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The Final Stages of Sedimentation in the Tethyan Zone of Zanskar and their Geodynamic Significance (Ladakh – Himalaya)

By GERHARD FUCHS & HELMUT WILLEMS*)

With 13 Figures and 2 Plates

Indien
Himalaya
Ladakh
Zanskar
Tethys
Stratigraphie
Geodynamik

Contents

Zusammenfassung

Gesteine der Ober-Kreide und des Alttertiärs – die jüngsten Schichten der Tibet-(Tethys-)Zone – haben in Zanskar (Ladakh) weite Verbreitung. Die Ausbildung dieser Schelfablagerungen gibt wesentliche Hinweise auf die geodynamischen Vorgänge vor dem Beginn der Himalaya-Gebirgsbildung.

Der Giumal-Sandstein (Unter-Kreide) ist noch einheitlich entwickelt, wenn man von Mächtigkeitsabnahme und Kornverfeinerung in nördlicher Richtung absieht. In der Mittel-Kreide macht sich eine auffällige Faziesdifferenzierung bemerkbar. Der Chikkim-Kalk (Ob. Alb bzw. Cenoman bis Campan) wurde in einem tieferen Becken als pelagischer Schlamm frei von terrigenen Verunreinigungen abgesetzt. Er findet sich nur im S von Zanskar. Den nördlichen Bereich charakterisieren die bunten kalkig-tonigen Schichten der Schillakong Formation (Ob. Alb bzw. Cenoman bis Campan), eine in sauerstoffreichem Milieu abgelagerte couches rouges-Fazies. Die Kangi La Formation, eine mächtige siltig-sandig-mergelige Beckenfüllung (Campan – U. Maastricht) ist auf den SW von Zanskar beschränkt. Im Campan bis Maastricht greift die euxinische Lamayuru-Fazies des Kontinentalhanges nach S über den Schelf über und verbindet sich mit dem Kangi La-Becken. Nach diesem Ereignis führt regressive Tendenz bereits im oberen Maastricht zu Seichtwasser-Karbonatbildungen in SW-Zanskar, welche im Paleozän auch Zentral-Zanskar erfassen. Die Aufschiebung der Spongtang-Deckscholle als Folge der Kollision mit Eurasien führt zur Belastung und Eintiefung des unterlagernden Schelfs. Dort werden noch marine Schichten – die Kong Formation – abgelagert. Auf Schwellen entstehen biogene Karbonate, die bei der herrschenden tektonischen Unruhe als debris flows in die schlammigen Tröge abgleiten. Nach der Platznahme der Spongtang-Klippe bilden sich im Vorfeld die Chulung La Red Beds in terrestrisch-fluviatilem Milieu.

Die paläomagnetischen Untersuchungen von APPEL (1989) in Tibet sprechen für eine Dehnung des Nordrandes des Indischen Kontinents im Gefolge der Drift. Die mit der Mittel-Kreide schlagartig einsetzende Faziesvielfalt wird dadurch erklärt: Der Schelf wird durch Zerrungszonen in Blöcke zerlegt. Die entstehenden Becken werden teils mit terrigenem Schutt aufgefüllt, teils herrscht euxinische Fazies. Auf den reliktischen Schelfblöcken entstehen die couches rouges.

Das Übergreifen der Beckenfazies im Maastricht wird mit Annäherung an die Subduktionszone erklärt, die überlagernden Seichtwasserbildungen als Folge der Kollision mit dem Inselbogen gesehen. Eine so frühe Kollision wird durch die Ausdehnung des Randes des Indischen Kontinents um 2000 km gegen N (APPEL, 1989) möglich. Erst nach der Kollision mit Eurasien im Unter-Eozän wird der Zanskar-Schelf in die Gebirgsbildung einbezogen (Überschiebung der Spongtang-Klippe und darauffolgende Faltung).

*) Authors' addresses: Doz. Dr. GERHARD FUCHS, Geologische Bundesanstalt, Rasumofskygasse 23, A-1031 Wien; Prof. Dr. HELMUT WILLEMS, Fachbereich 5 Geowissenschaften, Universität Bremen, Klagenfurterstraße, Postfach 330440, D-2800 Bremen 33.

Abstract

Upper Cretaceous and Early Tertiary series – the youngest beds of the Tibetan (Tethys) Zone of Zanskar cover large areas. Their facies gives information about the geodynamic processes before the beginning of the Himalayan orogenesis.

The Giumal Sandstone (Lower Cretaceous) is still uniform except its reduction in thickness and fining in northern direction. In the Mid Cretaceous a conspicuous diversification of facies commences. The Chikkim Limestone (Up. Albian resp. Cenomanian to Campanian) was deposited in a deeper basin as pelagic ooze free of terrigenous pollution. It is confined to southern Zanskar. In the northern parts of the Shelf we find varicoloured calcareous-argillaceous beds of Up. Albian or Cenomanian to Campanian age respectively. This Shillakong Formation represents couches rouges sedimentation in oxygen rich environment.

The Kangi La Formation (Campanian to L. Maestrichtian) filled a basin in SW Zanskar with thick silty-sandy-marly deposits. In the Campanian and the Maestrichtian the euxinic Lamayuru basin facies overlaps the shelf towards the S and becomes connected with the Kangi La basin. After this event regressive tendency leads to shallow-water carbonate sedimentation in Upper Maestrichtian (Marpo Limestone, SW Zanskar), which spreads to Central Zanskar in the Paleocene (Dibling-Lingshet Limestones). After final collision in the Lower Eocene the Spongtang Klippe overrides Zanskar and causes depression of the underlying shelf. There marine sedimentation is still persisting (Kong Slates). On sills biogenic carbonates form and triggered by active tectonics debris flows slump into the muddy troughs. After emplacement of the Spongtang thrust mass the Chulung La red beds are deposited in front of it in terrestrial-fluviatile environment.

The palaeomagnetic investigations by APPEL (1989) in Tibet suggest extension of the northern margin of the Indian Continent in the course of its drift. This explains the conspicuous diversification of facies commencing in Mid Cretaceous:

The shelf is disintegrated by tension zones into isolated blocks. On these remains of the shelf far from land the couches rouges are deposited. The tensional basins are either filled with land derived detritus or show euxinic facies.

The spreading of basin facies over the shelf in the Maestrichtian is explained as subsidence in front of the subduction zone. The succeeding shallow-water series are deposited after the collision with the island arc. Such early collision appears possible because of the extension of the margin of the Indian Continent for 2000 km towards the N (APPEL, 1989). Only after final collision with Eurasia in the Early Eocene the Zanskar Shelf is involved in orogenesis (thrust of the Spongtang Klippe and succeeding folding).

1. Introduction

The sedimentary belt of the northern (Inner) Himalaya is known as the Tibetan or Tethyan Zone. There we find a succession of Precambrian to Eocene formations, which were deposited on the northern margin of the Indian Continent. The environment was predominantly that of a shelf. Interesting information on the geodynamic evolution may be deduced from the distributions and changes of sedimentary facies in the final stages before the beginning of the Himalayan orogenesis (Pl. 2). Cretaceous and Early Tertiary formations, the youngest beds of the Tethyan Zone, cover large areas in Ladakh.

There exists a great variety of facies in the Cretaceous–Eocene sequence of Zanskar (FUCHS, 1982). Detailed studies of the stratigraphy, of the facies interrelations etc. were started by the authors in summer 1988. Of special interest is the correlation to the coeval series of southern Tibet, of which one of us (H. W.) is familiar.

2. The Cretaceous Sequence

(Pl. 1, 2)

After rather uniform sedimentation of shallow-water carbonates in the Triassic to Mid-Jurassic the Spiti Shales indicate deeper water in the Upper Jurassic – Lowest Cretaceous.

2.1. Giumal Sandstone

The Giumal Sandstone, a clastic arenaceous to argillaceous formation "reflects the multiple progradation of clastic detritus brought by deltaic systems onto a shelf influenced by storm-wave action" (GAETANI et al., 1986, p. 468). The provenance of the clastic material was from the craton in the S as shown by fining grain size and decrease in thickness as we go to the NE and the N (FUCHS, 1982, 1986). GAETANI et al. (1986) discovered basic volcanic arenites in the upper parts of the Giumal Sandstone and took it as indication of rifting. There are glauconitic, phosphatic or ferriferous beds in the Giumal sandstone, which characterize the sedimentary environment (see also GARZANTI et al., 1989). However, the glauconite content can not be taken as evidence for an orogenic event as assumed by SINHA & SRIVASTAVA (1978, 1986). Roughly speaking the Giumal Sandstone is Lower Cretaceous. At the top it is terminated by pelagic limestones of Albian or Cenomanian age (Pl. 2). Locally the Giumal Sandstone may reach up into the Late Cenomanian (GAETANI et al., 1986).

Up to the Mid Cretaceous the sedimentation was rather uniform all over the Zanskar Shelf, except the fining and decrease of thickness away from the source of detritus in the S mentioned in connection with the Giumal Sandstone. With the Mid Cretaceous the facies becomes diversified and changes in an irregular way.

2.2. Chikkim Limestone

In Albian to Cenomanian times, the influx of clastic detritus stops and pelagic limestones follow on the Giumal Sandstone with sharp boundary. The Chikkim Limestone consists of well-bedded, grey or blue foraminiferal limestones free of terrigenous detritus. The formation, always less than hundred meters thick, spans the time from Up. Albian to Cenomanian in other places Cenomanian to Campanian. The Chikkim Limestone was deposited in upper bathyal pelagic environment poor in oxygen and with low rate sedimentation (GAETANI et al., 1986).

2.3. Shillakong Formation

Towards the N and NE the Chikkim Limstone is more and more replaced by multicoloured limestones, marls and slates deposited in a well-aerated environment. This Shillakong Formation (synonym Fotu La Fm.) always succeeds the Chikkim Facies or replaces it entirely in the N. It is a cyclic pelagic series formed of pelitic-calcareous muds full of planktic but ill-preserved foraminifera. This couches rouges facies was deposited on ridges or oceanic plateaus not reached by adjoining basin facies (see below). From the Chirche area BAUD et al. (1982) report an Up. Albian to Mid Cenomanian age, whereas FUCHS (1987) found a Turonian to Lower Campanian age in the Oma Chu – Zangla region. In the Khurnak area FUCHS (1986) found comparable pelagic foraminiferal carbonates of Turonian and Coniacian–Maestrichtian age respectively. In NW Zanskar BASSOULLET et al. (1978) discovered an Up. Campanian fauna in the Shillakong Formation (Fotu La).

In SW Zanskar the passage beds between the Chikkim Limestone and the Kangi La Formation yielded Campanian forams (FUCHS, 1982), which implies that this clastic basin facies is synchronous with the younger portions of the couches rouges facies of northern Zanskar.

2.4. Kangi La Formation

The Kangi La Formation is composed of grey-green slates, sandy and silty slates and marls, and argillaceous or calcareous sandstones. The series weathers in ochre colour and disintegrates to irregular fragments, because bedding planes are badly developed. Trace fossils e. g. *Zoophycos* are frequent. The formation, which is several hundred meters thick is Campanian to Lower Maestrichtian in age (FUCHS, 1982; GAETANI et al., 1986, p. 472). It is a typical basin deposit with abundant terrigenous supply from the south. GAETANI et al. (1986) regard the Kangi La Formation as deposited in upper bathyal to outer shelf environment with overall shallowing trend. The sedimentation rate was several times that of the underlying Chikkim Limestones.

When the Kangi La basin was filling up the partly time equivalent Shillakong couches rouges facies was not reached by the detritus from the S. Therefore it may be concluded that it was deposited on morphological highs.

2.5. Lamayuru Formation (Goma Shales)

In the Maestrichtian all these swell areas and ridges submerged. The euxinic Lamayuru Facies (Goma Shales), which is a silty-calcareous flysch, transgresses the couches rouges from the N and becomes connected with the upper portions of the Kangi La Formation.

The transition of the two distinct facies can be observed in the Chulung Chu – Kong – upper Wakha Chu region (FUCHS, 1982). Further SE in the area Oma Chu – Zangla the overlap of black foraminiferal slates on couches rouges facies occurred already earlier in the Upper Campanian (Pl. 2). BAUD et al. (1982) record the facies change from couches rouges to euxinic beds even in the Mid Cenomanian.

Further E in the Khurnak area we find a quite different facies sequence (FUCHS, 1986): The Khurnak Formation replacing the Giumal Sandstone is followed by pelagic carbonates of Turonian age in one locality, in another section it is succeeded by black silty shales and then by foraminiferal limestones of Coniacian – Maestrichtian age.

Thus in the Upper Cretaceous the Zanskar Shelf shows a complicated system of troughs and sills. The diverse facies change laterally as well as in time. In chapter 4 we shall discuss the causes of this Upper Cretaceous facies variety.

2.6. Spanboth Limestone (Marpo Limestone Mbr.)

After the deposition of thick detrital series (Kangi La Fm.) shallow water carbonate sedimentation resumes in the Upper Maestrichtian in the south-western parts of Zanskar. In the Paleocene the carbonate facies spread to Central Zanskar. GAETANI et al. (1980, 1983, 1986) and NICORA et al. (1987) investigated the shallow water complex in much detail.

The Spanboth Limestone (FUCHS, 1982) was subdivided into three members (GAETANI et al., 1983, 1986), which were proposed to the rank of formations by NICORA et al. (1987): the Marpo Limestone, Stumpata Quartzarenite and Dibling Limestone.

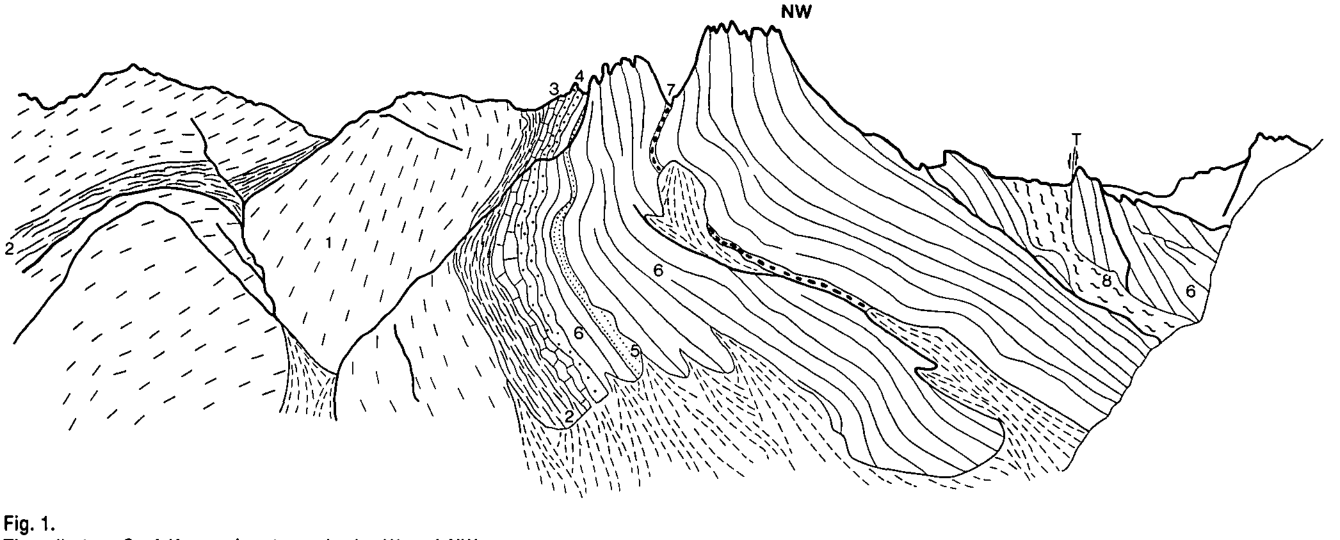

Fig. 1.
The tributary S of Kong, view towards the W and NW.
1 = Kangi La Formation; 2 = Dark slates, passage into Lamayuru Fm.; 3 = Marpo Limestone Mbr.; 4 = Stumpata Quartzarenite Mbr.; 5 = Upper quartzite; 6 = Dibling (Lingshet) Limestone; 7 = Haematitic oolite horizon; 8 = Kong Slates.
3–7 = Spanboth Formation.

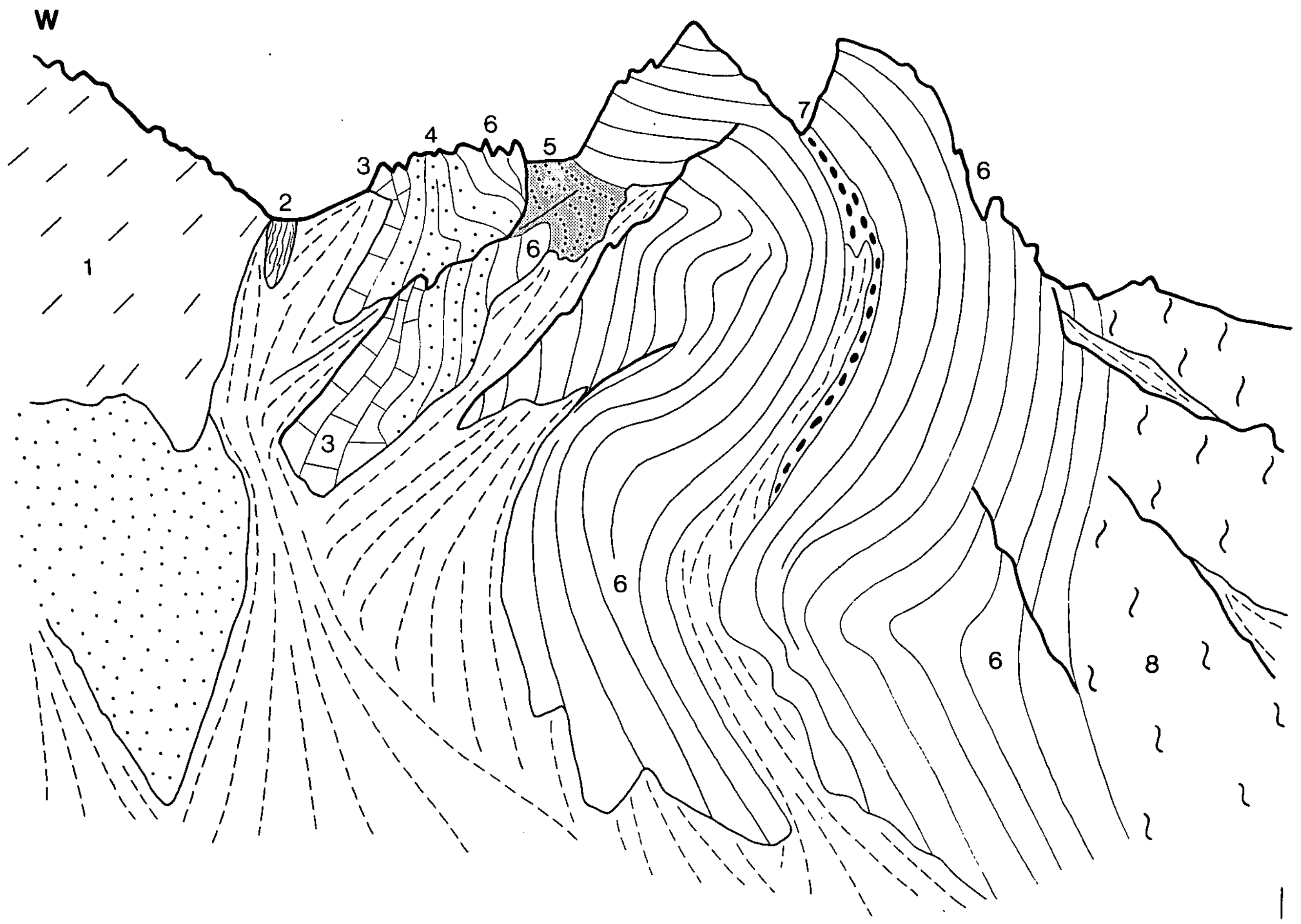

Fig. 2.
The Chulung Valley view towards the W.
1 = Kangi La Formation; 2 = Dark slates, passage to Lamayuru Fm.; 3 = Marpo Limestone Mbr.; 4 = Stumpata Quartzarenite Mbr.; 5 = Upper quartzite; 6 = Dibling (Lingshet) Limestone Mbr.; 7 = Haematitic oolite horizon; 8 = Kong Slates.
3–7 = Spanboth Formation.

Though these authors document the division lithologically and palaeontologically, we still prefer to treat the units as members.

1) The carbonate complex as a whole can be traced in satellite imagery and by binoculars in the field, not so the named subunits.
2) The thicknesses of the Marpo Limestone and the Stumpata Quartzarenite may dwindle down to a few meters only and a second quartzite horizon is developed in certain areas. Such thin units can not be shown on the small scale topographic maps available and thus are not mapable units, which is the definition of formation.

The Marpo Member (ca. 100 m at Marpo) represents the Upper Maestrichtian part of the Spanboth Formation. The member develops from the Kangi La Formation by increasing carbonate layers. The "Zoophycos Beds" represent the top of the Kangi La Formation and the above passage beds, but not the base of the Marpo Limestone as suggested by NICORA et al. (1987, p. 444). The Omphalocyclus Beds of these authors consisting of dark limestones, marls and silty shales and the Siderolites Beds composed of pelites, siltstones, marls and fine-grained sandstones make up the Marpo Limestone Member. NICORA et al. describe the reduction of thickness and carbonate content of the Marpo Member from the W to the E. Similarly we found its reduction from a few meters to zero in the Kong-Chulung Valley area (Pl. 1, 2; Figs. 1–3). NICORA et al. explain this reduction by the deepening of the deposition area in the NE direction and the passage into pelitic series.

3. The Early Tertiary Sequence

3.1. Spanboth Limestone (upper members)

GAETANI et al. (1980, 1983) found a thin quartzarenite horizon within the Spanboth carbonate complex, which was assumed by them as top of the Cretaceous series. The detailed studies by NICORA et al. (1987, p. 452) showed that the arenaceous beds represent the Early Paleocene.

The Stumpata Quartzarenite Member consists of white, brown-weathering quartzites, fine-grained sandstones, and calcareous sandstones at the top. The thickness increases from 13–20 m in the Spanboth area to 67 m in the type locality (NICORA et al., 1987).

The lower and central portions of the member are pure supermature quartzarenites. According to NICORA et al. (1987) the commonly cross-bedded quartzarenite and its petrography indicate a high-energy beach environment. The top portions may be interpreted "to represent a reworked lag deposited at the high-energy front of a transgression and to testify the drowning of the shoreline complex" (lit. cit., p. 456). These authors accept the quartzarenite member as deposited during an eustatic low sea level stand on the passive continental margin.

In the Kong region we observed a second clastic horizon a few meters to ca. 50 m above the top of the

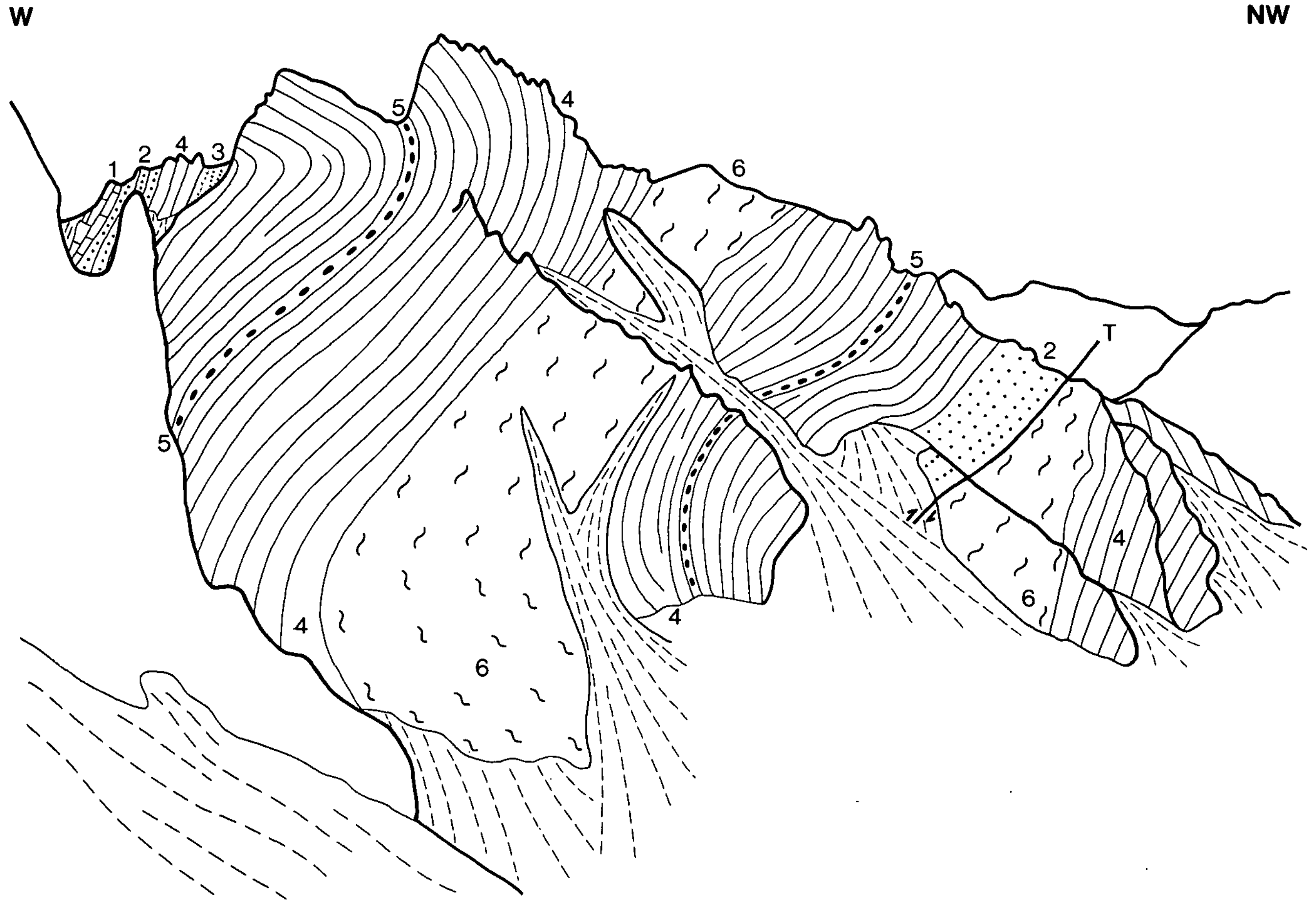

Fig. 3: The western flank of the Chulung Valley seen from the E.
1 = Marpo Limestone Mbr.; 2 = Stumpata Quartzarenite Mbr.; 3 = Upper quartzite; 4 = Dibling (Lingshet) Limestone Mbr.; 5 = Haematitic oolite horizon; 6 = Kong Slates.
T = thrust.
1-5 = Spanboth Formation.

Stumpata Quartzarenite Mbr. (Figs. 1–3). This rusty weathering band is between 3 and 15 m thick and consists of quartzites, green-grey silt- to sandstones, and dark silty shales with ferruginous concretions. We expect that this higher clastic horizon joins up with the Stumpata Quarzarenite Mbr. of the Spanboth area. This implies that this quartzarenite splits up into two horizons towards the NE. An interfingering with the Lingshet Limestone in direction to the open sea is indicated.

Above the Stumpata Quartzarenite Mbr. resp. the described interfingering we find a ca. 200 m carbonate complex which was treated as Upper Member of the Spanboth Formation by GAETANI et al. (1986). NICORA et al. (1987) named it the Dibling Limestone. The lithology and rich fossil content of the late Early Paleocene to earliest Eocene carbonate complex is described by GAETANI et al. (1980, 1983, 1986) and NICORA et al. (1987). According to them the Dibling Limestone was deposited on an inner carbonate shelf. The base indicates a sharp deepening event, and then an overall regressive trend leads to protected shelf-lagoonal conditions at the top of the member.

The Dibling Limestone correlates with the Lingshet Limestone (FUCHS, 1982) of central Zanskar. Recently this limestone was subdivided in the type area into offshore Shinge La pelagic limestones of Paleocene age and the Eocene Kesi peritidal dolomites (NICORA et al., 1987; GARZANTI et al., 1987).

In the Kong area there is a marker horizon about in the middle of the Lingshet (Dibling) Limestone (Figs. 1–3). It is a conspicuous light-weathering band of 20–30 m thickness, with an iron ore and bright green slate layer in the centre. ESE of Kong the following section was observed (from bottom to top):

3 m grey silty slates and thin layers of marl;
6 m grey schistose limestones partly brecciaceous and layers of marl;

Sample 43 yielded the following organisms:

- Forams: *Ranikothalia* sp.
  Operculina sp.
  Lockhartia sp.
  Daviesina sp.
  few Miliolidae and Textulariidae;
- Echinoderms, sponges, serpulids.

The biofacies corresponds to the Lithozone A of the Dibling Limestone according to NICORA et al. (1987, 462–463). The fossil assemblage, especially that of the forams is very much comparable to their Assemblage D with *Daviesina danieli* SMOUT. According to NICORA et al. (1987, 469) the limestones with a high amount of *Daviesina* indicate a Middle to (early) Late Paleocene age.

1 m khaki marl;
4 m nodular limestone without ore;
ca. 1 m ochreous weathering limestone with patches of green clay; dm thick impregnations of haematitic ore;
1 m bright green slates containing sporadic pieces and ooids of iron ore;
1.5 m light grey to khaki schistose limestone.

Fragments of ooidal haematite ore were already found in the course of the 1980 expedition (FUCHS, 1982, 17–18). The loose pieces were supposed to be derived from the basal clastic horizons (Stumpata). Now their provenance from the middle part of the Lingshet (Dibling) Limestone is ascertained. Doz. Dr. W. PROHASKA (Geoscience Inst. Montanuniversität Leoben) kindly examined three samples of Fe-oolite: They consist of haematite and Fe rich chlorite. The following elements were determined by microprobe:

	FeO_2	Mn	Cu	Ni	Co	Pb
88/24	58.21	125	49	322	22	<5
88/44	54.20	33	43	776	119	<5
80/29	62.12	131	47	362	61	<5

All values (except Fe, which is in %) are given in ppm.

It is noteworthy that the values of Ni are relatively high, those of Mn low. In a joint talk Dr. O. SCHERMANN (Geol. B.-A., Vienna) kindly developed the following model:

The element composition (particularly the Fe/Mn ratio) indicates a low relief source area weathering under humid-tropical climate. This fits well with India's equatorial position in the Paleocene. Further the high Ni values suggest the occurrence of basic to ultrabasic rock series in the source area. Certainly the Indian Craton was a source of the iron-rich waters. But we suspect that the Ni values may indicate provenance from the deformed suture zone units, which according to our view were already attached to the leading edge of the Indian Continent.

Anyhow the iron oolite formed in an environment rich in oxygen and with increased salinity (partial restriction). Under these conditions haematite and chamosite were directly precipitated in agitated water, whereas the forming clay was removed by currents. Apparently a short episode of further shallowing changed the environmental conditions completely. Closed connection with the open sea reduced salinity and oxygen exchange, which led to a stop of the iron deposition. Alumina and silicates could not be withdrawn and were sedimented as the green clay under reducing condition. This probably goes back to abundant organic matter caused by the drop of salinity and also supplied from the rivers. The reworked fragments of iron oolite in the clay point to partial emersion of the shelf.

Obviously it was a unique palaeogeographic situation which led to the formation of the iron oolite and the succeeding green shale. We suspect a short eposide of upheaval, which caused restricted lagoonal conditions in portions of the shelf.

Soon the normal open shelf conditions were restored and carbonate deposition continued.

The Paleocene to Lower Eocene carbonates are succeeded by very much different formations in southwestern and central Zanskar (FUCHS, 1982). In the first region the Chulung La Slates represent a terrigenous unfossiliferous red bed formation, whereas the Kong Slates and their carbonate intercalations abound in marine fossils of Lower Eocene age (Zone P 8, according to NICORA et al., 1987). These sedimentary series were taken as approximately time equivalent (FUCHS, 1982; GAETANI et al., 1983; NICORA et al., 1987; GARZANTI et al., 1987). In our recent survey we were able to study Chulung La and Kong Slates in one section (see Figs. 4–6).

3.2. Chulung La Slates

The Chulung La Slates of SW Zanskar commence with a few meters of grey slates containing a few layers of dark to green-grey impure limestone and marl. Then green silty slates follow (10–15 m). The main mass of the 200–300 m thick formation consists of predominantly purple slates, siltites, and impure fine-grained sandstones. Rare carbonate beds, nodules of palaeocaliche and intraformational breccias are recorded by GAETANI et al. (1986). They observed fining upward sequences, cross lamination, climbing ripples, channel fills with scoured bases, which points to a fluvio-dominated deltaic system in a shallow lagoon. The sedimentation rate was high. The sandstones are moderately sorted volcanic arenites, which indicate as a source a magmatic arc. Petrology compares well with "clastic wedges derived from initial arc – continental margin collisions..., even though volcanic lithics are extremely abundant" (GARZANTI et al., 1987, p. 304). Serpentinite schist fragments and common chromian spinel show that ophiolitic sequences are involved in the orogenic process. GARZANTI et al. stress that the sudden arrival of volcanic debris and detritus from obducted ophiolite belts signals the collision. These authors also report an angular unconformity at the base of the Chulung La Slates near Dibling. Commonly, however, the contact is conformable.

3.3. Kong Slates

The Kong Slates (FUCHS, 1982) are grey, green or cream-coloured slates, silty slates and marls with intercalations of blue, grey, limestone. Locally a few fine-grained sandstone beds up to 3 m thickness are observed. Load convolutions at their base and graded bedding point to turbiditic origin. The pelites weather in light beige to cream colours, which characterize the formation in the scenery. GARZANTI et al. (1987) report very fine-grained volcanic debris also from the Kong Slates. They point to the fact that up to the top of the Dibling Limestone clastic intercalations showed silt-sized quartzose detritus or were supermature quartzarenites, whereas in Chulung La- or Kong Slates volcanic arenites indicate provenance from a volcanic arc, pelagic sediments and ophiolites from the Indus Suture Zone. GARZANTI et al. observed a hardground at the base of the Kong Slates, which they are inclined to correlate with the unconformity below the Chulung La Slate. Similarly a hiatus between Maestrichtian pelagic carbonates and brecciaceous nummulitic limestones was recorded from NE-Zanskar (FUCHS, 1986, p. 424). This allodapic nummulitic limestones are very common on the Zanskar Shelf (see below).

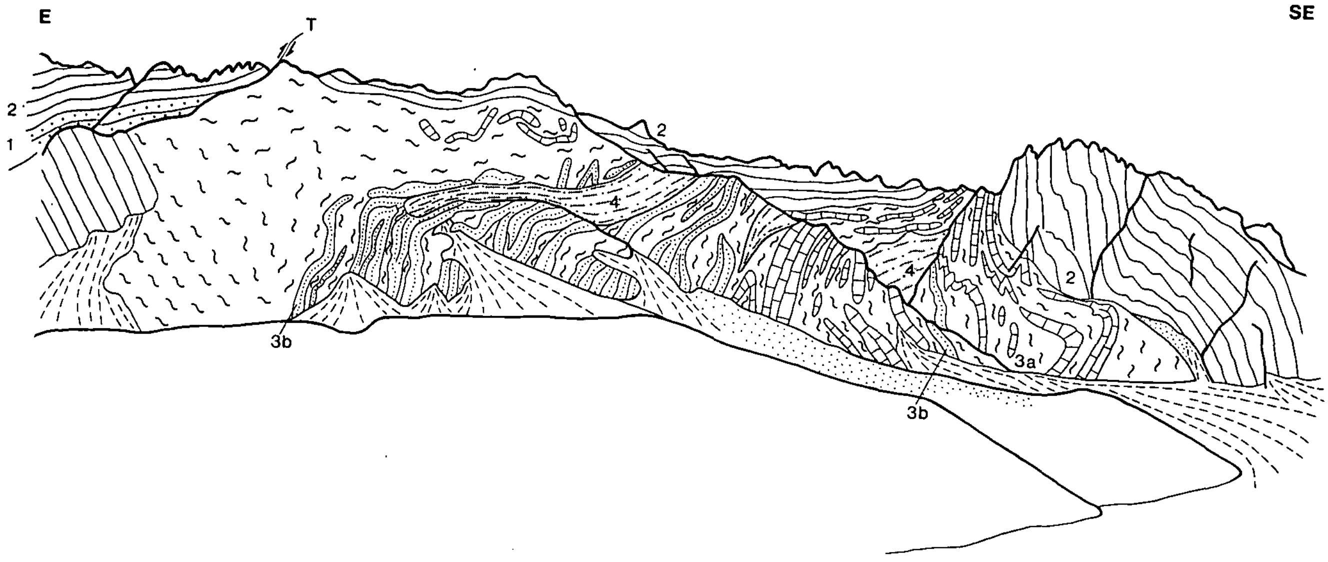

Fig. 4.
The Eocene syncline in the eastern flank of the Chulung Valley.
1 = Stumpata Quartzarenite Mbr.; 2 = Dibling (Lingshet) Limestone Mbr.; 3 = Kong Slates; 3a = Kong Slates interbedded with nummulitic limestones; 3b = Kong Slates with sandstone intercalations; 4 = Chulung La Slates.

The carbonates within the Kong Slates are of special interest. They are found interbedded with the argillites in a regular way (Figs. 4–6) or as huge lenticular masses representing olistostromes and debris flows (Fig. 7–9).

The latter were found in the northernmost Kong Slate syncline of the Kangi Valley: there the Lingshet Limestone is succeeded by 2.5 m of dark blue limestone breccia containing *Alveolinas* and *Nummulites* (Fig. 7). There are also some fragments of light-coloured limestone, which may be derived from the underlying Lingshet Limestone. The allodapic limestone shows a hardground with limonitic encrustations at the top. Overlying with sharp contact we find pelites of the

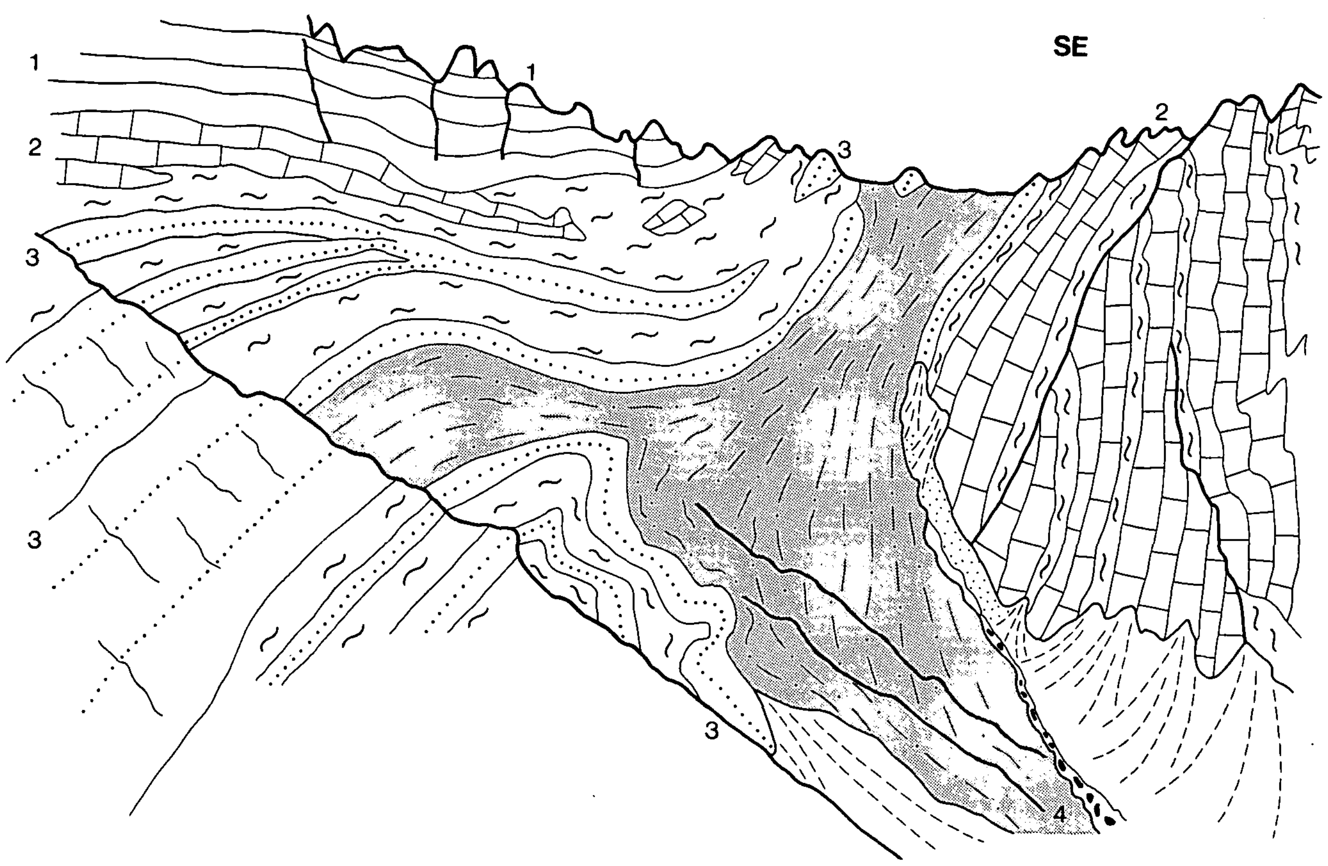

Fig. 5.
The Eocene Syncline E of the Chulung Valley.
1 = Dibling (Lingshet) Limestone Mbr.; 2 = Kong Slates and interbedded limestones; 3 = Kong Slates and interbedded sandstones; 4 = Chulung La Slates.

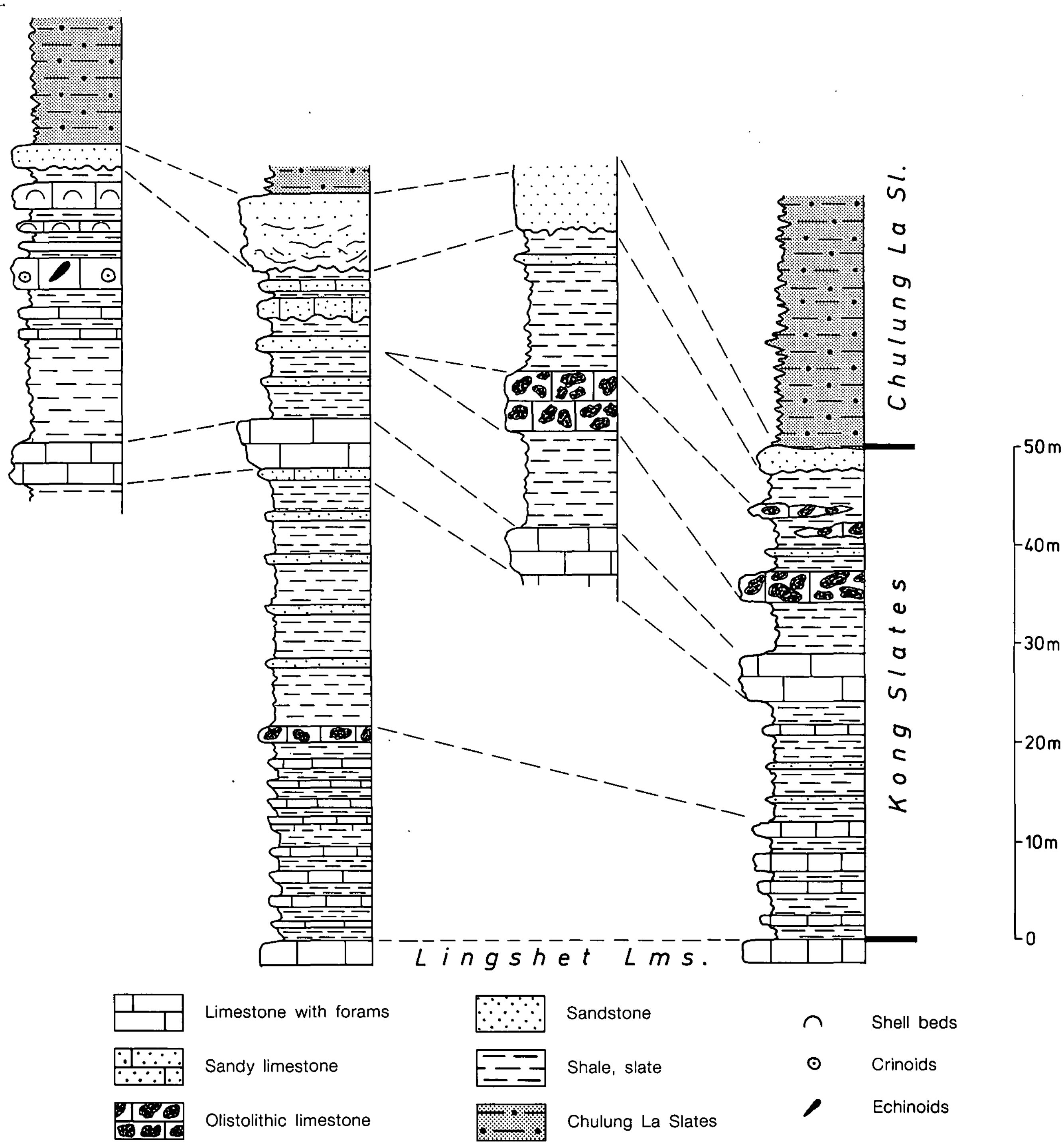

Fig. 6.
Reconstruction of the Kong Slates stratigraphy in the syncline E of the lower Chulung Valley (shown in Fig. 5).

Kong Formation. Traced along the strike the limestone breccia becomes reduced to dm thickness and finally pinches out.

Higher up in the sequence fine-grained silty sandstone with load convolutions and flute casts occurs in a lenticular body a few meters thick.

Still higher in the Kong Slates there are several lenticular masses of blue limestone breccia (up to 200 m long and several tens of meters thick – Fig. 8, 9). Patches of shale up to meter sizes are mixed up within the limestone breccia and in the surrounding pelites limestone fragments of various sizes are embedded. Nummulites are found in the components and the matrix. The argillites of this occurrence are somewhat different from other Kong Slates: They are dark grey, more silty, not so well bedded with uneven s-planes.

It is evident that the carbonates formed in shallow water, slumped in form of debris flows into troughs and mixed with the muddy sediments there.

Another occurrence instructive for the origin of the Kong Formation is the southernmost syncline on the orographic right side of the Chulung Valley (Figs. 4–6). There the Kong and Chulung La Slates can be studied in one section. Though there is much internal folding, the following succession can be reconstructed (from bottom to top):

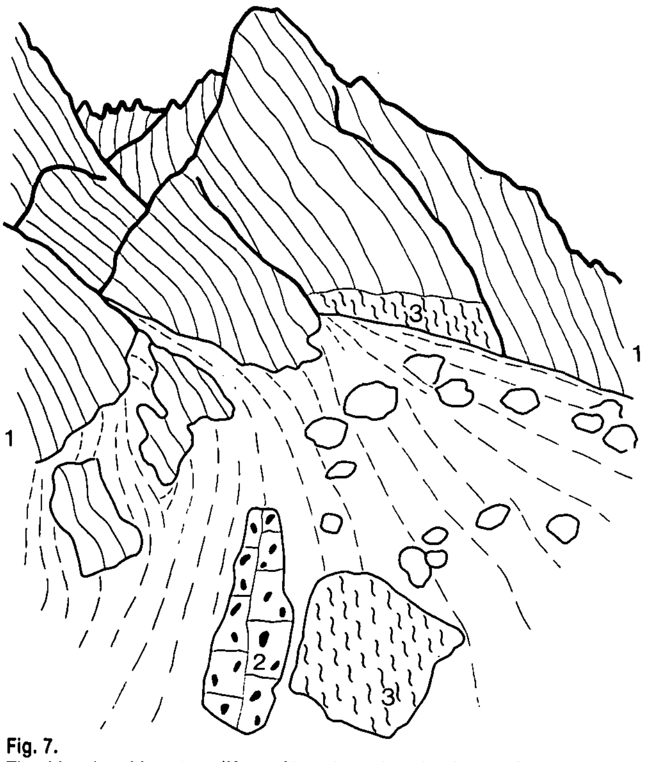

Fig. 7.
The Lingshet Limestone/Kong Slate boundary in the northernmost Kong slate Syncline of the Kangi Valley (view towards the E).
1 = Lingshet Limestone; 2 = Blue allodapic limestone at the base of Kong Formation; 3 = Kong Slates.
The allodapic limestone seems to be slightly discordant to the Lingshet Limestone (contact covered by float) and pinches out towards the E.

1) Thin-bedded alternation of light grey slates and blue limestones (12–20 m), cyclic units (ca. 2 m) starting with slates and grading into limestones; forams in pelites and carbonates:

Sample 28
- forams: *Nummulites* sp.
  Fasciolites sp.
  Lockhartia sp.
  Miliolidae
- udoteacean algae: *Ovulites* cf. *elongata* LAMARCK

Sample 36/37
- forams: *Nummulites* sp.
  Fasciolites sp.
  Discocyclina sp.
- bryozoa

These strata, which are very much characterized by very abundant *Nummulites* sp., are dated as Ilerdian *Fasciolites cucumiformis/ellipsoidalis* (HOTTINGER) biozones. Following the chronostratigraphic interpretations proposed by SCHAUB (1981) the assemblage is ascribed to the Early Eocene.

2) Brecciaceous nummulitic limestone (1.8 m) pinches out towards the SE.

3) Slates with thin layers of light grey, fine-grained sandstone exhibiting wavy s-planes (12–25 m).

4) Cross bedded, fine grained calcareous sandstone (1 m) passing into the blue limestone (5 m).

Sample 30
- udoteacean algae: *Ovulites* cf. *elongata* LAMARCK
- forams: *Lockhartia* sp.
  Miliolidea

Sample 32
Layers (2–3 m) with abundant concentrations of *Ovulites margaritula* (LAMARCK)

Sample 42
- forams: *Nummulites* sp.
  Rotaliidae (some of them *Lockhartia* sp.)
  Miliolidae
- algae: *Halimeda* sp.
- Rhodophycean algae: i. e. *Jania* sp.
- Sponge, echinoderms (i. e. crinoids, echinoid spines), gastropods, bivalves, serpulids, crustaceans

Age determination: same as above (especially according to *Nummulites*).

5) 15–25 m of slates with thin layers of fine grained argillaceous to marly sandstone; fucoids and burrows were observed. Towards the top sandstones increase in thickness; the fine grained argillaceous sandstones show cross bedding, normal grading and load casts. An 8 m thick bed of sandstone follows on top of the above series.

Sample 34
- echinoderms, sponge

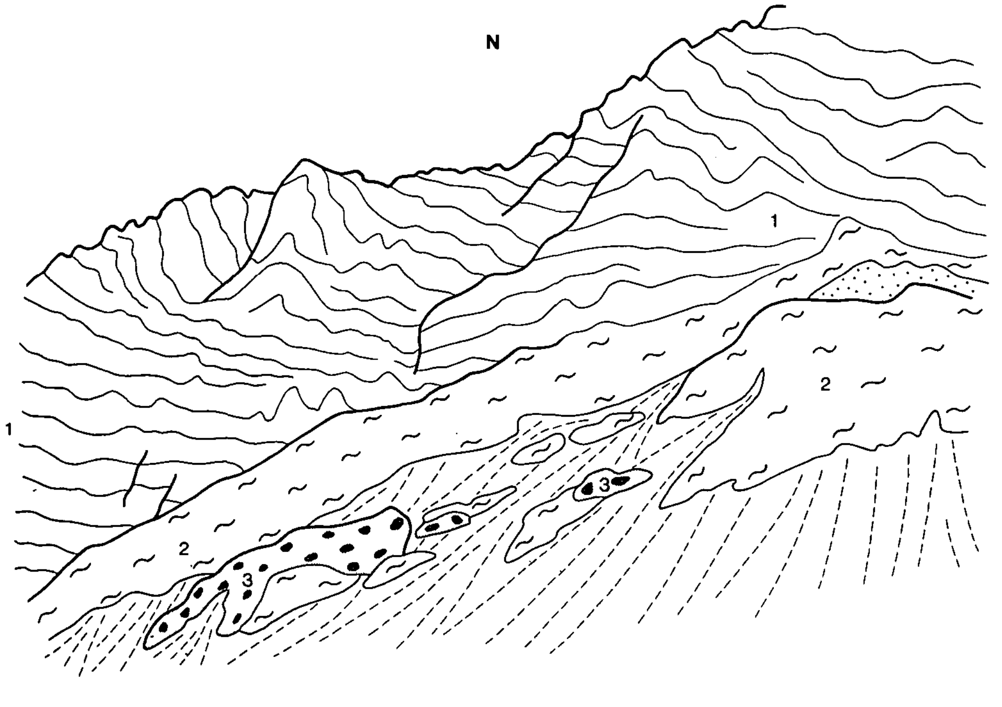

Fig. 8.
The northernmost Kong Slate syncline of the Kangi Valley, seen from the S.
1 = Lingshet Limestone; 2 = Kong Slates; 3 = Lenticular bodies of brecciaceous limestone (debris flow).

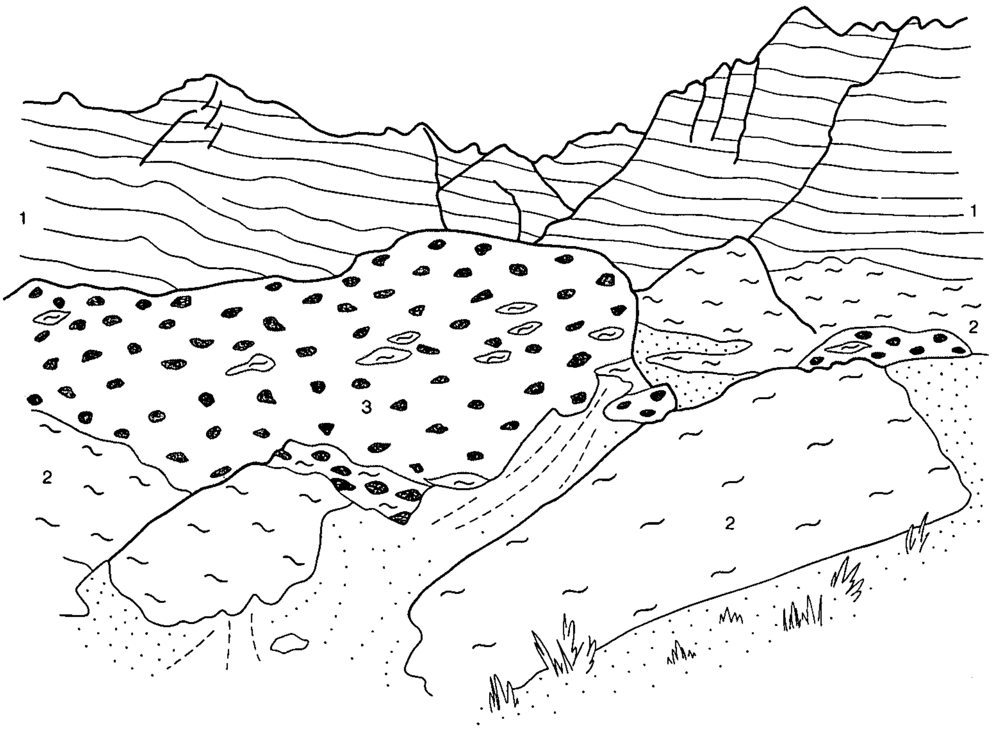

Fig. 9.
Olistostromes in the northernmost Kong Slate syncline of the Kangi Valley.
1 = Lingshet Limestone; 2 = Kong Slates; 3 = Limestone breccia with patches of slate; adjoining slates contain blocks of carbonates. The major carbonate lens is approximately 200 m long.

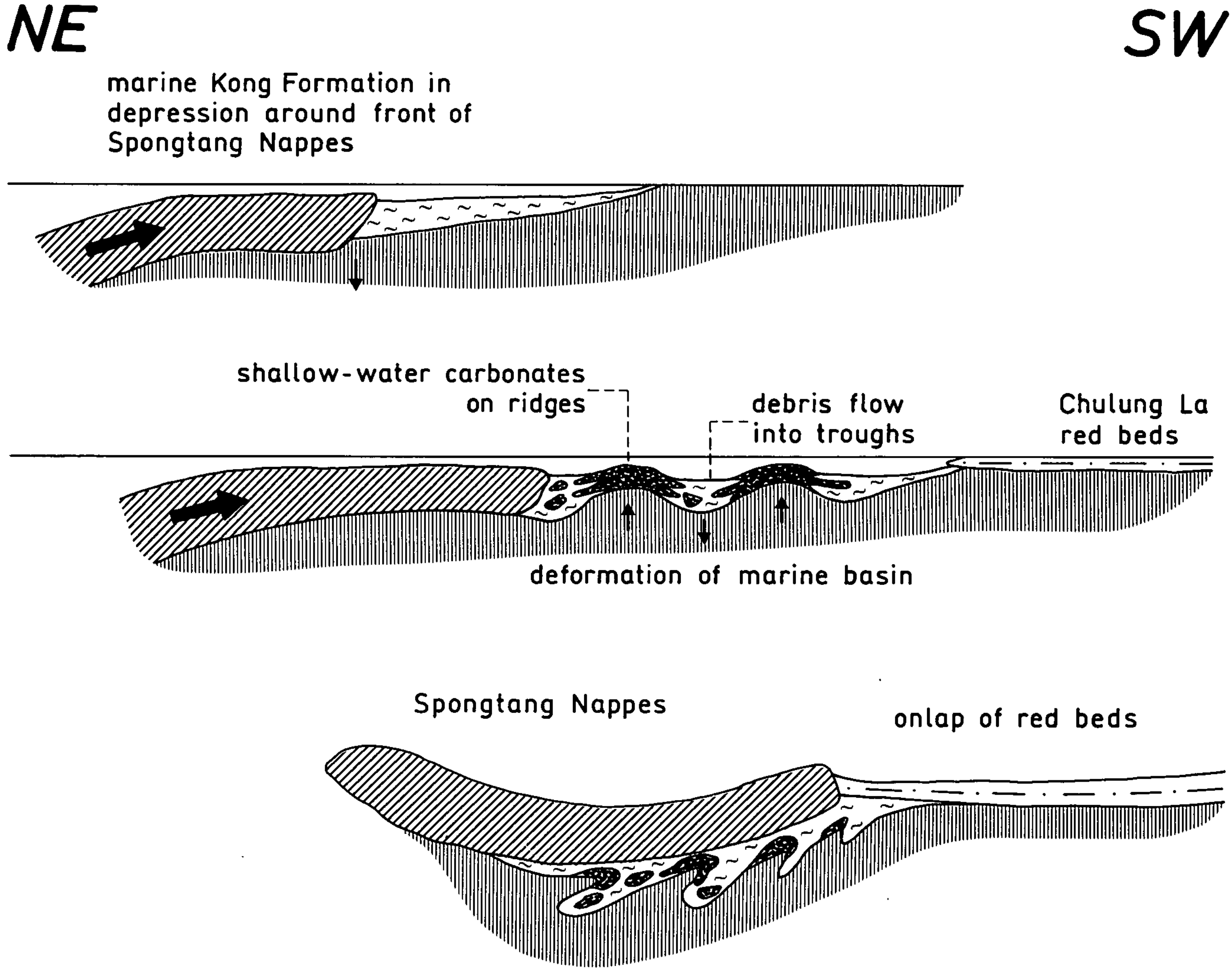

Fig. 10.
Model of the Eocene evolution of the Zanskar Shelf.

Sample 39
– bivalves: only ostrea

Sample 40
– gastropods (very small), few ostracods

These strata characterized by low diversity and poor fossil content indicate the end of marine sedimentation in Zanskar. Unfortunately, the organisms associations do not contain any fossil useful for an exact time determination.

In the series 5) lenticular bodies (3–6 m) of allochthonous blue limestone are observed. They show carbonates of various facies mixed up in a debris flow: poor or abundant in fossils, algal breccias, coral, crinoid, echinoid, sponge and ostrean limestones. Inbetween these components green clays are found.

Gryphaea shell beds and crinoid echinoid limestones were observed also in situ.

It is significant that series 5) which forms the top of the Kong Slates shows increasing green colours if traced southeastwards. The slates and sandstones, which form the matrix of the carbonate breccia lenses, become greenish. This indicates a lateral passage into the basal green horizons of the Chulung La Slates.

6) The thick-bedded sandstones at the top of the Kong Slates are overlain by purple and green Chulung La Slates, which form the core of the syncline. Their thickness is estimated 50–100 m.

The above Kong Slate occurrence shows slate – nummulitic limestone alternations in the lower part, towards the top the series becomes turbiditic, rich in fine-grained sanstones and most of the allochthonous limestone breccias occur in this upper part. Further there are indications that the topmost portion of the Kong Formation passes laterally into the Chulung La Formation. Thus the two formations are time equivalent only in part, in as much as the Chulung La Slates are in their major portions younger.

For the Eocene facies pattern we propose the following model (Fig. 10). After the collision with Eurasia and obduction along the Indus Suture Zone thrust masses slipped onto the Indian passive margin. The Spongtang allochthonous mass slumped onto the Zanskar Shelf and it may be assumed that by its weight a depression formed around the Spongtang Klippe.

Actually the Kong Formation is found only around this mass indicating that marine conditions persisted just there. Sedimentation, however, synchronous with the tectonic processes took place on unstable ground. Troughs and ridges formed and probably changed their position. On sills there was rich development of biogenic carbonates in warm shallow water. Tectonic unrest triggered sediment avalanches, which slumped as debris flows into the muddy environment of adjoining furrows. Finally the marine Lower Eocene sediments were overthrust and the Chulung La red beds formed in a wide fluvio-deltaic environment in front of the Spongtang Klippe (GARZANTI et al., 1987). We should like to stress that the Chulung La Formation is confined to SW Zanskar. There is no instance of Chulung La Slates underlying the Spongtang Klippe, they are only found in front of this thrust mass. Only the Kong Slates are underlying this klippe, which indicate that this formation was deposited during the emplacement, the Chulung La Slates however after this event. The folding of the Zanskar Shelf put an end to sedimentation in the Tethyan Zone.

4. Sedimentary Evolution and Geodynamics in the Cretaceous – Early Tertiary

The above considerations on Eocene facies distribution already showed the intimate connection with geodynamic processes. In this chapter we will discuss the Cretaceous – Lower Eocene sedimentary evolution and its causes and give a review.

We should like to stress that the Cretaceous – Early Tertiary sedimentary development in Zanskar seems to be representative for large portions of India's northern margin. The sedimentary history, especially from the Maestrichtian to the end of marine sedimentation in the Lower Eocene resembles very much the situation in S-Tibet (WILLEMS, 1987). Particularly in the area of Gamba (less distinct in Tingri area) many corresponding shallow-water environment microfacies types can be recognized: The Maestrichtian Marpo Limestone Member has its time equivalent counterpart in the fossiliferous Limestone Members II and III of the Zongshan Formation, except the occurrence of several remarkable rudist buildups in the Gamba section. The equivalent of the Stumpata Quartzarenite at the Cretaceous/Tertiary boundary is the Jidula Formation of Gamba, which at that locality consists of three Members, the lower and the upper quartz sandstone Members I and III which are separated by a black bituminous limestone (Member II) with a few dasycladacean and udoteacean algae. The Paleocene Dibling Limestone Member of Zanskar is comparable to the Middle Paleocene to Ilerdian Zongpu Group of Gamba, respectively the Thanetian to Lutetian Zeburi Shan Formation of Tingri, with special regard to the assemblages of larger foraminifera.

Throughout the Mesozoic sedimentation was rather uniform all over the Zanskar Shelf. Rare facies changes are easily explained by the distance from the source area, the gentle northward sloping of the shelf or slight differences in depth along the shelf. With the Mid-Cretaceous a conspicuous diversity of facies develops. But not after a major unconformity in the topmost Albian (GARZANTI et al., 1987, p. 299), which does not exist: the Lower Cretaceous Giumal Sandstone reaches locally up into the Late Cenomanian (GAETANI et al., 1986); in other places the pelagic limestones commence as early as in the Albian and range up into various stages of the Upper Cretaceous (BAUD et al., 1982; FUCHS, 1987). There must be another cause for this diversification of facies.

On the basis of palaeomagnetic studies in the Gamba area of southern Tibet APPEL (1989) and APPEL & LI (1988) came to the result that the Upper Cretaceous – Paleocene series deposited on the northern margin of the Indian Continent gave palaeolatitudes about 2000 km N from the position to be expected from India's wander path (Fig. 11). From Fig. 11 there is some palaeomagnetic indication that the northern margin of the Indian Continent was extended in course of the drift (APPEL, pers. comm.). Tension tectonics becoming active with India's drift explain the facies diversification in the Mid-Cretaceous in an excellent way

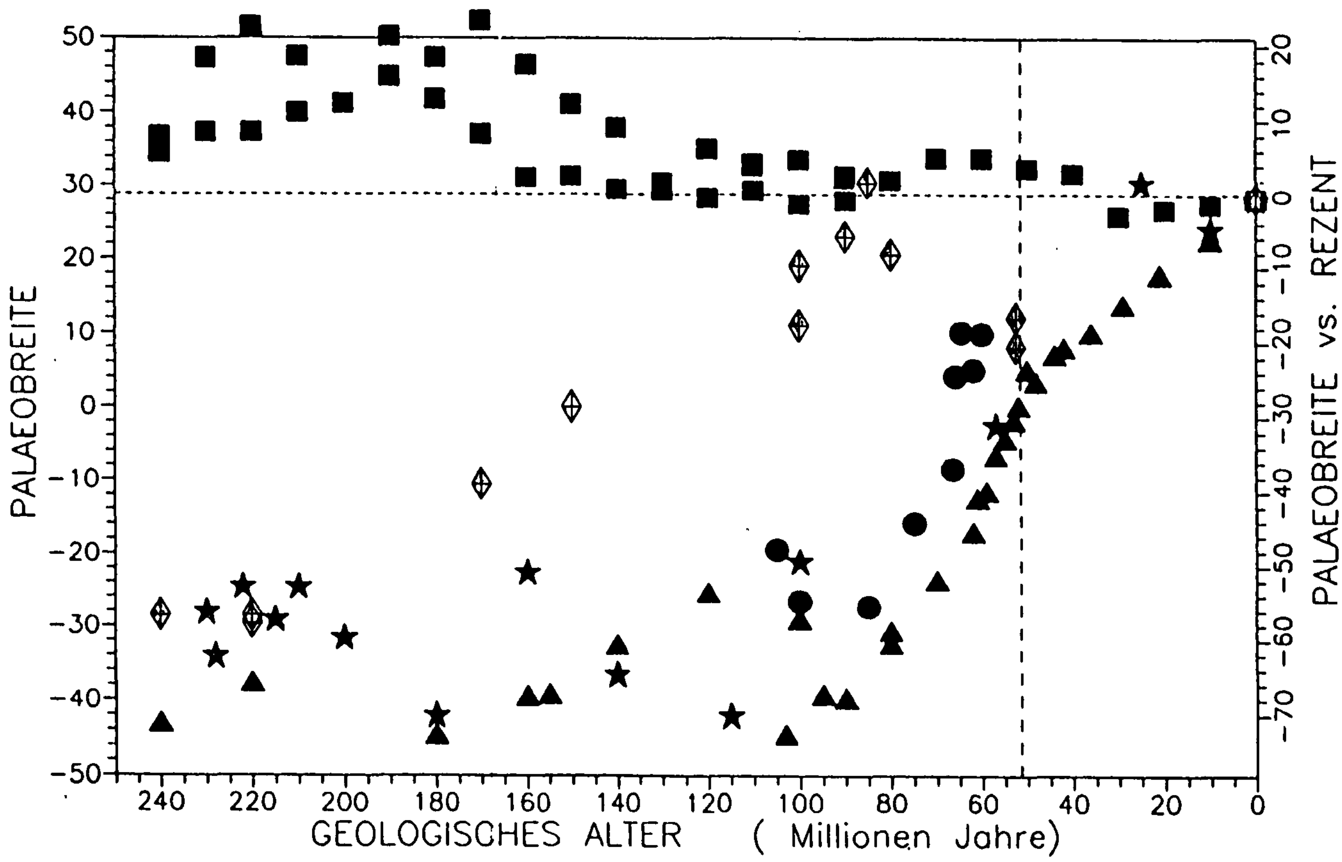

Fig. 11.
Palaeolatitudes for the Indian Continent (triangles), Eurasia (squares), Lhasa Block (rhombs), Tethys Himalaya (without Gamba, stars) and Gamba (full circles) as a function of the geological age (250–0 m.a.).
From APPEL (1989, Fig. 11.1). All values calculated for Gamba (28.3° N, 88.5°E); data from literature referred in APPEL (1989, 89–90). Note that the palaeolatitudes of the Late Cretaceous-Paleocene series of Gamba are far ahead from the position to be expected from their sedimentation on the northern margin of India..

(Fig. 13). The crust beneath the Tibetan Zone extended not harmoniously. Less extended blocks of the shelf formed the pelagic plateaus and sills, where far away from land the couches rouges scaglia (Shillakong) facies was deposited. Where extension was large basins developed with either starvation (Chikkim Limestone) or increased influx of detritus from the craton and adjacent sedimentaries (Kangi La Fm.). The latter trough acted as a trap for the detritus derived from the craton and kept it away from central and northern Zanskar.

Further away from the craton euxinic, silty sedimentation prevailed in the deeper troughs (Lamayuru, Goma Shales). From the fact that the couches rouges facies is succeeded by the dark euxinic facies at different times from place to place, it may be concluded that also the stable blocks successively submerged. Finally, in the Maestrichtian all sills disappeared and the euxinic Lamayuru basin facies became connected with the Kangi La basin in the SW.

This spreading of basin facies all over the Zanskar Shelf was accepted by FUCHS (1982) as indication of

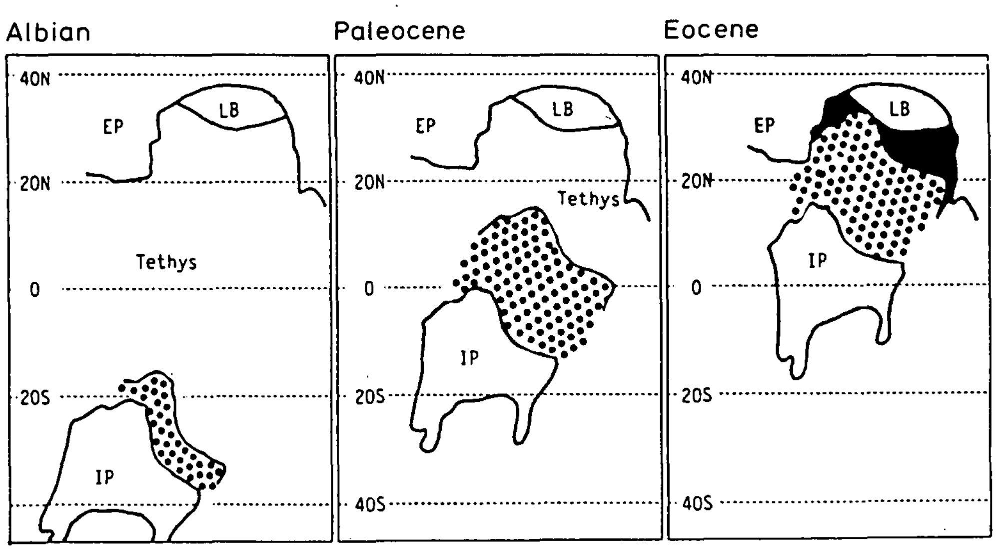

Fig. 12.
The northern margin of the Indian Continent (pointed area in Paleocene and Eocene times, as deduced from the results of Gamba and literature.
From APPEL (1989, Fig. 4.4).
IP = Indian Continent; EP = Eurasian Continent; LB = Lhasa Block; ITS = Indus-Tsangpo Suture.
The shapes of India and Eurasia (Lhasa Block resp.) correspond to their recent geometry. The continents are separated along the ITS. Other boundaries follow the 500 m bathimetric line. The northern boundary of the pointed area runs through the position of Gamba as calculated from palaeolatitudes and is drawn parallel to the northern boundary of India (ITS). Rotations of India and Eurasia are considered. The black area is the remaining space between the Lhasa Block and India (calculated) at the initial collision of India and Eurasia about 50 m. a. ago. It is assumed that the southern boundary of the Lhasa Block corresponds to the recent one. Note that according to this concept collision of India with an island arc in equatorial latitudes as suggested by KLOOTWIJK et al. (1979) is to be expected already in Maestrichtian-Paleocene times.

flexural downwarp just in front of the Indus Subduction Zone. Here we touch a major problem: According to palaeomagnetic data India was then still S of the equator and separated by 2500–3000 km from Eurasia according to PATRIAT & ACHACHE (1984) for the collision time 50 m.a. (anomaly 22). On the other hand there are series of arguments in favour of Late Cretaceous tectonic activity along the Indus Tsangpo Suture Zone: Orogenic sediments such as the wild flysch of Photak La (FUCHS, 1982) and ophiolitic melanges at the base of the Spongtang Klippe (COLCHEN & REUBER, 1987) suggest intraoceanic tectonics already in the Upper Cretaceous. According to BURG (1983) and PROUST et al. (1984) the block flysch or wild flysch of Tibet contains folded Mesozoic blocks, rocks from the Tethyan Zone as well as from the ophiolite belt in a matrix yielding Maestrichtian forams. This documents pre-Maestrichtian obduction. Being aware of the discrepancy with the results of palaeomagnetics these authors propose three alternative models implying the existence of more than one subduction zone.

In Ladakh BROOKFIELD & REYNOLDS (1981) observed undeformed syenite intruding folded ophiolitic melange and Dras Volcanics. As the syenite gave an age of 82 m. a., Late Cretaceous emplacement of the country rocks was inferred. These authors see the cause of the Late Cretaceous tectonics in the collision of India with the Dras Island Arc.

SEARLE (1983, 1986) and SEARLE et al. (1988) insist on pre-collision obduction at 80 to 60 m. a. ago. They argue that the ophiolite nappe of Spongtang – a slice of Tethyan ocean floor – must have been emplaced on the Zanskar Shelf before the closure of the Tethyan ocean. Such early emplacement of the Spongtang Klippe is ruled out by the arguments of GARZANTI et al. (1987, p. 301, 302) and the Eocene series underlying the Klippe (FUCHS, 1982; KELEMEN et al., 1988), but we agree with Late Cretaceous orogenic movements along the subduction zone.

All the above arguments in favour of Late Cretaceous obduction seem in contradiction to palaeomagnetic results (KLOOTWIJK, 1979, 1984; KLOOTWIJK et al., 1979, 1985; PATRIAT & ACHACHE, 1984, and many others). India was then more than 2000–3000 km S of Eurasia, how should such early collision be possible?

In our view there is no contradiction if we consider the following points:

1) On the basis of collision related secondary magnetization components KLOOTWIJK et al. (1985, p. 177) propose initial suturing in the Ladakh sector as early as in the Lower Paleocene (62–60 m. a.) and in equatorial latitudes.
2) India first collided with the trench arc system and then this composite unit drifted over more than 10° of latitude until final collision with Eurasia (KLOOTWIJK et al., 1979).
3) APPEL (1989, Figs. 4.1 and 4.4; Figs. 11, 12 in this paper) calculated the palaeolatitudes of the Upper Cretaceous – Paleocene series of Gamba (S Tibet) deposited on the northern margin of the Indian Continent. Their values are systematically 1000 and 2000 km respectively N from the positions to be expected from their deposition on the passive margin of India. The drift path of India is well established from Peninsular rocks and especially for 70–0 m.a. from India – Eurasia relative motion (summarized by KLOOTWIJK, 1985, and VERMA, 1989).

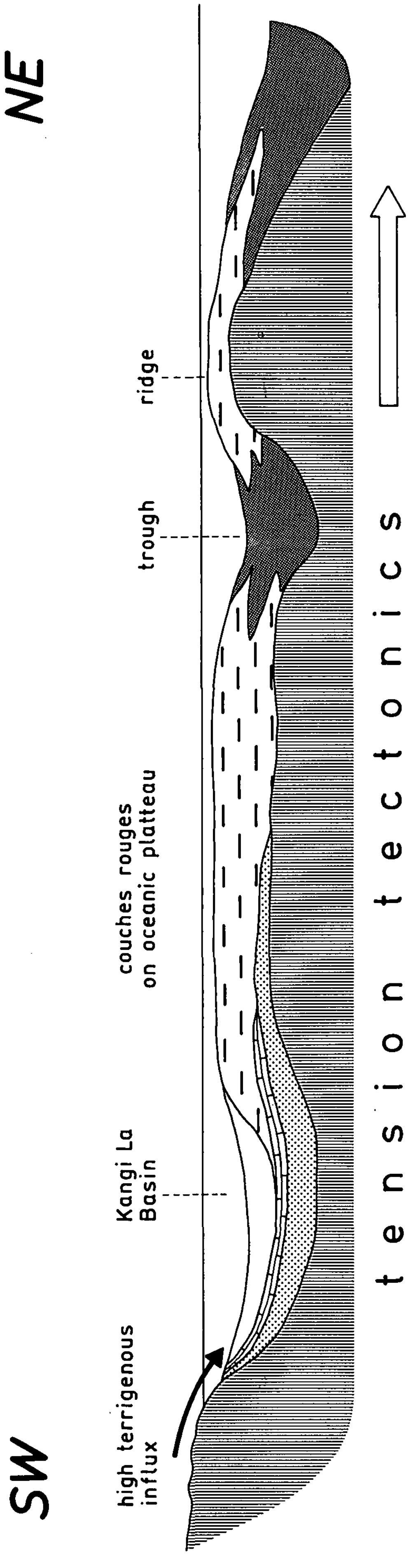

Fig. 13.
Upper Cretaceous disintegration of the Zanskar Shelf.
Basins open in tension zones, they show starvation, euxinic facies or are filled with thick clastic series. Stable blocks form oceanic plateaus with couches rouges deposition

APPEL's results suggest that the crust of India's northern margin was extended towards the N. Such a process is supported by Late Cretaceous facies diversification (see Fig. 13). As the drift positions of India are based mainly on data from Peninsular and the Indian Ocean, it may be expected from the above new results that India's leading edge collided much earlier than previously assumed.

Taking into account these points it appears not unlikely that the leading edge of India approached the subduction zone as early as in the Upper Maestrichtian. The collision with the trench island arc system in Late Maestrichtian – Paleocene times caused deformation along the suture zone (secondary magnetization at 62–60 m. a. found by KLOOTWIJK et al. [1985], orogenic sediments etc.). However, the orogenic processes were confined to the suture zone.

Zanskar was not involved in the orogeny before the Early Eocene when final collision occurred between the India-island arc welded unit and Asia. Then thrust masses were squeezed from the already deformed suture zone and slumped onto the Zanskar Shelf. It was then that clastic sediments on the shelf showed ophiolitic source for the first time (GARZANTI et al., 1987). Another proof for such late emplacement of the Spongtang thrust mass are the Early Eocene rock series underlying this klippe (see chapter 3.3.).

The change from basin facies to shallow water sedimentation on the Zanskar Shelf in Upper Maestrichtian resp. Paleocene times appears to be related with initial collision with the island arc. India and the attached trench-island arc system drifted further N until the collision with Eurasia and final suturing. During this drift sedimentation on the Zanskar Shelf was undisturbed by tectonic processes as shown by the character of the Paleocene formations. There is also no indication of further tension tectonics like those observed in the Upper Cretaceous.

The Lower Eocene collision between India and the Asian continental mass involves also the Zanskar Shelf in the orogeny. Sedimentaries of the continental slope and adjoining basin (Lamayuru Unit), deformed portions of the trench arc system (Dras–Nindam Unit) and ophiolites-ultramafics of the oceanic crust were squeezed out of the Indus Suture Zone and slumped onto the Zanskar Shelf. Probably these units were deformed when the island arc was attached to the Indian Continent, but the emplacement onto Zanskar occurred not before the collision with Eurasia in the Eocene. Contrary to SEARLE's suggestion of a Late Cretaceous emplacement of the Spongtang Klippe (1986; SEARLE & COOPER, 1988), GARZANTI et al. (1987) stress that all clastic sediments of Upper Cretaceous to Upper Paleocene age received terrigenous detritus from the craton in the S. There is no indication of an ophiolitic derivation, which should be expected in the case of the Spongtang Klippe resting on the northern parts of Zanskar since the Maestrichtian. With the Lower Eocene, however, there is a marked change:

The Kong as well as Chulung La Slates are rich in volcanic detritus derived from an ophiolitic source. Other arguments against SEARLE's view are advanced by KELEMEN et al. (1988).

The thrust masses from the Indus Suture Zone did not form continuous nappes but isolated glide masses (FUCHS, 1982). The occurrence of the Kong Formation only near the Spongtang Klippe suggests that this thrust mass by its weight caused a depression of the shelf where the marine facies persisted (Fig. 10). Due to the active orogeny the deposition area of the Kong Formation was highly unstable: Sills formed on which biogenic carbonates were produced and slipped as debris flows into troughs with muddy-turbiditic conditions. The major part of the deposition area of the Kong Formation was successively overridden by the Spongtang Klippe. SW of the latter in the Chulung Valley the change from Kong to Chulung La facies can be observed. There the Kong Formation passes upwards into a zone rich in fine-grained turbiditic sandstones which is followed by the green and red Chulung La Slates. These terrigeneous red beds probably represent the Eocene in southwestern Zanskar. GARZANTI et al. (1987, Fig. 8) report an unconformity from the base of the Chulung La Slates at Dibling. As far as the Kong Slates are not represented in the Dibling C Member of NICORA et al. (1987) they may correspond with the gap beneath the named unconformity. From our experience from the Chulung Valley we envisage a depositon of the Kong Formation d u r i n g the emplacement of the Spongtang Klippe. The Chulung La Slates formed in a wide fluvio-deltaic plain in front of the Spongtang Klippe a f t e r its emplacement.

After the deposition of the Chulung La Slates the sequence of the Zanskar Shelf was folded, which put an end to the long and rather complete sedimentary history of the Tethyan Zone.

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