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The Geology of the Markha-Khurnak Region in Ladakh (India)

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With 28 figures and 5 plates

Himalaya
India
Ladakh
Indus Suture Zone
Tibetan Zone
Tectonics
Palaeogeography

Content

Zusammenfassung

Meine Expedition 1983 konzentrierte sich auf die Erforschung des Gebietes Markha – Nimaling – Khurnak in Ladakh. Die Arbeit beschreibt die lithologischen und strukturellen Einheiten sowie deren wechselseitige Beziehungen. Das wichtigste Ergebnis ist die Tatsache, daß das Zanskar-Synklinorium (Tibet-Zone), die Lamayuru-Einheit und das Nimaling-Tso Morari-Kristallin miteinander verbunden sind. Letzteres bildet ein randliches Antiklinorium, in dem die basalen Formationen der Tethys-Schichtfolge aufgeschlossen sind. Deren jüngste Schichten – Kreide und Ober-Paleozän – bilden den Kern der im SW benachbarten Khurnak-Synklinale. Die Lamayuru-Formation nimmt an der Tethys-Schichtfolge teil und ist mit den Schelf-Karbonaten im S faziell verzahnt. Somit ist die ursprüngliche Faziesverteilung Schelf – Kontinentalabhang – Becken in Ost-Ladakh mehr oder weniger erhalten geblieben. Auch innerhalb der Lamayuru-Beckenfazies ist gegen N eine weitere Abnahme des Karbonatgehalts festzustellen, und schließlich ist die Lamayuru-Einheit durch Primärkontakte mit der Ophiolitischen Melange der Indus-Suturzone verbunden. Die Melange grenzt die Lamayuru-Einheit gegen die Indus-Molasse bzw. die Dras-Einheit ab. Die Grenze gegen letztgenannte Einheit ist jedoch meist als einfache Überschiebung ausgebildet.

Die Dras-Einheit endet im Markha-Gebiet zwischen sich gabelnden Ophiolitischen Melange-Zonen. Die Dras-Flysch-Vulkanitserie wurde von Ultrabasit-Massen überfahren, die durch ein olistostromes Konglomerat verbunden sind. Dieser Horizont signalisiert den Beginn der Deckenbewegungen. Die Sedimentation setzte auch nach diesem Ereignis fort, allerdings als Molasse. Gerölle von Foraminiferenkalken belegen ein post-ober-paleozänes Alter dieser Chilling-Molasse. Sie bildet die jüngsten Schichten der Dras-Einheit. Post-ober-paleozäne Konglomerate finden sich auch als verquetschte Bänder in der Melange Zone.

Die Indus-Molasse (s. l.) grenzt mit tektonischem Kontakt im N an. Die eozänen marinen Klastischen Basisschichten und Jurutze-Flysch wurden als gefalteter Komplex von den kontinentalen bunten Molasse-Formationen transgrediert.

Schließlich wird die Hypothese von BAUD et al. diskutiert, ob die Tibet-Zone als Deckenpaket dem Zentral-Kristallin tektonisch auflagert. Alle Ergebnisse meiner Expedition 1983 und andere Beweise sprechen gegen das Allochthonie-Konzept.

Summary

My 1983 expedition concentrated on the Markha-Nimaling-Khurnak area in Ladakh. The paper describes the lithologic

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and structural units and their interrelationship. Most important result is the coherence of the Zanskar Synclinorium, (Tibetan Zone), Lamayuru Unit, and Nimaling-Tso Morari Crystalline. The latter forms a marginal anticlinorium exposing the basal formations of the Tethys sequence. The youngest beds of Cretaceous – Upper Paleocene age form the core of the Khurnak Syncline adjoining in the SW. The Lamayuru Formation is a part of the Tethys succession and interfingers with the shelf carbonates in the S. Thus the original facies pattern shelf – continental slope – basin is more or less preserved in eastern Zanskar. Also within the Lamayuru basin facies there is further decrease in carbonate content towards the N, and finally it is linked by primary contacts with the ophiolitic melange of the Indus Suture Zone. The melange terminates the Lamayuru Unit against the Indus Molasse respectively the Dras Unit. The boundary against the latter unit, however, is mainly developed as a simple thrust.

The Dras Unit pinches out in the Markha area between bifurcating ophiolitic melanges. The Dras Flysch-Volcanics are overridden by ultrabasic masses, which are connected by a olistostromic conglomerate. This horizon signals the beginning of the nappe movements. After this event sedimentation continued, but of molasse type. Foraminiferal limestone pebbles prove a post-Upper Paleocene age of this Chilling Molasse, which represents the youngest beds of the Dras Unit. Post-Upper Paleocene conglomerates also occur as squeezed bands in the melange zone.

The Indus Molasse (s. l.) adjoins with tectonic contact. The Eocene marine Basal Clastics and Jurutze Flysch form a folded complex transgressed by continental multicoloured molasse formations.

Finally the hypothesis of BAUD et al. is discussed whether the Tibetan Zone represents a pile of nappes lying with tectonic contacts on the Central Crystalline. All the results of the 1983 expedition and other evidence are against the allochthony concept.

1. Introduction

In Ladakh W of the Zanskar River my work revealed a composite allochthonous mass in the Spongtang region; the surrounding series of the Zanskar Synclinorium, however, are autochthonous or parautochthonous (FUCHS, 1977b, 1979, 1982). On the contrary BASSOULLET et al. (1978, 1980, 1983) take the northern carbonate belt of Zanskar as allochthonous, their Zanskar-Shillakong Nappe. BAUD et al. (1982 a,b, 1983, 1984) accept this unit as allochthonous, also in the region E of the Zanskar River, and extend the allochthony to the whole of the Tibetan (Tethys) Zone. According to these authors the Tibetan Zone consists of a pile of nappes resting tectonically on the Central Crystalline of the Great Himalayan Range. As this hypothesis is opposed to all my experience of the Tibetan Zone, I extended my studies to the area from where the allochthony of the Tibetan Zone is reported.

From Leh I went to the Markha Valley via Ganda La and investigated the various zones along the Indus Suture. Then I tried to establish the succession of the metasedimentaries of the Nimaling Dome and studied the relations of the Lamayuru Unit to the adjoining rock belts. With this aim in mind I followed the south-western flank of the Nimaling Uplift SE until Yar La. In this Khurnak area the metasedimentaries of the Nimaling Dome and the series of the Zanskar Synclinorium form one stratigraphic succession from Early Palaeozoic up to Upper Paleocene.

The essential results of this expedition, carried out in summer 1983, are given in two preliminary notes (Fuchs, 1984a,b). The present paper describes the geology of the investigated area in more detail.

2. The Indus Molasse-observations along the Leh – Ganda La route

On the march to the Markha Valley cursory observations were made in the Indus Molasse traversed. In more detail the area was studied by BAUD et al (1982b) and BROOKFIELD & ANDREWS-SPEED (1984) to whom I refer.

From Spituk to the Rum Valley the trail crosses wide talus fans covering old, light-coloured lake deposits. The mountains to the S consist of thick-bedded molasse series intensely folded with NNE vergency. Where the Indus turns to the S and the valley becomes narrow the trail crosses this tick-bedded sequence: Green-grey, mainly fine- to medium-grained sandstones, arkoses and conglomerates predominate over the interbedded green slates. BAUD et al. (1982b) termed this series the "flyschoid unit of Nimu-Alchi", whereas BROOKFIELD & ANDREWS-SPEED (1984) designate the series as "Nimu Grits" (STERNE, 1979). Near the junction of the Rum and Indus Valleys the steeply folded molasse becomes richer in argillites. This is the passage from the Nimu Grits into the "Zinchon Molasse" (BROOKFIELD & ANDREWS-SPEED, 1984). The sandstones still rather thick are interbedded with several meters thick, dark grey to green, splintery slates and silty shales. Conglomerates are rare. Around the village Zinchon a series of large NE directed folds are observed (Pl. 3[3]).

The gorge N of Rumbok crosses a thick-bedded series of green sandstones, conglomeratic arkosic sandstones, and red, green or dark shales. This Rumbok Molasse (BROOKFIELD & ANDREWS-SPEED, 1984) is steeply dipping towards the SW in the N and towards NE in the S, the main mass being vertical (Pl. 3[3]).

The molasse formations crossed between the Indus and Rumbok are younging towards the N, regarding their age it may be only said that they are post-Eocene (probably Oligo–Miocene). The several thousands of meters thick succession was deposited in a continental basin with wide floodplains and braided rivers (BROOKFIELD & ANDREWS-SPEED, 1984).

At Rumbok the scenery changes: The rugged range built by the Rumbok Molasse (Multicoloured Molasse, BAUD et al., 1982b) is followed by morphologically soft terrain. First comes a band of soft, reddish rocks about 500–600 m thick, and then soft series weathering in light colour, these are the Eocene formations of the Jurutze area (Fig. 1).

The Eocene succession starts with red and yellow, very well-sorted, calcareous, felspatic and lithic greywackes and sandstones interbedded with sandy shales (BROOKFIELD & ANDREWS-SPEED, 1984). According to these authors mudcracks and the fossils found by DAINELLI (1933–1934, bivalves including oysters, and gastropods) point to a marginal marine environment.

The Basic Clastics are succeeded by the Jurutze Marls about 400 m of brownish calcareous sandstones, calcareous shales and thin limestones yielding Middle Eocene foraminifers (DAINELLI, 1933–1934). This author also records marine bivalves, gastropods and echinoids from that series. BROOKFIELD & ANDREWS-SPEED (1984) point to the fact that this Middle Eocene series passes up into the Jurutze Flysch, which further S is proved by fossils to be Lower Eocene. Their explanation is a lateral facies change towards the S from Basal Clastics and Jurutze Marls into flysch.

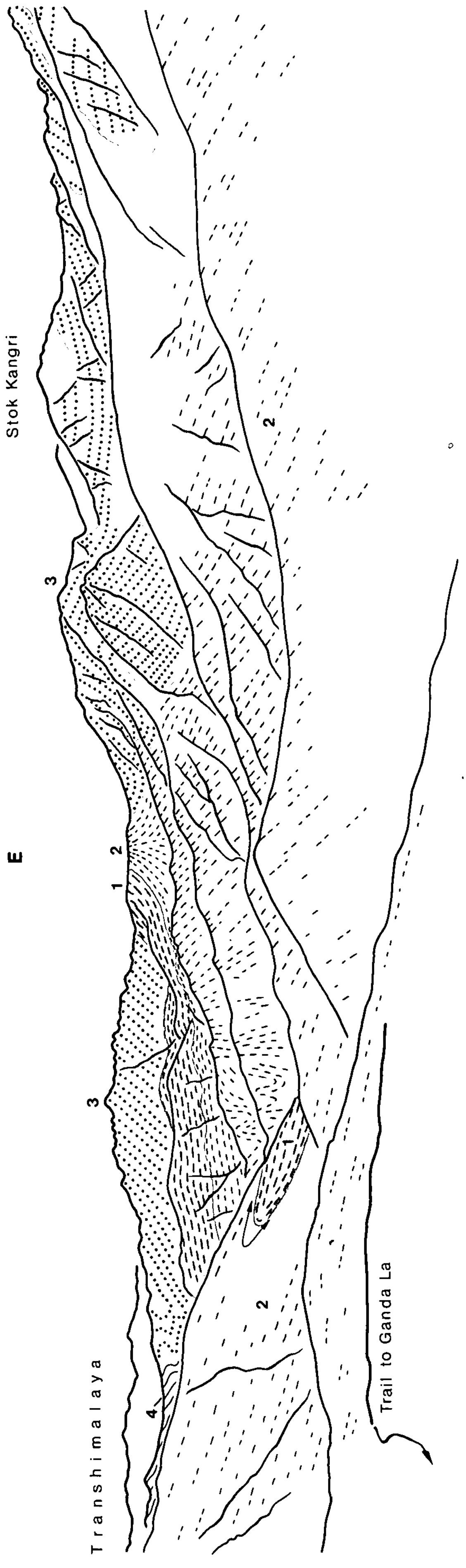


Fig. 1: The anticline of Jurutze seen from the ascent to Ganda La.
1 = Basal Clastics (Eocene); 2 = Jurutze Flysch (Eocene); 3 = Multicoloured molasses (Rumbok, Stok Kangri); 4 = Younger molasse.

The Jurutze Flysch is a thin-bedded alternation of grey, fine grained, calcareous greywackes, calcareous shales and rare blue foraminiferal limestones (BROOKFIELD & ANDREWS-SPEED, 1984). These authors report about Upper Paleocene – Lower Eocene foraminifera found in the southern portions of the Jurutze Flysch. One of my samples from NE of Shingo yielded fossils of the same age (kindly determined by Prof. Dr. L. HOTTINGER, Geol. Palaeont. Inst. Univ. Basle, Switzerland):

- Alveolinas ill-preserved
- Assilinas of the *exponens* group
- Nummulites
- *"Operculinoides"* probably nummulites of the *spirectypus* group
- *Operculina* ex gr. *alpina*
- Discocyclinas
- *Lockhartia* sp.
- *Orbitolites* sp.
- red algae

Besides these fossils I observed high-spired gastropods, bivalves, and nummulites W of Jurutze and SW of Ganda La. DAINELLI (1933–34) described the fossils of the Eocene series, which were observed first by LYDEKKER (1883).

The Jurutze Flysch was deposited in marine environment. The fine-grained and finely laminated sandstones along with sole marks suggest a distal turbidite environment (BROOKFIELD & ANDREWS-SPEED, 1984).

The Eocene sequence is exposed in a huge anticline, which, however, is not symmetrical (Fig. 1). The multicoloured basal series crop out along the boundary against the Rumbok Molasse and therefore BAUD et al (1982b) assume a structural plane there. BROOKFIELD (1983) and BROOKFIELD & ANDREWS-SPEED(1984) think that the Rumbok Molasse was deposited unconformably on the folded Eocene sequence. This explanation appears most probable also to me: the Eocene succession was folded with SSW-vergency. The basal series occur in 3 anticlinal cores, in part imbricated. One in the area of the uppermost houses on the way to Ganda La (Kunda La), a second between Rumbok and Jurutze before the ascent to the latter place and a third one along the northern boundary of the Eocene succession. This latter one has been truncated by erosion before the sedimentation of the Rumbok Molasse, which overlaps the Eocene series in the mountains W of the Rumbok Valley. The Rumbok Molasse crops out on the ridge WNW of Ganda La and N of Shingo, as can be seen from the talus. STERNE (1979) similarly found three anticlines in the Eocene sequence of the Zanskar Valley to the W. There the direction of the folds, however, is NE.

The asymmetry of the Jurutze Anticline may be accentuated by the fact that the facies of Basal Clastics and Jurutze Marls occurs only in the N and is replaced by flysch in the S.

BAUD et al. (1982b) and BROOKFIELD & ANDREWS-SPEED, (1984) note a passage from the Nummulite Beds respectively Jurutze Flysch into the overlying Stok Kangri Conglomerates. This formation consists of thick-bedded conglomerates and sandstones of yellow, green, or red colours. BROOKFIELD & ANDREWS-SPEED (1984) suggest depositional environment of meandering streams, proximal braided streams of alluvial fan deposits. BAUD et al. (1982b, Fig. 5, B) correlate the Stok Kangri Conglomerates with their Multicoloured Molasse-

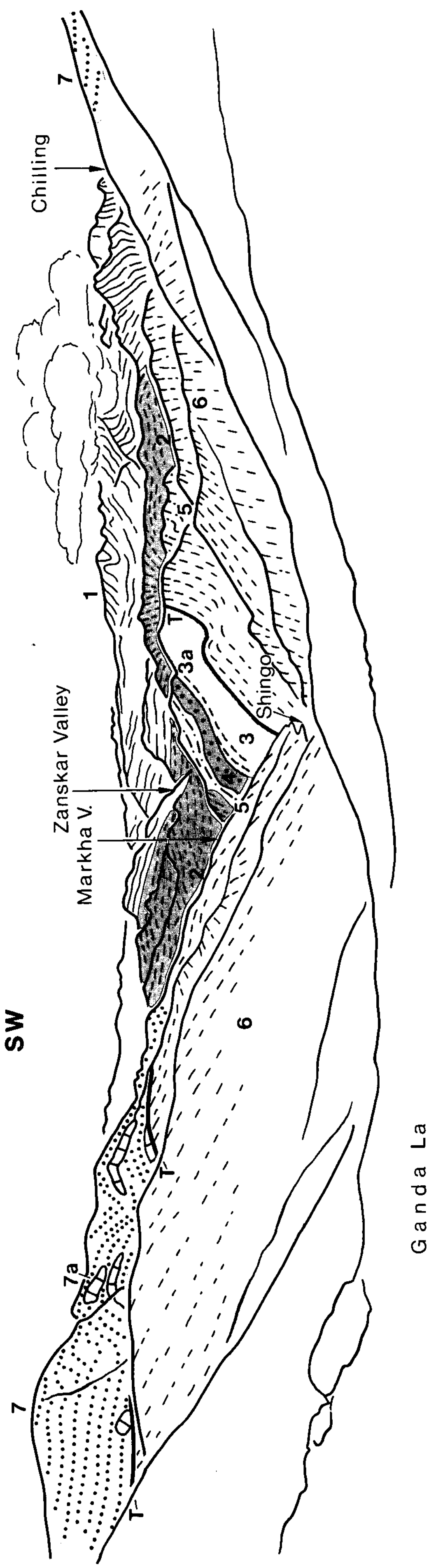


Fig. 2: View from the Ganda La towards the SW.
1 = Zanskar Carbonates (Triassic–Jurassic); 2 = Lamayuru Formation; 3 = Dras Flysch-Volcanics, 3a = Red horizon; 4 = Skiu Conglomerate; 5 = Chilling Molasse (post-Upper Paleocene); 6 = Jurutze Flysch (Eocene); 7 = Multicoloured molasse, 7a = Limestone klippes near subvertical thrust (T).

equivalent to Rumbok Molasse. From structural point of view this seems probable also to me (Pl. 3 [3, 4]).

Further E the Stok Kangri Conglomerates are succeeded by the Gongmaru La Molasse, a thick-bedded alternation of red and green fine-grained sandstones, siltstones, and shales with lenticular layers of conglomerate deposited in similar environment as the underlying formation (BROOKFIELD & ANDREWS-SPEED, 1984).

SSW of Ganda La, in the tributary valley E of Shingo the Jurutze Flysch is cut off along a vertical tectonic plane, obliquely to the NW–SE strike of the flysch (Pl. 1, Fig. 2). A series of klippes of rather massive, blue- and light grey limestone tens of meters thick, are found along this zone of disturbance. The slightly altered carbonates did not yield any fossils. On the eastern side of this tectonic line a vertical molasse series crops out. The talus consists of red friable breccias and conglomerates, hard green conglomeratic sandstones, red and green shales. Volcanic rocks only occur as pebbles, and there are no lavas or tuffs. From the lithology I do not agree with BROOKFIELD & ANDREWS-SPEED who designate the series as Khalsi Unit (= Cretaceous flysch), but I regard it as squeezed portion of the multicoloured molasses building up the high range NE of the Markha Valley. Confined by the NE-trending tectonic line the molasse series does not reach the valley leading from Ganda La to Skiu

According to BAUD et al., (1982b, Fig. 5, 6) the tectonic boundary between the Jurutze Flysch and the succeeding Dras-Nindam Unit crosses the valley NE of the place Shingo. BROOKFIELD (1983) and BROOKFIELD & ANDREWS-SPEED (1984) draw this line just S of Shingo. My sample 83/1 taken ENE of this village yielded an Ilerdian to Cuisian (Lower Eocene) foraminifer fauna proving that the rocks around Shingo still belong to the Jurutze Flysch. Prof. Dr. L. HOTTINGER (Geol.-Palaeont. Inst., Univ. Basle, Switzerland) kindly determined:

- Alveolinas (ill-preserved)
- Assilinas of the *exponens* group
- Nummulites
- *"Operculinoides"* probably Nummulites of the *spirectypus* group
- *Operculina* ex gr. *alpina*
- Discocyclinas
- *Lockhartia* sp.
- *Orbitolites* sp.
- Rotalids

Whereas the rocks around Shingo also lithologically resemble the Jurutze Flysch, the series further S of the village are doubtful. They consist of light slaty marls to marly limestones, and light green-grey, rusty weathering slates. As the samples yielded no determinable fossils, it is uncertain whether this calcareous flysch series belongs to the Jurutze Flysch or to the Dras-Nindam Unit. From the absence of volcanic beds and low arenite content, which contrast to the adjoining Dras-Nindam Unit, I am inclined to assume the first alternative.

The rocks steeply dip SW or are vertical.

3. The Dras Unit and overlying Ultrabasic Klippes

The above calcareous flysch is succeeded by flysch rich in green, grey and rather dark sandstones, siltstones, and argillites. This well-bedded series contains green, basic lavas and tuffs. Obviously this flysch-volcanic formation, several hundreds of meters thick, represents the Dras-Nindam Unit. BROOKFIELD & ANDREWS-SPEED (1984) correlate the series to their Khalsi Flysch. The calcareous flysch between Jurutze and Dras-Nindam Flysch apparently is taken by these authors as part of their Khalsi Flysch.

The rocks are much folded and dip steeply towards the SW or are vertical.

At the top the flysch-volcanic formation is succeeded by a 50–80 m thick conspicuous bright red zone of pebbly mudstone, siltstone to conglomeratic sandstone. This predominately shaly, red band passes upwards into green, massive conglomerates. The components of this coarse (cm to 0,5 m sizes) conglomerate are ill-sorted, but mostly rounded cobbles of red and green volcanics, tuffs and lavas of mainly basaltic composition, ultrabasics, amphibolites, epidote, red and green cherts, quartzites, sandstones, slates, phyllites, marls, and various carbonates (Fig. 3). The green matrix is a microbreccia to silty shale. The massive to very thick-bedded conglomerates are sheared, and folded with green argillites, which seem to be primarily interbedded. The thickness of the conglomerate is 100 to 150 m.

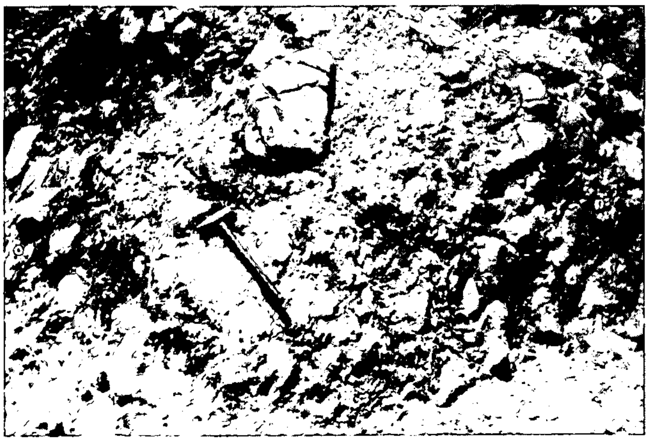


Fig. 3: The Skiu Conglomerate SW of Shingo.

BROOKFIELD & ANDREWS-SPEED (1984) regard the conglomerate an olistostrome and describe its apparent gradation into the overlying molasse. I also came to the conclusion that the molasse follows stratigraphically on the conglomerates.

This molasse is mostly thick-bedded and consists of red, green, and grey, fine- to medium-grained sandstones with pockets and layers of conglomerate or breccia, green siltstones and red, green, and grey shales. Cross-bedding, scour and fill structures, ripple marks, burrows and rare flute casts were observed. BROOKFIELD & ANDREWS-SPEED (1984) did detailed petrographic studies and found that "curiously, despite the abundance of spilitic pebbles in its lowermost beds, the molasse is mature like the Stok Kangri and Gongmaru La Red Molasse" ... "The whole molasse sequence resembles the deposits of moderately sinuous braided streams..." The above authors suggest a thickness of at least 700 m, an estimation, which, however, is difficult because of the intense folding.

For the age of this multicoloured molasse it is important that I found pebbles of blue nummulitic limestone in the conglomerates. LYDEKKER (1883, p. 108), who first mentioned the conglomerates of this section, reported about "numerous pebbles of the nummulitic limestone". However it is not clear whether he found these pebbles in the olistostromic conglomerate or the succeeding molasse sequence. I observed nummulitic pebbles only in the molasse.

The molasse may be traced to the Chilling area in the W (Pl. 1, 2). In a limestone pebble from a conglomerate bed there (83/66) Prof. Dr. L. HOTTINGER (Geol.-Palaeont. Inst. Univ. Basle, Switzerland) kindly determined fossils suggesting Middle Eocene(?) age:

– *Nummulites* sp.
– *Rotalia* sp.
– Alveolinas ex gr. *elliptica*

This indicates that after a significant tectonic phase the Early Tertiary carbonates of the Zanskar Shelf and (?) the Indus Molasse (e. g. Jurutze Anticline) were eroded and redeposited in transgressing molasse formations. In my view (FUCHS, 1984a) the olistostrome horizon, which connects isolated thrust masses of ultrabasics resting on the Dras Flysch-Volcanics, signals the SW-directed nappe movements. After the thrust masses slid onto the Dras Unit the sedimentation changed there to molasse type.

To the S the molasse of the Dras Unit is terminated by the SW-dipping thrust, which brings the Lamayuru Unit onto the Dras Unit.

BAUD et al. (1982b, Fig. 5) did not recognize the molasse character of the above series designating it as "green calcschist and volcanic sandstone" of their Dras-Nindam Unit.

The Dras Unit is rather thin in the Shingo-Skiu section, compared to the Lamayuru-Khalsi area or the region N of Mulbekh.

W of the Shingo-Skiu section the Dras Unit crosses the Zanskar Valley, a region described by STERNE (1979). According to this author the flysch crosses the Zanskar in a large anticline N of Chilling and S of Sumdah Doh. STERNE termed it the Zanskar Flysch. Overlying the flysch STERNE records reddish-maroon siltstones and conglomerates followed by volcanoclastics – the Skiu Conglomerate, which crosses the Zanskar 1 km N of Chilling village. There is not much doubt that this association of volcanoclastic conglomerate and red siltstones and conglomerates on top of the flysch represents the western continuation of the conglomeratic horizon observed in the Shingo-Skiu section (see above).

With tectonic contact to the above sequence STERNE describes a series of "green and purple siltstones and shales, grey shales, and green and brown sandstones" from the area around Chilling, which he termed the "Chilling Formation." From the lithologic variations, sedimentary structures and the occurrence of fresh-water *Unio* STERNE deduced a deltaic to estuarine deposition. Regarding structure STERNE correlates his "Chilling Formation" to the Spongtang Klippe and assumes it to represent a similar outlier. Contrary I found the gently S dipping "Chilling Formation" of the type area to form the western continuation of the molasse succeeding the Skiu Conglomerate in the Shingo-Skiu section. Additionally to the rock types described by STERNE I observed conglomerate beds containing pebbles of nummulitic limestone (see above). From the identity of the "Chilling Formation" with the molasse formation of the Shingo-

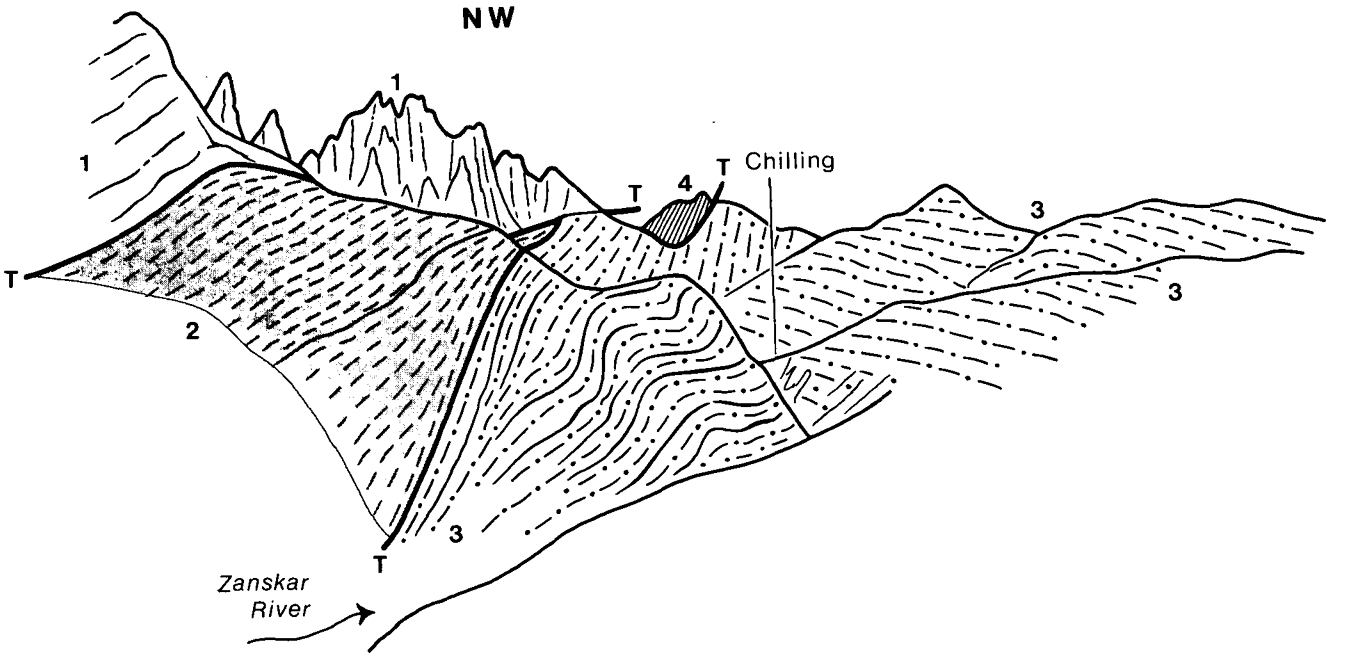


Fig. 4: View from the Zanskar Valley near Chilling towards the NW.
1 = Zanskar Carbonates; 2 = Lamayuru Formation; 3 = Chilling Molasse; 4 = Outlier of ultrabasics; T = Thrusts.

Skiu section first recognized by BROOKFIELD (1983), I name it the Chilling Molasse and regard it as the youngest portion of the Dras Unit. The gradational contact of the molasse with the underlying olistostrome (volcanoclastic conglomerate) seems to be tectonically overprinted at Chilling (STERNE, 1979). W of the Zanskar, however, all units appear to be highly disturbed: along a low angle thrust the steeply folded Zanskar carbonates override the Lamayuru Unit, which is squeezed out towards the crest of the ridge W of Chilling (Fig. 4). Close to the carbonates a major mass of ultramafics overlies the multicoloured rocks of the Chilling Molasse, which down-slope towards the Zanskar River is overthrust by the Lamayuru Unit. From Landsat imagery it appears that the ultramafics are connected with the ophiolitic melange and volcanoclastic conglomerates reported by STERNE from N of Chilling. These continue to the Shingo-Skiu section and can be traced on satellite imagery to the larger ultrabasic mass N of Chaluk (Pl. 1, 2). Contrary to STERNE the Lamayuru Unit does not underlie the Chilling Molasse but follows S of it with a tectonic contact (Pl. 1, 2, 3).

To the E of the Shingo-Skiu section the next traverse studied is along the side valley joining the Markha Valley at Chaluk (Pl. 2, 3 [4], Fig. 5): An ophiolitic melange Zone described in chapter 4 separates the Lamayuru and Dras Units. The Dras Unit in its southern portions is composed of intensely folded Chilling Molasse. The latter consists of medium to thick-bedded series (0,5–4 m) of red, green, and grey slates, grey, green or brownish, fine to medium-grained, partly calcareous sandstones and conglomerates, which may reach even 5–6 m thickness; the components of the latter – quartz, carbonates, volcanics etc. the sedimentary components prevailing – are well-rounded, but badly sorted. The pebbles may reach dm-sizes. The sandstones are generally lithic, with tuffaceous and calcareous beds. The components carbonate, quartz, chert, basic volcanics, chlorite, sandstone, siltstone and shale are commonly ill-rounded or angular. The sandstones pass into micaceous siltstones.

Cross-stratification, clay gall breccias, desiccation cracks, and burrows are observed in this series. The siltstones may show flame structures.

The Chilling Molasse is much folded in that section and the s-planes predominantly dip towards the SW. However near to the southern ultrabasic body the s shows a marked eastern dip and the molasse series plunges beneath this serpentinite mass. The northern ultrabasics appear to be stratigraphically overlain by the molasse, but the contact is not exposed. I suppose that the molasse was deposited after the emplacement of the ultrabasic thrust masses, but the southern serpentinite body slid further southwestward onto the Chilling Molasse in a younger phase.

The northern ultrabasic mass, which was just touched, seems to be composed of serpentinite, serpentinite breccia and peridotite; further radiolarite, chert- and volcanic breccias were found in the float. These latter rocks may be derived from the Dras Volcanics underlying the ultrabasics or from the ophiolitic melange zone separating the Dras Unit from the Indus Molasse.

Further E in the area N of Markha village the Dras Unit pinches out and reappears only E of the Leh-Manali road, as may be deduced from the map of THAKUR & VIRDI (1979). In the tributary valley N of Markha the Chilling Molasse is still cropping out in several hundred meters thickness, but was not observed farther E. The Dras Unit ends between two branches of ophiolitic melange. These melanges are particularly well-developed with large limestone klippes where the Dras Unit ends, but lose their melange character towards the NW. There they are represented by simple structural planes terminating the Dras Unit in the N and the S. Towards the SE the melanges join and continue as one ophiolitic melange zone separating the Lamayuru Unit from the Indus Molasse (Pl. 1, 2, 3).

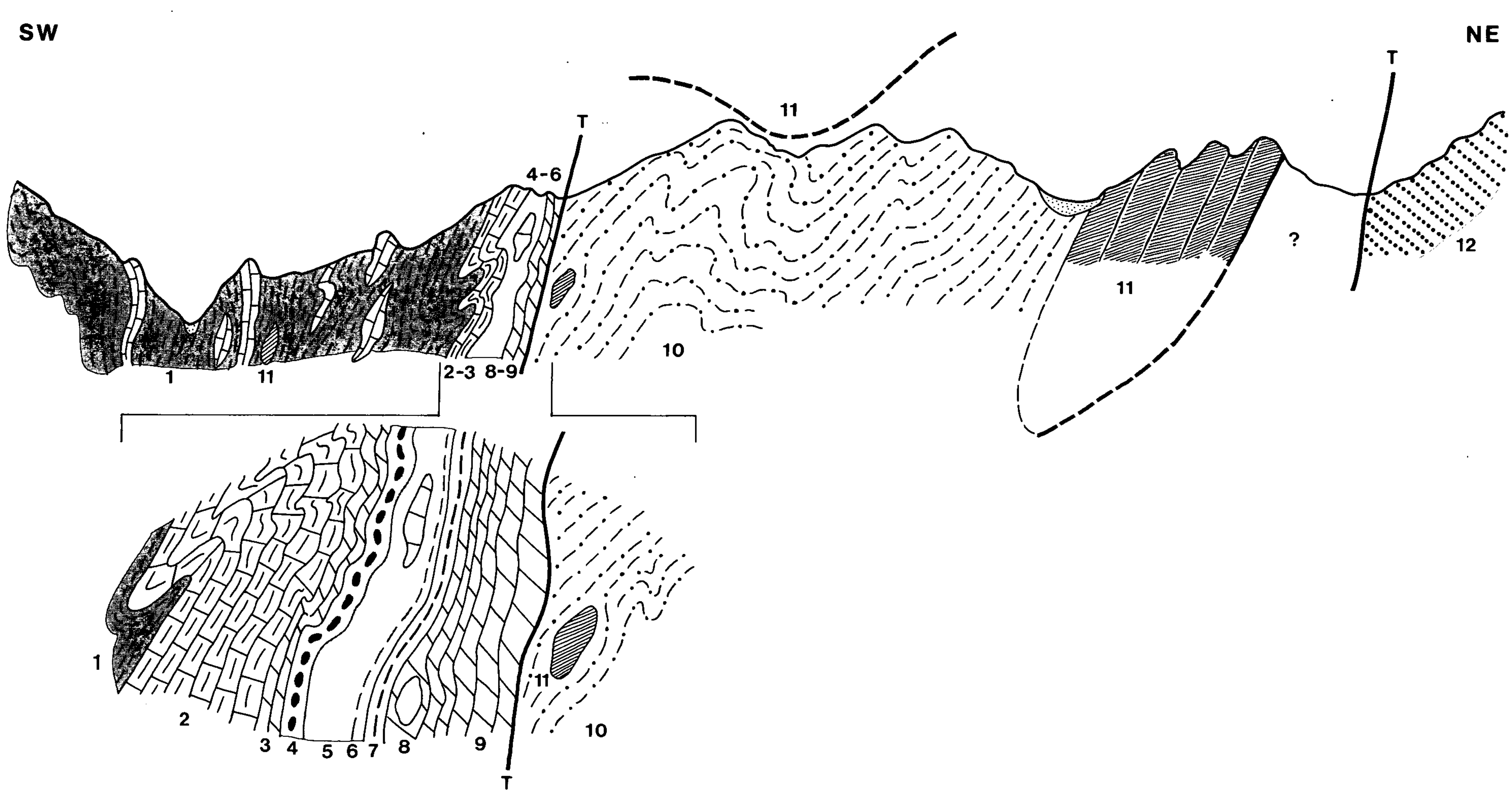


Fig. 5: The section along the side valley N of Chaluk (with a detail section across the ophiolitic melange).
1 = Lamayuru Formation (Triassic–Cretaceous?); 2 = Shillakong Formation (Up. Albian–Up. Campanian); 3 = Tuffaceous and cherty horizon; 4 = Agglomerates; 5 = Pillow lavas and layers of chert; 6 = Sheared basalt, inclosed lenticular body of limestone; 7 = Multicoloured slates; 8 = Blue nodular limestone inclosing a block of basic volcanics; 9 = Multicoloured marls, limestones and cherts; 10 = Chilling Molasse; 11 = Ultrabasics, mainly serpentinite; 12 = Indus Molasse; T = Thrusts.
Length of section approximately 5 km.

4. The Ophiolitic Melange Zones

As mentioned above an ophiolitic melange zone separates the Indus Molasse from the Lamayuru Unit in the region Lato to N of Hankar. In the Omlung-Markha area, where the melange zone splits into two branches, a series of large limestone klippes are found in that huge tectonic breccia. By their light colour they are identified also on satellite imagery. The southern branch, the lineament separating the Chilling Molasse of the Dras Unit from the Lamayuru Unit, still shows melange character in the section N of Chaluk (Pl. 2, 3 [4], Fig. 5). Further W towards the Zanskar I did not observe any melange along that lineament.

In the Chaluk section (Fig. 5) the much folded and steeply dipping Lamayuru Formation (1) is followed by Shillakong Formation in the N. The contact seems to be a sedimentary one. The Shillakong Formation (2) is 150–200 m thick and consists of green, cream, and red, brown-weathering slates, calc schists, marls and limestones. Towards their northern boundary these rocks become green, tuffaceous and cherty (3). The schistose rocks contain cm to dm lenses of limestone and layers or nodules of chert (radiolarite?). This passage zone to the adjoining agglomerates is about 7 m thick. Schistose green pebbly mudstones follow, which are 4 to 5 m thick (4). The components, which may reach 40 cm diameters are mostly carbonates, sandstones and basic volcanic rocks. There are also cm laminae of chert. Foliated green pillow lavas with dm-layers of chert reach a thickness of 8 m (5). Sheared basalts about 5 m thick follow (6). A lenticular body of light grey to cream coloured limestone, about 6 m thick, is inclosed in the above volcanics. This lens is exposed in the orogr. right slope of the valley. Again multicoloured slates of the Shillakong Formation follow about 6 m thick (7). Then come blue nodular limestones (8) inclosing a 3 m block of basic volcanite. The latter is a fine-grained, greenish rock showing foliation. The ophitic structure is well-preserved, though the primary minerals are replaced. Phenocrysts of pyroxene or hornblende are recrystallized to chlorite, carbonate, clinozoisite, sericite, sphene and ore, whereas laths of former basic plagioclase are replaced by albite, carbonate, sericite, and clinozoisite.

The blue limestones (8) contain brown weathering fine-brecciaceous layers, which show angular fragments of reddish sparitic limestone up to sizes of several mm in a greenish matrix appearing opaque under the microscope. This groundmass substance also forms shells in broken carbonate ooids, which also are found in the breccia. This rock seems to be the product of pelagic carbonate sedimentation and simultaneous submarine volcanic activity; glassy, cherty or metalliferous infiltrations and incrustations, as well as the red colour of the carbonate, indicate contemporaneous volcanism.

From the above blue limestone with reddish layers an alteration develops of well-bedded red, cream, green, grey and white marls, limestones and cherts (radiolarites?) (9). The whole siliceous carbonate series (8 + 9) N of the basic volcanic intercalation is several tens of meters thick.

The multicoloured carbonates are terminated by a steep thrust, which brings them in contact with the Chilling Molasse in the NE. Thus there is a sharp tectonic boundary between the ophiolitic melange zone and the Dras Unit, but not against the Lamayuru Unit adjacent to the SW. The dark carbonate flysch seems stratigraphically linked with the multicoloured pelagic Upper Cretaceous Shillakong Formation. The latter is interbedded with pyroclastics and basic flows of the ophiolitic melange zone. This indicates that the Lamayuru Unit was adjoining to an Upper Mesozoic subduction zone in

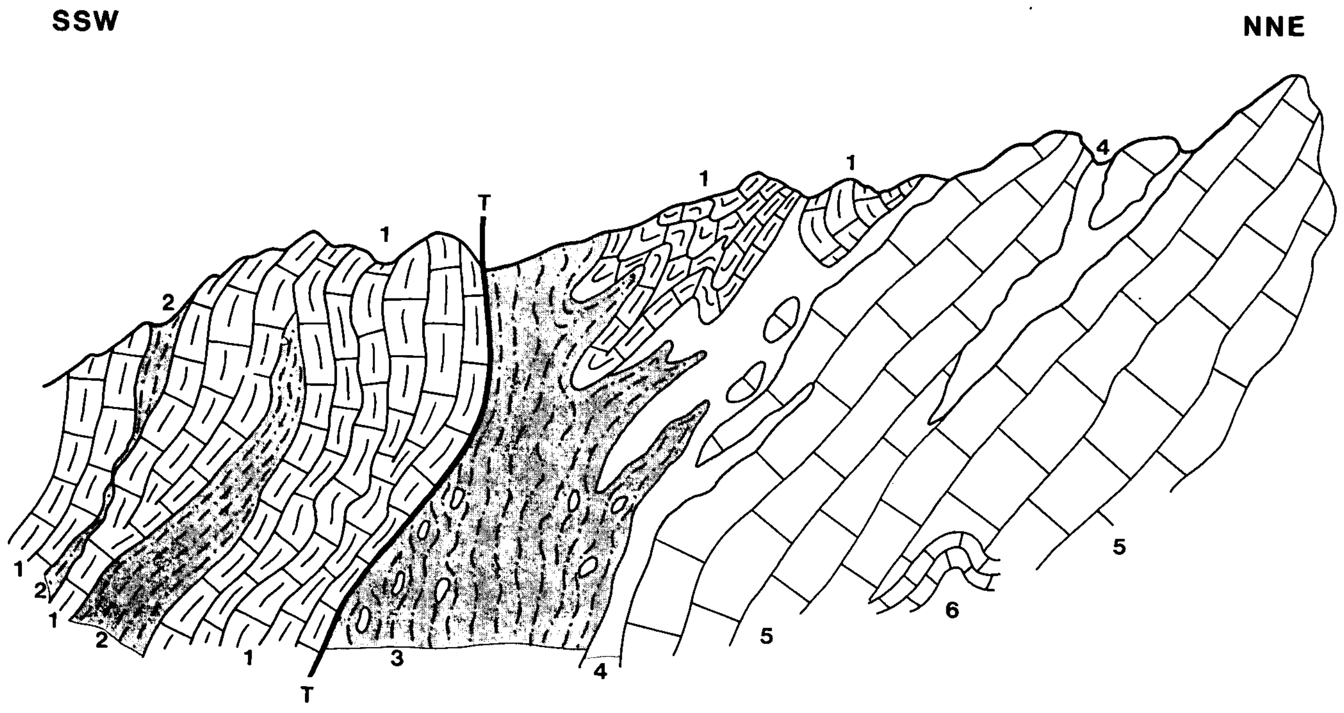


Fig. 6: Section along tributary N of Markha village.
1 = Shillakong Formation; 2 = Non-carbonate flysch; 3 = Olistostromic flysch (1–3: Lamayuru Unit); 4 = Basic volcanics (lavas, tuffs); 5 = Limestone klippes (white and grey); 6 = Red limestone; T = Thrust.
Length of section approximately 1 km.

the NE. The basic volcanism is confined to this northernmost portion of the Lamayuru Unit.

The described ophiolitic melange zone, which separates the Lamayuru and Dras Units, was again touched further E, N of Markha (Pl. 2, 3 [5, 6]): Like the Chaluk section the northernmost parts of the Lamayuru Unit are composed of Shillakong Formation (Fig. 6; 1). This multicoloured series is 300–400 m thick and contains intercalations of dark, non-carbonate flysch (2). The flysch consists of grey, green and black fissile slates alternating with dm to 0,5 m beds of fine-grained, rusty weathering sandstones, green, grey quartzites and manganiferous cherty layers; there are also a few beds of dark impure carbonates showing ferruginous weathering. Sole marks are frequent in the well-bedded sequence. In the N the Shillakong Formation is terminated by a tectonic plane. Along the zone of disturbance black olistostromic flysch (3) borders the Shillakong rocks. The s-planes of the much deformed flysch are mostly vertical and thus obliquely to the SW-dipping Shillakong Formation. The flysch is mainly composed of black slates containing irregular fragments of limestone, sandstone, and manganiferous cherty rocks. These components generally are of cm- to dm-dimensions. However there are also a few limestone klippes of decametric sizes. In the orogr. left flank of the tributary valley masses of basic volcanites (4), up to 10 m thick, are intercalated in the olistostromic flysch.

In the ridge W of the named valley Shillakong Formation occurs as a synform folded with the underlying flysch (Fig. 6). N of these Shillakong rocks respectively the flysch, conspicuous light limestone klippes follow several hundred meters thick (5). The klippes are composed of massive, partly schistose, grey and white slightly recrystallized limestones. Some minor parts of the klippe consist of thin-bedded red carbonates (6, binocular observation). In the orogr. right slope I studied the southern contact of the klippe: Throughout the contact is sharp, but meter blocks of the limestone are inclosed in the adjoining schistose rocks. These are either the dark pebbly flysch (see above) or grey, purple, and green volcanics, tuffaceous slates, and subordinate flows (4). Basic lavas also form decametric zones within the carbonates of the klippes. The contacts are magmatic, suggesting that the klippes slid into a basin with flysch deposition and simultaneous basic volcanism; the volcanics inclosed the klippes and intruded along fracture zones.

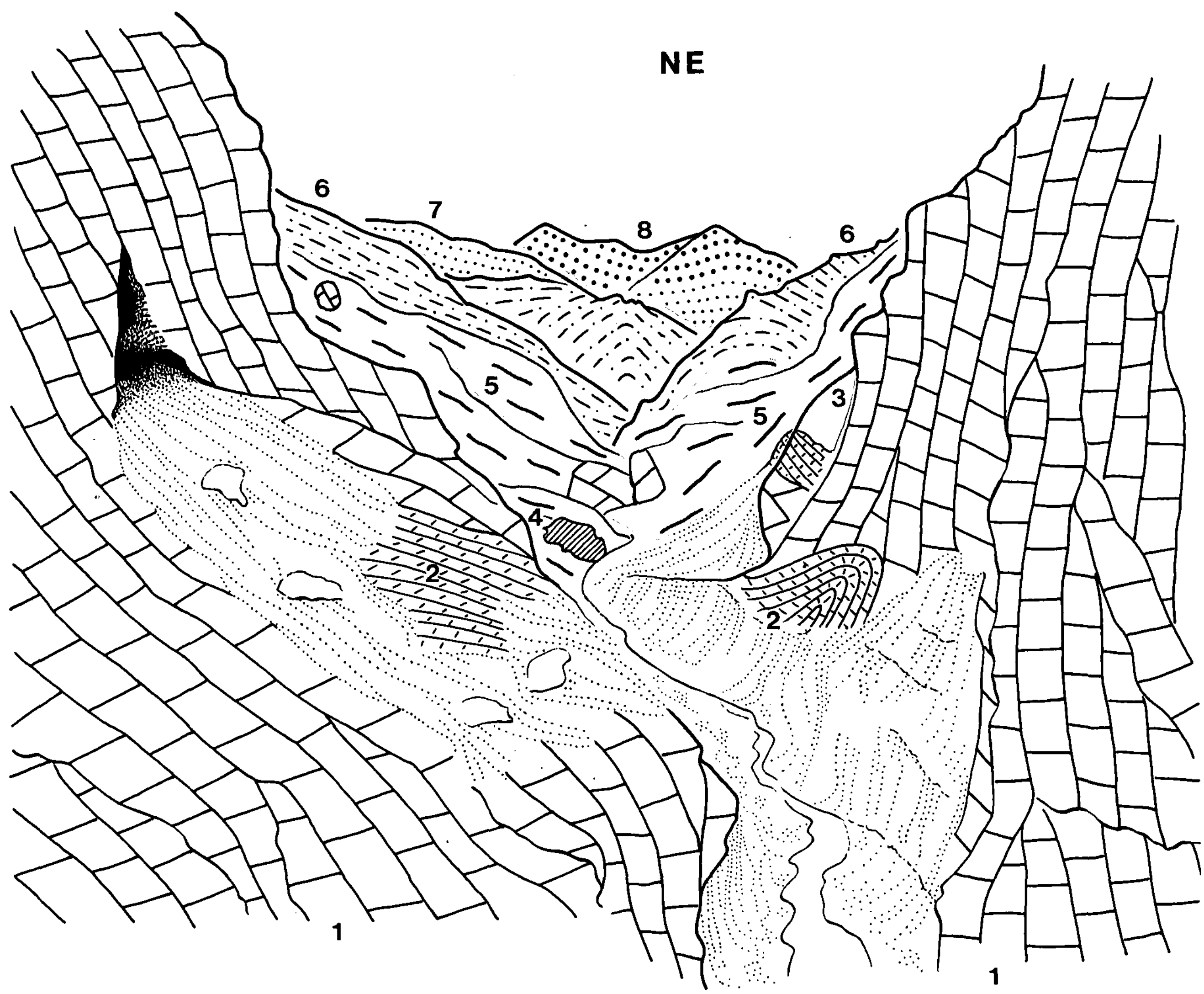


Fig. 7: View upstream the tributary N of Markha village.
1 = Klippe consisting of white and grey limestone; 2 = Red limestone; 3 = Basic volcanics; 4 = Serpentinite; 5 = Schistose rocks of the melange zone inclosing carbonate klippes; 6 = Chilling Molasse (Dras Unit); 7 = Eocene green molasse; 8 = Red molasse (7,8: Indus Molasse).

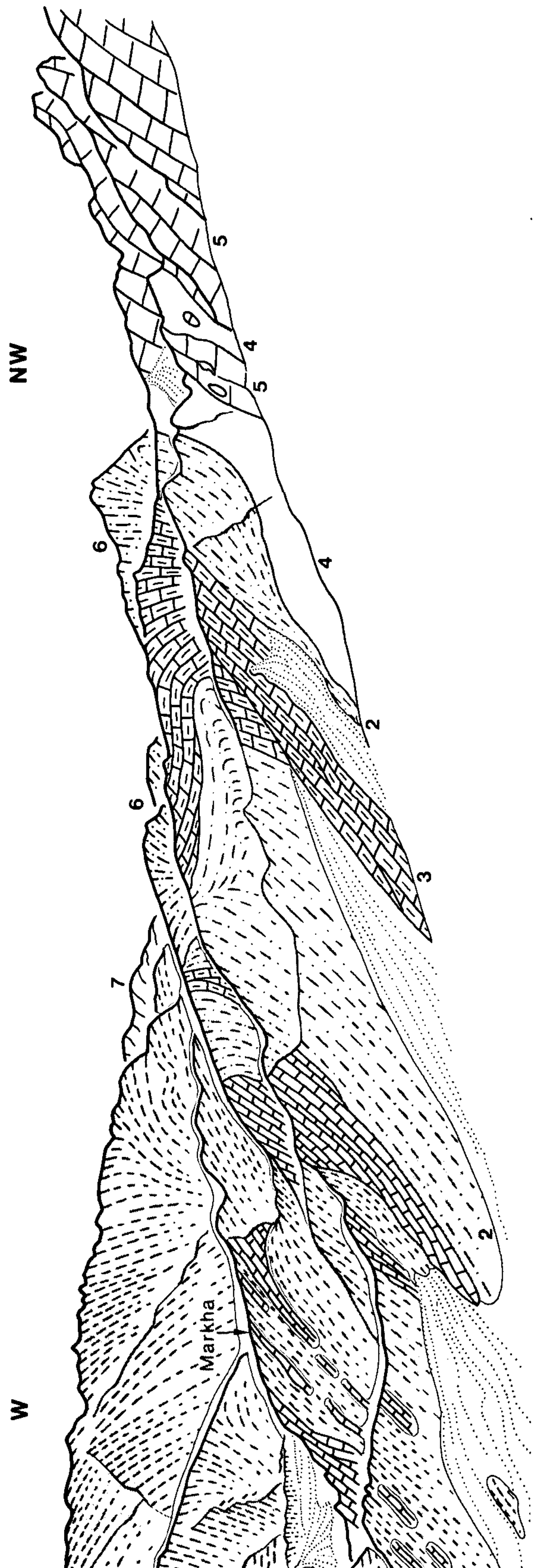


Fig. 8: Panorama view from the ridge W of the Omlung tributary towards the W and NW. The Lamayuru Unit exhibits domal structure S of the Markha valley, but is vertical along this valley.
1 = Lamayuru Formation (plus major bands of limestone); 2 = Non-carbonate flysch; 3 = Shillakong Formation (1–3: Lamayuru Unit);
4 = Basic volcanics; 5 = Limestone klippes (ophiolitic melange); 6 = Chilling Molasse (Dras Unit); 7 = Zanskar Carbonates.

The stream cut a gorge in the above klippe and waterfalls prevented access further upstream. By means of binocular and the boulders in the river it is indicated that N of the large carbonate klippes again basic volcanics crop out. They are associated by schistose argillites, multicoloured cherts and smaller klippes of serpentinite and carbonates (Fig. 7). These steeply dipping rocks belong to the melange zone; they abut against NNE-dipping variegated sandstones and slates of the Chilling Molasse (Dras Unit). The background in fig. 7 is formed by greenish (Eocene) molasse and red molasse building up the top of the range (see also Pl. 3 [5, 6]). Another melange zone not visible in fig. 7 is probably separating the Dras Unit from the Indus Molasse (satellite imagery).

The area E of the section just described is illustrated by the sketch view seen from the ridge W of the Omlung tributary (Fig. 8). The black argillites and associated carbonates of the Lamayuru Formation steeply dip SW or are vertical. They are succeeded in the NE by dark flysch containing bands of Shillakong Formation. Like the Markha section (see above) basic volcanics follow intimately connected with large carbonate klippes.

In the gorge of the tributary N of Omlung village the melange zone was studied again (Pl. 3 [7]): Ascending towards the N one first crosses vertical black argillites and carbonates of the Lamayuru Formation. Then comes a 10 m band of Shillakong Formation. N of the latter the Lamayuru carbonate flysch passes into non-carbonate flysch. This flysch consists of a thin-bedded alternation of black and grey-green, laminated argillites and grey, fine-grained, micaceous sandstones, carbonate sandstones and quartzites. The rusty weathering, arenaceous rocks show uneven bulbous s-planes and various sole marks, such as load casts, flute casts, burrows etc. (Fig. 9). Further there are dm-beds of siliceous rocks of conspicuous dark brown-violet colour, which points to a higher content of Fe and Mn.

Fig. 9: Non-carbonate flysch in the Omlung tributary. Sandstone shows various sole marks (load casts, flute casts?, burrows).

After a 200 m of flysch Shillakong Formation follows (about 100 m). An impure marly limestone of this series yielded a Campanian fauna (determination kindly by Prof. Dr. L. HOTTINGER, Geol.-Palaeont. Inst. Univ. Basle, Switzerland).

83/14: *Gavelinella* sp.
Hedbergella sp.

Heterohelicids
one- and two-carinated Globotruncanas
Lagenids
small Rotalias
small agglutinative foraminifers
Orbitoides douvillei (SILVESTRI)
fragments of *Inoceramus*, bryozoans, echinoderms, etc.

In the N the Shillakong Formation is underlain by flysch again, then come green, grey, and purple tuffaceous slates, pyroclastica and green lavas. The latter are fine-grained amygdaloidal rocks. Sporadic phenocrysts of plagioclase are embedded in a matrix of slender laths of plagioclase in a devitrified glassy base. The amygdales consist of coarse-grained carbonate with some quartz. Some amygdales are rimmed by chlorite. There is strong alteration into albite, carbonate, chlorite and ore, which makes the determination of the plagioclase impossible.

These volcanics border and intrude large klippes of white and grey massive carbonates. They also inclose blocks of the latter. Fig. 10, Pl. 4 show the complicated geology of the melange zone N of Omlung. By binoculars it was found that N of the carbonate klippes red argillites and basic volcanics follow. A series of comparatively small serpentinite bodies marks the tectonic boundary against the Indus Molasse.

Like in the other sections described it was not possible to draw a sharp boundary between the Lamayuru Unit and the ophiolitic melange zone in the N. The carbonate flysch passes into dark flysch containing few carbonate beds, and finally into non-carbonate flysch. The multicoloured Shillakong Formation occurring in several bands is associated with both types of flysch. The basic volcanics of the ophiolitic melange are in magmatic contact with the flysch, Shillakong Formation, and the carbonate klippes. Thus it is impossible to say where the Lamayuru Unit exactly ends and the ophiolitic melange begins.

Approximately 1,5 km E of Omlung village I climbed a ridge towards the N and traversed the ophiolitic melange (Pl. 3 [8]; Fig. 11): Again the Lamayuru Formation grades into non-carbonate flysch towards the N. Both formations contain decametric bands and lenses of bluish grey limestone, which are rather resistant and thus overtower the soft terrain formed by the surrounding rocks. These limestones show the characteristic structure of microbreccia or grainstone of the type described by BASSOULLET et al. (1981). According to these authors the carbonates formed on the Zanskar Shelf and were resedimented by grain flows in the adjacent trough.

The flysch series containing many lenticular bodies of the above limestone attains thickness up to 1000 m. In the highly disturbed melange zone a characteristic orange weathering conglomerate occurs either within the flysch or between the flysch and other series of the melange (Fig. 11). The conglomerate, which is 10 to 20 m thick, is coarse-grained, ill-sorted with well-rounded components up to 0,5 m sizes (Fig. 12). The pebbles and boulders are various carbonates, basic volcanics, quartzite, radiolarite, and granite in a carbonate matrix. A good portion of the carbonate boulders were identified as nummulitic already in the field. Prof. Dr. L. HOTTINGER (Geol.-Palaeont. Inst. Univ. Basle, Switzerland) kindly determined:

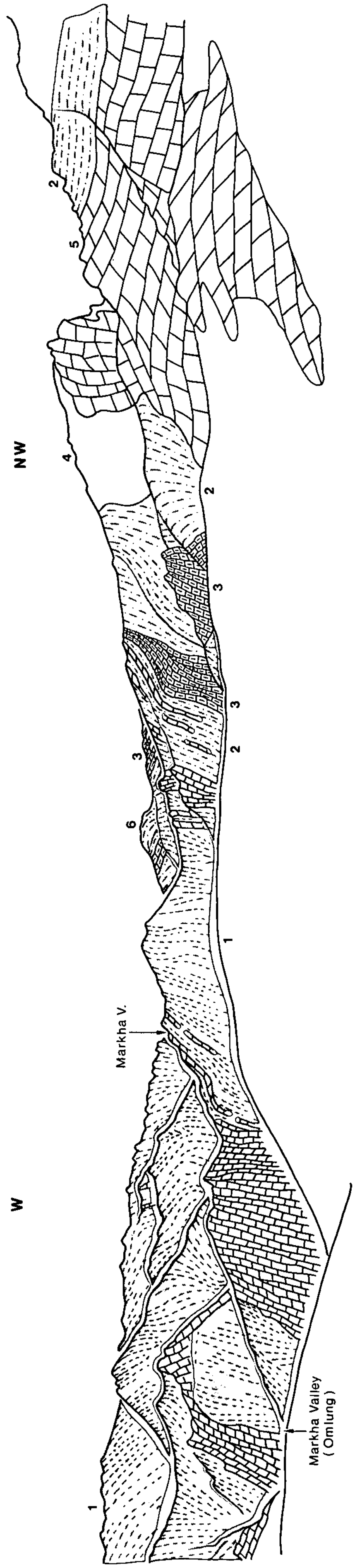


Fig. 10: Panorama view of the Omlung area towards the W and NW.
1 = Lamayuru Formation with bands of limestone; 2 = Non-carbonate flysch; 3 = Shillakong Formation; 4 = Basic volcanics; 5 = Limestone klippe; 6 = Chilling Molasse.
The Lamayuru Unit joins the ophiolitic melange without a sharp boundary.

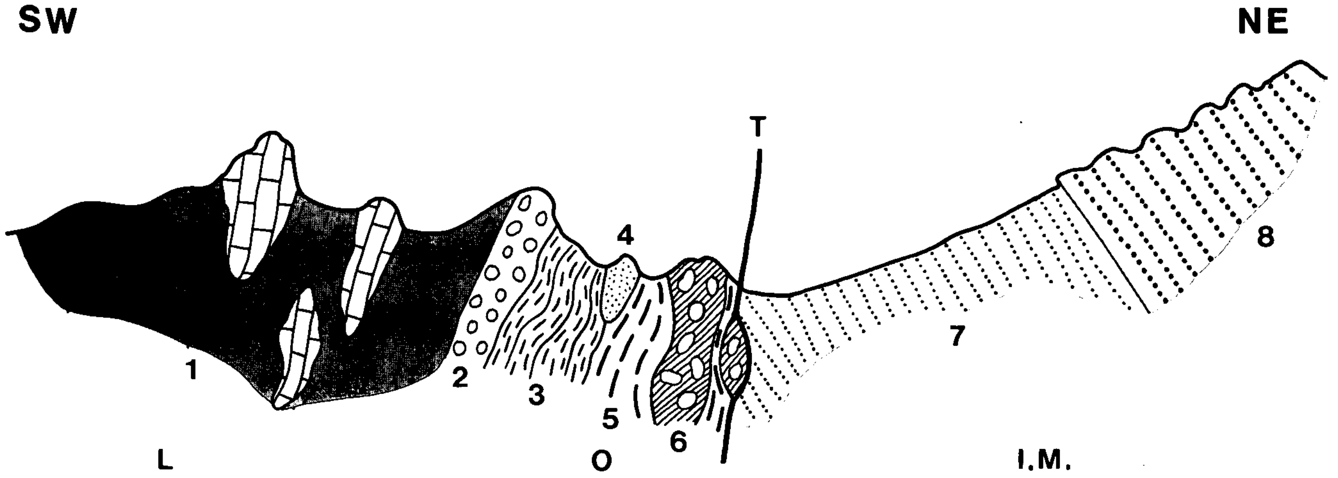


Fig. 11: Section across the ophiolitic melange zone NE of Omlung.
1 = Non-carbonate flysch with lenticular bodies of allodapic limestones; 2 = Orange-weathering conglomerate (post-Upper Paleocene); 3 = Red cherts; 4 = Black silt- to sandstone; 5 = Red argillites and red chert breccias; 6 = Serpentinite conglomerate; 7 = Green molasse containing nummulites; 8 = Varicoloured molasse; T = Thrust; L. = Lamayuru Unit; O. = Ophiolitic melange; I.M. = Indus Molasse.
Length of section ca. 1 km.

83/19: *Miscellanea* sp. *?Linderina* sp.
Daviesina cf. *danieli* SMOUT
Lockhartia conditi NUTTAL
Nummulites sp.
Discocyclinas
Truncorotalia

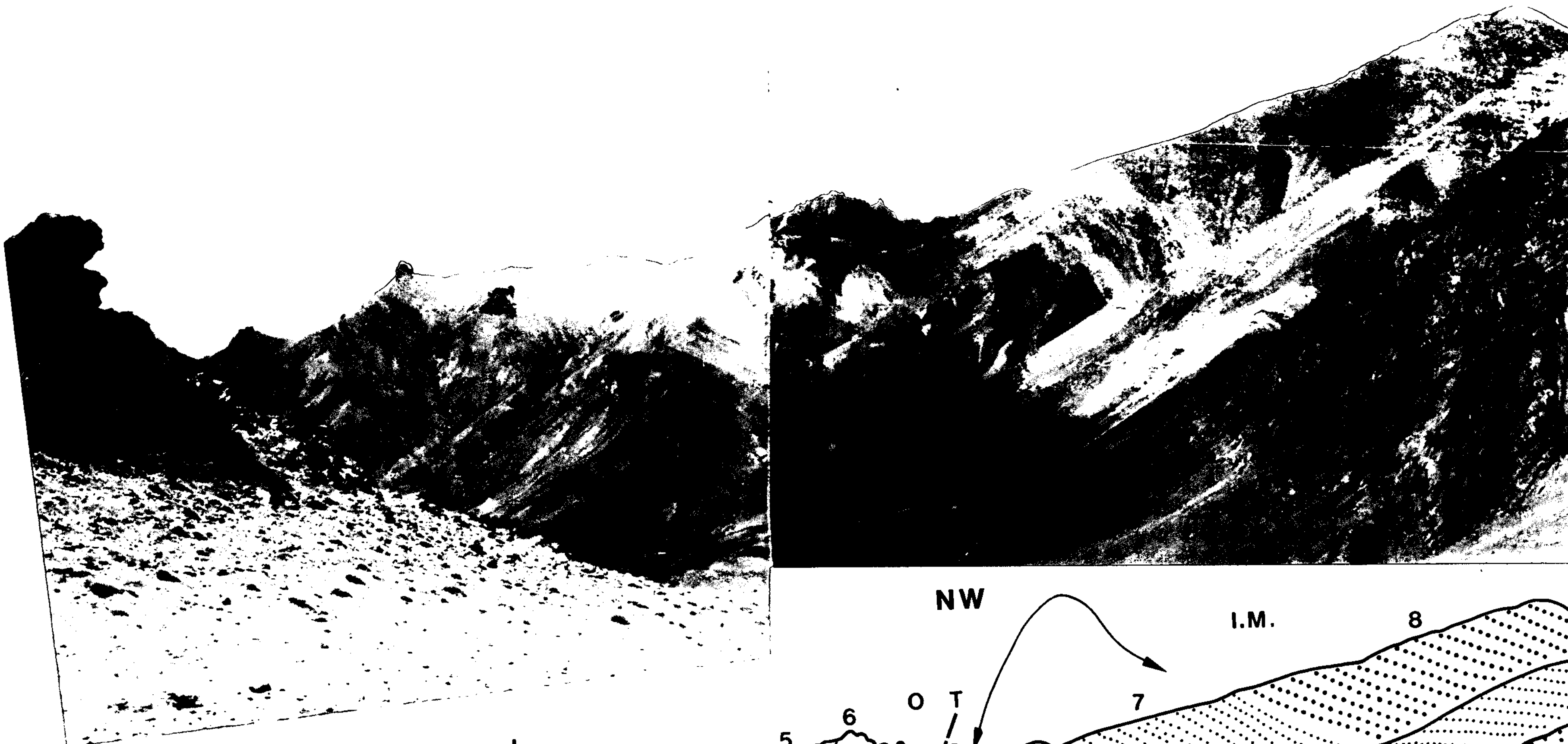
This fauna indicates Middle–Upper Paleocene age (*primaeva-cuccuniformis*-Zone). Thus the age of the conglomerate is definitely post-Paleocene and like the Skiu Conglomerate also this coarse-clastic horizon signals the first significant phase of the Himalayan orogenesis. In the course of later tectonic phases the conglomerate and the other series of the melange zone became much deformed. Coarse-clastic sediments subsequent to the first phase of the Himalayan orogenesis appear to occur all along the Indus-Tsang Po Suture Zone (HONEGGER, 1983, Fig. 9a; "Kargil formation" of SE-Ladakh, [THAKUR & VIRDI, 1979]; Liuqu Conglomerates of Tibet [BURG, 1983]).

Fig. 12: The post-Upper Paleocene conglomerate of the melange zone NE of Omlung. The components are well-rounded, but ill-sorted.

N of the conglomerate red cherts follow (3 in Fig. 11). Then comes a lens of black, grey weathering, fine-grained silty sandstone to siltstone (4). In thin-section only a shell remain was found, which is similar to an aptychus. Red argillites succeed, which followed along the strike also contain red chert breccia. The bright red rocks are succeeded by dark green serpentinite conglomerate (6). The well-rounded components reach up to 40 cm diameters.

Whereas all series described above are subvertical, after a steep plane of disturbance a greenish formation follows dipping NE at medium angles (7). It is a well-bedded alternation of green, fine- to medium-grained sandstones with conglomeratic or brecciaceous layers and green shales. The sandstones are lithic composed of ill-sorted, angular grains of quartz, feldspar and fragments of sand- and siltstone, basic volcanics, quartz porphyry, and carbonate rocks. There are further sporadic shells of large foraminifera, which were identified by Prof. Dr. L. HOTTINGER (Geol.-Palaeont. Inst. Univ. Basle, Switzerland) as *Nummulites* sp. indicating Upper Paleocene-Eocene age. This formation belongs to the Indus Molasse and probably corresponds with the Jurutze Flysch further N. Like the latter it is overlain by multicoloured, mainly purple, thick-bedded molasse series. The Eocene molasse seems to form the core of an anticline, partly overturned towards the SW. The thrust terminating the ophiolitic melange zone in the NE cuts the internal structures of the Indus Molasse unconformably. Thus either the core of the fold or the steep and rather reduced SW-limb are in contact with the melange.

Fig. 13 shows the melange zone in the area where the described section (Fig. 11) was studied, and Pl. 5/1



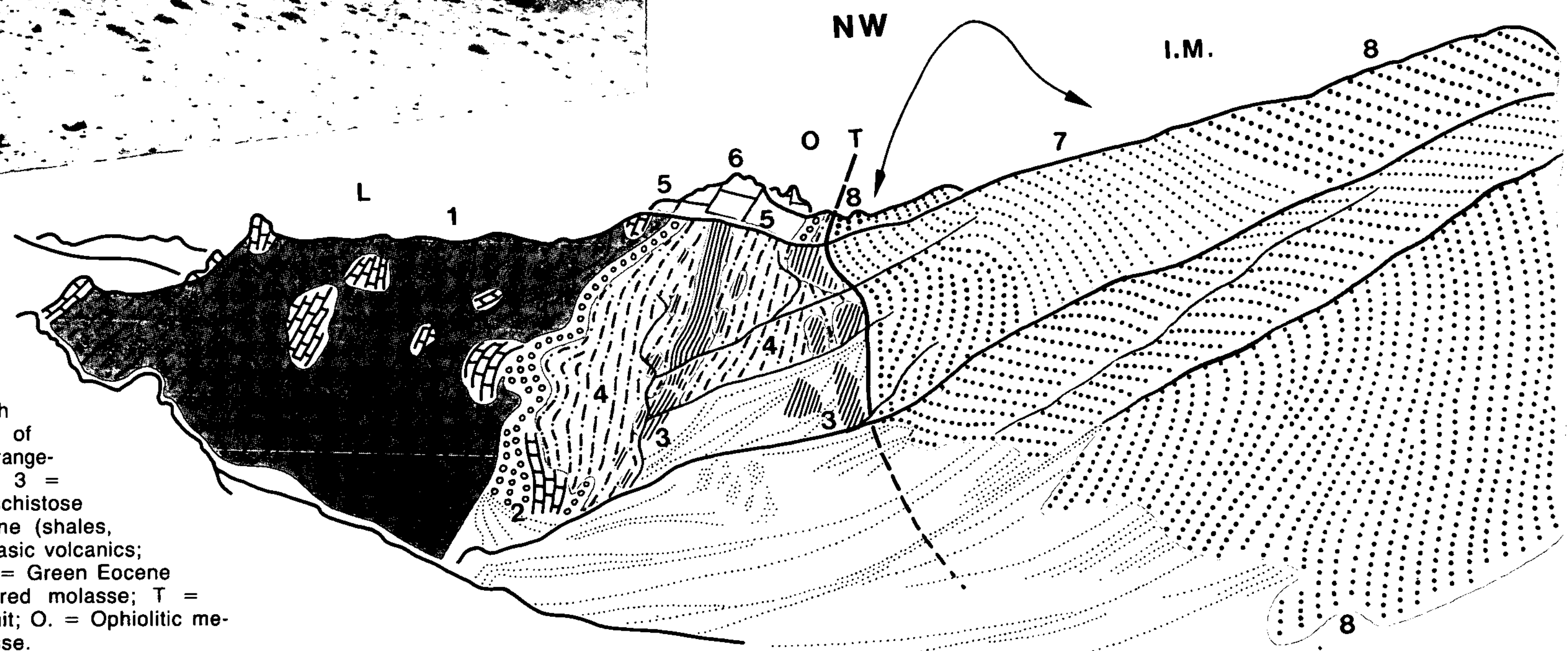


Fig. 13: Panorama view of the ophiolitic melange zone NE of Omlung seen from SE.
1 = Non-carbonate flysch inclosing lenticular bodies of allodapic limestone; 2 = Orange-weathering conglomerate; 3 = Serpentinite; 4 = Various schistose rocks of the melange zone (shales, cherts, flysch etc.); 5 = Basic volcanics; 6 = Limestone klippes; 7 = Green Eocene molasse; 8 = Multicoloured molasse; T = Thrust; L. = Lamayuru Unit; O. = Ophiolitic melange; I.M. = Indus Molasse.

is a panoramic view from this section towards the NW illustrating the northern continuation of the section studied in the Omlung tributary.

At the village Hankar a side valley joins the Markha Valley from the NE. I ascended this tributary and like in the described sections I found a gradual decrease in carbonates and increase of silty and sandy beds in the Lamayuru Formation towards the NE. Thus this series passes into thin-bedded black flysch. In the melange zone the flysch is succeeded by 60–80 m thick carbonate breccia to conglomerate. The components, which reach up to sizes of several dm, are various carbonates radiolarites, volcanics etc. There are also cobbles of blue nummulitic limestones. Prof. Dr. L. HOTTINGER (Geol.-Palaeont. Inst. Univ. Basle, Switzerland) kindly determined:

83/22: *Alveolina "ovicula"* NUTTAL →
→ *Alveolina decipiens* or *leupoldi* gr.
A. (Glomalveolina) lepidula SCHWAGER
Nummulites ex gr. *globulus* LEYM
Assilina sp.
Lockhartia sp.
small Rotalias
Miliolids
Valvulinids
various benthonic small foraminifera (indet.)

The fauna suggests Middle Ilerdian (Upper Paleocene) age. Thus the coarse clastic horizon represents the post-Upper Paleocene conglomerate exhibiting the characteristic orange weathering.

In the valley the melange is largely covered by talus and better outcrops are found on the ridge W of the valley:

A series of serpentinite bodies marks the tectonic contact melange / Indus Molasse. It is multicoloured, predominately red molasse, which abuts against the melange. The molasse consists of thick-bedded alternation of red and green conglomerates, sandstones, red, green, and yellow shales and few carbonate sandstone beds weathering in brown colour. The conglomerates are ill-sorted, but the components are mostly well-rounded. These are sandstones, argillites, radiolarites, basic volcanics and carbonates densely packed or sporadic in sandstone matrix.

The subvertical molasse ist tectonically mixed up with the lenticular serpentinite bodies and dark grey flysch sandstones and shales.

The orange-weathering carbonate conglomerate S of the serpentinites is only 10 m thick in this section. The northern portions consist of grey rock exhibiting rusty porous weathering surface resembling a carbonate sandstone. By means of the lens, red, black, and green patches are discernible in the rock. Under the microscope we find grains and fragments of carbonate, haematite ore, ore-, carbonate- and chlorite-aggregates in a quartz-carbonate matrix. Chlorite frequently rims the ore grains. Thus the rock represents a tuffaceous carbonate-arenite, which indicates volcanic activity simultaneous with sedimentation. Towards the S this tuffaceous carbonate rock passes into coarse breccia with boulders and rock fragments up to 75 cm length.

The components of the coarse breccia are mainly carbonates, further multicoloured argillites, cherts (radiolarites?) and serpentinite in a carbonate matrix. SW from the psephitic horizon the ridge is formed by dark flysch and after about 60 m a sheared 4 m block of carbonate breccia is found surrounded by red radiolaritic rocks. The breccia resembles the main horizon (see above). A pebble of foraminiferal limestone from the breccia block yielded the following fauna (det. Prof. Dr. L. HOTTINGER, Geol.-Palaeont. Inst. Univ. Basle, Switzerland):

83/24: *Alveolina "ovicula"* NUTTAL
A. (Glomalveolina) lepidula SCHWAGER
Orbitolites biplanus LEHMANN
Opertorbitolites sp.
Nummulites ex gr. *globulus*
Miliolids
Valvulinids

As this fauna indicates Middle Ilerdian (Upper Paleocene) age, the breccia is post-Upper Paleocene.

Southwards along the ridge the section shows non-carbonate flysch grading southwards into the calcareous Lamayuru Flysch. But in both flysch series we find bands and klippes of blue, microbrecciaceous limestones. Pl. 5/2, a panorama view seen from the Nimaling Mountains, shows the region where the ophiolitic melange zone was studied in a series of sections (see above). Further SE in the area N of Lalung La the melange zone seems to be ill-exposed, covered by talus and was not followed by me. From satellite imagery the melange is clearly recognized: It crosses the Manali-Leh road N of Lato and continues SE in a straight line in the orogr. right slope of the valley in which the village Rumtse is situated. This is conform with the information provided by THAKUR & VIRDI (1979).

5. The Lamayuru Unit

All along western Ladakh there is a zone of soft, dark, calcareous flysch with intercalated lenticular bodies of limestone between the Dras Volcanics and Dras (Nindam) Flysch in the N and the rugged carbonate range of Zanskar in the S. SHAH et al. (1976), SRIKANTIA & RAZDAN (1980) and SHARMA & SHAH (1983) took this argillaceous-calcareous belt as the stratigraphic base of the Mesozoic Zanskar Carbonates, most workers, however, agree that it represents a distinct stratigraphic-tectonic unit (GANSSER, 1976; FRANK et al., 1977; FUCHS, 1977, 1979, 1982; BASSOULLET et al., 1977, 1978a, 1980a, 1981, 1983; ANDREWS-SPEED & BROOKFIELD, 1982; BROOKFIELD & ANDREWS-SPEED, 1984). Stratigraphically I use the term Lamayuru Formation for the dark calcareous flysch, which makes up the bulk of the zone, the name Lamayuru Unit demarcates the belt tectonically. This very characteristic zone is also represented E of the Zanskar River. BAUD et al., (1982b, 1983) subdivided the belt into the Markha Unit (flysch) in the N, which they regard as continuous with the Lamayuru Unit, and the southern Langtang group (schistes lustrés). According to these authors the two units are lithologically separable and demarcated by a tectonic plane. I do not agree with this view, because I found only one dark calcareous-argillaceous complex in the Markha region, which is quite similar to the Lamayuru Unit of western Ladakh. This unit, however, is demarcated there by tectonic planes in the N and the S, whereas in the Markha area I was surprised to find passages into the ophiolitic melange zone in the N and the Zanskar Shelf carbonates in the S (FUCHS, 1984 a, b).

All along the Markha Valley the Lamayuru Formation is excellently exposed. It is composed of soft dark grey, black slates, phyllites, green silty slates, thin layers of sandstone, calc schists, frequently interbedded with black marls and blue limestone. The carbonaceous dark series show frequent efflorescences and are bleaching on weathered surfaces. Therefore the Lamayuru belt appears as a light band on satellite imagery.

The carbonates alternate in dm to m-rhythm or form lenticular bodies up to 100 m thickness and lengths of several km. The thicker limestones resemble the blue variety of the Kioto Limestone. The rock is mainly fine-grained, rich in white calcite veins along fractures, and rarely cherty. There are calcilutites, peletal limestones, calcarenites to microbreccias.

Crinoid stems are not rare in the carbonates and in thin-section corals are observed. These fossils, though not conclusive to the age, indicate shelf provenance. Sample 83/17 was kindly examined by Dr. R. OBERHAUSER (Geol. B.-A., Vienna). It is an oolite with fragments of other limestones and dolomites, and shell remains. One of the components contains a small foraminifer cf. *Textularia*. Dr. OBERHAUSER stresses the shallow-water character of the carbonate rock. This is in accordance with the views of FUCHS (1977, 1979) and BASSOULLET et al. (1981) that the Lamayuru Unit is characterized by dark flyschoid basin facies interfingering with shelf carbonates. BROOKFIELD & ANDREWS-SPEED (1984) came to the result that the Lamayuru flysch is a distal turbidite facies having been deposited on a basin plain, or possibly the outer part of a deep-sea fan. The environment suggests a passive continental margin.

Fine-brecciaceous limestones are particularly frequent in the northern parts of the Lamayuru Unit of the upper Markha Valley (Markha – Omlung – Hankar). The components are predominantly of mm-sizes, but may reach cm-size. They are grains or fragments of micritic limestone, calcarenite, oolite, ooids, fine-crystalline dolomite, dark argillite, carbonate sandstone and crinoid stems. The cement is sparitic.

These brecciaceous limestones within the dark basin facies derived their material from the adjoining shelf by gliding mechanisms envisaged by BASSOULLET et al. (1981). The brecciaceous limestones occur in the Lamayuru Formation, but also in the non-carbonate flysch. The non-carbonate flysch grades from the Lamayuru Formation by decrease of carbonate and increase of silt- and sand content. This flysch forms the groundmass for the ophiolitic melange adjacent in the N. It is associated with the basic volcanics and the huge carbonate klippes of the melange zone.

The Shillakong Formation is another important rock series of the passage zone between the Lamayuru Unit and the ophiolitic melange. It is associated with the Lamayuru Formation, the non-carbonate flysch, and the volcanics of the melange zone. The Shillakong Formation consists of red, purple, green, white, cream, grey, blue banded alternation of slates, phyllites, calc schists, marls, and limestones (rarely dolomitic). Transversal cleavage is frequent in this varicoloured series. BASSOULLET et al. (1978b) first discovered an Upper Campanian microfauna S of Fotu La. For the stratigraphic range of the formation it is important that BAUD et al. (1982b) found Upper Albian to Turonian microfaunal horizons in eastern Ladakh. Their fossils are derived from the Shillakong Formation of the Tibetan Zone (Zanskar Shelf), whereas my sample 83/14 was taken from the Shillakong Formation adjacent to the melange zone. My sample yielded a Campanian fauna (see chapter 4.). The formation represents a pelagic multicoloured facies of Mid to Upper Cretaceous age, which is replaced by the pelagic blue grey facies of the Chikkim Limestone (Cenomanian – Campanian) and the Kangi La Flysch (Campanian – Lower Maestrichtian) in southwestern Zanskar (FUCHS, 1982).

In the Markha area the Shillakong Formation was not observed in the Ganda La – Skiu section and was met first in the landslide material NW of Sera. It was brought down to the valley floor from the orogr. right slope by rockslide causing the damming up of the Markha River. Thick conglomerates accumulated in higher terraces of the Markha River are found in the Sera-Chaluk area, and up to Markha, they are evidence of this mountainslide.

In the section along the tributary N of Chaluk the Shillakong Formation was observed in situ (Fig. 5). Though there is strong folding the Shillakong Formation seems to be stratigraphically associated with the Lamayuru Formation. A small lenticular body of serpentinite occurs far from the contact within the Lamayuru argillites and documents the intensive tectonization within the Lamayuru Unit. From the Chaluk section eastwards to the area N of Omlung Village bands of Shillakong Formation are found associated with Lamayuru Formation, non-carbonate flysch and the rocks of the melange zone (Pl. 2, 3; Fig. 6, 8, 10; Pl. 4, 5/2). It is a problem where the Lamayuru ends and the melange zone begins; apparently no sharp tectonic boundary exists.

The southern boundary of the Lamayuru Unit against the Zanskar Shelf carbonates provides a similar problem: In the area W of the Zanskar River this boundary is generally tectonic, E of the Zanskar it is not easy to delimitate the Lamayuru Unit from the Zanskar Carbonates.

In order to demarcate the Lamayuru Unit in the SW I made traverses southwestwards from the Markha Valley S of Sera and SSW of Tilnespa. In this area the black argillites and carbonates are stronger recrystallized. Additionally to the blue carbonates there occur white, grey, cream, and rare pink limestones; further white limestones containing nodules and boudins of grey dolomite are observed. These carbonates are interbedded with the black argillites. There are decametric zones either rich in carbonates or in argillites. High up in the side valley WSW of Tilnespa when I supposed to be already within the Zanskar Carbonates again I came across interstratified black argillites. Though the rocks are steeply dipping and much folded it is evident from the contacts that it is stratigraphic interfingering and not thrusting which led to the multiple repetition of Lamayuru Formation and carbonates of Zanskar type. My interpretation is that the above series represent a passage from deeper Lamayuru into shallow shelf facies. High up in the crest of the range SW of the Markha Valley the passage zone is overlain by the thickbedded uniform carbonate series of Zanskar.

The carbonate rich zones within the passage zone can be recognized on Landsat imagery as light bands striking N–S obliquely to the NW–SE direction of the Markha Valley and the parallel geologic zones (Lamayuru Unit, melange zones, Dras Unit, Indus Molasse).

The fact that the southern marginal parts of the Lamayuru Unit strike N–S and the northern portions continue to strike SE results in a widening of the Lamayuru belt in the area Tilnespa – Hankar (Pl. 1, 2, 3). Finally, in the Hankar-Langtang area the Lamayuru Unit branches: A northern belt continues towards the ESE to Lato – Gya – Rumtse, whereto the Lamayuru Unit can be traced on Landsat imagery as a light-coloured zone built up by soft rocks. The southern branch, the Langtang Group of BAUD et al. (1982b) was traced by me from Zalung Karpo La via Khurna Kur to Yar La. From there the zone continues SE to Pang, where it was taken as Jurassic (Spiti Shales) by GUPTA et al. (1970) on their traverse along the Manali-Leh road.

The widening of the Lamayuru belt and its bifurcation are related to the NW plunge of the Nimaling Dome. The Lamayuru Formation forms part of the domal structure and covers the Tso Morari Crystalline and its metasedimentary mantle, which builds up the core of the anticlinorium. The Lamayuru Formation is subvertical or steeply dipping NNE in the northern branch, dipping steeply SW in the southwestern branch, and plunges WNW in the Langtang area. Fold axes and lineations plunging NW at medium to rather steep angles I observed at several places in the Lamayuru Unit of the Markha region. The steeply folded Lamayuru Unit of the lower course of the Markha Valley plunging WNW beneath the Zanskar Carbonates W of the Zanskar River is the western extention of the Nimaling domal structure.

The Lamyuru Unit is an independent lithotectonic unit in western Ladakh, terminated by thrusts in the N and the S. In the Zanskar Valley the southern thrust seems to die out and the primary contact Lamayuru Unit – Zanskar Carbonates is more or less preserved; the facies of the shelf and the continental slope are still coherent E of the Zanskar River. In the N a tectonic plane separates the Lamayuru Unit from the Dras Unit. From N of Chaluk towards the SE an ophiolitic melange zone terminates the Lamayuru Unit in the N. The recent studies show that the ophiolitic melange developed adjacent to the Lamayuru Unit and that the two units are primarily connected. The Lamayuru Unit comprises the facies of the continental slope, and the adjoining basin right to the subduction zone. In the S it is intimately intertonguing with the shallow-water carbonates of the shelf. Northwards the carbonate content of the Lamayuru Unit decreases merging into non-carbonate flysch, which is in primary contact with the klippes and basic volcanics of the melange zone.

Besides the facies change within the Lamayuru Unit from the SW towards the NE there is another important result: The Tso Morari Crystalline plunges towards the NW and the metasediments, which form the mantle of the crystalline, build the Nimaling Dome. These metasediments dip beneath the rocks of the Lamayuru Formation in the NE, W and SW (see Pl. 1, 2, 3). There is a gradational boundary from the dark siltites, quartzites and crinoid limestone series into the calcareous siltites of the Lamayuru Formation. Thus the contact is stratigraphic and there is no indication of a thrust at the base of the Lamayuru rocks. In the NE the Lamayuru Unit is terminated by the ophiolitic melange zone – a zone of disturbance. In the SW, however, the Lamayuru rocks are regularly succeeded by the Kioto Limestone. I examined this contact carefully and in several sections. Due to the difference in material – soft argillites and thick-bedded limestones – the boundary is locally tectonized, but the increasing frequency of limestone layers in the topmost parts of the Lamayuru Formation suggests a stratigraphic contact. Therefore the Lamayuru Formation, in my view, forms a member of the metasedimentary sequence of the Nimaling Dome and of the Zanskar succession as well. The Tibetan Zone of Zanskar is linked with the Tso Morari – Nimaling Dome, inasmuch, as the latter represents a huge marginal anticline of the Tibetan Zone. In this anticline the marginal portions of the shelf carbonates interfinger with the Lamayuru basin facies, as we have seen in the Tilnespa area (see above). These parts of the Lamayuru Formation which cover the Nimaling Dome, thus were deposited on continental crust. The northern portions, however, which are in primary contact with the ophiolitic melange may be sediments on oceanic crust. According to this concept the northernmost marginal parts of the Indian continent are exposed in the Nimaling Dome. The Lamayuru Formation covers the continental slope, being connected with the Zanskar Shelf in the S, and the subduction zone adjacent in the N.

The Lamayuru Unit represents a facies belt, which became an individual tectonic unit in W-Ladakh; in E-Ladakh the facies zones are still coherent and arranged in their original order. Thus in eastern Ladakh the term Lamayuru Unit does not mean an individual tectonic unit but a facies belt attached in the N to the Zanskar Shelf. These facies zones are connected by a passage zone and there is no sharp tectonic separation.

The geological age of the Lamayuru Formation appears to be different from place to place. Fossil finds from the Lamayuru belt document a Triassic (FRANK et al., 1977; FUCHS, 1979) and Jurassic age (BASSOULLET et al., 1981; BAUD et al., 1983). From the allochthonous Lamayuru Formation of the Spongtang Klippe BROOKFIELD & WESTERMANN (1982) report a Callovian–Oxfordian ammonite. Lamayuru Formation overlapping the northern parts of the Zanskar Shelf (N.Z.U.) yielded a Maestrichtian microfauna (FUCHS, 1982). Tentatively I expect that the Lamayuru Formation of the Lamayuru Unit comprises not only the Triassic–Jurassic, but too may range up into the Cretaceous. Anyhow, the stratigraphic range is considerably larger in the N than in the S near the Zanskar Shelf, where the dark argillaceous facies seems to represent the major part of the Triassic only. The underlying Siltite-Quartzite-Limestone Series yielded *Gondolella* sp. (Permian–Triassic) in its topmost portion (kindly det. by. Dr. H. KOZUR, Geol. Survey Budapest, Hungaria). The Lamayuru Formation of the SW-flank of the Nimaling Dome is overlain by the Kioto Limestone (Upper Noric – Lower Dogger). From the above facts and the lithology of the Siltite-Quartzite-Limestone Series I regard the Lamayuru Formation Triassic, but pre-Upper Noric.

Further SW dark argillites occur in the core of a steep, tightly folded anticline of the Zanskar Carbonates. They were observed in a traverse along the Khurna River W of the place Kurio. Blue-grey marly limestones and dark slates and phyllites are exposed in a thickness of approximately 40 m. There are some beds rich in crinoid and brachiopod remains. Sample 83/60, kindly examined by Dr. H. LOBITZER (Geol. B.-A., Vienna) allowed no determination of the age. It is a fine-grained rock almost free of clasts, a former biomicrite.

Recrystallization has affected the matrix. Regarding facies an open marine environment is indicated, possibly a sill; shallow-water may be excluded.

These beds suggestive of deeper water among the shallow-water carbonates of Zanskar seem to represent southern interfingerings of the Lamayuru facies.

6. The Metasedimentary Sequence of the Nimaling (Tso Morari) Dome.

The high grade crystallines, the Puga Formation (THAKUR & VIRDI, 1979) forming the core of the Tso Morari Anticlinorium, crop out in the SE far from the region studied. The Nimaling Range is built by the Thaglang La Formation of THAKUR & VIRDI (1979). This formation comprises a variety of metasedimentary series of low to high grade alteration, now subdivided in this paper. VIRDI et al. (1978) discovered Upper Carboniferous and Lower Permian fossils in a limestone member of their Thaglang La Formation. The lower parts of the metasedimentary succession are intruded by metagranites, the so-called Rupshu Granites (BERTHELSEN, 1953).

6.1. The Basal Flysch

The central parts of the Nimaling Range are built up of a thick, (about 1000 m) monotonous formation weathering in sombre, brownish tints, and disintegrating to blocky talus. This oldest formation of the Nimaling metasedimentary sequence consists of a rhythmic alternation of dark grey to green, fine-grained metasandstones to quartzites, metasiltites, and slates. Characteristically the rocks are laminated and banded. Graded bedding, ripple-cross lamination, lenticular bedding, disturbed bedding, and load convolutions are frequently observed (Figs. 14–17). S-planes not rarely show flute casts and burrows (Figs. 18, 19). Occasionally ripple marks occur in this series. The graded lamination is also observed in thin-section. Quartz (rare feldspar) occurs in angular grains and there is also detrital mica (muscovite). The groundmass is mostly recrystallized under conditions of the greenschist facies; newly grown sericite, muscovite, biotite, and clinozoisite are observed in small individuals.

Fig. 14: Metasiltite of Basal Flysch (Precambrian – Early Palaeozoic) showing graded bedding, partly disturbed by synsedimentary movements (upper left). Lesilungpa, Nimaling Mountains.

Fig. 15: Metasiltite of Basal Flysch. The bedding is heavily disturbed by bulbous load convolutions. Lesilunpga, Nimaling Mountains.

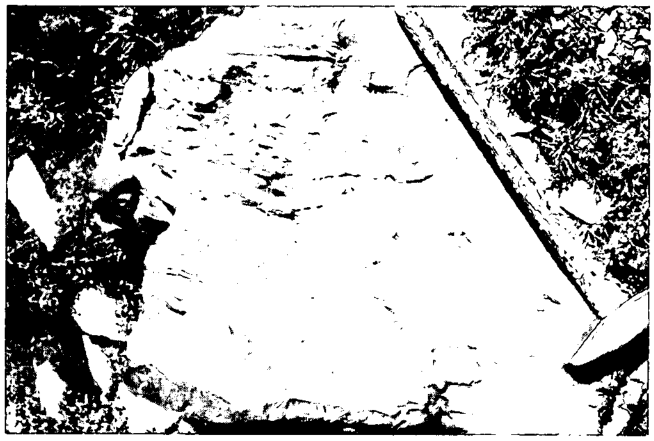


Fig. 16: Laminated metasiltite of Basal Flysch; the bedding shows synsedimentary disturbances. Lesilunpga, Nimaling Mountains.

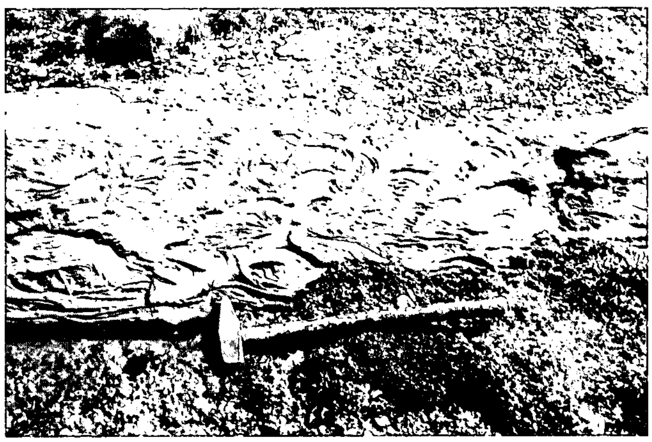


Fig. 17: Basal Flysch showing ripple-cross lamination and load convolutions. Lesilunpga, Nimaling Mountains.

The sedimentary features indicate a flysch environment with rhythmic and rapid deposition, partly from turbidity currents. The formation very much resembles the Haimantas of Spiti and most probably corresponds to similar arenaceous-argillacious formations like Martolis, Dogra Slates, Simla Slates, Hazara Slates etc. From this correlation, without fossil evidence, a Precambrian – Early Palaeozoic age is suggested.

The metagranites of the Nimaling Range form a series of smaller and larger intrusions in the Basal

Fig. 18: Basal Flysch; bulbous flute casts on s-plane of metasiltite. Lesilunpga, Nimaling Mountains.

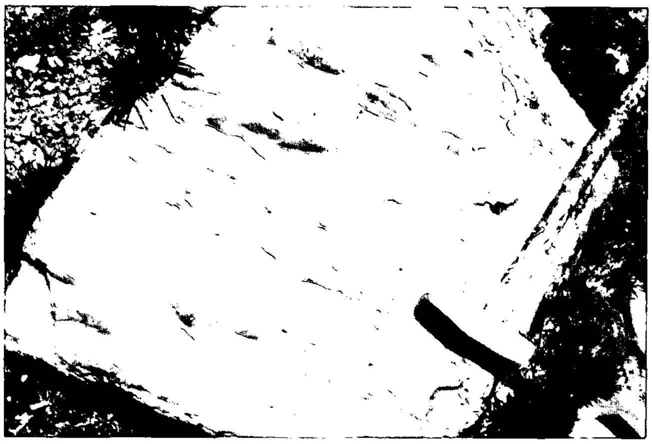


Fig. 19: Flute casts in metasiltite of Basal Flysch. N of Yar La.

Flysch Formation. There are coarse-grained porphyric two mica granites. The microcline phenocrysts are twinned (Karslbad) idiomorphic and reach sizes of 10 to 15 cm. They show inclusions of plagioclase orientated parallel to the crystal planes of the host feldspar. Some of the megacrysts are rimmed by plagioclase. There are basic fish rich in biotite, and inclusions of the country rock, mainly from the intruded flysch formation.

Under the microscope the microcline proves to be perthitic; quartz occurs in large undulous grains and fine-grained mortar aggregates; albite with polysynthetic twinning; biotite shows green-brown colour and is rich in sagenite; muscovite forms irregular flakes; sericite is mainly of secondary origin filling plagioclase and rimming the biotite; apatite, tourmaline, sphene, clinozoisite, zircon and opaques.

There are also medium-grained granite varieties and fine-grained aplite-granites poor in mica.

The granites form composite intrusions penetrating each other. The medium- to fine-grained types generally are younger. Some of the granites are almost unfoliated and others are sheared to augengneiss; we find all varieties between these extreme types. Secondary alteration, such as chloritization and sericitization are frequently observed. The granites suffered greenschist alteration like the country rocks.

6.2. The Micaschist-Dolomite Series

The dark flysch is succeeded by light green-grey, shining, phyllitic micaschists and metasiltites, which contain decametric lenticular bodies of grey dolomite showing characteristic dark rusty weathering colour. This sequence varies between 150 and 800 m thickness.

The micaschists are generally, finegrained rocks; sericite is prevailing mica; biotite is rather sporadic. Quartz forms a fine plaster together with rare plagioclase. A very fine sedimentary lamination is often recognizable, the mica does not form continuous layers and thus the micaschists break in larger plates. Weathered, the rocks show a typical smooth surface.

The dolomites are medium to light grey, finely recrystallized, rather pure carbonate rocks. A few lentils of sericite schist along shear planes and sporadic veinlets of quartz are the only impurities. The rocks are rather hard and disintegrate in blocks. The weathered surface is ochre, seen from afar the dolomites are easily recognized by their dark brown colour. Generally the dolomites occur in lenticular bodies and the question arises whether the dolomites originally formed a continuous horizon, which was disrupted by tectonics or their form is primary. As the dolomites occur in lenses all over the whole area studied and the accompanying rocks appear not so much disturbed I favour the latter view. The dolomites might have formed as algal or sponge reefs or mounds in a silty to arenaceous-argillaceous environment.

In the western flank of the Nimaling Range the schists are intruded by a small (20–30 m) body of metagabbro (sample locality 64 on the map, Pl. 2). It is a light to dark green speckled, medium- to coarse-grained schistose rock. In thin-section we find coarse intergrown green hornblende marginally replaced by chlorite, epidote-clinozoisite, chlorite and carbonate. There are sporadic flakes of brown biotite. Between the coarse hornblende aggregates there are fine-grained shear zones composed of albite, epidote-clinozoisite, sericite, and chlorite. Sphene forms large, partly skeletal and idiomorphic aggregates frequently intergrown with chlorite. The original gabbroic intrusive was sheared and altered under conditions of greenschist metamorphic grade like the granites and accompanying metasediments.

6.3. The Carbonate Series

Above the micaschists and dolomite lenses a carbonate formation follows varying between 150 and 600 m thickness. In the landscape this formation is recognized as an ochre-weathering band. Blue and blue-grey-white banded limestones are most common. Intercalated in these rocks we also find dark phyllitic schists, calc phyllites, calc-micaschists, light-coloured dolomites and carbonate quartzites. These rocks are more or less recrystallized depending on their composition; thus several of the carbonates may be termed marbles.

The stratigraphic position of the carbonate formation is between the Micaschists-Dolomite Series and the succeeding Siltite-Quartzite-Limestone Formation. SSE of the Lesilungpa grazing grounds, however, the carbonate formation is missing. There the Siltite-Quartzite-Limestone Formation follows directly above the horizon with dolomite lenses. Probably the carbonate formation is sheared out in this section, but W thereof, in the Langtang it is fully developed. Another irregularity is found in the area ENE of Khurnak, where micaschists and rusty weathering dolomites follow between the Carbonate Formation and the Siltite-Quarztite-Limestone Series. As the whole metasedimentary sequence is vertical or overturned in this area, it is more likely that this repetition is tectonic than stratigraphic. I regard this a local complication due to imbrication within one stratigraphic succession.

6.4. The Siltite-Quartzite-Limestone Series

Normally the above dealt Carbonate Formation is succeeded by a series of silty or sandy argillites, quartzites, and sporadic crinoid limestones. The thickness of this series varies between 250 and 1200 m. The argillaceous rocks are grey to dark grey phyllites, slates, silty slates passing into schistose siltstones. The quartzites are generally coarse-grained with sporadic fine-brecciaceous layers. The schistose rocks are thick-bedded. Their light colour, white, yellow, and grey, contrasts to the dark argillites and siltites associated. The quartzites form bands 5 to 30 m thick. The limestones are of grey to blue colour and show frequent remains of crinoids. Most of the limestones are more or less impure by content of sandy or silty material: angular grains of quartz and rare plagioclase, flakes of muscovite and rare green biotite, and black pigment. Part of the mica is grown during metamorphism, partly across schistosity. Though the carbonate is partly recrystallized the crinoid stems are nicely preserved. But no age determination was possible. Whereas my other samples taken from the metasedimentary succession of the Nimaling Dome proved to be devoid of conodonts, sample 83/29 is an exception. It is a crinoid bearing limestone from the uppermost portion of the formation, which yielded *Gondolella* sp. indet. The specimen was kindly examined by Dr. H. KOZUR (Geol. Surv. Budapest, Hungaria) by the good offices of Dr. L. KRYSTYN. The fossil allows a Permian to Triassic age. The fauna discovered by VIRDI et al. (1978) in limestones of the middle part of their Thaglang La Formation proves a Permo-Carboniferous age. As these authors mention crinoids also, which are rather common in the limestones of my Siltite-Quartzite-Limestone Series, I suppose that our fossils are derived roughly from the same level of the metasedimentary succession. From my experience in other parts of the Tethyan Zone I prefer a Permian rather than a Triassic age for the Siltite-Quartzite-Limestone Series on lithological basis. Particularly there is similarity to the Kuling Formation of Spiti and the Thini Chu Formation of Dolpo (Nepal).

The contact of the succeeding Lamayuru Formation is gradational and generally it is not easy to locate the boundary. Distinction is based on the absence of quartzites, a general decrease in sand-silt content, and a regular alternation of dark argillites and blue thin-bedded limestone in the Lamayuru Formation.

6.5. The Lamayuru Formation

The Lamayuru Formation is dealt in chapter 5, but a few remarks seem to be necessary on the formation in the SW limb of the Nimaling anticline. The Lamayuru Formation of the named area is composed of dark grey to black silty slates and phyllites, calc phyllites, marls, and blue, frequently impure limestones. Weathered limestones and marls show ochre surfaces. Crinoid remains are not rare.

There are zones richer or poorer in carbonates, but due to the strong internal deformation, mainly by folding, no subdivision is possible. From this reason it is also difficult to estimate the thickness of the formation which is certainly several hundred meters.

The lower boundary is a passage to the Siltite-Quartzite-Limestone Series, which in its upper parts yielded *Gondolella* sp. indet. allowing Permian to Triassic age. From lithology I prefer a Permian age (see preceding chapter). Against the succeeding thick-bedded limestones and dolomites of the Zanskar Carbonates, mainly Kioto Limestone, the boundary is relatively sharp. There is some shearing along the contacts, which is explained by the different material of the two formations. Increasing frequency of limestone beds in the Lamayuru Formation in direction to the contact suggests a stratigraphic boundary. As the Kioto Limestone commonly is regarded Upper Noric to Lower Dogger the Lamayuru Formation comprises mainly the Triassic. This is a much smaller stratigraphic range than in the northern Lamayuru belt, where Jurassic age is documented by allodapic limestones derived from the shelf (BASSOULLET et al., 1981). These klippen-like carbonate intercalations, which are so characteristic for the Lamayuru belt from Mulbekh to the Hankar region, are missing in the Lamayuru belt of the Khurnak area (SW of Nimaling Range). My explanation is: The Quartzite Series and the Kioto Limestone mark a regression in the Uppermost Triassic–Liassic all along the Tethys Zone. This regression influenced the Lamayuru basin also – by increase of shelf derived carbonate material. The northern parts of the Lamayuru facies belt were reached by a few tongues of shelf derived allodapic carbonates interfingering with the prevailing basin facies. In the southern portions of the Lamayuru facies belt, however, the regression brought shelf carbonates to rest on dark basin sediments. This shallow-water deposition was dominant until the sedimentation of the Spiti Shales (Upper Jurassic) or Giumal Sandstone (Neocomian).

It may appear inconsequent to deal with one and the same geological unit in different chapters of this paper. Thus the Lamayuru Formation of the Khurnak region was mentioned as connected with the Lamayuru Unit forming a south-eastern branch of it. In the present chapter on the metasedimentary sequence of the Nimaling Dome it is dealt as a formation of that stratigraphic succession, and in the following chapter it must be mentioned as part of the Tibetan (Tethys) Zone. This results from the connection of the named units in eastern Ladakh. The Lamayuru basin facies interfingers with the Zanskar Shelf, and the Nimaling Dome is an anticlinorium exposing continental crust of the transitional area between these facies – the continental margin.

6.6. The Age of the Metasedimentary succession of the Nimaling Dome

Before concluding the chapter on the metasedimentary sequence of the Nimaling Dome we have to discuss the geological age of this succession. There are very few evidences by fossils, and correlation on the basis of lithologic similarity must be treated with great caution because of facies changes. Such changes are to be expected, if we try to correlate between the southern and northern parts of the Tibetan (Tethys) Zone.

The succession commenced with thick monotonous deposits indicating rapid and rhythmic sedimentation in a subsiding trough. Such type of sedimentaries are very common forming the basal parts of the Tethyan Zone. They are either flyschoid silty slate-greywake-sandstone formations e. g. Dogra Slates and Cambro-Silurian of Kashmir, Haimantas, Martolis or impure calcareous series, e. g. Garbyang S., Dhaulagiri Limestone, Nilgiri Limestone. The „geosynclinal" formations are rather constant also in direction across the strike of the synclinoria. In the border range between Dolpo and Tibet which represents a large anticline, the basal formation shows the same character as in the southern flank of the Dolpo Synclinorium (FUCHS, 1977a). The Garbyang Formation with type locality in the Great Himalayan Range of Kumaun seems to mantle also the Gurla Mandata Crystalline uplift in the N (HEIM & GANSSER, 1939). Thus there is rather high degree of probability that the Basal Flysch of the Nimaling Dome does not only resemble the Haimantas, but also correlates with it.

The Micaschist Series with the rusty weathering dolomite lenses is much more doubtful. According to personal communication by Prof. W. FRANK (Geol. Inst. Univ. Vienna) such brownish weathering dolomites underlie the Ordovician conglomerates in SE-Zanskar, which suggests correlation to the Parahio Series of Spiti (M. to Up. Cambrian [HAYDEN, 1904]). There seems to be resemblance to the Karsha Formation (NANDA & SINGH, 1976), which however is regarded either as Cambrian (see BAUD et al., 1983, p. 176) or Ordovician to Silurian (THAKUR & GUPTA, 1983). Though there are fossils the age of the Karsha Formation is ambiguous. A third possibility is that the micaschists and basic intrusions, which remind of the Tanols, replace the Devonian Muth Quartzite of the Spiti-Kenlung region. Such a replacement of terrestrial-littoral arenaceous facies by a somewhat deeper silty-argillaceous facies is common in Kashmir and Chamba (FUCHS, 1975).

The Carbonate Formation succeeding the Micaschist-Dolomite Series provides the same age problem. Possibly it corresponds with the carbonates of the Siluro-Ordovician of Spiti. From the gradational contact of the Carbonate Formation to the following Siltite-Quartzite-Limestone Series, which I regard mainly as Permian (see chapter 6.4.), a Carboniferous age seems more suggestive. Comparable formations are particularly the Lower Carboniferous Tilicho Lake Formation (Nepal), Lipak Formation (Spiti), Syringothyris Limestone (Kashmir), and Tanze Formation (southern Ladakh [NANDA & SINGH, 1976]). The latter formation is termed Luneak Formation by THAKUR & GUPTA (1983, p. 13).

The Siltite-Quartzite-Limestone Formation yielded a *Gondolella* sp. from the uppermost portion of the series, which indicates Permian–Triassic age. The lithology, particularly the thicker intercalations of quartzite, resemble the Thini Chu Formation of Dolpo (Nepal) and the Kuling Formation of Spiti. Therefore a Permian age of the Siltite-Quartzite-Limestone Formation and a Triassic age of the succeeding Lamayuru Formation are suggested.

I do not doubt that these metasedimentary formations of the Nimaling Dome represent a stratigraphic sequence. The pinching out of the Carbonate Formation in the Lesilungpa area and the repetition of the Mica-schist-Dolomite Series ESE of Khurnak are probably due to tectonic disturbance. These are local faults, imbrications within one sedimentary succession, but no nappe tectonics. In case of thrusts it should be possible to trace them around the Nimaling Dome, instead of that normal stratigraphic contacts are found in adjoining sections.

7. The Tibetan (Tethys-) Zone of Zanskar

As already stressed no sharp distinction can be made between the Lamayuru Unit, the Nimaling Dome and the series of the Zanskar Synclinorium. The Nimaling-Tso Morari Crystalline represents an uplift terminating the Zanskar Synclinorium in the NE. Thus the SW-flank of the Nimaling Anticlinorium at the same time is part of the adjacent synclinorium. With the description of the sedimentary record of the Tibetan Zone I might have started also with the Basal Flysch of the Nimaling Dome. As I have already dealt with the metasedimentaries up to the Lamayuru Formation, I continue with the following formation, the Zanskar Carbonates.

7.1. The Zanskar Carbonates

In the central and southern parts of the Synclinorium almost the whole of the Triassic to Middle Jurassic is represented by well-bedded carbonate series 1000 to 1500 m thick. SRIKANTIA et al. (1980) term this complex Lilang Group using the old name Lilang of STOLICZKA (1865) and HAYDEN (1904) and subdivide into several formations. Due to facies changes the lithounits of south-eastern Zanskar are not applicable to the northern region.

Near to the northern margin of the synclinorium part of the Triassic is developed in Lamayuru facies. The Kioto Limestone (Up. Noric – M. Jurassic) shows uniform development throughout the Zanskar Synclinorium as it is found all along the Tethys Zone from Hazara in Pakistan to Nepal. The Quartzite Series at the base of the Kioto Limestone, which signals a regression all along the Tethys Zone, is not developed in the north-eastern marginal parts of the Zanskar Synclinorium. There the dark argillaceous-calcareous Lamayuru Formation is directly succeeded by Kioto Limestone.

Rocks of the Quartzite Series fine to medium-grained, cross-bedded quartzites of light grey to khaki colour were observed (not in situ) in the Khurna Valley about 6 km W of Kurio. Further NE they are missing.

The Kioto Limestone is a thin-, mostly thick-bedded formation composed of grey, blue and white limestones, dolomites and subordinate dark splintery marls and shales. Where the series is rather thick-bedded and poor in argillaceous layers, we find massive rock faces and conspicuous rock towers. The dolomites are mainly the product of secondary dolomitization. S-planes are plain or nodular. Layers of oolite, microbreccia to coarse intraformational breccia indicate a shallow agitated environment. There are also fine-grained to micritic rocks. Rare nodules of chert are observed. Fossils are corals, bryozoans, gastropods, belemnites, and crinoids. Characteristic are coarse shell beds of *Megalodon* and *Dicerocardium* respectively *Lithiotis* (Fig. 20, 21). These are rather common in the Khurna Valley around the place Kurio.

Fig. 20: Megalodon limestone, block from the Kioto Limestone, Khurna Valley W of Kurio (for scale compare rucksack in lower left).

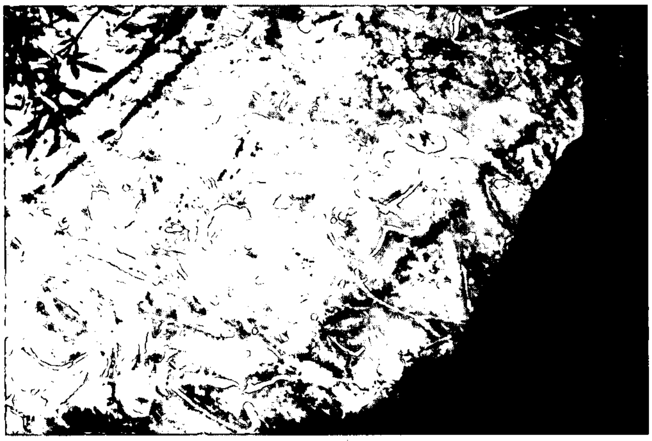


Fig. 21: Coarse shell bed in Kioto Limestone, Khurna Valley W of Kurio.

Near the upper boundary of the Kioto Limestone detrital limestones are very common: Rounded or angular fragments of micrite, calcarenite (matrix partly replaced by ore) and oolite are embedded in a sparitic matrix; crinoid stems and remains of corals and shells are not rare, but undeterminable.

At the top the Kioto Limestone becomes thin-bedded with shaley and marly intercalations and passes into the Upper Dogger or is overlain directly by Giumal Sandstone or Khurnak Formation (e. g. Kurio to Khurnak).

7.2. The Upper Dogger

In upper Khurnak the Kioto Limestone is overlain by 25–30 m of blue crinoid limestones, impure sandy limestones, and marls. This thin-bedded alternation is marked in the scenery by its ochre, ferruginous weathering colour. Besides crinoid remains belemnites are found. The shallow-water series was observed at the village Khurnak and E thereof, towards the W it is missing.

Though no determinable fossils were found, the lithology of these beds and their gradation from the Kioto Limestone suggest Upper Dogger age.

7.3. The Giumal Sandstone and the Khurnak Formation

At the Upper Jurassic – Cretaceous boundary an epirogenetic event is indicated: In north-eastern Zanskar the Upper Jurassic Spiti Shales seem to be missing at all, and Lower Cretaceous silty-arenaceous beds follow on the Upper Dogger or directly on the Kioto Limestone (see above). In this concern it may be of interest that RAINA & BHATTACHARYA (1977) and KANWAR & BHANDARI (1979) report on volcanic intercalations in the Spiti Shales of Sarchu area.

The Giumal Sandstone is a coarse-clastic formation composed of quartzites, breccias, greywackes, sandstones and silty slates, up to 250 m thick in the southern portions of the Tibetan (Tethys) Zone. In western Zanskar I observed that towards the N the thickness of the formation as well as the grain size are reduced. The Khurnak Syncline, found in the course of the 1983 Expedition in eastern Zanskar, exhibits a thick Cretaceous series, the Giumal Sandstone, however, occurs locally only and in rather small thickness. It appears to be confined to the western parts of the named syncline. There the Giumal Sandstone consists of a 30–50 m of dark grey to green, fine-grained sandstones interbedded with siltstone and silty slates. The rocks weather to brown coloured irregular splintery fragments. It is the typical lithology of the Giumal Sandstone of southern Zanskar, the coarse- and medium-grained rock types, however, are missing.

The Giumal Sandstone is succeeded by several hundred meters of a flyschoid, more silty-argillaceous series termed the Khurnak Formation (FUCHS, 1984a). In most parts of the Khurnak Syncline, where the Giumal Sandstone is missing, the Khurnak Formation overlies either the Upper Dogger or the Kioto Limestone. The Khurnak Formation consists of dark grey to greenish siltstone, and silty slate, subordinate fine-grained sandstone, carbonatic-silty shales and rare impure blue limestone. The s-planes are uneven showing zoophycus, burrows and other hieroglyphs. The series builds soft geomorphological forms and weathers in typical ochre colour, distinct from the darker brown of the Giumal Sandstone. Only some sporadic crinoids and belemnites were found, which did not allow determination of the age. Indirectly, however, the age is given by the fossiliferous marls and limestones overlying. These beds yielded a Turonian fauna, where they follow directly the Khurnak Formation, and gave Santonian – Maestrichtian age, where black slates are intercalated between the Khurnak Formation and the pelagic marls and limestones. This proves the Khurnak Formation to be pre-Turonian. Therefore it is not possible to correlate it with the lithologically very similar Kangi La Flysch, a formation of Campanian – Lower Maestrichtian age. It appears that the Khurnak Formation mainly replaces the Giumal Sandstone, partly or totally. Thus its major portion represents the Lower Cretaceous.

7.4. The Upper Cretaceous

In the core of the Khurnak Syncline pelagic marls and limestones follow the flyschoid Khurnak Formation. S of the village Khurnak these rocks occur in a squeezed syncline approximately 15 m thick. They consist of light red, grey, or green limestones and slaty marls. The rocks are dense and their content of foraminifera is recognizable by means of a lens already in the field. Dr. R. OBERHAUSER (Geol. B.-A., Vienna) kindly determined:

(83/38): *Praeglobotruncana* ex gr. *helvetica* BOLLI (frequent)
Praeglobotruncana div. sp.
cf. *Rugoglobigerina*
small Hedbergellas
cf. *Rotalipora*

Though *Globigerina helvetica* is not entirely identical with the forms of the Seewer Limestone of the Helveticum of the Austroalpine Turonian shales of the Alps, OBERHAUSER suggests a Turonian age for the above fauna.

83/39: *Rotalipora turonica thomei* HAGN
Globotruncana aff. *sigali* REICHEL
Praeglobotruncana ex aff. *praehelvetica* (TRUJILLO) – *helvetica* (BOLLI) transitional forms
Globotruncana div. sp. (partly beginning development of double carinae)
small Hedbergellas
cf. *Schackoina*
Age: Turonian (Cenomanian may be excluded).

These Cretaceous marls and limestones are associated with Upper Paleocene limestones (83/40, see chapter 7.5.) as shown by fallen blocks.

Not far from the above occurrence black silty slates are found between the Khurnak Formation and the light-coloured pelagic marls and limestones. The black slates contain sporadic dm-beds of impure carbonates. Large concretions are not rare. The series exhibits rusty weathering colour. The thickness of the black argillites is several tens of meters. No determinable fossils were found.

The black silty slates are succeeded by white, cream and grey limestones, marls and marly slates, several tens of meters thick. These rocks are rather dense. Some of the limestones are massive disintegrating to block talus. Lithologically the series is rather similar to the pelagic limestones and marls S of Khurnak, the rich foraminifer fauna, however, documents a younger age. R. OBERHAUSER (Geol. B.-A., Vienna) kindly determined:

83/43: *Globotruncana* ex gr. *elevata* BROTZEN
Globotruncana aff. *concavata* BROTZEN
other single and double carinated Globotruncanas
small Heterohelicids
Age: higher parts of Upper Cretaceous, most probably Lower Campanian.

83/44: *Globotruncana* ex gr. *stuarti* (LAP.)
double carinated Globotruncanas (div. sp.)
Age: Campanian – Maestrichtian

83/46: *Globotruncana* ex gr. *lapparenti* BROTZEN
Globotruncana (div. sp.)
Age: Santonian age is suggested by the prevalence of flat-spiral, double carinated Globotruncanas (Conacian and Campanian can not be excluded with certainty).

Thus the pelagic foraminiferal limestones and marls of the Khurnak Syncline gave a Santonian – Maestrichtian age where they are underlain by the black silty slates, where the latter are missing they are proved as Turonian. This fact suggests that the black slates replace the Turonian pelagic carbonates. Thus the interfingering of a silty muddy basin facies with rather pure pelagic carbonates in the Upper Cretaceous is indicated within a small area (Fig. 23).

7.5. The Upper Paleocene Limestones

Associated with the Cretaceous foraminiferal rocks described above we find blue and grey "nummulitic" limestones. These are generally brecciaceous and the large foraminifers occur in the fragments as well as in the matrix. In one sample 83/45 such fragmentary limestone of Upper Paleocene age is in direct contact with Upper Cretaceous pelagic limestone, as can be observed in one slide: Prof. Dr. L. HOTTINGER (Geol. Pal. Inst. Basle, Switzerland) kindly determined Globotruncanas, Heterohelicids and small indeterminable benthic foraminifers in the Upper Cretaceous portion. The Tertiary part of the slide contains:

- *Miscellanea* cf. *miscella* (D'ARCH.)
- *Alveolina* cf. *cylindrata* HOTT.?
- *Kathina selveri* SMOUT
- *Daviesina kathyaki* SMOUT
- *Opertorbitolites* sp.
- ?*Nummulites* = *Ranikothalia nuttalli* DAVIES (fragments).

This fauna proves Lower to Middle Ilerdian (Up. Paleocene) age.

Another sample 83/40 from S of Khurnak village yielded:

- *Alveolina „ovicula"* NUTTALL
- *A. subpyrenaica* LEYM or transitional form to *ilerdensis* HOTT.
- *A.* sp. div. indet.
- *A. (Glomalveolina) lepidula* SCHWAGER
- *Orbitolites biplanus* LEHMANN
- *Daviesina ruida* (SCHWAGER)
- *Daviesina* cf. *kathyaki* SMOUT
- *Lockhartia hunti pustulosa* SMOUT
- Dasycladaceas

Age: Middle Ilerdian (Up. Paleocene).

From the fact that all my Tertiary samples taken in the course of my expeditions 1976, 1980 and 1983 gave Upper Paleocene or Lower Eocene age it appears that there was a phase of non-deposition between the Maestrichtian and the Upper Paleocene. Sample 83/19, a pebble of nummulitic limestone from the conglomerate of the melange zone N of Omlung, is the only exception suggesting Middle- to Upper Paleocene age. The direct contact of Upper Cretaceous and Upper Paleocene limestone observed in slide 83/45 indicates a gap in the lower portion of the Paleocene. GAETANI et al. (1983), who investigated the Cretaceous – Early Tertiary sequence of SW-Zanskar, also came to the result that the Lower Paleocene seems to be missing.

A problem is the brecciaceous nature of the Paleocene limestones of the Khurnak Syncline. Obviously it is the product of a sedimentary process such as slumping (debris flow) or reworking in a shallow environment. Possibly synsedimentary gliding was triggered by starting tectonics, which put an end to marine sedimentation in Zanskar in the Eocene.

In the Khurnak Syncline no younger beds than the Upper Paleocene limestones are found.

8. The Markha-Nimaling Area and the Geology of Ladakh

From the descriptions in chapters 4 to 7 it is evident that the litho-tectonic zones are intimately connected with each other. Now I shall try to show them as an integrated part of the regional geology of Ladakh with the aim to reconstruct the geological history of this area.

8.1. Stratigraphy and Palaeogeography

In the area studied the oldest rock series are exposed in the Tso Morari-Nimaling Anticlinorium. The high-grade crystallines reported by THAKUR & VIRDI (1979) as Puga Formation and parts of Thaglang La Formation crop out in the eastern portions of the anticlinorium and seem to be missing in the Nimaling Mountains. There greenschist metamorphic series are intruded by discordant granites, which suffered the same alteration. The distribution of low- and high-grade crystallines is caused by the NW-plunge of the axis of the anticlinorium.

The Tso Morari Crystalline corresponds with the Central Crystalline. Both form one and the same polymetamorphic complex at the base of the Tibetan (Tethys) Zone and as such are exposed in anticlinal uplifts NE and SW of the Zanskar-Spiti Synclinorium. Where the Spiti Synclinorium ends in the Sutlej region the two crystallines actually seem to join up (HAYDEN, 1904; GANSSER, 1964 a. o.). Thus the Tso Morari Crystalline can be compared with the Gurla Mandata Uplift (HEIM & GANSSER, 1939; GANSSER, 1964) or the northern flank of the Dolpo Synclinorium, where high-grade metamorphics are exposed in the range along the Nepal-Chinese border (FUCHS, 1977a).

If we accept the correlation of the Tso Morari Crystalline to the Central Crystalline, we may expect a polymetamorphic complex, the product of Precambrian, Early Palaeozoic and Tertiary orogenies (age datings: BHANOT et al., 1977 a,b; MEHTA, 1977; FRANK et al., 1976; KRUMMENACHER et al., 1978; a. o.). The discovery of Upper Palaeozoic fossils in metamorphic rocks of the Thaglang La Formation (VIRDI et al., 1978) is consistent with the above view. There are no radiometric datings on the rocks of the Nimaling area. From the fact that the granites only penetrate the Basal Flysch and the Micaschist-Dolomite Series a Lower Palaeozoic age seems suggestive. I should like to compare the Nimaling metagranites with the intrusive granites of S-Lahul (FRANK et al., 1976) or the Suru area (HONEGGER et al., 1982).

In the Nimaling Mountains the metagranites intrude the Basal Flysch, which represents the oldest metasedimentary formation there. From its great thickness, monotony and cyclic character, which indicate rapid sedimentation in a subsiding trough, the series resembles other basal formations of the Tethyan Zone: Dogra Slates and Cambro-Silurian of Kashmir, Phe Formation of Zanskar, Haimantas of Spiti, Martoli and Garbyang Formation of Kumaun und Dhaulagiri (Nilgiri) Limestone of Nepal. These formations document trough conditions in Late Precambrian – Early Palaeozoic times in the Himalaya and, in my view, the argillo-arenaceous flysch of the Nimaling Dome correlates with them.

The succeeding Micaschist-Dolomite Series and Carbonate Series are of doubtful age as discussed in chapter 6.6. But they are definitely Paleozoic as proved by the find of *Gondolella* sp. in the overlying Siltite-Quartzite-Limestone Series. This conodont occurs in the Permian – Triassic, from the lithology, however, I prefer a Permian age for this latter formation.

The Panjal Traps (synonym Ralakung Volcanics [NANDA & SINGH, 1976]) which are represented in southern and south-western Zanskar, are missing in the Nimaling area, NE of Zanskar.

Whereas in the northern parts of the Tibetan Zone of Zanskar Palaeozoics are confined to the Nimaling Dome Mesozoics have wide extent. There are two facies: the southern shallow-water carbonate facies of the Zanskar shelf and the deeper silty-argillaceous-calcareous Lamayuru facies in the N. These two facies border each other along a tectonic plane and form individual structural units in western Ladakh. E of the Zanskar River, however, the passage zone is preserved and the shelf facies interfingers with the dark basin facies. The Nimaling – Tso Morari Crystalline represents the northern margin of the Indian Continent. It builds up the continental slope, which is exposed in the domal uplift. In the southern flank of the dome the major portion of the Triassic is developed in the dark basin facies overlain by the shallow-water Kioto Limestone (Up. Noric – L. Dogger). The argillaceous Lamayuru facies extends still further S into Zanskar and is exposed in the core of an anticline W of Kurio in the Khurna Valley.

N of the Nimaling Dome the black flyschoid Lamayuru facies represents the whole of the Triassic, the Jurassic and probably also the Cretaceous. This is proved by Triassic fossils (FRANK et al., 1977; FUCHS, 1979) the intertonguing with Jurassic carbonates slumped from the Zanskar shelf (BASSOULLET et al., 1981) and the intercalation of the Upper Cretaceous Shillakong Formation (FUCHS, 1979, 1982, 1984a). Obviously the passage from the shelf carbonate facies into the flyschoid basin facies occurs on the crest of the Nimaling Dome. As the axis of this anticlinorium plunges towards the NW, the passage zone is expected in the wide area built up by Lamayuru rocks SW of the Markha Valley. Actually the frequent intercalation of carbonates of Zanskar type makes it impossible to draw a boundary between the Lamayuru facies belt and the carbonate zone adjacent to the S. Also within the Lamayuru Unit of the Markha region a facies change is indicated: the argillaceous-calcareous Lamayuru Formation grades towards the N into flysch poor or free of carbonates. As this non-carbonate flysch is frequently associated with Shillakong Formation, it is possible that this facies change is not only lateral but also vertical. This means that the non-carbonate flysch and intercalated Shillakong Formation may represent the Cretaceous portion of the Lamayuru Unit. Along the northern margin of the Lamayuru Unit I further observed the connection of the Shillakong Formation with pyroclastics, basic flows and chert (Figs. 5, 6; Pl. 4), which suggests that the subduction zone was rather close. Thus the Lamayuru facies belt formed on the continental slope – covering the continental complex exposed in the Nimaling Dome – and in the basin N thereof. BROOKFIELD & ANDREWS-SPEED (1984) on the basis of petrologic studies suggest for the Lamayuru flysch deposition along a passive continental margin on a basin plain and also possibly on the outer part of a deep sea fan. This environment was already very close to the subduction zone in Upper Cretaceous times, as shown by my observations. Though the ophiolitic melange zone is a very much disturbed zone the primary connection with the Lamayuru Unit adjacent in the S is still recognizable: The non-carbonate flysch and Shillakong Formation of the Lamayuru Unit are in original contact with the basic volcanics and limestone klippes of the melange zone.

After dealing with the Palaeozoic succession of the Nimaling Dome and the facies changes in the Mesozoic from the shelf to the basin and right to the subduction zone, I shall review the sequence of the Khurnak Syncline, which gives information about the Triassic – Palaeocene development in the north-eastern parts of the Zanskar Shelf.

The Triassic up to the Upper Noric is developed in Lamayuru facies and is stratigraphically overlain by Kioto Limestone. The Quartzite Series is missing and appears further SW. The Kioto Limestone (Upper Noric – Lower Dogger) is a typical shallow-water sediment like the succeeding Upper Dogger. Both formations show rather uniform development all along the Tethys Zone. It is characterisic that the Triassic – Jurassic boundary is not marked, the Kioto carbonates reach from the Upper Noric into the Lower Dogger and fossils indicating the age are rather scarce. In the central and south-western parts of Zanskar the whole of the Triassic and the Kioto Limestone form one thick sequence, predominantly carbonates. This uniform development of carbonates – particularly in the higher parts of the Triassic and Jurassic – resembles the Kashmir sequence. At the present state of exploration and as leading fossils are very rare I am treating the Triassic – Jurassic carbonate complex as the Zanskar Carbonates, synonymous with the Lilang Group (SRIKANTIA et al., 1980). In SE Zanskar a subdivision seems possible (SRIKANTIA et al., 1980; BAUD et al., 1984).

The Spiti Shales (Oxfordian – earliest Cretaceous), a marker horizon of the Tethys Himalaya, is reported from the southern parts of the Zanskar Synclinorium and may attain even 150 m there (BAUD et al., 1984). In the Khurnak Syncline it is missing, where the Giumal Sandstone follows directly on the Kioto Limestone.

The Giumal Sandstone (Lower Cretaceous), which reaches 250 m thickness in the SW-limb of the Zanskar Synclinorium, is only 30–50 m thick in the NW-part of the Khurnak Syncline. It is of much finer grain size and in the major part of the named syncline it is missing at all. There the Giumal Sandstone is replaced by siltstones and silty shales of the Khurnak Formation (Fig. 22).

The Khurnak Formation is several hundred meters thick and overlies either the Kioto Limestone, the Upper Dogger or the Giumal Sandstone. It replaces the Giumal Sandstone partially or totally and hence is of Lower Cretaceous age. In agreement with BAUD et al. (1984) I accept the detritus as derived from the SW. This ex-

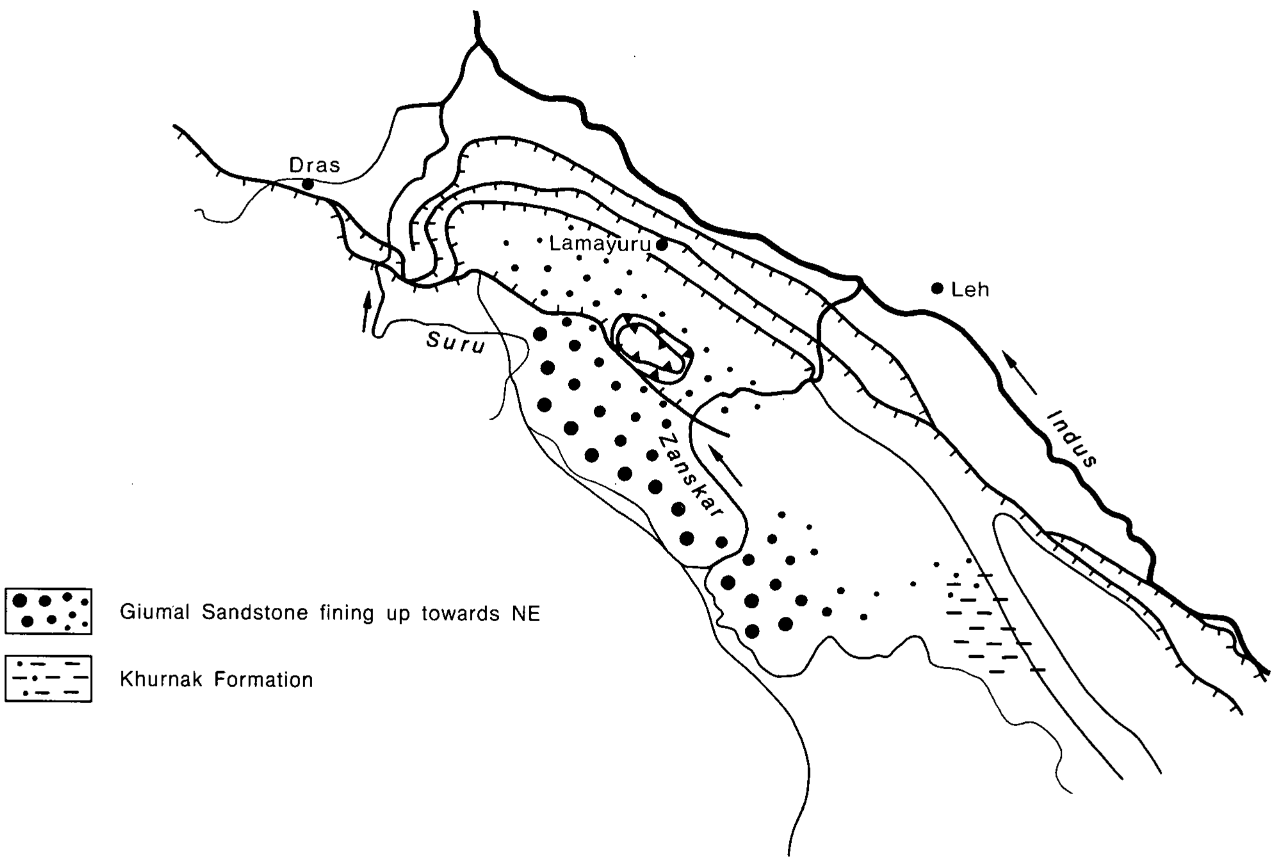


Fig. 22: Palaeogeographic sketch map for the Lower Cretaceous. The clastic material reached Zanskar from the SW and therefore it is fining up towards the NE.

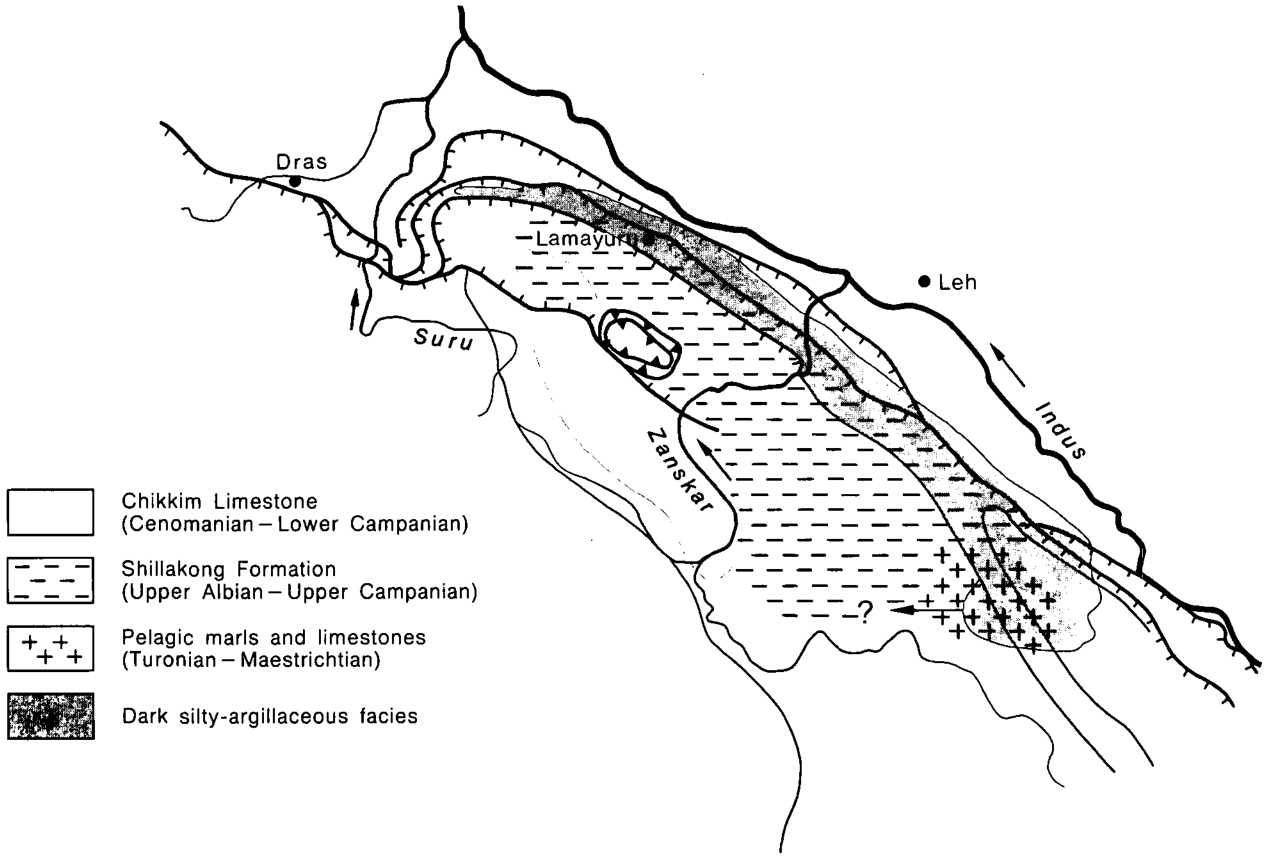


Fig. 23: Palaeogeographic sketch map for the lower Upper Cretaceous (Cenomanian – Turonian – Santonian). Shillakong facies overlaps the Chikkim facies in western Zanskar and interfingers with the basin facies in the N. Note the Turonian ingression of basin facies in the Khurnak area and later overlaps by pelagic limestones.

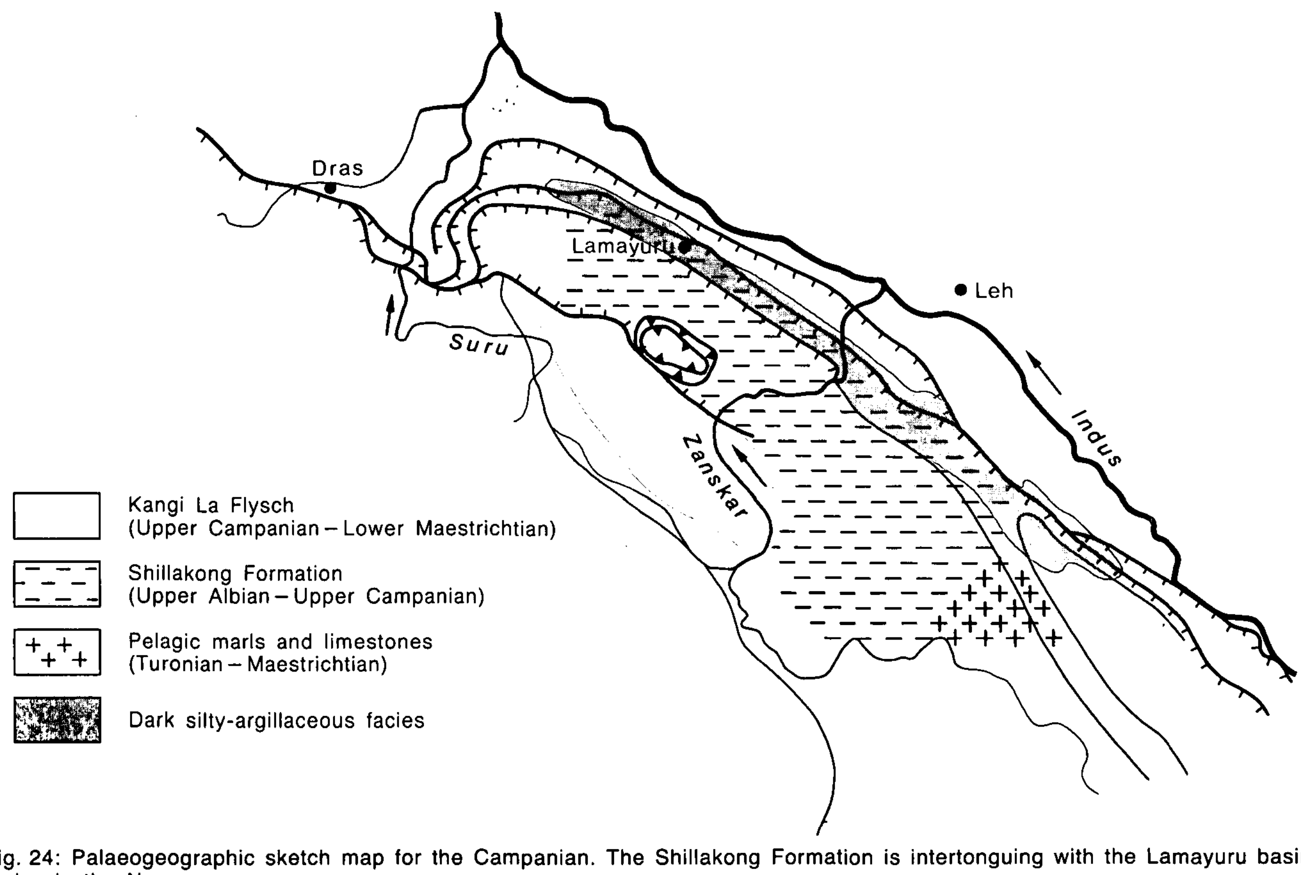


Fig. 24: Palaeogeographic sketch map for the Campanian. The Shillakong Formation is intertonguing with the Lamayuru basin facies in the N.

plains the coarser material and great thickness of the Giumal Sandstone in the SW and fining towards the NE. There it looses its sandstone character and passes into a flyschoid siltstone-shale formation, the Khurnak Formation. After a long period of shallow-water carbonate deposition under stable conditions the above clastic formations mark a significant change in the type of sedimentation. FUCHS (1979, 1982) interpreted this change as a first indication of the approaching Himalayan orogeny, whereas BAUD et al. (1984, p. 185) see its cause in eustatic sea level fluctuations (regressions). Possibly both phenomena are linked.

Regarding the environment of the Giumal Sandstone BAUD et al. (1984) envisage deposition on an outer shelf in 100–200 m depth, and BROOKFIELD & ANDREWS-SPEED (1984) suggest a shallow marine environment, but not in the high-energy coastal zone.

With the Middle Cretaceous the facies distribution becomes more complicated (Fig. 23). In northern and eastern Zanskar multicoloured pelagic shales, marls, and limestones are deposited in Upper Albian to Upper Campanian times (Shillakong Formation). This formation is intertonguing with the dark flyschoid basin facies (Lamayuru) in the N. In the Khurnak Syncline the pelagic foraminiferal marls and limestones are documented Turonian to Maestrichtian. The Turonian portion is locally replaced by black silty slates. In SW-Zanskar the Chikkim Limestone represents a pelagic, but not multicoloured facies in the Cenomanian – Lower Campanian. According to GAETANI et al. (1983) the Chikkim Limestone was deposited mainly under anoxic conditions.

In the area of the Chikkim Limestone the pelagic basin carbonates are succeeded by arenaceous-argillaceous-marly series, the Kangi La Flysch (Fig. 24). This formation is of Campanian to Lower Maestrichtian age. The detritus of this basin facies is derived from the S, because in the N the pelagic Shillakong Formation, which is free of coarse terrigenous material, was deposited at the same time. FUCHS (1982) envisaged for the Shillakong Formation sedimentation on a sill N of the Kangi La basin and GAETANI et al. (1983) speak of a pelagic plateau. For their Kangi La Formation GAETANI et al. (1983) assume the distal part of a turbiditic fan complex, whereas the lower part of the formation locally suggests muddy anoxic bottom conditions. BROOKFIELD & ANDREWS-SPEED (1984, p. 257) also state that the lithology suggests classification as distal flysch, but hesitate to accept this because of the "heavy bioturbation and stratigraphic position between deep shelf (Chikkim Limestone) and shallow shelf (Maestrichtian limestones) deposits." Thus they assume a shelf environment and stress the lithologic resemblence with sediments of foreland uplift provenance. In my view the older pelagic carbonates were deposited in a southern trough (Chikkimi Limestones) and on a northern sill or pelagic plateau (Shillakong Formation). In the Campanian – Maestrichtian the basin was filled up by detritus from the craton adjacent to the S and from limestone formations exposed in surrounding areas. The northern sill was not reached by this clastic influx. The clastic deposition was probably caused by epirogenetic movements of the Indian craton related with first disturbances in the region of the subduction.

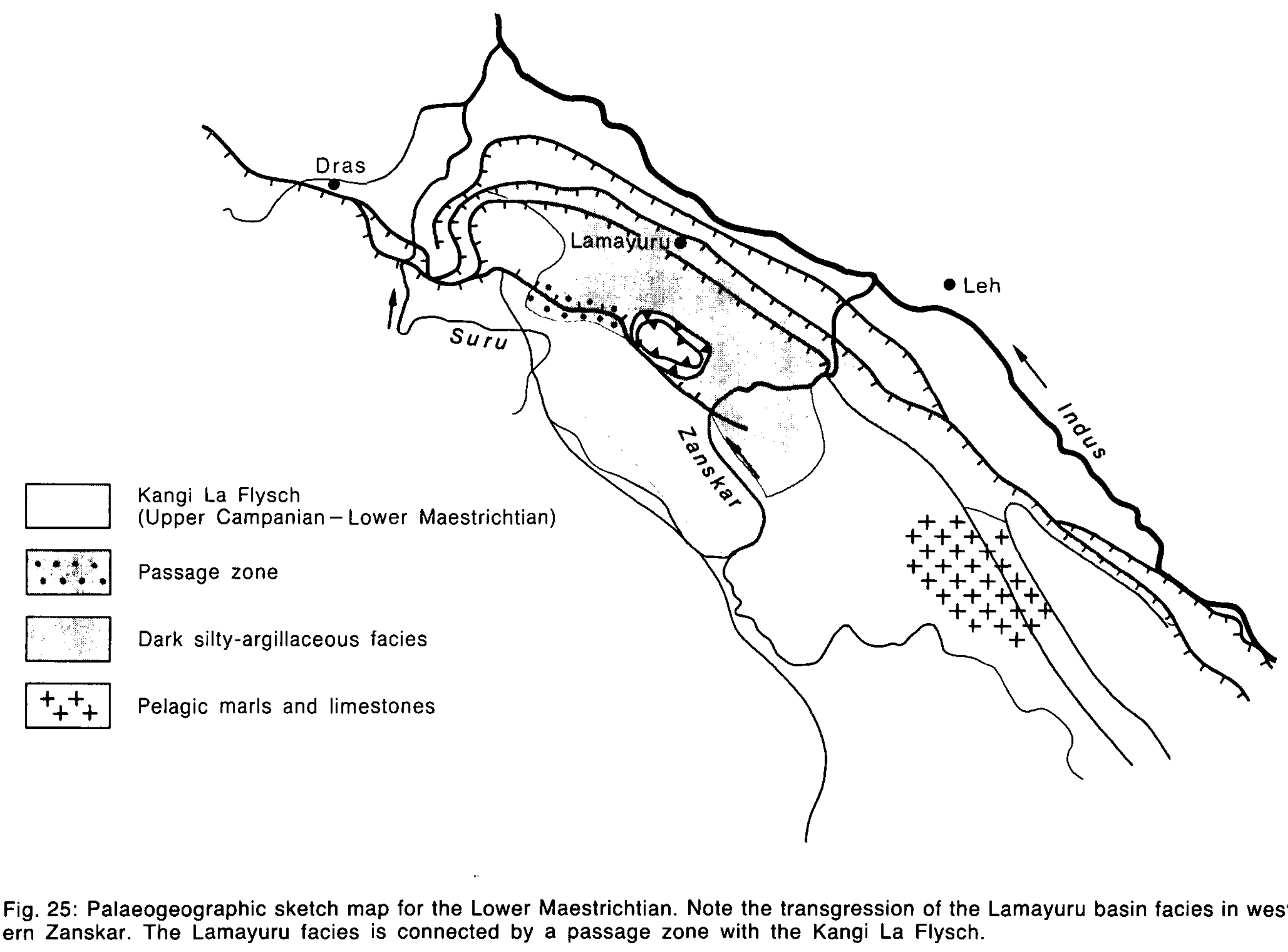


Fig. 25: Palaeogeographic sketch map for the Lower Maestrichtian. Note the transgression of the Lamayuru basin facies in western Zanskar. The Lamayuru facies is connected by a passage zone with the Kangi La Flysch.

In the Maestrichtian the Shillakong sill of western Zanskar submerged and was covered by the dark flyschoid Lamayuru facies, which became connected with the Kangi La Flysch (Fig. 25). FUCHS (1982) explains this by the approach of the Zanskar Shelf to the zone of subduction. In the Khurnak area this overlap of the Lamayuru facies is missing and the deposition of pure pelagic marls and limestones continued. But there was an older ingression of black silty argillites in the Turonian (Fig. 23).

In western Zanskar the Kangi La Flysch is succeeded by shallow-water carbonates in Upper Maestrichtian times (Fig. 26). This may be an indication that the Kangi La basin was filled up by this time. GAETANI et al. (1980, 1983) record a quartzarenite horizon marking a distinct regressive phase at the top of the Cretaceous. The Early Paleocene is missing and by the end of that time the shallow-water carbonate sedimentation resumed and extended towards the N (Fig. 27). GAETANI et al. (1983, p. 101) suggest that the littoral to sublittoral sediments of their Middle Member of the Spanboth Formation following the quartzarenite, correlate with my rusty weathering quartzites at the base of the Lingshet Limestone (FUCHS, 1982). Thus the shallow-water carbonate deposition started in the S in the Maestrichtian and after a regression and gap in the Lower Paleocene it spread to the N (Fig. 29, 30). This signals the beginning collision of the Indian Continent and the Dras Island Arc.

In the Khurnak area the Maestrichtian pelagic marls and limestones are directly followed by Upper Paleocene foraminiferal limestones. Obviously there was a hiatus in sedimentation, but no clastic beds were found between the two limestone formations like in western Zanskar.

The youngest beds of the Zanskar Synclinorium are the marine Lower Eocene Kong Slates of the Spongtang area and the Chulung La slates, a multicoloured fresh-water formation of SW-Zanskar (FUCHS, 1982) (Fig. 28). The latter is devoid of fossils, but certainly post-Paleocene, probably it marks the end of sedimentation in Zanskar with the beginning of the nappe tectonics.

By the Eocene tectonic phase, which is documented also by palaeomagnetic data (KLOOTWIJK et al., 1979), Zanskar was involved in the Himalayan orogeny. Thrust masses slid from the Indus Zone into the series of the Zanskar Shelf. As Lower Eocene beds underlie the nappes this event is well-dated. The just deposited Paleocene and Lower Eocene limestones were eroded and pebbles are found in several conglomerate or breccia horizons. Such a conglomerate deposited after this tectonic phase is sandwiched in the ophiolitic melange zone N of the Markha Valley.

From the melange zone separating the Dras Volcanics and the Lamayuru Unit in the Dras-Suru area HONEGGER (1983, fig. 9a) reports multicoloured conglomerates and breccias. These rocks occur along the boundary against the Lamayuru Unit, that is the position of the conglomerate horizon in the Markha area.

Isolated thrust masses of ultrabasics slid onto the Dras Volcanic-Flysch complex and a marked horizon of conglomerates connects these allochthonous masses (Skiu Conglomerate; ophiolitic olistostrome [BROOKFIELD, 1983]). I did not find pebbles of nummulitic limestones in the Skiu Conglomerate but in the overlying

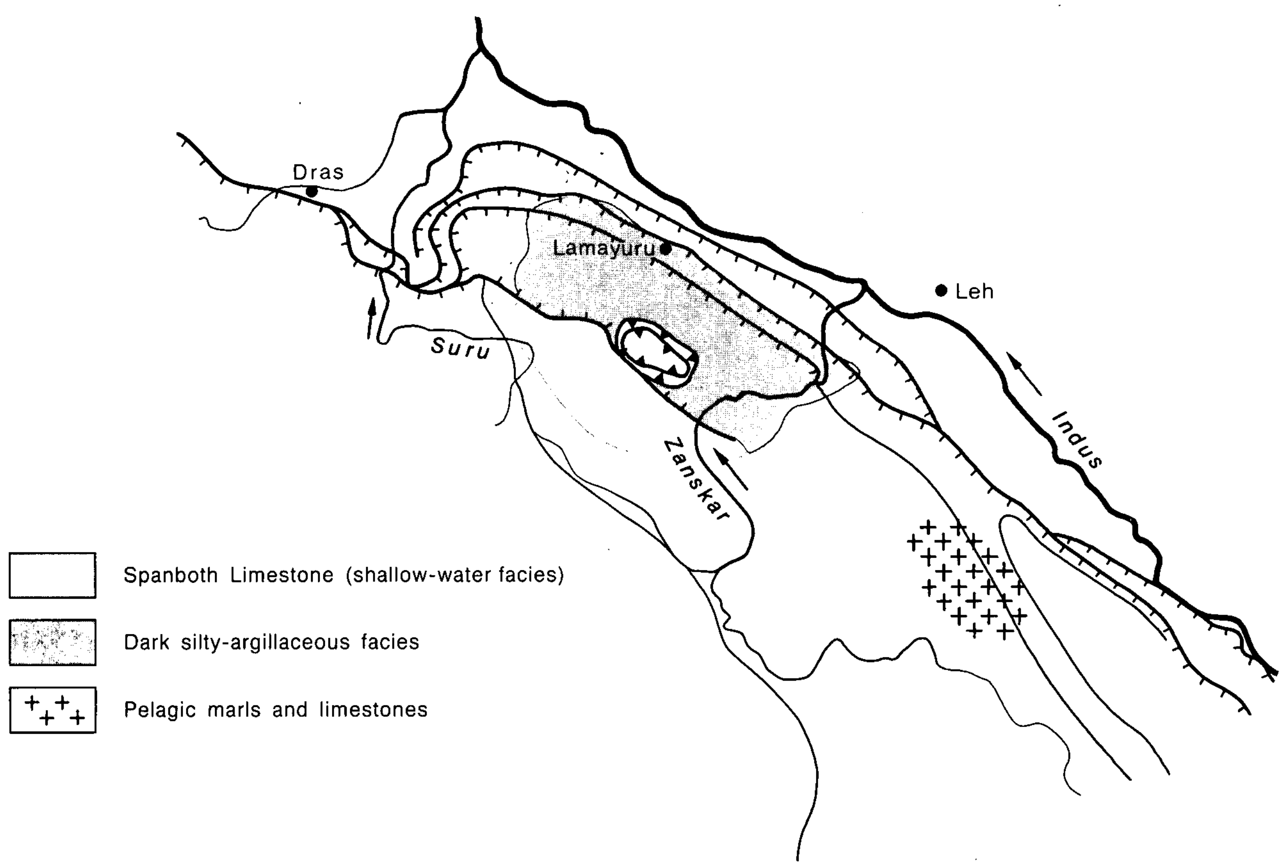


Fig. 26: Palaeogeographic sketch map for the Upper Maestrichtian.

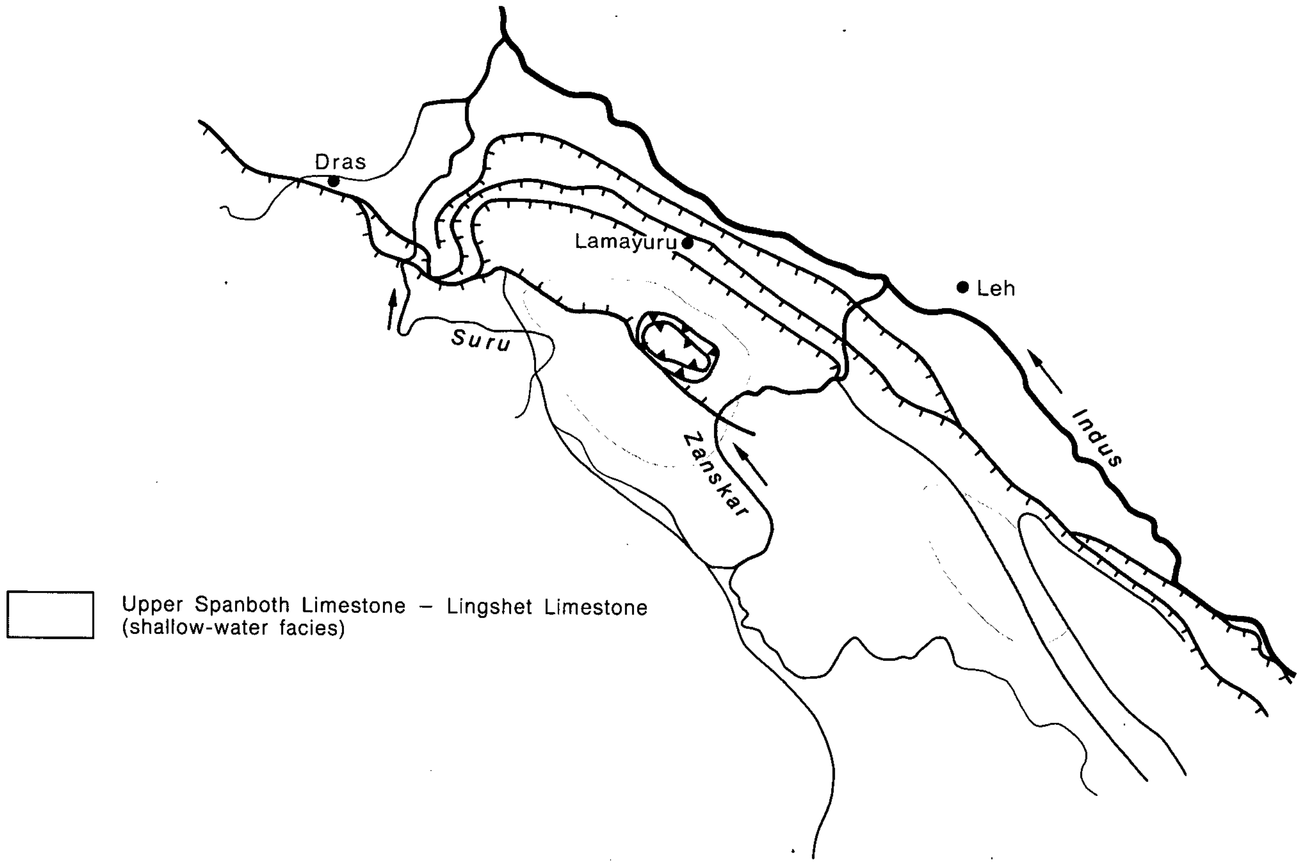


Fig. 27: Palaeogeographic sketch map showing areas with Upper Paleocene outcrops; they may have been continuous.

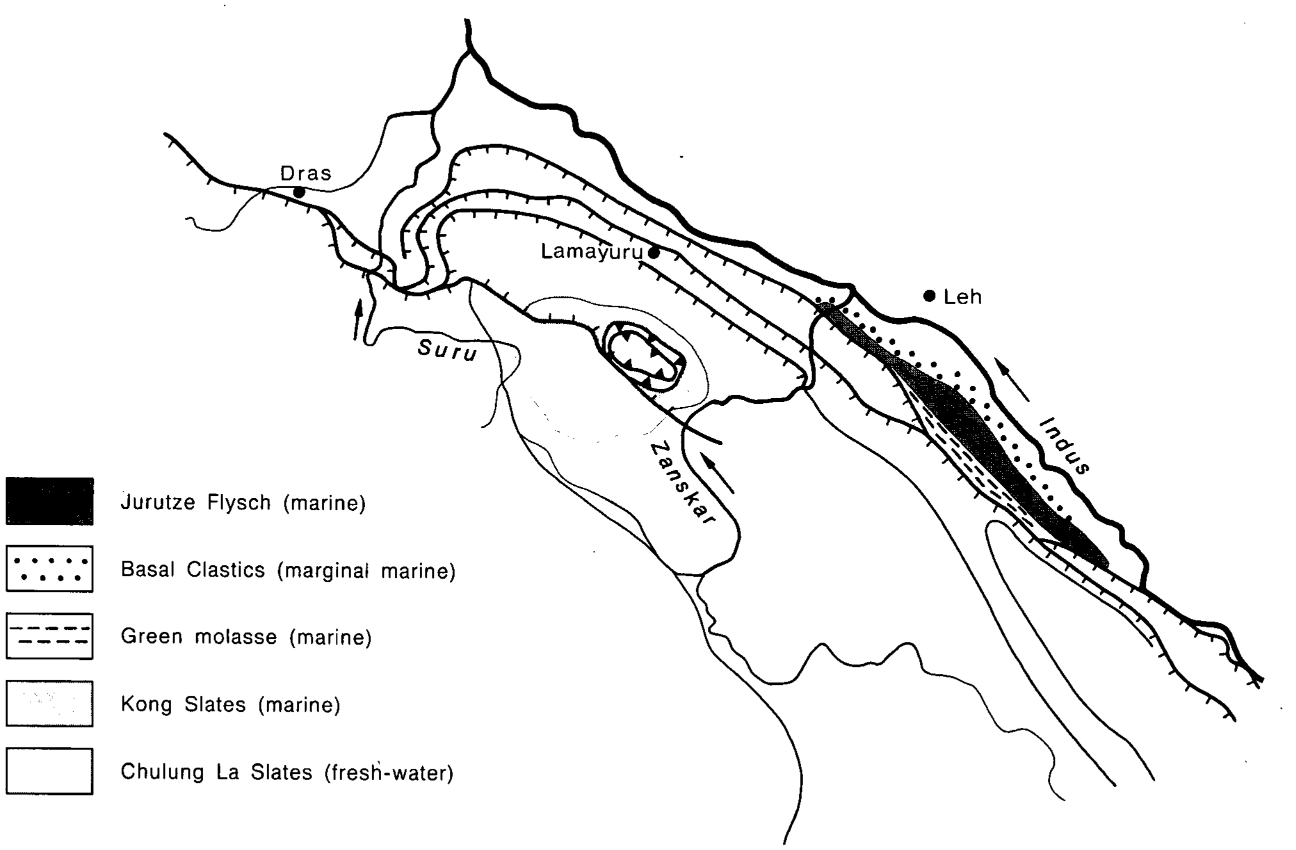


Fig. 28: Palaeogeographic sketch map for the Lower Eocene. The fresh-water Chulung La Slates seem to replace the marine Kong Slates, which formations are the youngest in Zanskar. In the Indus Molasse the Jurutze Flysch is replaced by the Basal Clastics in the N and possibly by the green molasse in the S.

Chilling Molasse developing from it. Thus this orogenic phase is marked by a coarse conglomerate horizon and the conditions of sedimentation have changed from flysch to molasse type.

THAKUR & VIRDI (1979) discovered similar molasse formations transgressing on various ophiolitic series and the Tso Morari Crystalline further E in Ladakh. These isolated molasse occurrences, which they call "Kargil Formation", are very well comparable with the Chilling Molasse, particularly in their position on the Dras Unit. Of great interest also is the report of BURG (1983) from Tibet, where he found the Conglomerates of Liuqu in the ophiolitic melange zone terminating the Xigaze (Shigatse) Series in the S. This Xigaze complex seems to correlate with the Dras Unit of Ladakh. The Liuqu conglomerate is regarded Oligo-Miocene, deposited after the first nappe movements and was affected by the later imbrications and counter thrusts. Thus conglomeratic and molasse formations formed between the major tectonic phases and appear to be rather common along the Indus-Tsang Po Suture Zone.

Finally on the Indus Molasse a few remarks are given, which may be brief, as I visited that zone only cursorily. The oldest parts of the Indus Molasse are exposed in the core of the Jurutze Anticline of the Miru Unit (BROOKFIELD & ANDREWS-SPEED, 1984, p. 270; own observations see chapter 2). This thick marine trough complex is underlain in the N in the area of Rumbok by the red Basal Clastics and Jurutze Marls. These beds suggest a marginal marine shallow-water environment, possibly a lagoon. The faunas of these basal series described by DAINELLI (1933–34) give Lower to Middle Eocene age, which indicates a lateral facies change: the Lower to Mid-Eocene portion of the flysch is replaced by shallow marine deposits towards the N. Similar facies change is observed by STERNE (1979) in the section along the Zanskar River: The Miru Conglomerate, which may correspond with the Basal Clastics, shows coarsening towards the N, and also the succeeding Eocene series reflect lateral facies variation.

S of the Stok Kangri Range adjacent to the ophiolitic melange I found a green molasse exposed in anticlines beneath the red Stok Kangri Molasse. The green molasse yielded nummulites proving an Upper Paleocene to Lower Eocene age and marine deposition. This green molasse in the S seems to correlate with the Jurutze Flysch in the N (Fig. 28).

Generally the Eocene orogenic phase put an end to the development of the Dras (Nindam) Flysch and changed the type of sedimentation to molasse. In my views the deposition of the Indus Molasse was initiated by this event. As documented by the Jurutze Flysch marine conditions persisted in the axial region of the basin at least up to the Mid-Eocene. The trough facies changes to marginal marine, as we go to the N, and probably is replaced by continental facies still further N.

The succeeding thick-bedded and often multicoloured molasse formations (Stok Kangri Conglomerate, Gongmaru La-, Rumbok-, Zinchon Molasse, Nimu Grits, etc) are continental, deposited mostly by braided rivers (BROOKFIELD & ANDREWS-SPEED, 1984). These authors noted that this younger molasse complex overlies the Eocene flysch unconformably in the northern flank of the Miru Anticline. I came to the result that the Jurutze Flysch and the underlying Jurutze Marls and Basal Clastics were folded with SW-vergency and after that were transgressed by the Rumbok Molasse. Thus another tectonic phase put an end to the marine sedimentation of the Jurutze Flysch and brought about molasse deposition in a continental environment.

8.2. Tectonics

As shown in the preceding chapters a marked structural line delimitates the Lamayuru Unit in the N, separating it from the Dras Unit or the Indus Molasse respectively. It is the Indus Suture Zone, which is partly developed as an ophiolitic melange. All the units SW of this zone of disturbance, the Nimaling-Tso Morari Dome, Lamayuru Unit and Tibetan Zone form one major tectonic unit.

The Nimaling-Tso Morari Dome is a large anticline composed of a core of high-grade crystallines mantled by Palaeozoic metasedimentaries. The Rupshu Granites form numerous intrusions in the crystallines and lowest metasedimentary formations. In the Nimaling Mountain the anticline plunges towards the NW. At Lesilungpa the succession of metasedimentaries dips towards the N at medium angles. The conspicuous fold in the Siltite-Quartzite-Limestone Series shows southern vergency. In the Langtang the strike swings around to SW and S with western dip at medium angles. Megafolds in the orogr. left slope of the Langtang Valley also show southern direction. From Zalung Karpo La to the Khurnak area the strike swings from S to the SE, whereas the dip changes from medium angles to vertical.

In the Khurnak – Yar La region the SW-flank of the dome is partly overturned with steep NE-dip. In this area also the stratigraphic sequence is somewhat disturbed, inasmuch as micaschists and dolomite lenses occur not only below but also above the Carbonate Series. The Lamayuru Formation exhibits intricate subvertical folding there. Also the succeeding Kioto Limestone is much folded, particularly in the area Kurio – Khurnak. SE of Khurnak the dip is SW at medium angles in the Kioto Limestone. S of Yar La the dip swings around to W, NW, N and finally NE. This is related with the closure of the Khurnak Syncline (see Pl. 2).

The Khurnak Syncline exposes the Mesozoic – Upper Paleocene sequence. It is a wide, almost symmetrical synform in the SE and becomes rather tight towards the NW (Kurio).

W of the Khurnak Syncline a steep and narrow zone of dark argillites marks an anticline, which seems to be continuous with a wider anticline in the upper Nari Narsang Valley (binocular observation).

SW of the above antiform a steep, narrow syncline composed of Cretaceous rocks strikes NW from the knee of the Zara River (S of Khurnak, interpretation of satellite imagery).

Between the Zara and the Zanskar Rivers the Zanskar Carbonates exhibit distinct NNW–SSE strike, which is discordant to the NW–SE trending zones of the Markha Valley. The unconformable strike is clearly shown on Landsat imagery. This conspicuous structure is related with the Tso Morari Anticlinorium plunging along NW axis. It is the convergence of the flanks of the plunging anticlinorium causing the discordant strike. The northern limb, however, is reduced by shear along the Markha zone of disturbance. The Zanskar Carbonates change from the NNW- to their normal

NW strike in the drainage divide between the Zanskar and the Yapola Rivers. Thus the Tso Morari Anticlinorium is a very important structure, which reaches even W of the Zanskar.

In the Khurnak – Markha region the Zanskar Synclinorium and the Lamayuru Zone are connected by interfingering facies. W of the Zanskar this primary coherence becomes lost and we may discern two individual tectonic units: the Northern Zanskar Unit (N. Z. U.) and the Lamayuru Unit. The horizontal displacement between these units increases towards the W, being about 20 km in the Phulungma – Wakha Chu area (see Pl. 1). It is an interesting question, why the adjacent facies belts are less disturbed in the SE. I think it was the Tso Morari Crystalline, a rigid mass underlying the zone of facies change, which preserved it from tectonization. Further, in the NW-plunging anticlinorium the southwestern limb, if followed SE, becomes more distant from the highly disturbed Suture Zone (Pl. 1, 2). This zone is very much affected by the younger N-directed movements (counterthrusts), which are responsible for the 20 km displacement in the Wakha area mentioned above. Farther away from the Suture Zone, in the southwestern flank of the anticlinorium the facies belts remained connected.

There is not much information about the vast terrain of the Zanskar Carbonates. KELEMEN & SONNENFELD (1983) discovered three synclines composed of Cretaceous formations on their adventurous boat trip down the gorge of the Zanskar. The vergency of these folds seems to be NE.

Another traverse was made by BAUD et al (1982b, 1983) along the Zumlung, Chirche, Nari Narsang and Langtang Valleys. In the area of Charcha La and upper Zumlung Valley they found a major syncline. The core consists of Shillakong Formation. From BAUD et al. (1982b, Fig. 4) and Landsat imagery it is apparent that the SW-limb is well developed, whereas the NE-limb is sheared. Zanskar Carbonates come in contact there with the Upper Cretaceous series along a reversed fault dipping NE. The distinct brown colour of the Giumal Sandstone and light colour of the Mid–Upper Cretaceous allows to trace the syncline further SE. Also E of the Zara River patches of the Cretaceous formations mark the trend of the synclinal axis. The most southeastern synforms are close to Lachung La (Manali – Leh road).

SW of this Zumlung Syncline BAUD et al. (1982b) found another syncline in the area of Zang La. The syncline pinches out in the lower Zumlung Valley, but widens towards the NW to a synclinorium (Pl. 1). The Spongtang Outlier forms the core of this large synform (FUCHS, 1977b, 1979, 1982; BASSOULLET et al., 1980, 1983; REIBEL & REUBER, 1982; KELEMEN & SONNENFELD, 1983, a. o.). The NE-limb of the syncline is sheared by a reversed fault, the Kangi-Naerung Fault (KELEMEN & SONNENFELD, 1983), and is partly overturned towards the SW. This is similar to the Zumlung Syncline.

W of the Zanskar the above synclinorium is disturbed by another tectonic plane. This thrust terminates the Northern Zanskar Unit (N. Z. U.) in the S (FUCHS, 1982). Though there are certain differences in the stratigraphic development N and S of this disturbance, the horizontal displacement is a few km at the most. It is a wedge structure, which seems to lose its importance when followed towards the SE. Like all the other named reversed faults it is a scale structure post-dating the thrust of the Spongtang Nappes and the isoclinal folding of the Zanskar sedimentaries. In my view these imbrications are caused by late compression, which also formed the fan structure of the Honupatta Anticlinorium (KELEMEN & SONNENFELD, 1983). The scales of central Zanskar are hading N or NE, whereas they dip S or SW at the northern margin of the Zanskar Carbonates and in the Indus Zone (counterthrusts). These disturbances are to be understood as a fan-shaped system of scales, the product of late compression, but has nothing to do with nappe tectonics, which have preceded.

After dealing with the regions S of the Indus Suture Zone we shall consider this complicated belt.

The Lamayuru Zone of the Markha Valley reflects the domal structure of the NW plunging Tso Morari Anticlinorium: It dips WSW to SW at medium angles beneath the Zanskar Carbonates; towards the Markha Valley the dip becomes gently NE and steepens to subvertical. The fold axes plunge towards the NW, partly at rather steep angles. The domal structure is responsible for the widening of the Lamayuru Zone in the Markha area and its branching. In the Zanskar Valley the Lamayuru/Zanskar Carbonates contact is tectonic. Steeply folded carbonates override the Lamayuru Formation, which is squeezed NW of Chilling (Pl. 3 [1], Fig. 4). From Landsat imagery it appears that a large mass of ultrabasics overlying the Dras Unit is in tectonic contact with the Zanskar Carbonates. These moved NE-wards on a counterthrust (Zanskar Thrust [FRANK et al., 1977]). The displacement along this thrust increases towards the W. In the type area the Lamayuru Unit shows isoclinal SW-dipping structure and is sandwiched between the Zanskar Carbonates and the Dras Unit.

A zone of disturbance demarcates the Lamayuru Unit in the NE. In the Chilling – Skiu area it is a SW-dipping thrust, from Chaluk eastwards it is an ophiolitic melange zone like in the Mulbekh – Lamayuru region. The melange zone is particularly well-developed, where the Dras Unit pinches out N of the village Markha. There are large klippes of exotic limestones and the melange zone shows considerable thickness. I think that this development is related with the branching of the melange zone and the end of the Dras Unit. Further SE the melange zone consists of a 200–300 m thick belt marked by ultrabasic blocks in a matrix of flysch, radiolarites etc. and a band of conglomerate or breccia. As already noted there is no sharp tectonic line between the Lamayuru Unit and the ophiolitic melange of the Chaluk – Omlung area. These are primarily linked and the significant thrust is N between the ophiolitic melange and the Chilling Molasse of the Dras Unit.

The Dras (Nindam) Unit composed of basic to intermediate volcanics and flysch is an important element of the Indus Suture Zone. In the Khalsi region this belt can be subdivided into the southern Dras Unit and the Indus Flysch in the N (FUCHS, 1977b, 1979). The two units are separated by ophiolitic melange. The northern flysch is called the Khalsi Flysch by BROOKFIELD & ANDREWS-SPEED, 1984).

E of the Zanskar River the whole flysch-volcanics complex is reduced and ends somewhere E of the Shingo – Skiu section. BROOKFIELD & ANDREWS-SPEED (1984) accept this eastern extention as the Khalsi Flysch (my Indus Flysch), whereas I prefer to correlate it with the Dras Unit (Pl. 1). From the lithological studies of the named authors (p. 262–265) the rocks of

Shingo show more resemblance to the Nindam Flysch, which is mainly a distal turbidite facies, than to the coarser-grained Khalsi Flysch. Further the Khalsi Flysch is associated with Mid-Cretaceous shallow-water (Khalsi) limestones, which are missing in the SE. From the Zanskar River STERNE (1979) reports on Khalsi Limestone and accompanying flysch forming a wedge between his Zanskar Flysch (= Dras Unit) and the Indus Molasse. STERNE correlates this scale to the Indus Flysch of the Khalsi area. The bands and lenticular bodies of the Khalsi Limestone can be traced by their light colour on satellite imagery (Pl. 1). From their strike STERNE seems to be right in his correlation: His Mid-Cretaceous limestone and associated beds appear to represent the south-eastern end of the Indus Flysch. This unit forms a wedge N of the Dras Unit, extending from the Zanskar Valley to somewhere W of Khalsi. I assume that the Indus Molasse of the Zanskar Valley, particularly the three anticlines studied by STERNE, plunge beneath the Indus Flysch in the range W of the valley. Thus I accept the Indus Flysch overriding the Indus Molasse along a counterthrust.

Whereas the Indus Flysch (= Khalsi Unit [BROOKFIELD & ANDREWS-SPEED, 1984]) represents a wedge extending from the Khalsi area to the Zanskar Valley, the Dras Unit is the more important structural element, continuing from the Dras region to the Markha area. So, contrary to BROOKFIELD & ANDREWS-SPEED I correlate the flysch-volcanic series S of Shingo with the Dras Unit.

The Skiu Conglomerate (= olistostrome, BROOKFIELD & ANDREWS-SPEED) follows stratigraphically on the Dras Flysch-Volcanics and passes into the succeeding Chilling Molasse. Satellite imagery shows that the Skiu Conglomerate connects ultrabasic masses of NW Chilling and N of Chaluk. This provides very important information: The ultrabasics slid as thrust masses onto the Dras Unit and this tectonic event is marked by the Skiu Conglomerate (= olistostrome). After this post-Upper Paleocene tectonic phase sedimentation changed from flysch to molasse type. Structurally the Chilling Molasse forms the youngest part of the Dras Unit. In the Chaluk section the Chilling Molasse overlies the northern ultrabasic mass, but is overthrust by the southern one. This documents that also after the sedimentation of the Chilling Molasse ultrabasics slid onto adjoining zones. The Chilling Molasse, and thus the Dras Unit, is terminated by a SW-dipping thrust against the Lamayuru Unit. N of Markha the Dras Unit pinches out between bifurcating ophiolitic melange zones. The ending of the Dras Unit was recognized by BAUD et al (1982b, Fig. 2), but they accepted the Chilling Molasse as a part of the Dras Flysch-Volcanics.

From the paper of THAKUR & VIRDI (1979) it appears that the Dras Unit comes in again along the Suture Zone NE of Debring. The authors further report on occurrences of "Kargil Formation" (= molasse) transgressing on various units. I should like to compare these molasses with the Chilling Molasse, which, however, is affected by younger N-directed thrusts. THAKUR & VIRDI do not mention such disturbances.

The Dras Unit is terminated by a thrust also in the N. Along the subvertical thrust the NE-dipping beds of the Indus Molasse abut discordantly. S of Shingo, where this thrust separates the Dras Flysch-Volcanics from the Jurutze Flysch of the Indus Molasse (s. l.), there is no indication of an ophiolitic melange like N of Markha-Omlung.

E of Shingo the Jurutze Flysch is cut obliquely to its strike by a subvertical thrust. A series of decametric blocks of limestone occur along the zone of disturbance. Judging from the float multicoloured molasse adjoins on the eastern side of the thrust (see Pl. 2). BROOKFIELD & ANDREWS-SPEED (1984, Fig. 11) show Khalsi Flysch in their map. However, from the lithology of these multicoloured conglomerates, sandstones, and shales, which are very different from the rocks of the Dras Unit SW of Shingo, I am rather certain that it is younger molasse (Stok Kangri). But I do not fully understand the nature of the disturbance. The limestone blocks suggest a thrust and not a simple vertical fault. Possibly it is a wrench fault, which spreads off from the thrust demarcating the Dras Unit in the N. Section 3 of Pl. 3, which is approximately parallel to the discussed thrust, does not show the relations properly: It gives the impression of a horizontal nappe, which is not the case, because the zone of disturbance is subvertical.

Concerning the tectonics of the Indus Molasse a few remarks are given. The Ganda La traverse (Pl. 3 [3]) shows a large anticline in the Jurutze-Rumbok area, which continues to Miru in the SE (BAUD et al., 1982b; BROOKFIELD, 1984) and to the Zanskar River in the NW (N of Sumdah Doh, STERNE, 1979). Obviously the marine Eocene Basal Clastics and Jurutze Flysch, which form the core of the anticline, were folded before the transgression of the multicoloured fresh-water molasses. Thus the basal red series, which form several subsidiary antiforms, come in contact with the younger molasse, and the Jurutze Flysch, which is to be expected in between, is missing. This points to an erosive phase after the first folding, and then the younger molasses were deposited on the denuded older fold complex. Finally the whole pile of molasses was folded. The subsidiary antiforms of the basal series show SW-vergency, whereas all the folds in the younger molasses are directed NE.

8.3. Is the Tibetan Zone Allochthonous? – a Discussion

Since BAUD et al. (1982 a, b, 1983, 1984) suggested the Zanskar Synclinorium to be allochthonous, consisting of a pile of nappes, the tectonic nature of the Tibetan (Tethys) Zone became a problem of primary importance. In case that the Zanskar Synclinorium is really found to be allochthonous, the whole of the Tibetan Zone and the Kashmir-Chamba Synclinoria are to be regarded as thrust sheets and their contact to the underlying Central Crystalline is tectonic. In my paper 1984b I put reasons against this view and a series of arguments come from my work in the Markha-Nimaling area.

The northern margin of the Zanskar Synclinorium can be studied in the named region. According to BAUD et al. (1982b, 1983) the Langtang Group (schistes lustrés) underlies the Zalung Karpo Unit and Khurna Unit, which are subunits of the "Zanskar Nappes". These comprise the Triassic–Jurassic carbonates, whereas the Langtang Group consists of a dark calcareous argillite complex of great thickness. With tectonic contact the Langtang Group overlies the quartzites and dolomites representing the metasedimentary mantle of the Nimaling Crystalline. The latter forms a dome, which in its northern flank again is succeeded by the Langtang Group. Along a steep tectonic plane the Langtang Group borders to the Markha Unit, which is correlated with the Lamayuru Unit by BAUD et al. The Markha Unit and Dras-Nindam Unit make up the Suture Zone. It appears that BAUD et al. regard their nappes (Ringdom-Phugtal Unit, Zangla Unit, Zumlung Unit, Khurna Unit and Zalung Karpo Unit) derived from the Suture zone. That implies that the nappes building the Tibetan (Tethys) Zone have their roots in the Suture Zone, N of the Nimaling Dome.

I disagree with the above views of BAUD et al. from following reasons:

1. The Langtang Group and the Markha Unit form one inseparable complex, which represents the Lamayuru Unit of western Ladakh.
2. This Lamayuru complex is stratigraphically linked with the metasedimentary series of the Nimaling Dome and with the Zanskar Carbonates in the S. The Nimaling metasedimentaries represent the Precambrian–Palaeozoic part of the stratigraphic sequence, the Lamayuru Formation the Triassic–Jurassic– Cretaceous (?) part (northern limb of the Dome) respectively Triassic portion (southern limb). The Zanskar Carbonates interfinger with the Lamayuru complex, gradually replacing it laterally towards the S. The Kioto Limestone of the Khurnak area follows stratigraphically on the Lamayuru Formation and does not represent a separate structural unit (Zalung Karpo Unit on Langtang Group, BAUD et al.). Contrary to BAUD et al. I did not find nappe boundaries, but was surprised that units, which are tectonically separated in western Ladakh, are stratigraphically connected in eastern Ladakh. There are lokal disturbances within one stratigraphic succession, but not thrusts terminating nappes. The pinching out of the Carbonate Series S of Lesilungpa, or the reduplication of the Micaschist-Dolomite series E of Khurnak may be cited. The folds in the Siltite-Quartzite-Limestone Series of Lesilungpa or the recumbent folds of the Langtang Valley show SW-vergency and document tectonic pressure acting from the NE. Shearing led to the local pinching out of formations in the NE flank of the dome. In the SW-limb, in the pressure shadow, folding and imbrication caused reduplications. There the succession up to the Lamayuru Formation is locally overturned towards the SW. The boundary between the Lamayuru Formation and the succeeding Kioto Limestone not rarely is tectonized, but this is due to the contrasting material of the two formations.
3. The Nimaling – Tso Morari Crystalline is an anticlinorium, which brings up the basal portions of the Tibetan Zone. It is comparable to the Gurla Mandata Uplift of Kumaun Himalaya (HEIM & GANSSER, 1939; GANSSER, 1964) or to the anticline along the Nepal-Tibet border in Dolpo (FUCHS, 1977a). The Nimaling Dome is very close to the Suture Zone and this shows us the stratigraphic development just at the margin of the Indian Continent. The thick Lamayuru complex overlapping the Nimaling Dome indicates that in the Mesozoic the Nimaling region formed the continental slope down to the Lamayuru basin.

Thus in my view it is not possible to draw nappe boundaries between the carbonate sequence of Zanskar, the succession of the Nimaling Dome and the Lamayuru belt. The named complexes are still intimately linked and therefore allow the reconstruction of the facies pattern (see chapter 8.1.).

There are also a series of arguments against the allochthony of the Tibetan Zone from outside the Markha-Nimaling area (FUCHS, 1984b), which shall be mentioned briefly in this paper:

1. There are no remnants of a root zone of the "Zanskar Nappes". The exotic limestone klippes of the ophiolitic melange zone are of different type and therefore can not be regarded as the root of the Zanskar Carbonates.
2. Outliers of the "Zanskar Nappes" are missing. In the Spongtang Outlier and the large thrust sheets of Tibet the ophiolitic series form the highest tectonic units and the thick Tethyan Series are always at the base. THAKUR & VIRDI (1979) record three outliers of ophiolite complexes resting directly on the Tso Morari Crystalline. According to the views of BAUD et al. (1982b, 1983) the "Zanskar Nappes" are to be expected between these ophiolite klippes and the crystallines. As there is no trace of the "Zanskar Nappes" it is highly improbable that they were transported across the Tso Morari Crystalline.
3. BAUD et al. (1982a, 1983, 1984) subdivide the Tibetan Zone into 5 nappes, but in their general cross-section they show the folded Precambrian – Cretaceous sequence of the Zanskar Synclinorium disturbed by a series of imbrications. Such a tectonic style is known from many regions and is typical for the Tibetan Zone, but does not suggest the existence of nappes. Further it is surprising that the assumed thrusts did not disturb the stratigraphic sequence of formations. Normally thrusts are recognized as such because older series rest on younger ones. But according to the sections (BAUD et al., 1982a, 1982b, Fig. 4; 1984, Fig. 3) the stratigraphic order seems to be preserved; figures 9 and 10 suggest that the Upper Palaeozoic unconformity was accepted as a thrust by BAUD et al. (1984). Thus it appears that stratigraphic boundaries, somewhat tectonized because of material differences, were mistaken for nappe boundaries.
4. BAUD et al. (1982 a,b, 1983, 1984) suggest a thrust also between the Central Crystalline and the succeeding sedimentaries (Phe-Formation). Considering the whole of the Tibetan Zone and the Kashmir- and Chamba Synclinoria, we come to the result that normally there is a passage from the sedimentaries to the Crystalline (GRIESBACH, 1981, p. 209; HAYDEN, 1904, p. 9–10; HEIM & GANSSER, 1939; FUCHS, 1967, 1975, 1977 a,b; BORDET et al., 1971, 1975; GANSSER, 1983; HONEGGER et al., 1982; HONEGGER, 1983). Alteration increases gradually and the metamorphics still show the sedimentary characteristics of the overlying formations. No doubt, the upper portions of the crystallines consist of altered parts of the Tethyan succession. My observations that even the Mesozoic carbonates have become high-grade crystallines in the Nun-Kun area (FUCHS, 1977b) are proved now by the careful and detailed studies of HONEGGER (1983). It is impossible there to separate the Tethyan series as allochthonous masses from the Central Crystalline.

Locally the contact crystalline-sedimentaries may be tectonic (e.g. Malari Fault [SHAH & SINHA, 1974]). BURG

(1983) observed tectonic contacts N of Everest. In his view the sedimentary sequence dissociated from the crystalline and slid along N-dipping planes following gravity, when the Great Himalaya was uplifted. But all that does not mean that the Tibetan Zone represents a nappe. In such a case nowhere a primary connection of this zone with the underlying crystallines should exist. Contrary this is normal.

BAUD et al. (1982b, 1983) correlate their "Zanskar Nappes" to the "Zanskar-Shillakong Nappe" of western Zanskar (BASSOULLET et al., 1983). These authors were misled by the fan structure of the carbonate belt of the Honupatta-Photaksar area to accept it as a nappe. If followed to the W the fan structure disappears and it is evident that the rocks of the "Zanskar-Shillakong Nappe" are a part of the Triassic–Eocene sequence underlying the Spongtang Klippe (FUCHS, 1982). Thus it belongs to the Tibetan Zone (s. l.) and does not form a higher nappe. The Lamayuru Formations around the Spongtang Outlier overlie the series of the "Zanskar-Shillakong Nappe" in the W and the SE (see Pl. 1; FUCHS, 1982, Pl. 1,2) and thus can not be connected beneath the Honupatta carbonate belt with the Lamayuru Zone in the N.

The very complicated evolutionary picture of the French geologists (1983, Fig. 11) is not consistent with the present day geology. So they do not take account of the Paleo-Eocene sequence underlying the Spongtang Outlier. This is evidence that the Spongtang Nappes were thrust onto Zanskar in the Eocene and not in the Upper Cretaceous.

There is no indication that the Dras Formation represents a synform underlain by Lamayuru Flysch as shown by the French geologists; there exists no Lamayuru zone between the Dras belt and the Indus Molasse; the dark flyschoid beds of the melange zone at Hangru in the Yapola Valley were mistaken by the French as Lamayuru Flysch, which seems to have caused the above assumption.

The "Himalayan (Tethysian) Series", parts of the "Lamayuru Flysch" and the "Mesozoic Tethysian Series" and Up. Cretaceous "Fatula Limestone" of the "Zanskar-Shillakong Nappe" form one stratigraphic complex. This is evident in the area of the upper Phulungma – Wakha – Kangi Valleys and in the Lingshed region (FUCHS, 1982). Therefore the named units can not belong to three different structural units as opined by BASSOULLET et al. (1983).

Thus a "Zanskar-Shillakong Nappe" exists neither in western nor in eastern Zanskar.

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