? | r | r | cf | | | r | | | |
| *Dicarinella canaliculata* | | | r | | | | | | | | | |
| *Dicarinella imbricata* | | | r | | | | | | r | | | |
| *Whiteinella baltica* | | | r | | f | | | r | | | | |
| *Whiteinella* spp. | | | r | | C | r | r | r | r | r/f | | |
| *Dicarinella algeriana* | | | r | cf | | | | | | | | |
| *Whiteinella aumalensis* | | | r | | | | | | | | | |
| *Praeglobotruncana gibba* | | | r | r | r | | | | | | | |
| *Hedbergella simplex* | | | r | r | | | r | | | | | |
| *Praeglobotruncana stephani* | | | r | r | | | | | | | | |
| *Rotalipora greenhornensis* | | | r | r | r | | | | | | | |
| *Rotalipora cushmani* | | | r | ? | r | | | | | | | |
| *Globigerinelloides bentonensis* | | r | r | r | | | | | | | | |
| *Hedbergella planispira* | | r | | r | | | | | | | | |
| *Rotalipora appenninica* | | cf | r | | | | | | | | | |
| *Planomalina buxtorfi* | | ? | | | | | | | | | | |
| *Biticinella breggiensis* | | r | | | | | | | | | | |
| *Ticinella primula* | | ? | | | | | | | | | | |
| *Hedbergella* spp. | vr | | | | | | | | | | | |
| PLANKTONIC FORAMINIFERA – ABUNDANCE | vr | vr | AAA | f | A | f | f | C | A | AAA | C | C |
| PLANKTONIC FORAMINIFERA – PRESERVATION | p | p | vp | p | vp | vp | vp | vp | p | p/m | p | vp/p |
| PLANKTONIC FORAMINIFERA – DEFORMATION | | | h | m | h | | h | | | | | m |
| BENTHIC FORAMINIFERA | | f | r | | | r | | | r+sh | r | f+sh | r+sh |
| RADIOLARIANS | | | ? | | | | | | | | | |
| ECHINOIDS | r/f | | | | | | | | | | | |
| INOCERAMIDS | | | | f | | | | | | | | |
| QUARTZ | AAA | AAA | | | | | | | | | | |
| PHOSPHATES | f | C | | | | | | | | | r | f |
| RESEDIMENTATION | | | h | m | h | m | ? | | m | h | h | m? |
| TECTONIC DEFORMATION | | | h | m | m | | h | | m/h | | | |
| LAMINATION | | | h | m | h | m | h | | h | | h | h |
| ZONES | ? | R.app | Helvetoglob. helvetica | | | | | M. sigali | | G.ele | G.ven | G.cal |
| AGE | ALBIAN | | TURONIAN | | | | | | | CAMPANIAN | | |

Fig. 16 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Lari La section, Zumlung Unit. Plain line) normal zonal boundary; dashed line) hiatus. R.app) *Rotalipora appenninica*; G.ele) *Globotruncanita elevata*; G.ven) *Globotruncana ventricosa*; G.cal) *Globotruncanita calcarata*. For other symbols see caption of Fig. 10.

| SAMPLES / SPECIES | TAKH BRIDGE | | | | | | | | | | | | TAKH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ZD 22 | ZD 23 | ZD 24 | ZD 25 | ZD 26 | ZD 27 | ZD 28 | ZD 29 | ZD 30 | ZD 31 | ZD 32 | ZD 33 | ZD 77 |
| *Heterohelix striata* | | | | | | | | | | | | f | |
| *Heterohelix globulosa* | | | | | | | | | | | | f | |
| *Rugoglobigerina rugosa* | | | | | | | | | | | | r | |
| *Archaeoglobigerina cretacea* | | | | | | | | | | | | r | |
| *Contusotruncana fornicata* | | | | | | | | | | | | r | |
| *Globotruncana lapparenti* | | | | | | | | | | | | r | |
| *Globotruncana rosetta* | | | | | | | | | | | | r | |
| *Globotruncana ventricosa* | | | | | | | | | | | | r | |
| *Globotruncana arca* | | | | | | | | | | | | f | |
| *Globotruncanita stuartiformis* | | | | | | | | | | | | f | |
| *Globotruncanita elevata* | | | | | | | | | | | | r | |
| *Marginotruncana tarfayaensis* | | | | | | | | | | ? | r | | |
| *Marginotruncana marginata* | | | | | | | | | | ? | | | |
| *Dicarinella concavata* | | | | | | | | | | ? | | | |
| *Marginotruncana coronata* | | | | | | | | | r | | r | | |
| *Whiteinella inornata* | | | | | | | | r | r | vr | | | |
| *Marginotruncana pseudolinneiana* | | | | | | | vr | r | r | r | | | |
| *Whiteinella aumalensis* | | | | | | r | r | | | | | | |
| *Marginotruncana sigali* | | | | | | cf | | | cf | cf | r | | |
| *Marginotruncana* spp. | | | | | | r | vr | r | r/f | r | r/f | | |
| *Dicarinella ? oraviensis* | | | | | r | r | r | r | r | cf | | | |
| *Dicarinella canaliculata* | | | | | r | | | r | rr | | | | |
| *Helvetoglobotruncana helvetica* | | | | r | r | ? | r | r | | ? | | | |
| *Whiteinella praehelvetica* | | | | r | | | | | | | | | |
| *Whiteinella archaeocretacea* | | | | r | ? | | | cf | r | r | | | |
| *Whiteinella aprica* | | | | r | | r | | r | | | | | |
| *Whiteinella baltica* | | | | r | r | r | r | r | r | r | r | | |
| *Whiteinella kingi* | | | | r | | | cf | | r | r | | | |
| *Praeglobotruncana gibba* | | | | r | r | r | r | r | | | | | |
| *Dicarinella algeriana* | | | | r | | cf | r | r | r | | | | |
| *Heterohelix reussi* | | | | r | f | r | f | r | r | r | r | | |
| *Heterohelix moremani* | | | | C | C | f/C | f/C | C | C | f | f | | |
| *Rotalipora cushmani* | | | | r | r | r | r | r | r | | r | | |
| *Schackoina* sp. | | | r | | r | | | | | | | | |
| *Rotalipora greenhornensis* | | | vr | r | r | r | r | r | r | | r | | |
| *Whiteinella brittonensis* | | | cf | | | r | | | | | | | |
| *Whiteinella* spp. | | | r | f | r | | f | r | | r | r | | |
| *Globigerinelloides caseyi* | | r | | r | | | | | | | | | |
| *Rotalipora* spp. | | r | r | r | | | | | | | | | |
| *Rotalipora appenninica* | | vr | r | r | r | ? | ? | | | | | | C |
| *Planomalina buxtorfi* | | C | ? | | | | | | | | | | r/f |
| *Praeglobotruncana stephani* | r | f | ? | r | r | r | r | r | | | ? | | f |
| *Globigerinelloides bentonensis* | f | f | | f | f | r | | r | | r | | | r |
| *Hedbergella simplex* | f | r | r | r | f | r | r | r | | r | | | f |
| *Hedbergella planispira* | r | f | r | r | f | r | r | | | r | | | C |
| *Hedbergella delrioensis* | f | r | | | r | | r | | | | | | f |
| *Praeglobotruncana delrioensis* | r | C | r | | r | | | | | | | | |
| *Ticinella primula* | r | | | | | | | | | | | | ? |
| *Planomalina praebuxtorfi* | r | | | | | | | | | | | | r |
| *Rotalipora praeappenninica* | r | | | | | | | | | | | | |
| *Rotalipora balernaensis* | r | vr | | | | | | | | | | | r |
| *Rotalipora praebalernaensis* | r | r | | | | | | | | | | | |
| *Rotalipora ticinensis* | f | r | | | | | | | | | | | |
| *Rotalipora subticinensis* | r | r | | | | | | | | | | | |
| *Ticinella raynaudi* | f | r | | | | | | | | | | | f |
| *Biticinella breggiensis* | r | r | | | | | | | | | | | f |
| *Ticinella roberti* | r | | | | | | | | | | | | |
| *Favusella washitensis* | r | | | | | | | | | | | | |
| PLANKTONIC FORAMINIFERA – ABUNDANCE | AAA | f/C | r-f | A | C | f/C | f-C | AA | AA | AA | AA | AA | AA |
| PLANKTONIC FORAMINIFERA – PRESERVATION | m | m | vp | vp | vp/p | vp | vp | vp | vp | vp | vp/p | vp/p | p |
| PLANKTONIC FORAMINIFERA – DEFORMATION | | | h | | | | | | h | h | m | | h |
| BENTHIC FORAMINIFERA | f+sh | f+sh | | | | r | r | | r | | | f | r/f |
| RADIOLARIANS | | r | C | | r | | | | | | | | |
| CALCISPHERES | f | | f/C | | | | f | ? | r | r | | | |
| ECHINOIDS | | | | | | | | r | | | | | |
| INOCERAMIDS | | | | | | | | | | A | r | | |
| QUARTZ | f | | | | | | | | | | | | f |
| PYRITE | | | | | | | | | | r | r | r | |
| RESEDIMENTATION | h | m? | m/h | h | | | m | m/h | h | h | h | h | h |
| TECTONIC DEFORMATION | | | | | | | | | h | h | m/h | | h |
| LAMINATION | | | h | | | | | | h | h | h | h | h |
| ZONES | R. ticin | R.app. | Warch | Helvetoglobotruncana helvetica | | | | | | M. sigali | | Gvent | R.app |
| AGE | ALBIAN | | TURONIAN | | | | | | | | | CAM | ALB |

Fig. 17 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Takh Bridge and Takh sections, Zumlung Unit. Plain line) normal zonal boundary; dashed line) hiatus. R.ticin) *Rotalipora ticinensis*; R.app) *Rotalipora appenninica*; Warch) *Whiteinella archaeocretacea*; Gvent) *Globotruncana ventricosa*. For other symbols see caption of Fig. 10.

| SPECIES / SAMPLES | FL 1 | | ZD143 |
|---|---|---|---|
| *Contusotruncana fornicata* | | | r |
| *Hedbergella flandrini* | | | r |
| *Dicarinella concavata* | | | cf |
| *Archaeoglobigerina* sp. | | | r |
| *Marginotruncana coronata* | | | r |
| *Marginotruncana pseudolinneiana* | r | | r |
| *Marginotruncana schneegansi* | r | | cf |
| *Marginotruncana sigali* | r | | r |
| *Marginotruncana renzi* | r | | r |
| *Heterohelix reussi* | f | | f |
| *Globigerinelloides bentonensis* | r | | |
| *Praeglobotruncana stephani* | r | | |
| *Rotalipora greenhornensis* | r | | |
| *Rotalipora cushmani* | r | | |
| PLANKTONIC FORAMINIFERA — ABUNDANCE | A | | f |
| PLANKTONIC FORAMINIFERA — PRESERVATION | p | | p |
| BENTHIC FORAMINIFERA | | | r |
| RESEDIMENTATION | h | | ? |
| ZONES | hel / sig | | asy ? |
| AGE | TUR. | | S? yg |

Fig. 18 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in samples FL 1 (north of Honupatta, Shillakong Unit), and ZD 143 (west of Ningri La, Zumlung Unit). hel/sig) *Helvetoglobotruncana helvetica* or *Marginotruncana sigali*; asy?) *Dicarinella asymetrica* ?; S ? yg) Santonian ? or younger. For other symbols see caption of Fig. 10.

dant but mainly poorly preserved and concentrated preferentially in layers as in the previous zones.

Planktonic foraminiferal assemblages are dominated by marginotruncanids including the large *M. tarfayaensis*, *M. undulata* along with *M. sigali*, *M. schneegansi*, *M. marginata*, and *M. renzi*. *Heterohelix reussi*, some whiteinellids and rare specimens attributable to *Hedbergella flandrini* and *Dicarinella primitiva* also occur. The occurrence of the latter taxa would suggest that only the upper part of the *M. sigali* Zone is present, whereas the lower portion is apparently missing.

Reworking is still detectable and involves not only a few Cenomanian species but also a Turonian species from portion of the *Helvetoglobotruncana helvetica* Zone as testified by rare specimens of the named taxon found together with *Dicarinella* ? *oraviensis*, *Praeglobotruncana stephani*, *P. gibba*, and *Dicarinella hagni*. All of these species become extinct within or at the end of the *H. helvetica* Zone. Calcispherulids still occur rarely but they are considered reworked from older layers as are the planktonic species mentioned above.

*Occurrence*. Takh Bridge section, ZD 31, ZD 32; Lari La section, ZD 121, ZD 122; Pingdon La section, HZ 216; Honupatta section, FL 1?. Possibly part of the Zangla section.

| SPECIES / SAMPLES | HN 75 | HN 76 | HN 77 | HN 78 | HN 79 | HN 80 | HN 81 | HN 82 | HN 83 | HN 84 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Rotalipora balernaensis* | | | | | | | | r | r | r |
| *Globigerinelloides caseyi* | | | | | | | | r | r | r |
| *Rotalipora ticinensis* | | | | | | | | r | r | r |
| *Planomalina buxtorfi* | | | | | | | | r | | r |
| *Planomalia praebuxtorfi* | | | | | | | r | r | | |
| *Biticinella breggiensis* | | | | | | | r | r | r | ? |
| *Hedbergella simplex* | | | | | r | | r | r | r | r |
| *Globigerinelloides ultramicrus* | | | | | | | | | | |
| *Globigerinelloides asper* | | | | r | | | | | | |
| *Rotalipora* spp. | | | ? | | | | | | | |
| *Ticinella roberti* | | | cf | | | | r | r | r | |
| *Globigerinelloides bentonensis* | | | r | r | r | | r | r | f | f |
| *Ticinella raynaudi* | | | r | r | | | r | r | r | r |
| *Rotalipora subticinensis* | | | r | | | | | r | | r |
| *Ticinella praeticinensis* | | | r | ? | | | r | r | | |
| *Ticinella primula* | | | r | C | C | | f | r | r | r |
| *Praeglobotruncana stephani* | | | r | | | | | | vr | r |
| *Praeglobotruncana delrioensis* | | | r | | | | r | r | vr | r |
| *Hedbergella planispira* | | | r | r | r | | r | r | r | r |
| *Hedbergella delrioensis* | | | r | r | r | | r | r | r | r |
| *Praeglobotruncana* spp. | | cf | | | | | | | | |
| *Hedbergella rischi* | | cf | r | r | r | | r | r | | |
| *Hedbergella* spp. | vr | | | | | | | | | |
| PLANKTONIC FORAMINIFERA — ABUNDANCE | vr | vr | f | f | r/f | vr | C | C | C | C |
| PLANKTONIC FORAMINIFERA — PRESERVATION | p | m | m | m | m | | m | m | m | m |
| BENTHIC FORAMINIFERA | r | r | f | f | f | | | C+sh | C+sh | r |
| RADIOLARIANS | C | | | | | | | C | | f/C |
| OSTRACODS | r | | | r | | | r | | r | |
| CALCISPHERES | | | | | | | | f | C | r |
| CALCAREOUS ALGAE | | | | | | | | | f | r |
| ECHINOIDS | f | r | | | | | | f | | |
| INOCERAMIDS | | r | C | r | r | r | | | | |
| OTHER MOLLUSKS | f | | | | | | | | | |
| QUARTZ | A | AAA | AA | C | C | AA | AA | C | C | |
| PHOSPHATES | | C | f | r | r | C | C | vr | r | r |
| GLAUCONY | | AA | AA | C | C | AA | AA | C | C | |
| ZONES | ? | B. breggiensis / R. subticinensis | | | | | | R. appenninica | | |
| AGE | ALB | LATE ALBIAN | | | | | | | | |

Fig. 19 - Distribution and abundance of planktonic foraminifera, other organisms, and mineral components in the Dzong ridge section, Thakkhola (Nepal) (see inset in Fig. 1). Plain line) normal zonal boundary; dashed line) possible hiatus. For other symbols see caption of Fig. 10.

*Dicarinella concavata* Zone.

In the Pingdon La section a single sample yielded a few specimens of the zonal marker associated with common *Marginotruncana coronata, M. pseudolinneiana, M. marginata, Heterohelix reussi*, rare to few *D. primitiva, Hedbergella flandrini, Archaeoglobigerina cretacea*, and *Marginotruncana undulata*. This assemblage is attributed to the named zone especially in absence of younger taxa.

Planktonic foraminifera are abundant, poorly preserved and resedimented. Because most of the species constituting the assemblage of the *D. concavata* Zone are mainly long-ranging species, it is difficult to estimate the amount of reworking. The occurrence of rare specimens of *Dicarinella* ? *oraviensis* suggests that a portion of the *H. helvetica* Zone is involved in the reworking.

*Occurrence.* Pingdon La section, HZ 217.

A single, isolated sample from west of Ningri La (Sample ZD 143) yields a similar, but poorly preserved and less abundant assemblage than that described above. The presence, however, of *Contusotruncana fornicata* suggests that the sample may belong to the overlying *Dicarinella asymetrica* Zone.

*Globotruncanita elevata* Zone.

This zone was identified on the basis of the presence of taxa such as *Pseudotextularia elegans, Globigerinelloides prairiehillensis, Pseudoguembelina costulata, Hedbergella holmdelensis*, which are known to appear or to become more frequent in the *Globotruncanita elevata* Zone. Planktonic foraminifera are very abundant and often concentrated in layers, moderately well preserved and diversified, but are also heavily mixed with forms reworked from older zones (Pl. 38, fig. 3). Thus, the lower boundary of the *G. elevata* Zone could not be determined precisely due to the reworking of *Dicarinella asymetrica* and the range of several taxa that extends from the *D. asymetrica* and *Dicarinella concavata* Zones upwards into the *G. elevata* Zone.

Beside the species mentioned above on which the *G. elevata* Zone was identified, planktonic species considered in situ are few *G. elevata*, common *G. stuartiformis, Globotruncana arca, G. bulloides, Contusotruncana fornicata, Globigerinelloides bollii*, and frequent ventilabrellids (i.e. *V. browni, V. glabrata*).

*Occurrence.* Lari La section, ZD 123; Pingdon La section, HZ 218; Sneatse section, HZ 256 to 259; Sumstek section, HZ 251, HZ 252?

*Globotruncana ventricosa* Zone.

This zone is identified by the appearance of the nominal species (Pl. 38, fig. 4) frequently associated with *Globotruncana rosetta, G. orientalis, Contusotruncana patelliformis*, and *Rugoglobigerina rugosa*. The planktonic foraminifera occur in layers and their preservation is fair. The assemblages are generally strongly mixed as testified by the numerous marginotruncanids along with few, sometimes common, *D. concavata* and *D. asymetrica* and few whiteinellids occurring in most layers.

*Occurrence.* Pingdon La section, HZ 219; Lari La section, ZD 124; Sneatse section, HZ 260, HZ 261; Takh Bridge section, ZD 33; Sumstek section, HZ 252?

*Globotruncanita calcarata* Zone.

The occurrence of the nominal taxon identifies this zone as corroborated by the appearance of few *Globotruncanita stuarti.* The last few studied levels, where *G. calcarata* is apparently absent, are tentatively attributed to the *Globotruncanella havanensis* Zone. The rarity of *G. calcarata* and the difficulty of its identification in thin section prevents the precise placement of the upper zonal boundary. Moreover, planktonic foraminiferal assemblages are extremely abundant, but clearly resedimented as in the underlying zones.

*Occurrence.* Sumstek section, HZ 253, HZ 254; Pingdon La section, HZ 220; Lari La section, ZD 125; Sneatse section, HZ 262.

*Globotruncanella havanensis* Zone.

This zone is identified in the absence of *G. calcarata* and in the presence of numerous *Globotruncanita stuarti* and occasionally the zonal marker. These conditions can be matched only at Sumstek, Sneatse and possibly at Pingdon La, where *G. calcarata* was not found.

*Occurrence.* Sumstek section, HZ 255; Sneatse section, HZ 263, HZ 264, and H88; Pingdon La section, HZ 222.

The following biostratigraphic intervals are missing in the Chikkim, Fatu La and Kangi La Formations based on the absence of either in situ or displaced marker species of planktonic foraminifera:

- the upper part of the *Rotalipora appenninica* Zone. The recorded assemblages still contain *Rotalipora ticinensis, R. subticinensis*, few ticinellids, and *Biticinella breggiensis*, which are indicative only of the lower part of the named zone;

- the *Rotalipora brotzeni* Zone. It should be noted, however, that planktonic foraminiferal assemblages of the named zone are difficult to separate from the previous and following zones, as most of the taxa range below or above the zone itself;

- the *Rotalipora reicheli* Zone. Only one very doubtful specimen of *R. reicheli* was recovered from the poorly preserved Zangla section.

On the contrary, faunal elements attributable to the other missing zone, the *Rotalipora cushmani* Zone, possibly in its interity, occur reworked within the *Whiteinella archaeocretacea* and *Helvetoglobotruncana helvetica* Zones, whereas those attributable to the *Dicarinella concavata* and *Dicarinella asymetrica* Zones occur reworked into the *Globotruncanita elevata, Globotruncana ventricosa*, and even in the *Globotruncanita calcarata* Zones as testified by the occurrence of abundant marginotruncanids including the large *M. tarfayaensis* and *M. undulata.* Remnants of the *D. concavata* and *D. asymetrica* Zones apparently occur in a single sample at Pingdon La and west of Ningri La, respectively.

**Age of the zones and duration of the hiatuses.**

Recent investigations based on ammonite biostratigraphy (Fig. 20) demonstrate the following correlations: (1) the *Whiteinella archaeocretacea* Zone is mostly Late Cenomanian in age; (2) the *Helvetoglobotruncana helvetica* Zone begins just above the base of the Turonian and is confined to the Early and early Middle Turonian; (3) the *Marginotruncana sigali* Zone is dated as late Middle Turonian; and (4) the beginning of the *Dicarinella concavata* Zone is Late Turonian in age. The latter zone thus ap-

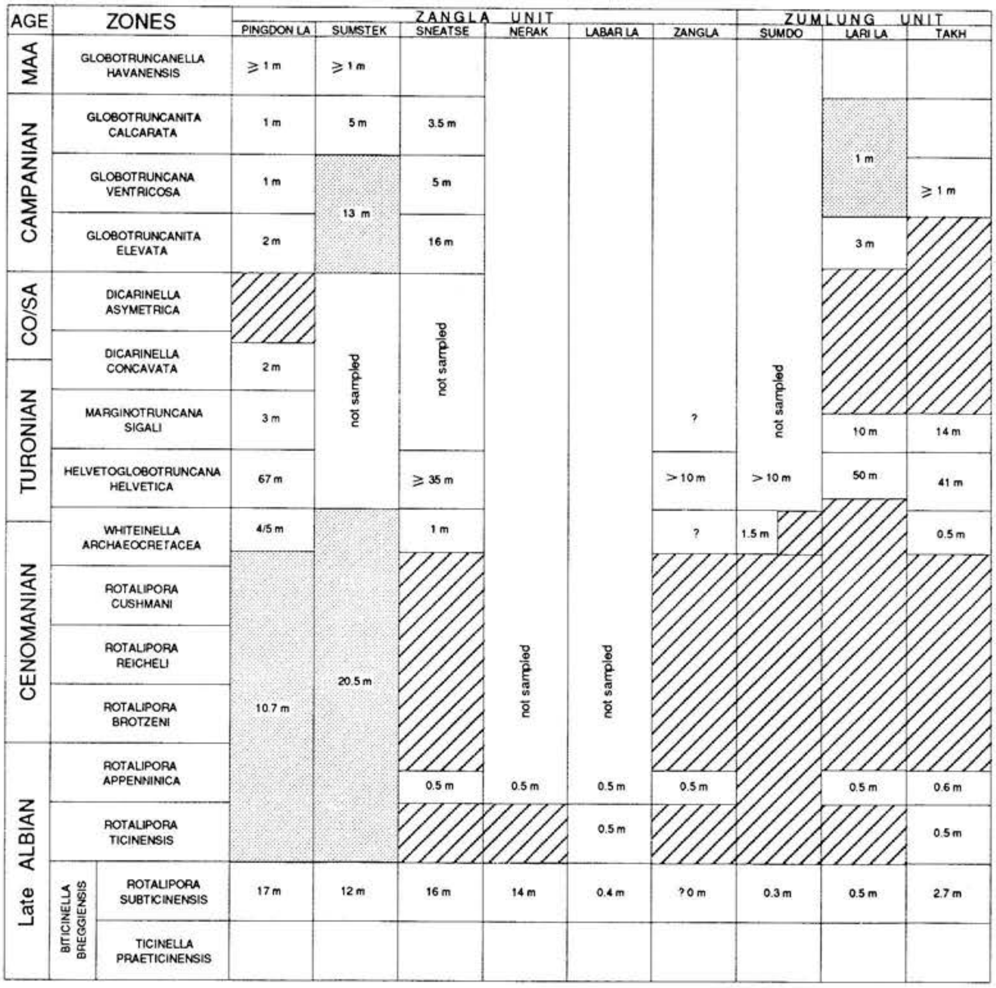


Fig. 20 - Scheme of the zonal intervals, with their thickness shown in meters, and the hiatuses (oblique patterns) identified in the studied sections, plotted against the planktonic foraminiferal zonation of Sliter (1989) and ages according to Robaszynski et al. (1990). Dotted patterns) uncertain biostratigraphic position.

parently spans the Late Turonian through at least the earliest Santonian, whereas it is not clear whether the beginning of the *Dicarinella asymetrica* Zone is Early or Late Santonian in age (Donze et al., 1967; Porthault, 1969; Robaszynski et al., 1990). The ages of the other zones is maintained as known in the literature (see references in Sliter, 1989).

Figures 10 to 20 show the major hiatuses detected in the studied sections. They span the latest Albian, the entire Cenomanian, the latest Turonian to Early Campanian. On the basis of the reworked faunas recorded higher in the sequence, however, such hiatuses were of shorter duration in the source area(s), where they apparently span only the latest Albian to Middle Cenomanian and the latest Turonian and part of or possibly the entire Coniacian.

Minor hiatuses are implicitly present because of the resedimented character of the sediments studied, but they are difficult to demonstrate except in the cases of: (1) the *Whiteinella archaeocretacea* Zone, mainly recorded in a single sample from each of the sections. Although the time involved is short, the *Whiteinella archaeocretacea* Zone, occurring only in layers few cm thick, is clearly under-represented in order to accommodate its total duration. The faunal assemblage suggests that the missing portion is the lower part of the zone as the portion present is in apparent stratigraphic continuity with the overlying *H. helvetica* Zone. (2) The three zones attributed to the Campanian. The sedimentation in this time interval is very condensed within each of the three zones, i.e. the *Globotruncanita elevata, Globotruncana ventricosa* and *Globotruncanita calcarata* Zones. Each of these is represented by a single, to a maximum of two samples for a sediment thickness of one to few metres. Only the G. *elevata* Zone in the Sneatse section is recorded in a package of sediments that exceeds 10 meters in thickness. (3) In the Takh Bridge section, the Campanian is represented by only a single sample attributed to the G. *ventricosa* Zone. The sample was collected immediately above a layer yielding planktonic foraminiferal fauna from the Middle Turonian *M. sigali* Zone. Thus, the G. *elevata* Zone is apparently missing in the Takh Bridge section.

The *Whiteinella archaeocretacea* Zone and the lower part of the *Helvetoglobotruncana helvetica* Zone (without marginotruncanids) are not recorded in the Lari La section (see Fig. 16). Their absence may be due to the sampling interval (e.g., a 2 meter space between samples ZD 115 and ZD 116).

#### Other organisms.

Other organisms are a minor component of the assemblages except in few cases described below. They are separated in two groups, composed by autochthonous versus definitely allochthonous forms.

The autochthonous organisms include the radiolarians, calcispheres and small benthic foraminifera. Radiolarians occur in few layers, with common specimens in the *R. subticinensis* Subzone only at Sumdo, few in the *R. appenninica* Zone, few to common in the *Whiteinella archaeocretacea* Zone, common to abundant in the lower *H. helvetica* Zone. Their occurrence with some abundance in the heavily resedimented layers of the upper *H. helvetica* Zone as in the Pingdon La section is ascribed to reworking. Calcispheres display a distribution similar to the radiolarians and are generally associated either as autochthonous or allochthonous components, except in the Sumstek and Nerak sections where both groups are missing.

Small benthic foraminifera are a rather consistent component of the assemblages, but their abundance and composition vary from layer to layer. Autochthonous forms are generally rare and can be mainly attributed to the genera *Gavelinella, Osangularia* and more rarely *Gyroidinoides*. This association indicates an upper bathyal environment and it occurs mainly in the *W. archaeocretacea* and *H. helvetica* Zones, and occasionally in some samples belonging to the *R. appenninica* and *M. sigali* Zones.

A greater abundance of benthic foraminifera occurs in strongly resedimented layers, in which the taxa mentioned above are accompanied by forms indicative of shallower depths. These allochthonous forms include large-sized coarse-textured agglutinants, costate lagenids, and small shallow-water planispiral forms. This assemblage frequently occurs associated with fragments of shallow-water mollusks, echinoids, and inoceramids or pelagic pelecypods. The allochthonous forms occur preferentially in the top part of the Giumal Group and at the base of the Chikkim and Fatu La Formations in the Late Albian *R. subticinensis* Subzone and *R. appenninica* Zone from the Sneatse, Sumstek, Zangla, Sumdo, Takh Bridge, and Lari La sections, and in the Campanian interval of the Lari La and Sneatse sections. In the latter section the same Campanian layers are also rich in inoceramids, which are rarely recorded in older layers. In the Pingdon La section allochthonous shallower-water benthic foraminifera have a somewhat different distribution: they occur not only at the top of the Giumal Group but were recovered also from several layers belonging to the *H. helvetica* Zone, where they are associated with calcispheres and radiolarians as mentioned above; on the contrary, they are absent in the Campanian and Maastrichtian layers.

### Dzong ridge section, Thakkhola (Nepal) (Fig. 19).

On the basis of planktonic foraminifera the Dzong ridge section can be attributed to the upper part of the *Biticinella breggiensis* Zone, *Rotalipora subticinensis* Subzone, from sample HN 76 to HN 81 (Pl. 37, fig. 2), and to the *Rotalipora appenninica* Zone from sample HN 82 to HN 84. The measured section is, thus, entirely of Late Albian age. The planktonic foraminiferal faunas are poorly diversified and scarce at the base of the measured section, then gradually increase in both total abundance and diversity. The *Rotalipora ticinensis* Zone could not be identified: it possibly occurs in the basal 3 meters of the Muding Formation, which was not sampled. Sample HN 84 yielded also a moderately preserved and diversified calcareous nannofossil assemblage attributable to the *Eiffellithus turriseiffellii* Zone of Late Albian age (E. Erba, pers. comm., 1990).

Radiolarians are common along with some fragments of echinoids and mollusks in the lowermost sample (HN 75) collected in the black shales of the upper Dzong Formation and higher in the *R. appennnica* Zone (HN 82 to HN 84), where they are associated with few to common calcispheres. The samples from the *R. appenninica* Zone yield common shallow-water benthic foraminifera associated with fragments of calcareous algae (dasycladaceans) (Pl. 37, fig. 3). Inoceramids occur throughout the *R. subticinensis* Subzone but are common only in a single layer close to the base of the subzone.

## Evolution of the Neo-tethyan margin

### Glauco-phosphorites and drowning unconformities.

The Indian continental shelf, roughly NW-SE trending, lying around 35° S paleolatitude and facing the some thousands km wide Neo-Tethys Ocean to the north (Scotese et al., 1988; Ricou et al., 1990), drowned at the close of the Early Cretaceous. Biostratigraphic data indicate that at Late Albian time, all along the margin from Zanskar to Nepal, volcaniclastic deposits (Giumal and Chukh Groups) were capped by condensed intervals (Nerak Glauco-phosphorite and Glauconitic Horizon) and covered by pelagic marly limestones (Fatu La and Muding Formations). Water-depth rapidly increased from a few tens of metres, as indicated by storm-dominated muddy shelf sediments sporadically yielding nektonic and shallow-dwelling planktonic fauna, to more than 150 m, as testified by Scaglia-like mudstones characterized by deeper-water typical Tethyan planktonic foraminifera (Leckie, 1987).

At the boundary between clastic and pelagic facies, thin to relatively thick glauco-phosphorites display scours overlain by microconglomeratic lags, large-scale cross-lamination and a variety of other high-energy features (Garzanti et al., 1989). Phosphates tend to replace glaucony both upwards and towards distal areas, indicating formation in deeper-waters, probably close to the shelfbreak (Cruickshank & Rowland, 1983). Eutrophication is suggested by the abundance of radiolaria and calcispheres. Sedimentary characteristics indicate variable but generally reduced oxygenation and strong action of oceanic currents (Flemming, 1978; Delamette, 1988; Föllmi, 1989). Sedimentation was controlled by the previous coastal and shelfbreak morphology. Closer to long-lasting entry points of coarser-grained siliciclastic detritus, palimpsest arenites on the outer shelf (Swift et al., 1971) were repeatedly reworked by oceanic currents during the Cenomanian (Oma Chu Glauco-phosphorite), and covered by the Chikkim pelagic mudstones only in the Early Turonian.

### What caused the death of the clastic shelf?

A complex interplay of several factors resulted in the drowning of the Indian margin clastic shelves:

1) long-term worldwide eustatic rise, leading to the highest sea-level stand of the Mesozoic in the Turonian (Haq et al., 1988). Global rise was probably induced by anomalous mid-plate volcanism in the Pacific and other ocean basins (Schlanger et al., 1981).

2) Thermo-tectonic subsidence at the end of a major alkaline magmatic episode, recorded all along the Indian margin during the Early Cretaceous (Garzanti & Jansa, 1990). Eruption of phonotephrites, trachyandesites or trachytes and intrusion of nepheline syenites occurred until the Late Albian (Rb/Sr biotite/feldspar age of 96.7 ± 2.8 my; Arita et al., 1991).

3) Waning of terrigenous detritus owing to the previously listed factors: 3a) during rapid transgression river-mouths are flooded and turned into sediment-trapping

estuaries, while terrigenous detritus is mostly supplied by erosional coastal retreat and reworking of the sea-floor; 3b) cessation of magmatism and tectonic uplift of continental blocks after the final stage of disintegration of Gondwana-Land, which indirectly affected also the northern India passive margin.

4) Global changes and intensification of oceanic currents after this major plate reorganization, with progressive opening of oceanic seaways between northward-drifting India, Madagascar and Africa to the west, and Australia-Antarctica to the east. Modern reconstructions of mid-Cretaceous oceanic circulation predict an eastbound boundary current off the northern margin of India (Barron & Peterson, 1990), and paleoceanographic conditions were highly favourable to strong upwelling and associated phosphogenesis (Cook & McElhinny, 1979; Barron, 1985).

5) Global anoxic events, with impingement of an expanded oxygen minimum zone onto the outer shelf. The Late Albian and Late Cenomanian Tethys Himalayan glauco-phosphorites correlate well with oceanic anoxic events OAE 1c and OAE 2 respectively (Arthur et al., 1990), and these correspond in turn with two major global condensed sections (marked at 98.5 and 91.5 my on the chronostratigraphic chart of Haq et al., 1988). Association of glauco-phosphorites with stages of flooding, starvation and anoxia has been emphasized by several workers (Jenkyns, 1980; Bréhéret & Delamette, 1989; Garzanti, 1991).

6) Minimal accumulation of calcareous skeletal debris, ascribed to: 6a) rapidly increasing water-depths below the photic zone; 6b) eutrophication and oxygen depletion, hampering the proliferation of benthic communities, save organisms adapted to low oxygen levels such as inoceramids or echinoderms (Kauffman & Sageman, 1990; Hottinger, 1991). Extreme paleoceanographic conditions during anoxic events also affected nektonic cephalopods, which rapidly disappear above the clastic/limestone transition zone, and keeled planktonic foraminifera (Arthur et al., 1987; Premoli Silva, 1991); 6c) oceanic currents strong enough to rework and prevent deposition of micro- and nanno-fossils.

## The Chikkim and Fatu La Formations of the Zanskar Range: pelagic sediments on a drowned shelf.

### Latest Albian to Cenomanian.

The condensed intervals deposited during the *R. subticinensis* Subzone (Nerak Glauco-phosphorite and Glauconitic Horizon) were sharply overlain by pelagic mudstones (Fatu La and Muding Formations). Open marine foraminifera at the base of the latter mostly document the lower part of the *R. appenninica* Zone, with the *R. ticinensis* Zone found only locally. Next, hiatuses become widespread and, save the proximal area where the Oma Chu Glauco-phosphorite was deposited, the Cenomanian is generally testified by only a few decimeters of reworked and burrowed sediments ascribed to the *W. archaeocretacea* Zone. The period of time comprised between the *B.*

*breggiensis* and the *H. helvetica* Zones (7 to 9 my according to the Haq et al., 1988, and Harland et al., 1989 time scales respectively) is represented by 1.6 m of sediment at most in the Zumlung Unit (Sumdo to Takh sections). Where hiatuses are maximum (E Sumdo section), mudstones yielding marginotruncanids (upper *H. helvetica* Zone) are found in paraconformable contact with condensed phosphatic deposits of the *B. breggiensis* Zone, and up to 6 foraminiferal zones including the whole Cenomanian are not represented. Fuchs & Willems' (1990, p. 269) contention that the "major unconformity in the topmost Albian (Garzanti et al., 1987, p. 299) does not exist" is therefore pretentious.

#### Early-Middle Turonian.

The *H. helvetica* and part of the *M. sigali* Zones, corresponding to a time span of 2 my at most (Haq et al., 1988: Harland et al., 1989), are well represented in the Zanskar Range, with thicknesses of 54 to 70 m even in proximal sections characterized by Chikkim or Fatu La/Chikkim facies (accumulation rates around or over 30 m/my). Reworked shelfal faunas occur frequently only in the mudstones of the Chikkim Formation, and both bioturbation and reworking are generally less extensive. Inferred water depths for the upper bathyal Chikkim and Fatu La pelagic sediments at this stage were over 150 m and 200 m respectively (calculations are based on the long-term eustatic curve and absolute ages of Haq et al., 1988, and assume for the Late

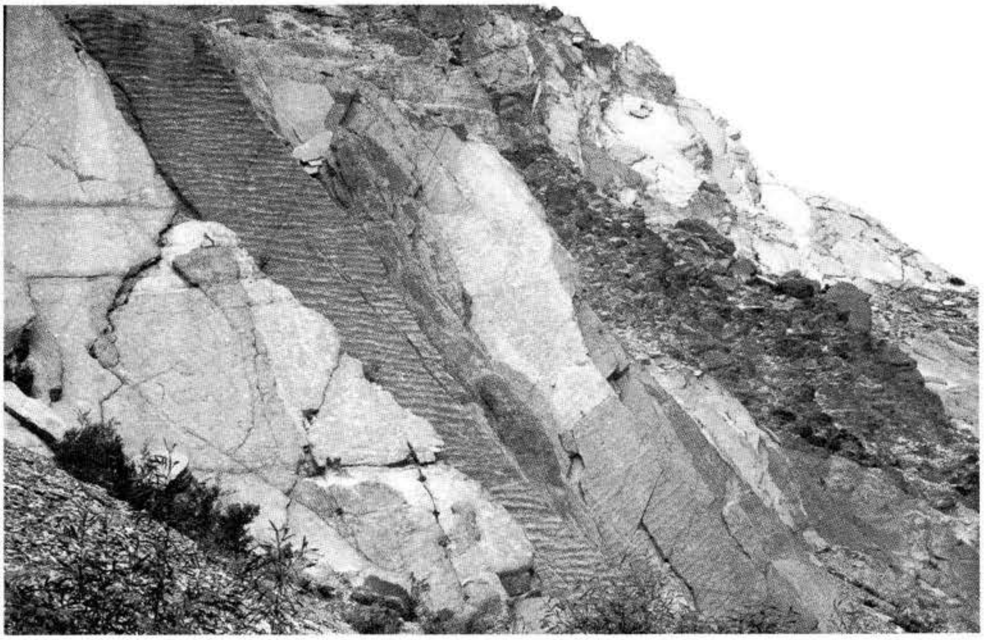

Fig. 21 - Wave ripple marks with NW/SE-oriented crests observed in the grey Fatu La Fm. foraminiferal wackestones of Coniacian/Santonian age west of Ningri La (sample ZD 143).

Cretaceous constant tectonic subsidence rates around 10 m/my, corrected for sediment loading but not for compaction). The substantial increase in mud content at upper bathyal depths is related to a decrease in frequency of currents exceeding the threshold velocities needed to erode fine sediments, which occurred on the upper continental slope (Stanley & Wear, 1978; type II "mudline" of Stanley et al., 1983).

Exclusive grey colours in the limestones of the Chikkim Formation, overlying pyritic condensed intervals, are ascribed to deposition in poorly oxygenated waters, whereas reddish marlstones occurring mostly in the middle part of the Fatu La Formation suggest better oxygenation in deeper areas, lying seaward of coastal upwelling zones. Red marlstone bands may be found already in the *R. appenninica* Zone (Nerak, Thakkhola) and up to the lower *G. elevata* Zone (Sneatse).

### Coniacian/Santonian to Campanian.

The *D. concavata* to *G. calcarata* Zones, corresponding to a time span of about 15 my (Haq et al., 1988; Harland et al., 1989), are represented by few metres at most in the Zumlung Unit, reach a maximum of 25 to 30 m at Sneatse and Labar La, and then decrease again northwestward down to a few metres at Pingdon La (accumulation rates everywhere less than 2 m/my). The *D. concavata* and *D. asymetrica* Zones, and locally also the upper part of the *M. sigali* Zone, are generally not represented and mostly found reworked in the Campanian. The *G. elevata, G. ventricosa* and *G. calcarata* Zones are commonly preserved, but with reduced thickness and invariably intense reworking.

Grey colours again become predominant at this stage, suggesting poor oxygenation, possibly under the influence of an expanded oxygen minimum zone during the poorly defined oceanic anoxic event OAE 3 (Arthur et al., 1990).

Relatively shallow water depths are suggested by:

a) common occurrence of reworked shelfal benthic foraminifera and reappearance of inoceramids, other bivalves and echinoderms at the top both of the Chikkim and Fatu La Formations. Also burrowing activity became again more intense;

b) symmetrical ripples observed west of Ningri La in the grey limestones of the *D. concavata/D. asymetrica* Zones (Fig. 21). The sea-bottom was thus relatively shallow (200 m?), since it could be stirred by very exceptional waves during hurricanes or tsunamis. Alternatively, ripples could have formed under the action of internal waves (Karl & Carlson, 1982).

### What caused hiatuses and intense reworking at the base and top of the pelagic units?

Thin to medium-bedded limestone layers invariably contain planktonic species of incompatible ages and display anomalous ratios between foraminiferal tests and micrite (either too high or too low). These features are both widespread and recurrent, and cannot be entirely accounted for by bioturbation, winnowing, sediment failure triggered by eustatic lowstands or other processes.

The lack of significant hard-grounds associated with hiatuses several million years long suggests that sedimentation was almost continuous, but pelagic oozes were constantly removed from the seafloor in the uppermost slope between the shelfbreak and the mudline ("transition zone" of Stanley et al., 1983). Oceanic currents flowing eastward along the Indian margin, as part of gyre circulation predicted in the mid-Cretaceous Neo-Tethys between Asia and Africa (Barron & Peterson, 1990), may have exceeded velocities of 20 cm/s even at depths around 200 m for a long period of time, and caused almost continuous shear-induced resuspension of clay, micrite and foraminiferal tests. A modern analogue may be found in the Indian Ocean, where the Agulhas Current reaches a surface velocity of 2 m/s just seaward of the SE Africa shelfbreak (Flemming, 1978).

### Maximum water depth: inferences and implications.

Deposition of the Chikkim and Fatu La Fms. pelagic sediments on the drowned Zanskar shelf testifies to a major deepening episode in the early Late Cretaceous, during the most pronounced global highstand of the Mesozoic (Haq et al., 1988).

If tectonic subsidence is assumed to be constant throughout the Late Cretaceous (rates around 10 m/my), progressive deepening is inferred to have continued during condensed deposition of the upper Chikkim and Fatu La Formations, with maximum depths (about 250 m and 300 m respectively) reached at the close of the Campanian. However, frequent occurrence of bivalves and echinoderms in the upper part of the pelagic units suggests a shallowing trend in the post-Turonian. Therefore, either the Turonian sea-level rise is underestimated by several tens of metres in the eustatic curve of Haq et al. (1988), or tectonic subsidence decreased from higher values in the Late Albian and Cenomanian (around 30 m/my), down to zero in the post Turonian. If we assume that no subsidence occurred during the Maastrichtian filling of the basin, water depths between 300 m (Spanboth area) and 400 m (Oma Chu area) can be calculated for the top of the Chikkim Formation, since the Maastrichtian succession is 490 to 670 m thick in the Spanboth - Oma Chu area and its top was deposited in very shallow waters (Gaetani et al., 1980, 1983, 1986; Nicora et al., 1987). Greater depths would imply a Maastrichtian phase of tectonic uplift.

The lack of information on the latest Cretaceous succession of distal areas does not allow us to make the same calculation for the top of the Fatu La Formation. Water depth at this stage was a few hundred metres in the Sneatse - Zangla - Sumdo area, and gradually increased northwards in the Nerak - Chirche area and then in the Shillakong Unit. The occurrence of coastal Paleocene facies in the Lingshed Nappe beneath the Spongtang Klippe (Nicora et al., 1987) suggests upper bathyal depths even in the distal continental terrace. Lower bathyal depths were probably reached only in the Lamayuru-Markha zone (Stutz, 1988).

Gradual facies changes in the 150 km long and 20 km wide study area point to:

1) rough parallelism between paleo-isobaths and tectonic strike, with the margin gradually deepening towards the present NE. A deeper embayment is documented in

the Labar La - Zangla - Sumdo area, with shallower conditions both to the W (Spanboth - Oma Chu area) and to the E (Lari La - Takh area);

2) not very steep upper continental slope (1° or less), since differences in water depth between proximal sections with Chikkim-like facies and distal sections characterized by multicoloured Fatu La facies were of few hundred metres at most. The morphology of the sea-bottom was thus probably controlled by the previous extent of the Jurassic Kioto carbonate platform, which characterizes the whole Shillakong and Khurna Units (Baud et al., 1982; Bassoullet at al., 1983);

3) little tectonic shortening between the Zangla and the Zumlung Units.

#### The Maastrichtian shallowing.

In the Zanskar Range, a 490 to 670 m thick shallowing-upward section was deposited during the Maastrichtian (7.5 to 9 my long, according to Haq et al., 1988, and Harland et al., 1989, respectively), at distinctly increased accumulation rates of around 70 m/my. The base of the Kangi La Formation is still very rich in deeper-dwelling planktonic foraminifera, but shelfal faunas become gradually more important upwards. Inoceramids and phosphate nodules rarely encasing ammonoids are particularly common in the lower member of the unit, while in the upper member trace fossils become larger and more abundant (*Rhizocorallium* and *Zoophycos*-type), indicating better oxygenation (Gaetani et al., 1986). Next, at the close of the Cretaceous, the Marpo carbonate ramp prograded onto the proximal Spanboth-Oma Chu areas, whereas in more distal settings pelagic limestones extend up to the middle Maastrichtian, and deep-water facies are found up to the top of the Cretaceous (Baud et al., 1987; Nicora et al., 1987). The development of carbonate platform facies is ascribed to a marked decrease in water depth, with shelf bottoms again within the photic zone, and to latitudinal shift towards equatorial conditions, as a consequence of the rapid northward flight of India towards Eurasia (Patriat & Achache, 1984).

#### Depositional supersequences: tectono-eustatic control.

Contrary to reasonable expectations, sedimentation on the Tethys Himalaya passive margin does not appear in the field as primarily controlled by third-order eustatic "Vail"-type cycles. Since accumulation rates are highly variable, several depositional sequences may be condensed in single laterally-continuous thin beds, while others are surprisingly thickened due to changes in sedimentary conditions. Instead, a mirror-like repetition of sedimentary facies is apparent in the mid- to Late Cretaceous succession as a whole (clastic shelf -> glaucony -> phosphates -> hiatuses -> pelagic oozes -> hiatuses -> phosphates -> mixed clastic-carbonate shelf). This supersequence is assumed to represent the upper part of a long Cretaceous sedimentary cycle (Valanginian? to Maastrichtian; supersequence V of Gaetani & Garzanti, 1991). Clastic and biochemical sediment supply was controlled by the complex interplay of tectonic, eustatic, oceanographic and climatic processes. If the model of van Wagoner et al. (1988) is applied tentatively to this long-term tectono-eustatic cycle, the following correspondence may be established:

- Giumal Sandstone Group: Lowstand and Transgressive system tracts;
- Nerak Glauco-phosphorite: major flooding horizon;
- Oma Chu Glauco-phosphorite: maximum flooding horizon;
- Chikkim/Fatu La Formations: early Highstand (deepening) system tract;
- Kangi La and Marpo Formations: late Highstand (progradation) system tract.

## Conclusions

Detailed study of planktonic foraminiferal assemblages from mid-Cretaceous pelagic units of the Zanskar Range revealed that: 1) hiatuses several million years long and mainly coeval and similar in duration in the Chikkim and Fatu La Formations occur; 2) no hard-grounds or disconformities mark such hiatuses in the outcrop; 3) resedimented layers and reworking are a common, important sedimentary feature throughout the Late Cretaceous, and particularly in Cenomanian and Late Turonian to Campanian times.

Sedimentologic characteristics and planktonic and benthic foraminiferal distribution in the Thakkhola area (central Nepal) suggests a sedimentary evolution closely comparable with the Zanskar margin. After a major episode of alkaline magmatism recorded all along the Tethys Himalayan Zone, widespread glauco-phosphoritic horizons were deposited during the *R. subticinensis* Subzone. The condensed intervals were unconformably overlain by pelagic mudstones during the *R. ticinensis* to *R. appenninica* Zones (Fatu La Formation in Zanskar and Muding Formation in Nepal). Drowning of the Indian passive margin thus occurred with the same modalities and synchronously at Late Albian time, contrary to what was previously inferred (Bordet et al., 1967, 1971). The base of the Chikkim Formation in Zanskar is younger, and overlies palimpsest arenites and reworked glauco-phosphorites deposited during the latest Cenomanian *W. archaeocretacea* Zone. Glauco-phosphorite deposition occurred during major worldwide transgressive pulses and associated periods of depleted oxygen in the world ocean (oceanic anoxic events OAE 1c and OAE 2).

At Cenomanian time, oceanic currents impinged on the drowned shelf during progressive transgression and caused continuous resuspension of fine-grained pelagic sediment in the uppermost slope between the shelfbreak and the mudline. In the Early-Middle Turonian, deposition occurred seaward of the high-velocity core of the current, at greater upper bathyal depths below the mudline, and accumulation rates increased rapidly: about 90% of the entire mid-Cretaceous section was deposited in less than 2 my (no more than 10% of total elapsed time). Stronger influence of the minimum oxygen zone are suggested for the Chikkim Formation by invariably grey colours, while common occurrence of reworked shelfal faunas points to slightly shallower environments with respect to the Fatu La Formation.

Widespread hiatuses and reworking returned again in the Coniacian/Santonian, when the sea-bottom was stirred by the continuous action of oceanic currents and occasionally also by exceptional (or internal?) waves. The effects of another oceanic event at this stage (OAE 3) are poorly defined. In the Campanian, accumulation rates remained very low, but nevertheless a shallowing-upward trend is indicated by the common occurrence of inoceramids or echinoderms and by intensified burrowing activity. Accumulation rates increased enormously in the Maastrichtian, when offshore marls with sparse phosphate nodules were gradually replaced by inner shelf carbonate facies. Continental shelf progradation may have occurred by sediment-drift accretion processes, under the action of an offshore boundary current system (Fulthorpe & Carter, 1991).

The Cretaceous succession of the Tethys Himalaya passive margin thus shows first a deepening and then a shallowing-upward trend, with a mirror-like repetition of sedimentary facies interpreted as a sedimentary cycle 65 to 70 my long. This long-term evolution was controlled by a complex interplay of phenomena active at both global and regional scales: final fragmentation of Gondwana-Land, widespread magmatic activity, increased $CO_2$ content in the atmosphere, global tendency to eustatic rise, "greenhouse" climates, latitudinal shifts due to continental drift, modified patterns of paleoceanographic circulation, anoxic oceanic events in the world oceans, and related effects on the biosphere.

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I. Premoli Silva is responsible for microfossil identification and biostratigraphy. M. Gaetani and E. Garzanti studied the succession in the field and worked out the regional stratigraphic framework.

## List of identified species.

The list of species is rich. This signifies the abundance and high diversity of planktonic foraminiferal faunas encountered in the Cretaceous sediments from the Himalaya area despite their poor preservation. Species are listed in alphabetical order per genus. The generic and specific concepts used by Pessagno (1967), Robaszynski et al. (1984), Caron (1985), Sliter (1989), and Robaszynski et al. (1990) are retained in this paper.

*Archaeoglobigerina cretacea* (d'Orbigny, 1840)
*Biticinella breggiensis* (Gandolfi, 1942)
*Contusotruncana fornicata* (Plummer, 1931)
*Contusotruncana patelliformis* (Gandolfi, 1957)
*Dicarinella algeriana* (Caron, 1966)
*Dicarinella asymetrica* (Sigal, 1952)
*Dicarinella canaliculata* (Reuss, 1854)

*Dicarinella concavata* (Brotzen, 1934)
*Dicarinella hagni* (Scheibnerova, 1962)
*Dicarinella imbricata* (Mornod, 1950)
*Dicarinella ? oraviensis* (Scheibnerova, 1960)
*Dicarinella primitiva* (Dalbiez, 1955)
*Favusella washitensis* (Carsey)
*Globigerinelloides alvarezi* (Eternod Olvera, 1959)
*Globigerinelloides asper* (Ehrenberg, 1854)
*Globigerinelloides bentonensis* (Morrow, 1934)
*Globigerinelloides bollii* Pessagno, 1967
*Globigerinelloides caseyi* (Bolli, Loeblich & Tappan, 1957)
*Globigerinelloides messinae* (Brönnimann, 1952)
*Globigerinelloides prairiehillensis* Pessagno, 1967
*Globigerinelloides subcarinatus* (Brönnimann, 1952)
*Globigerinelloides ultramicrus* (Subbotina, 1949)
*Globotruncana arca* (Cushman, 1926)
*Globotruncana bulloides* Vogler, 1941
*Globotruncana hilli* Pessagno, 1967
*Globotruncana lapparenti* Brotzen, 1936
*Globotruncana linneiana* (d'Orbigny, 1839)
*Globotruncana orientalis* El Naggar, 1966
*Globotruncana rosetta* (Carsey, 1926)
*Globotruncana ventricosa* White, 1928
*Globotruncanella havanensis* (Voorwijk, 1937)
*Globotruncanita elevata* (Brotzen, 1934)
*Globotruncanita calcarata* (Cushman, 1927)
*Globotruncanita stuarti* (de Lapparent, 1918)
*Globotruncanita stuartiformis* (Dalbiez, 1955)
*Globotruncanita subspinosa* (Pessagno, 1960)
*Hedbergella delrioensis* (Carsey, 1926)
*Hedbergella flandrini* Porthault, 1970
*Hedbergella holmdelensis* Olsson, 1964
*Hedbergella monmouthensis* (Olsson, 1960)
*Hedbergella planispira* (Tappan, 1940)
*Hedbergella rischi* Moullade, 1974
*Hedbergella simplex* (Morrow, 1934)
*Helvetoglobotruncana helvetica* (Bolli, 1945)
*Heterohelix glabrans* (Cushman, 1938)
*Heterohelix globulosa* (Ehrenberg, 1840)
*Heterohelix moremani* (Cushman, 1938)
*Heterohelix reussi* (Cushman, 1938)
*Heterohelix striata* (Ehrenberg, 1840)
*Marginotruncana coronata* (Bolli, 1945)
*Marginotruncana marginata* (Reuss, 1845)
*Marginotruncana marianosi* (Douglas, 1969)
*Marginotruncana paraconcavata* Porthault, 1970
*Marginotruncana pseudolinneiana* Pessagno, 1967
*Marginotruncata renzi* (Gandolfi, 1942)
*Marginotruncana schneegansi* (Sigal, 1952)
*Marginotruncana sigali* (Reichel, 1950)
*Marginotruncana sinuosa* Porthault, 1970
*Marginotruncana tarfayaensis* (Lehmann, 1963)

*Marginotruncana undulata* (Lehmann, 1963)
*Planomalina buxtorfi* (Gandolfi, 1942)
*Planomalina praebuxtorfi* Wonders, 1975
*Praeglobotruncana delrioensis* (Plummer, 1931)
*Praeglobotruncana gibba* Klaus, 1960
*Praeglobotruncana stephani* (Gandolfi, 1942)
*Pseudoguembelina costulata* (Cushman, 1938)
*Pseudoguembelina palpebra* Brönnimann & Brown, 1953
*Pseudotextularia elegans* (Rzehak, 1891)
*Rotalipora appenninica* (Renz, 1936)
*Rotalipora balernaensis* Gandolfi, 1957
*Rotalipora cushmani* (Morrow, 1934)
*Rotalipora deeckei* (Franke, 1925)
*Rotalipora gandolfii* Luterbacher & Premoli Silva, 1962
*Rotalipora greenhornensis* (Morrow, 1934)
*Rotalipora praeappenninica* Sigal, 1966
*Rotalipora praebalernaensis* Sigal, 1969
*Rotalipora reicheli* Mornod, 1950
*Rotalipora subticinensis* (Gandolfi, 1957)
*Rotalipora ticinensis* (Gandolfi, 1942)
*Rugoglobigerina rugosa* (Plummer, 1926)
*Schackoina* sp.
*Ticinella madecassiana* Sigal, 1966
*Ticinella praeticinensis* Sigal, 1966
*Ticinella primula* Luterbacher, 1963
*Ticinella raynaudi* Sigal, 1966
*Ticinella roberti* (Gandolfi, 1942)
*Ventilabrella browni* Martin, 1972
*Ventilabrella eggeri* Cushman, 1928
*Ventilabrella glabrata* Cushman, 1928
*Whiteinella aprica* (Loeblich & Tappan, 1961)
*Whiteinella archaeocretacea* Pessagno, 1967
*Whiteinella aumalensis* (Sigal, 1952)
*Whiteinella baltica* Douglas & Rankin, 1969
*Whiteinella brittonensis* (Loeblich & Tappan, 1961)
*Whiteinella gigantea* (Lehmann, 1963)
*Whiteinella inornata* (Bolli, 1957)
*Whiteinella kingi* (Trujillo, 1960)
*Whiteinella paradubia* (Sigal, 1952)
*Whiteinella praehelvetica* (Trujillo, 1960)

## REFERENCES

Arita K., Sakai H. & Koide Y. (1991) - Cretaceous alkaline magmatism in the Nepalese Lesser Himalayas. *Géol. Alpine,* Mém. H.S., n. 16, pp. 9-10, Grenoble.

Arthur M.A., Brumsak H. -J., Jenkyns H.C. & Schlanger S.O. (1990) - Stratigraphy, geochemistry and paleoceanography of organic carbon-rich Cretaceous sequences. In Ginsburg R.N.

& Beaudoin (Eds.) - Cretaceous resources, events and rhythms, pp. 75-119, 11 fig., 4 tab., Kluwer Acad. Publ., Amsterdam.

Arthur M.A., Schlanger S.O. & Jenkyns H.C. (1987) - The Cenomanian-Turonian oceanic anoxic event. II. Palaeoceanographic controls on organic-matter production and preservation. In Brooks J. & Fleet A.J. (Eds.) - Marine petroleum source rocks. *Geol. Soc. Spec. Publ.*, n. 26, pp. 401-420, 6 fig., London.

Barron E.J. (1985) - Numerical climate modeling, a frontier in petroleum source rock prediction: results based on Cretaceous simulations. *Am. Ass. Petr. Geol. Bull.*, v. 69, n. 3, pp. 448-459, 13 fig., Tulsa.

Barron E.J. & Peterson W.H. (1990) - Mid-Cretaceous ocean circulation: results from model sensitivity studies. *Paleoceanography*, v. 5, n. 3, pp. 319-337, Washington.

Bassoullet J.-P., Bellier J.-P., Colchen M., Marcoux J. & Mascle G. (1978) - Découverte de Crétacé supérieur calcaire pélagique dans le Zanskar (Himalaya du Ladakh). *Bull. Soc. Géol. France*, v. 20, n. 6, pp. 961-964, Paris.

Bassoullet J.-P., Colchen M., Gilbert E., Marcoux J., Mascle G., Sutre E. & Van Haver T. (1984) - L'orogène himalayen au Crétacé. *Mém. Soc. Géol. France*, N.S., n. 147, pp. 9-20, 5 fig., Paris.

Bassoullet J.-P., Colchen M., Juteau T., Marcoux J., Mascle G. & Reibel G. (1983) - Geological studies in the Indus suture zone of Ladakh (Himalayas). In Gupta V.J. (Ed.) - Stratigraphy and structure of Kashmir and Ladakh Himalayas. Contribution to Himalayan Geology, v. 2, pp. 96-124, 11 fig., Hindustani Publ. Co., Delhi.

Bassoullet J.-P & Mouterde R. (1977) - Les formations sédimentaires Mésozoiques du domain Tibetain de l'Himalaya du Nepal. Ecologie et géologie de l'Himalaya, *Coll. Int. C.N.R.S.*, n. 268, pp. 53-60, 1 fig., Paris.

Baud A., Arn R., Bugnon P., Crisinel A., Dolivo E., Escher A., Hammerschlag J.-G., Marthaler M., Masson H., Steck A. & Tiecke J.-C. (1982) - Le contact Gondwana - péri-Gondwana dans le Zanskar oriental (Ladakh Himalaya). *Bull. Soc. Géol. France*, s. 7, v. 24, n. 2, pp. 341-361, 10 fig., Paris.

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, 12 fig., Basel.

Baud A., Garzanti E. & Mascle G. (1987) - Late Cretaceous stratigraphy and facies model of the Tethys Himalaya in Zanskar (NW India). *Terra Cognita*, v. 7, n. 2-3, pp. 110-111, Strasbourg.

Bordet P., Colchen M., Krummenacher D., Le Fort P., Mouterde R. & Remy M. (1971) - Recherches géologiques dans l'Himalaya du Nepal, region de la Thakkhola. Ed. du C.N.R.S., v. of 279 pp., 3 pl., 86 fig., Paris.

Bordet P., Colchen M., Le Fort P., Mouterde R. & Remy M. (1967) - Données nouvelles sur la géologie de la Thakkhola (Himalaya du Nepal). *Bull. Soc. Géol. France*, s. 7, v. 9, pp. 883-896, 4 fig., Paris.

Bréhéret J.-G. & Delamette M. (1989) - Correlations between Mid-Cretaceous Vocontian black shales and Helvetic phosphorites in the Western External Alps. In Wiedmann J. (Ed.) - Cretaceous of the Western Tethys. *Proc. 3rd Int. Cretaceous Symp.*, Tübingen 1987, pp. 637-655, 4 fig., E. Schweizerbart'sche Verlagsbuch., Stuttgart.

Caron M. (1985) - Cretaceous planktic foraminifera. In Bolli H.M., Saunders J.B. & Perch-Nielsen K. (Eds.) - Plankton stratigraphy, pp. 17-86, Cambridge Univ. Press, Cambridge.

Cook P.J. & McElhinny M.W. (1979) - A reevaluation of the spatial and temporal distribution of sedimentary phosphate deposits in the light of plate tectonics. *Economic Geol.*, v. 74, pp. 315-330.

Cruickshank M.J. & Rowland T.J. (1983) - Mineral deposits at the shelfbreak. *S.E.P.M. Spec. Publ.*, n. 33, pp. 429-436, 7 fig., Tulsa.

Delamette M. (1988) - Relation between the condensed Albian deposits of the Helvetic domain and the oceanic current-influenced continental margin of the northern Tethys. *Bull. Soc. Géol. France*, s. 8, v. 4, n. 5, pp. 739-745, 4 fig., Paris.

Donze P., Porthault B., Thomel G. & Villoutreys O. (1967) - Le Sénonien inférieur de Puget-Théniers (Alpes Maritimes) et sa microfaune. *Géobios*, v. 3, n. 2, pp. 41-106, 6 pl., 4 fig., Lyon.

Flemming B.W. (1978) - Underwater sand dunes along the Southeast African continental margin - observations and implications. *Marine Geol.*, v. 26, pp. 177-198, 13 fig., Amsterdam.

Föllmi K. (1989) - Mid-Cretaceous platform drowning, current-induced condensation and phosphogenesis, and pelagic sedimentation along the eastern Helvetic shelf (Northern Tethys margin). In Wiedmann J. (Ed.) - Cretaceous of the Western Tethys. *Proc. 3rd Int. Cretaceous Symp.*, Tübingen 1987, pp. 585-606, 7 fig., E. Schweizerbart'sche Verlagsbuch., Stuttgart.

Fuchs G. (1977) - Traverse of Zanskar from the Indus to the Valley of Kashmir. A Preliminary note. *Jahrb. Geol. Bundesanst.*, v. 120, n. 2, pp. 219-229, 1 pl., 1 fig., Wien.

Fuchs G. (1979) - On the geology of western Ladakh. *Jahrb. Geol. Bundesanst.*, v. 122, n. 2, pp. 513-540, 8 pl., 5 fig., Wien.

Fuchs G. (1982) - The geology of western Zanskar. *Jahrb. Geol. Bundesanst.*, v. 125, n. 1/2, pp. 1-50, 18 fig., 5 tab., Wien.

Fuchs G. (1984) - Note on the geology of the Markha - Nimaling area in Ladakh (India). *Jahrb. Geol. Bundesanst.*, v. 127, n. 1, pp. 5-12, 2 fig., Wien.

Fuchs G. (1986) - The geology of the Markha - Khurnak region in Ladakh (India). *Jahrb. Geol. Bundesanst.*, v. 128, n. 3/4, pp. 403-437, 5 pl., 28 fig., Wien.

Fuchs G. (1987) - The geology of southern Zanskar (Ladakh). Evidence for the autochthony of the Tethys Zone of the Himalaya. *Jahrb. Geol. Bundesanst.*, v. 130, n. 4, pp. 465-491, 3 pl., 14 fig., Wien.

Fuchs G. & Willems H. (1990) - The final stages of sedimentation in the Tethyan Zone of Zanskar and their geodynamic significance (Ladakh - Himalaya). *Jahrb. Geol. Bundesanst.*, v. 133, n. 2, pp. 259-273, 2 pl., 13 fig., Wien.

Fulthorpe C.S. & Carter R.M. (1991) - Continental shelf progradation by sediment-drift accretion. *Geol. Soc. Am. Bull.*, v. 103, pp. 300-309, 9 fig., 1 tab., Boulder.

Gaetani M., Casnedi R., Fois E., Garzanti E., Jadoul F., Nicora A. & Tintori A. (1986) - Stratigraphy of the Tethys Himalaya in Zanskar, Ladakh. *Riv. It. Paleont. Strat.*, v. 91, n. 4, pp. 443-478, 16 fig., 1 tab., Milano.

Gaetani M. & Garzanti E. (1991) - Multicyclic history of the northern India continental margin (Northwestern Himalaya). *Am. Ass. Petr. Geol. Bull.*, v. 75, n. 9, pp. 1427-1446, 14 fig., Tulsa.

Gaetani M., Garzanti E. & Jadoul F. (1985) - Main structural elements of Zanskar, NW Himalaya (India). *Rend. Soc. Geol. It.*, v. 8, pp. 3-8, 2 fig., Roma.

Gaetani M., Nicora A. & Premoli Silva I. (1980) - Uppermost Cretaceous and Paleocene in the Zanskar Range (Ladakh - Himalaya). *Riv. It. Paleont. Strat.*, v. 86, n. 1, pp. 127-166, 9 pl., 6 fig., Milano.

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., 6 fig., Milano.

Gansser A. (1964) - Geology of the Himalayas. V. of 289 pp., Wiley Interscience Publ., London.

Garzanti E. (1991) - Non-carbonate intrabasinal grains in arenites: their recognition, significance and relationship to eustatic cycles and tectonic setting. *Journ. Sedim. Petrol.*, v. 61, n. 6, pp. 959-975, 8 fig., Tulsa.

Garzanti E. (1992) - Stratigraphy of the Early Cretaceous Giumal Group (Zanskar Range, Northern India). *Riv. It. Paleont. Strat.*, v. 97 (1991), n. 3-4, pp. 485-510, 14 fig., Milano.

Garzanti E., Baud A. & Mascle G. (1987) - Sedimentary record of the northward flight of India and its collision with Eurasia (Ladakh Himalaya, India). *Geodinamica Acta*, v. 1, n. 4/5, pp. 297-312, 13 fig., Paris.

Garzanti E. & Brignoli G. (1989) - Low temperature metamorphism in the Zanskar sedimentary nappes (NW Himalaya, India). *Ecl. Geol. Helv.*, v. 82, n. 2, pp. 669-684, 8 fig., Basel.

Garzanti E., Haas R. & Jadoul F. (1989) - Ironstones in the Mesozoic passive margin sequence of the Tethys Himalaya (Zanskar, Northern India): sedimentology and metamorphism. In Young T.P. & Taylor W.E.G. (Eds.) - Phanerozoic ironstones. *Geol. Soc. Spec. Publ.*, n. 46, pp. 229-244, 8 fig., 4 tab., London.

Garzanti E. & Jansa L.F. (1990) - Geodynamic significance of Early Cretaceous volcaniclastic sandstones from the northern passive margin of the Indian Plate. *V Himalaya - Tibet - Karakorum Workshop*, p. 19, Milano.

Garzanti E. & Pagni Frette M. (1991) - The stratigraphic succession of the Thakkhola region (central Nepal) - comparisons with the northwestern Tethys Himalaya. *Riv. It. Paleont. Strat.*, v. 97, n. 1, pp. 3-26, 8 fig., Milano.

Gradstein F.M., Gibling M.R., Jansa L.F., Kaminski M.A., Ogg J.G., Sarti M., Thurow J.W., von Rad U. & Westermann G.E.G. (1989) - Mesozoic stratigraphy of Thakkhola, central Nepal. Spec. Rep. n. 1, Centre for Marine Geology, Dalhousie Univ. V. of 115 pp., 7 pl., 51 fig., 3 tab., Halifax.

Haq B.U., Hardenbol J. & Vail P.R. (1988) - Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In Wilgus C.K. et al. (Eds.) - Sea-level changes - an integrated approach. *S.E.P.M. Spec. Publ.*, n. 42, pp. 71-108, 17 fig., Tulsa.

Harland W.B., Armstrong R.L., Cox A.V., Craig L.E., Smith A.G. & Smith D.G. (1989) - A geologic time scale. V. of 263 pp., Cambridge Univ. Press, Cambridge.

Heim A. & Gansser A. (1939) - Central Himalaya, geological observations of the Swiss expedition, 1936. *Mém. Soc. Géol. Helv. Sc. Nat.*, v. 73, n. 1, pp. 1-245, Basel.

Hottinger L. (1991) - Effects of eutrophication on marine, biogenous calcium carbonate production. *Géol. Alpine,* Mém. H.S., n. 17, pp. 63-64, 1 fig., Grenoble.

Jenkyns H.C. (1980) - Cretaceous anoxic events: from continents to oceans. *Journ. Geol. Soc.*, v. 137, pp. 171-188, 6 fig., London.

Karl H.A. & Carlson P.R. (1982) - Large sand waves in Navarinsky Canyon head, Bearing Sea. *Geo-marine letters*, v. 2, n. 3/4, pp. 157-162, 3 fig.

Kauffman E.G. & Sageman B.B. (1990) - Biological sensing of benthic environments in dark shales and related oxygen-restricted facies. In Ginsburg R.N. & Beaudoin (Eds.) - Cretaceous resources, events and rhythms, pp. 121-138, Kluwer Ac. Publ., Amsterdam.

Kelemen P.B. & Sonnenfeld M.D. (1983) - Stratigraphy, structure, petrology and local tectonics, central Ladakh, NW Himalaya. *Schweiz. Min. Petr. Mitt.*, v. 63, n. 2/3, pp. 267-287, 1 pl., Zürich.

Leckie R.M. (1987) - Paleoecology of mid-Cretaceous planktonic foraminifera: a comparison of open ocean and epicontinental sea assemblages. *Micropaleont.*, v. 33, n. 2, pp. 164-176, 8 fig., New York.

Nicora A., Garzanti E. & Fois E. (1987) - Evolution of the Tethys Himalaya continental shelf during Maastrichtian to Paleocene (Zanskar, India). *Riv. It. Paleont. Strat.*, v. 92 (1986), n. 4, pp. 439-496, 7 pl., 14 fig., 7 tab., Milano.

Oloriz F. & Tintori A. (1991) - Upper Jurassic (Tithonian) ammonites from the Spiti Shales in Western Zanskar (NW Himalayas). *Riv. It. Paleont. Strat.*, v. 96 (1990), n. 4, pp. 461-486, 3 pl., 3 fig., Milano.

Patriat P. & Achache J. (1984) - India-Eurasia collision chronology has implications for crustal shortening and driving mechanism of plates. *Nature*, v. 311, pp. 615-621, 4 fig., 2 tab., London.

Pessagno E.A. (1967) - Upper Cretaceous planktonic foraminifera from the western Gulf Coastal Plain. *Paleont. Amer.*, v. 5, n. 37, pp. 245-445, 53 pl., 63 fig., Ithaca.

Porthault B. (1969) - Foraminifères planctoniques et biostratigraphie du Cénomanien dans le sud-est de la France. In Brönnimann P. & Renz H.H. (Eds.) - *Proc. 1st Int. Conf. plankt. microfossils*, Geneva 1987, v. 2, pp. 526-546, 2 pl., 2 fig., Leiden.

Premoli Silva I. (1991) - The latest Cenomanian anoxic event: an update. *Géol. Alpine*, Mém. H.S., n. 17, p. 109, Grenoble.

Ricou L.-E., Besse J., Marcoux J. & Patriat P. (1990) - Une reconstruction du Gondwana révisée à partir de données pluridisciplinaires. *C.R. Ac. Sc.*, s. 2, v. 311, pp. 463-469, 2 fig., 1 tab., Paris.

Robaszynski F., Caron M., Dupuis C., Amédro F., Gonzalez Donoso J.- M., Linares D., Hardenbol J., Gartner S., Calandra F. & Deloffre R. (1990) - A tentative integrated stratigraphy in the Turonian of central Tunisia: formations, zones and sequential stratigraphy in the Kalaat Senan area. *Bull. Centres Rech. Explor.-Prod. Elf- Aquitaine,* v. 14, n. 1, pp. 213-384, 44 pl., 35 fig., Boussens.

Robaszynski F., Caron M., Gonzales Donoso J.M., Wonders A.M. & EWGPF (1984) - Atlas of Late Cretaceous Globotruncanids. *Rev. Micropaléont.*, v. 26, pp. 145-305, 54 pl., 11 fig., Paris.

Schlanger S.O., Jenkyns H.C. & Premoli Silva I. (1981) - Volcanism and vertical tectonics in the Pacific basin related to global Cretaceous transgressions. *Earth Pl. Sc. Lett.*, v. 52, pp. 435-449, 7 fig., Amsterdam.

Scotese C.R., Gahagan L.M. & Larson R.L. (1988) - Plate tectonic reconstructions of the Cretaceous and Cenozoic ocean basins. *Tectonophysics*, v. 155, pp. 27-48, 12 fig., 1 tab., Amsterdam.

Searle M.P. (1986) - Structural evolution and sequence of thrusting in the High Himalayan, Tibetan-Tethys and Indus suture zones of Zanskar and Ladakh, western Himalaya. *Journ. Struct. Geol.*, v. 8, n. 8, pp. 923-936, 10 fig., Oxford.

Sigal J. (1987) - Une échelle zonale du Crétacé méditerranéen et quelques réflexions suscitées par son établissement, particulièrement à propos du Danien. *Rev. Micropaléont.*, v. 30, pp. 32-51, Paris.

Sinha A.K. (1989) - Geology of the Higher Central Himalaya. V. of 219 pp., 12 pl., 124 fig., J. Wiley & Sons, Chichester.

Sliter W.V. (1989) - Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section. *Journ. Foram. Res.*, v. 19, n. 1, pp. 1-19, 3 pl., 6 tab., Lawrence.

Stanley D.J., Addy S.K. & Behrens E.W. (1983) - The mudline: variability of its position relative to shelfbreak. *S.E.P.M. Spec. Publ.*, n. 33, pp. 279-298, 11 fig., Tulsa.

Stanley D.J. & Wear C.M. (1978) - The "mud-line": an erosion-deposition boundary on the upper continental slope. *Marine Geol.*, v. 28, pp. M19-M29, Amsterdam.

Stoliczka A. (1866) - Summary of the geological observations during a visit to the provinces Rupshu Karnag, South Ladakh, Zanskar, Sumdo and Dras of western Tibet. *Mem. Geol. Surv. India*, v. 5, pp. 337-354, Calcutta.

Stutz E. (1988) - Géologie de la chaîne de Nyimaling aux confins du Ladakh et du Rupschu (NW-Himalaya, Inde) - évolution paléogéographique et tectonique d'un segment de la marge nord-indienne. *Mém. Géol.*, n. 3, 149 pp., 38 fig., Lausanne.

Swift D.J.P., Stanley D.J. & Curray J.R. (1971) - Relict sediments on continental shelves: a reconsideration. *Journ. Geol.*, v. 79, pp. 322-346, 15 fig., Chicago.

van Wagoner J.C., Posamentier H.W., Mitchum R.M., Vail P.R., Sarg J.F., Loutit T.S. & Hardenbol J. (1988) - An overview of the fundamentals of sequence stratigraphy and key definitions. *S.E.P.M. Spec. Publ.*, n. 42, pp. 39-45, 3 fig., Tulsa.

## PLATE 37

Fig.1 - Photomicrograph of Sample H 36, Pingdon La section, topmost Giumal Group, Zangla Unit, *Rotalipora subticinensis* Subzone. Planktonic foraminifera are dispersed, sometimes phosphatized with abundant quartz grains; x 40.

Fig. 2 - Photomicrograph of Sample HN 78, Dzong ridge section, Glauconitic Horizon, Thakkhola (Nepal), *Rotalipora subticinensis* Subzone. Planktonic foraminifera are dispersed, sometimes phosphatized with abundant quartz grains; x 45.

Fig. 3 - Photomicrograph of Sample HN 83, Dzong ridge section, Muding Formation, Thakkhola (Nepal), *Rotalipora appenninica* Zone. Note an oblique section of a dasycladacean alga, an agglutinated benthic foraminifer, dispersed planktonic foraminifera, and some calcispherulids. Quartz and glauconitic grain are also present; x 45.

Fig. 4 - *Planomalina buxtorfi* (Gandolfi), axial section. Takh Bridge section, Sample ZD 23, base of the Fatu La Formation, Zumlung Unit, *Rotalipora appenninica* Zone; x 90.

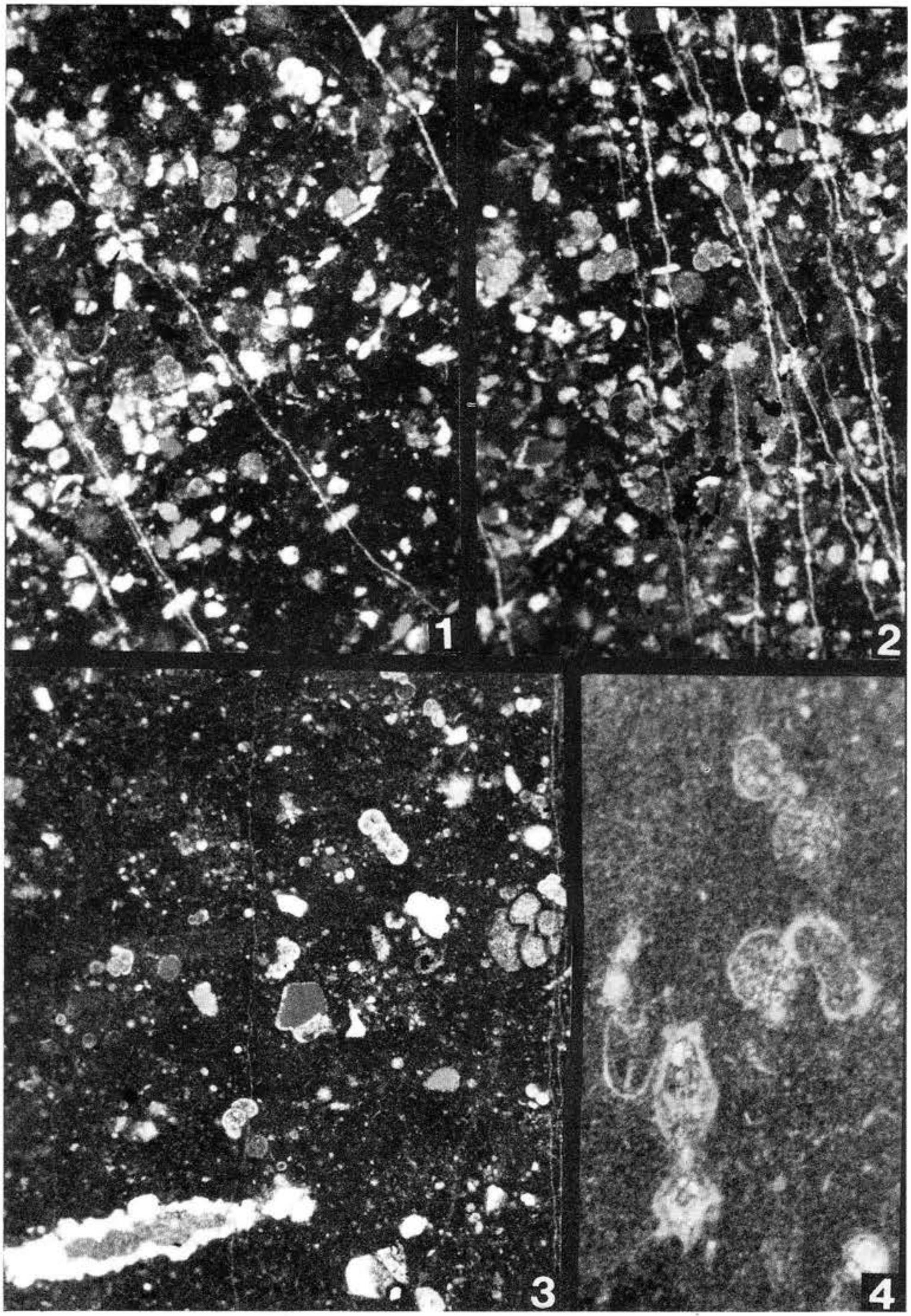
## PLATE 38

Fig. 1 - Photomicrograph of Sample ZG 138, Sneatse section, Chikkim Formation, Zangla Unit, *Helvetoglobotruncana helvetica* Zone. Note the abundant, oriented organisms almost without micrite. An axial section of *Dicarinella canaliculata* (Reuss), numerous *Heterohelix* and calcispherulids are also visible; x 70.

Fig. 2 - Photomicrograph of Sample HZ 215, Pingdon La section, Chikkim Formation, Zangla Unit, *Helvetoglobotruncana helvetica* Zone, with common planktonic foraminifera and several calcispherulids. *Helvetoglobotruncana helvetica* (Bolli), axial section (a); *Dicarinella* ? *oraviensis* (Scheibnerova), axial section (b); x 45.

Fig. 3 - Photomicrograph of Sample HZ 218, Pingdon La section, Chikkim Formation, Zangla Unit, *Globotruncanita elevata* Zone, clearly showing that planktonic foraminifera are concentrated and graded with scarce micrite. *Globotruncanita stuartiformis* (Dalbiez) in axial section and some marginotruncanids are visible; x 45.

Fig. 4 - Photomicrograph of Sample HZ 261, Sneatse section, Chikkim Formation, Zangla Unit, *Globotruncana ventricosa* Zone. Note the abundant, slightly oriented planktonic foraminifera with scarce micrite. An axial section of *Globotruncana ventricosa* White, numerous *Heterohelix* and possibly reworked marginotruncanids are also visible; x 45.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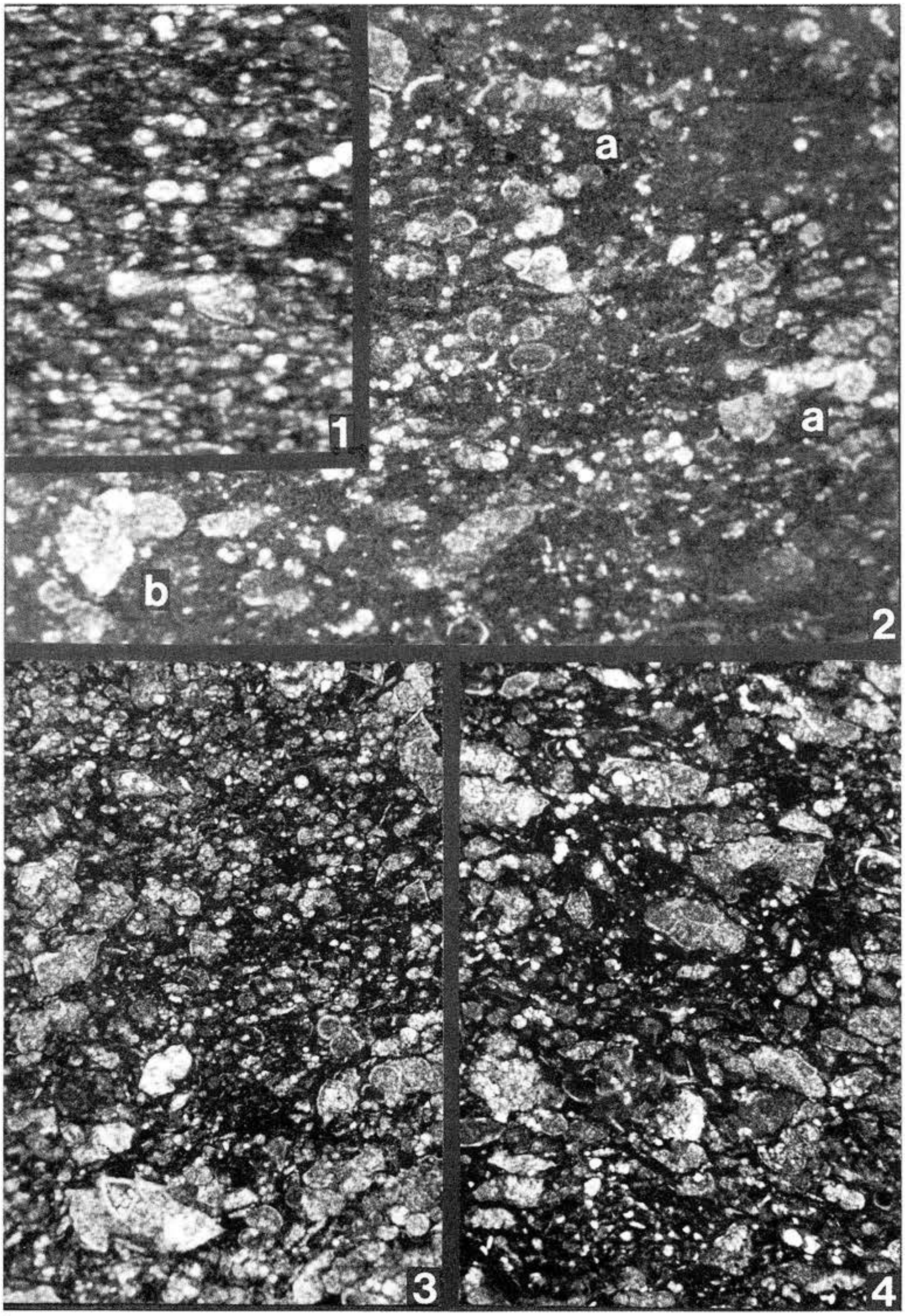
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