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On the Geology of the Suture Zone and Tso Morari Dome in Eastern Ladakh (Himalaya)

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7 Text-Figures

Indien
Ladakh
Himalaya
Tso Morari
Stratigraphie
Tektonik

Contents

Die Geologie der Sutur-Zone und des Tso Morari-Domes in Ost-Ladakh (Himalaya)

Zusammenfassung

Der vorläufige Bericht bringt die Ergebnisse unserer Feldarbeit im Tso Morari Gebiet und in der Suturzone im Bereich Tiri-, Kiari-, Kalra- und Changlung-Gebiet. Außerdem enthält der Bericht die Ergebnisse der mikropaläontologischen Bearbeitung der Proben durch I. PREMOLI SILVA (Univ. Milano).

1) Die Eklogite des Tso Morari Gneiskomplexes wurden von BERTHELSEN (1953) entdeckt und von GUILLOT et al. (1995) im Nordflügel des Tso Morari Domes studiert. Wir fanden die Eklogite auch im Südflügel des Gneiskomplexes. Dies zeigt eine Versenkung des ganzen Kernes an.
2) Die Sedimentserien des Domes zeigen noch Sedimentstrukturen und sind höchstens amphibolitfaziell metamorph. Sie haben sicher nie eklogitfazielle Bedingungen erlebt.
3) Während die Sedimentfolge des Tso Morari-Domes im NW ziemlich komplett entwickelt ist, wird die Karzok Synklinale vorwiegend von permo-mesozoischen Gesteinen aufgebaut. Das Perm besteht aus Seichtwasserkarbonaten, Quarziten und Schiefern, die mit Laven und pyroklastischen Gesteinen des Panjal Trap, mit Serpentinit und Chromit vergesellschaftet sind. Darüber folgt die Lamayuru Formation mit einem Basiskonglomerat. Serpentinit und Chromit repräsentieren somit nicht Teile einer Ophiolitdeckscholle, sondern sind mit dem permischen Vulkanismus (Panjal Trap) verbunden. Das Permo-Mesozoikum wurde in einem Graben abgelagert, der durch permisches Rifting entstanden ist. Das Rifting ist möglicherweise verantwortlich für die Loslösung des Nordrandes der Indischen Kontinentalplatte und die spätere tiefe Versenkung bei der alpidischen Kollision.
4) Die Lamayuru Zone kann auch im Untersuchungsgebiet weiter verfolgt werden. Dabei repräsentiert sie das Mesozoikum der Nordflanke des Tso Morari Domes. Im Sumdo-Puga-Gebiet ist die Lamayuru Formation mit dem Gneiskomplex durch gemeinsame Regionalmetamorphose innig verbunden.
5) Der Tso Morari Dom und die Lamayuru Zone sind im NE durch eine Sutur begrenzt, entlang der Linsen von Flysch, Melange und Klippen von Ultramafitit, Basalt, Kalk und Hornstein auftreten. Dieses Lineament kann von Omlung über Lato, Rumtse, Kiameri La bis zur Zildat Melange verfolgt werden.

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6) Wir vermuten, daß die vulkanischen Komplexe aus Basaltbrekzien, Radiolariten und Flysch im Tiri Tal, die vulkanoklastischen Serien im Kiari Gebiet und die Basaltlaven und -pyroklastika des Kalra Tales verschiedene Teile eines deformierten Inselbogenkomplexes darstellen.
7) Der Vulkanitkomplex vom Tiri Tal wurde auf den im N angrenzenden untereozänen Miru Flysch aufgeschoben, was der marinen Sedimentation ein Ende setzte. Belegt wird dieses Ereignis durch die roten Tonschiefer der Gonmaru La Formation, welche die nördlichen Bereiche des Miru Flysch überlagern. Die überschobenen Vulkanite und Serpentinitspäne wurden von lokaler terrestrischer Molasse transgrediert. Diese Molasse ist mit dem Liuqu Konglomerat von Tibet (BURG, 1983) und der Chilling Molasse (FUCHS, 1986) vergleichbar.
8) Nach der Ablagerung der lokalen Molasse wurde diese von Ultramafititmassen überschoben. Noch jüngere tektonische Phasen führten zur gemeinsamen Verfaltung von Ultramafititdeckschollen, Molasse und unterlagernden Einheiten.
9) Im Kalra-Changlung-Gebiet findet sich zwischen dem Vulkanitkomplex und einer Ophiolitsequenz eine eindrucksvolle Melangezone. Die Ophiolitsequenz aus Ultramafititen, Gabbros, Basalten und vulkanoklastischen Sedimenten stellt ein Stück ozeanischer Kruste dar, welche steil gegen NE überkippt ist. Nach unserer Auffassung markiert die Melangezone eine S-fallende Subduktionszone, an der die ozeanische Kruste des Indusbeckens subduziert wurde.
10) Das NW-Achsengefälle, welches vom Markha Tal bis ins Tso Morari Gebiet festzustellen ist, geht auf die Hebung des Tso Morari Domes zurück. Diese Hebung blieb aber nicht auf den Tso Morari Dom beschränkt, sie betraf auch die Indus Molasse und die Suturzone. So hebt die Indus Molasse gegen SE aus, und es kommen vulkanische Komplexe, ozeanische Kruste und eine Melangezone zum Vorschein. Die Indus Molasse ist in diesem Gebiet auf eine schmale Zone entlang der SW-Grenze des Ladakh-Plutons beschränkt. Lokale kontinentale Molasse transgredierte aber die bereits deformierten Einheiten der Suturzone im Süden. Diese Molasseschichten wurden im Zuge jüngerer Verformungsphasen in Falten- und Schuppenstrukturen einbezogen (siehe Punkt 8).

Abstract

The preliminary note presents results of field work carried out in the Tso Morari region and the Suture Zone of Tiri-, Kiari-, Kalra-, and Changlung areas. Further the micropalaeontological work done on the samples by I. PREMOLI SILVA (Univ. Milano) is presented in the paper.
1) The eclogites in the Tso Morari Gneiss complex were discovered by BERTHELSEN (1953) and were studied by GUILLOT et al. (1995) in the northern limb of the Tso Morari Dome. We found them also in the southern flank of the gneiss complex. Thus the whole core has undergone deep burial.
2) The sedimentary series of the dome still show sedimentary structures and reached amphibolite facies grade at the maximum. They certainly never have undergone eclogite facies metamorphism.
3) Whereas the sedimentary succession of the Tso Morari Dome is rather complete in the NW, the Karzok Syncline consists mainly of Permo-Mesozoic rocks. The Permian shallow-water carbonates, quartzites, and pelites are associated with Panjal Trap flows and pyroclastics, serpentinite, and chromite. The Lamayuru Formation overlies with a basal conglomerate. There are no "ophiolite outliers", but the above sequence is deposited in a basin produced by Permian rifting. This rifting may be responsible for the detachment of the northern edge of the Indian continental crust and its deep burial in the course of Himalayan orogenesis.
4) The Lamayuru Zone can be traced throughout the investigated area. It represents the Mesozoic in the northern limb of the Tso Morari Dome. In the Sumdo – Puga area it is intricately linked with the gneiss complex, which we explain as welding by the regional metamorphism.
5) The Tso Morari Dome and Lamayuru Zone are demarcated in the NE by a suture with lenses of flysch, melanges and klippen of ultramafitite, basalts, limestones and chert. This lineament can be traced from Omlung via Lato, Rumtse, Kiameri La to the Zildat Melange.
6) We suspect that the volcanic complexes of basalt breccia, radiolarite, and flysch in the Tiri Valley, volcaniclastic sediments in the Kiari area, and basaltic flows and pyroclastics in the Kalra Valley may represent different portions of a deformed island arc.
7) The volcanic complex of the Tiri Valley was thrust onto the adjacent Lower Eocene Miru Flysch, terminating marine sedimentation. Red beds (Gonmaru La Fm.) overlying the northern portions of the Miru Flysch document this event. Local terrestrial molasse transgressed the thrust-sheet of volcanics and serpentinite slivers. The molasse may be compared to the Liuqu Conglomerates of Tibet (BURG, 1983) and the Chilling Molasse (FUCHS, 1986).
8) After the deposition of local molasse large masses of ultramafitite were emplaced. Later tectonic phases led to folding of ultramafitite outliers, molasse, and underlying units. Partly the molasse was sandwiched along reactivated tectonic lineaments.
9) In the Kalra – Changlung area the volcanic complex is separated by a conspicuous melange zone from an ophiolite sequence. This slab of oceanic crust is composed of ultramafitites, gabbros, basalts, and volcaniclastic sediments. The named sequence is steeply overturned to the northeast. We think that the melange zone marks a S-dipping subduction zone, along which the oceanic crust of the Indus Basin was consumed.
10) The NW axial plunge observable from the Markha Valley to the Tso Morari region goes back to the uplift of the dome. But the uplift was not confined to the Tso Morari Dome. The uplift also affected the Indus Molasse and Suture Zone. Thus the Indus Molasse strikes into the air and towards the SE a volcanic complex, ophiolite, and melanges are exposed. There the Indus Molasse is confined to a narrow belt along the boundary to the Ladakh Pluton. Local Continental Molasse, however, transgressed the already deformed Suture Zone units in the S. These molasse beds were involved in fold and schuppen structures by younger deformation phases (see above 8.).

1. Introduction

Pioneer work was done by STOLICZKA (1865), LYDEKKER (1883), OLDHAM (1888), HAYDEN (1904), and others. BERTHELSEN (1951, 1953) investigated eastern Ladakh and Spiti in the course of his traverse from the Lesser Himalaya to the Indus Valley. He discovered the eclogites in the Tso Morari Crystalline, which were recently confirmed by GUILLOT et al. (1995). THAKUR & VIRDI (1979) made a regional survey of eastern Ladakh and developed the first plate tectonic concept of the area. Their map was a valuable aid for our work and their discovery of molasse series transgressing on deformed Suture Zone units is of particular importance.

In continuation of our earlier work (FUCHS, 1986; FUCHS & LINNER, 1995) we studied the Indus Suture Zone in three sections and the Tso Morari Dome S thereof (Text-Fig. 1). We found that the mentioned molasse formations were involved in later tectonics indicating complex multiphase deformation. The crystalline core and sedimentary series of the Tso Morari Dome give interesting hints as to palaeogeographic history, particularly Permian rifting. Though the elaboration of our sample material is in process, we want to present the results of field work in this preliminary report. The micropalaeontological examination of the carbonate samples was kindly done by I. PREMOLI SILVA (Univ. Milano).

2. The Tso Morari Dome

(Text-Figs. 1 & 2)

Crystallines build up the core of the wide dome, the series showing the highest metamorphic grade were called Tso Morari Gneiss (BERTHELSEN, 1953) or Puga Formation (THAKUR & VIRDI, 1979). They consist of predominant coarse-grained augen granite-gneiss and leucocratic orthogneisses interbedded with subordinate garnet micaschist and paragneiss. The granitic gneisses vary from almost massive to highly schistose. All over the crystalline we find lenticular bodies of basic rocks (m- to 10 m dimensions). They are garnet amphibolites, eclogite-amphibolites, and eclogites. According to GUILLOT et al. (1995) these rocks indicate that the Tso Morari Crystalline was subsided to approximately 55 km of depth. The augen granite-gneisses and micaschists exhibit strong deformation and amphibolite facies metamorphism. This complex is overlain by partly phyllitic micaschists and paragneisses progressively metamorphosed to the garnet zone of amphibolite facies. The contact is more or less sharp, but obviously not a brittle fracture. It can be easily traced in the field by the contrast of dirty brown metapelites and the almost white granite gneisses. The probably Palaeozoic metapelites are sometimes only a few hundred meters distant from the next well-preserved eclogites. Occasionally several hundred meter bodies of metapelites are found within the orthogneisses. These metapelites show distinctive higher metamorphic grade than the overlying metapelites.

The described gneiss complex is intruded by the Polokongka Granite (THAKUR & VIRDI, 1979). The coarse-grained biotite granite is not foliated and characterised by its well-preserved hypidiomorphic texture and the idiomorphy of the potassium feldspar, plagioclase, and biotite. The granite occurs in the area of Polokongka La, E of Tso Kar, in form of small bodies and slightly discordant dikes (m to 10 m scale). Thus it does not form a well-defined intrusion. In the map (Text-Fig. 1) we indicated the area where Polokongka Granite penetrates the augen gneiss, the latter, however, is prevalent.

Whereas the Polokongka Granite forms part of the crystalline core of the Tso Morari Dome, the Rupshu Granite intruded in the Precambrian to Early Palaeozoic Haimantas of the SW-limb. The coarse-grained porphyric granite shows sharp magmatic contacts and is foliated particularly along its northern boundary. Very probably the Rupshu Granite continues towards NW to the thick, also concordant granite body N of Sangtha (FUCHS & LINNER, 1995). This granite body correlates to the granites in the core of the Nimaling Dome dated by STUTZ & THÖNI (1987) as 460±8 Ma.

The Rupshu Granite may represent the core of an antiform, which was thrust over the Permo-Triassic zone of Karzok. The inverted northern flank of the antiform consisting of Haimantas and small granite bodies is highly sheared and corresponds with the counterthrust NE of Jakang (FUCHS & LINNER, 1995). East of the Tso Morari Lake we found only small granite bodies in the Haimantas, which represent the eastern continuation of the Rupshu Granite of Mata Mountain. These granites are rather sheared.

The Tso Morari Gneiss complex is overlain by metasedimentary series to the NW and the SW. The boundaries are well-defined. Concordant layers and small bodies of augen granite-gneiss are rather common in the schists W of Tso Kar. Thus the gneiss complex seems to represent a granitic intrusion. The metamorphism of the metasedimentary rocks increases from greenschist facies in the Nimaling area to the garnet zone of amphibolite facies in the Tso Kar region.

Northwest of the Tso Kar we find the succession of the Taglang La area: Karsha Formation (Cambrian) composed of micaschists and brown weathering dolomite bodies representing algal reefs; carbonates, quartzites, arkoses and metapelites of probably Devonian age; the characteristic light-coloured carbonates, quartzites, metaarkoses, and dark phyllites of Taglang La, which were dated in the Nimaling area by means of fossils as Permian (STUTZ, 1988). In the Tso Kar area the Permian series is interbedded with flows and tuffs of Panjal Trap. Like to the Nimaling and Taglang La areas the Permian is stratigraphically overlain by Lamayuru Formation (FUCHS, 1986; FUCHS & LINNER, 1995).

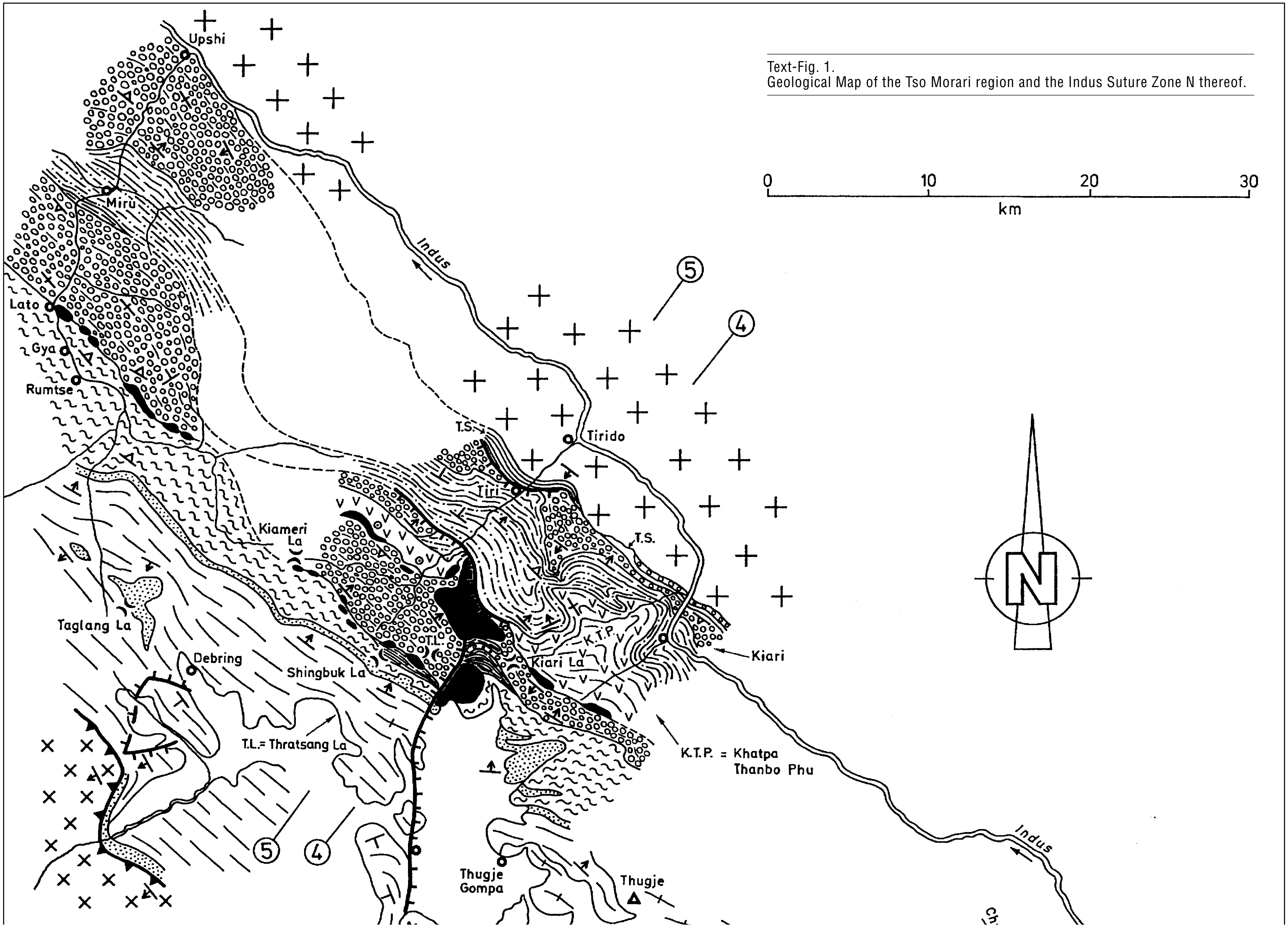
In the region of Tso Morari, that means in the southern flank of the Tso Morari Dome, the gneiss complex is overlain by metamorphosed flyschoid series of Haimanta type. They are succeeded by a thick development of the Permian series: light and blue calcareous and dolomitic marbles, quartzites, dark phyllites, and interlayered lavas and pyroclastic rocks of Panjal Trap. Also small bodies of serpentinite and the chromite W of Karzok belong to these volcanics. BERTHELSEN (1953) suggested the ultramafitites to be thrust up along a tectonic lineament, whereas THAKUR & VIRDI (1982) interpreted the occurrence of these rocks as an ophiolite outlier, a view adopted by FUCHS (1986, Pl. 1). The Karzok basic and ultrabasic rocks as well as the "ophiolite outlier" between Tso Kar and Kiari La belong to the Permian Panjal Trap and thus are part of the stratigraphic sequence of Zanskar.

STUTZ (1988) used the term Kuling Formation for the Permian series of the Nimaling area and we adopted this name for the occurrence of the Taglang La – Sangtha region (FUCHS & LINNER, 1995). There is no doubt about the Permian age, but the lithology differs considerably from the Kuling Formation of Spiti: There are the carbonates, the repeated volcanic intercalations, and the much larger thickness in the Karzok area. Therefore a new name for this formation seems appropriate and we propose Karzok Formation.

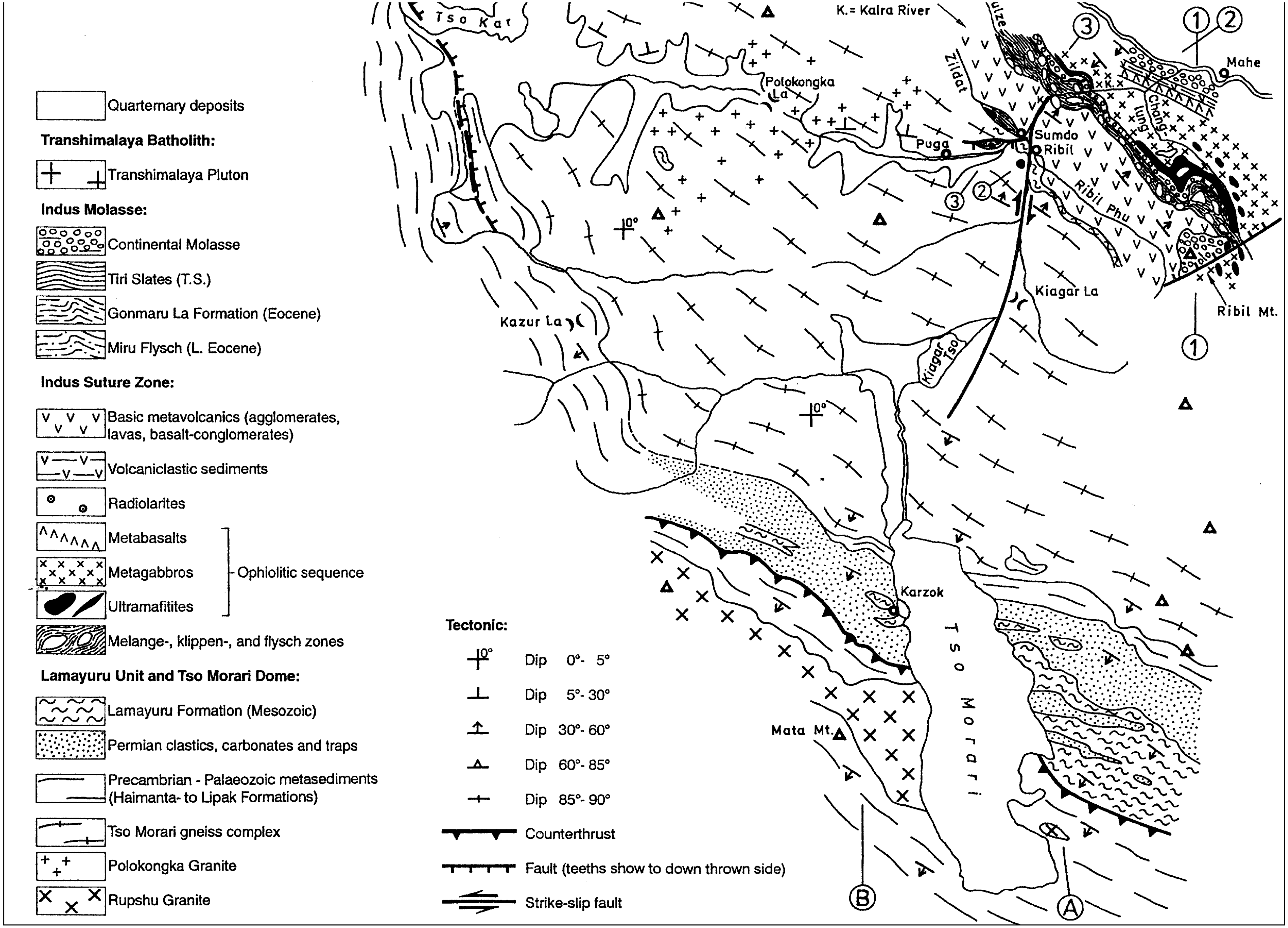
COLCHEN et al. (1994) divided the Upper Palaeozoic into a series of formations, but their formations 3–5 are all part of the formation "Fil d'Ariane" (STUTZ, 1988). This formation consists of very characteristic carbonates, quartzites, and metapelites, which we found associated with Panjal Trap in the Tso Kar – Tso Morari region. They form one thick Permian formation (Karzok Formation). Only in a few cases Lipak Formation (Lower Carboniferous) may be occurring.

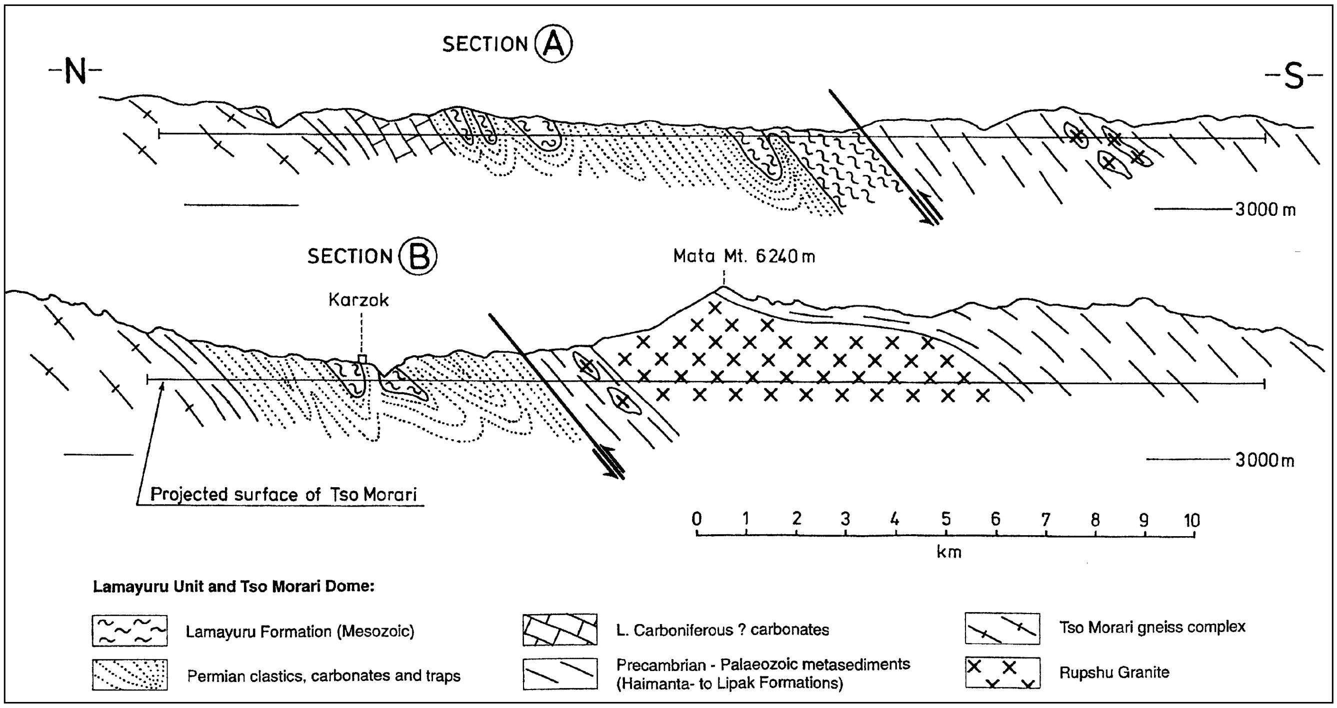
The Permian series build up a large area in the syncline of Karzok and in its continuation E of the Morari Lake. The rocks are intricately folded with NE vergency. Certainly the large thickness of the Karzok Formation is partly due to this folding.

The core of the mentioned syncline is formed of Lamayuru Formation. The dark calcareous siltites and pelites



Text-Fig. 1.
Geological Map of the Tso Morari region and the Indus Suture Zone N thereof.


Quarternary deposits
Transhimalaya Batholith:
Transhimalaya Pluton
Indus Molasse:
Continental Molasse
Tiri Slates (T.S.)
Gonmaru La Formation (Eocene)
Miru Flysch (L. Eocene)
Indus Suture Zone:
Basic metavolcanics (agglomerates, lavas, basalt-conglomerates)
Volcaniclastic sediments
Radiolarites
Metabasalts
Metagabbros
Ultramafitites
Ophiolitic sequence
Melange-, klippen-, and flysch zones
Lamayuru Unit and Tso Morari Dome:
Lamayuru Formation (Mesozoic)
Permian clastics, carbonates and traps
Precambrian - Palaeozoic metasediments (Haimanta- to Lipak Formations)
Tso Morari gneiss complex
Polokongka Granite
Rupshu Granite
Tectonic:
Dip 0°- 5°
Dip 5°- 30°
Dip 30°- 60°
Dip 60°- 85°
Dip 85°- 90°
Counterthrust
Fault (teeths show to down thrown side)
Strike-slip fault
Tso Kar
K.= Kalra River
Polokongka La
Zildat
Puga
Sumdo
Ribil
Ribil Phu
Chang-lung
Mahe
Ribil Mt.
Kiagar La
Kiagar Tso
Kazur La
Karzok
Tso Morari
Mata Mt.
10°
A
B
1
2
3



Text-Fig. 2.
Sections across the Tso Morari region, E and W of the lake.

are metamorphosed to phyllitic rocks. The contact of the Triassic Lamayuru Formation with underlying Permian rocks is concordant, but at some places E of Tso Morari we observed conglomerates and breccias in the basal Lamayuru Formation. The basal beds are up to 20 m thick. The components are derived from the underlying formation, they are mostly well-rounded and show sizes up to 25 cm.

The Lamayuru rocks weather in light beige colour and exhibit soft geomorphological forms and thus contrast to the brown and greenish colours and rougher terrain of the Karzok Formation. So the fold and schuppen structures within the Karzok Syncline can be easily identified in the field, particularly E of Morari Lake. There the southern limb of the Karzok Syncline is cut out by the counterthrust and thus the Lamayuru Formation comes in contact with the overthrust Haimantas.

3. The Lamayuru Zone

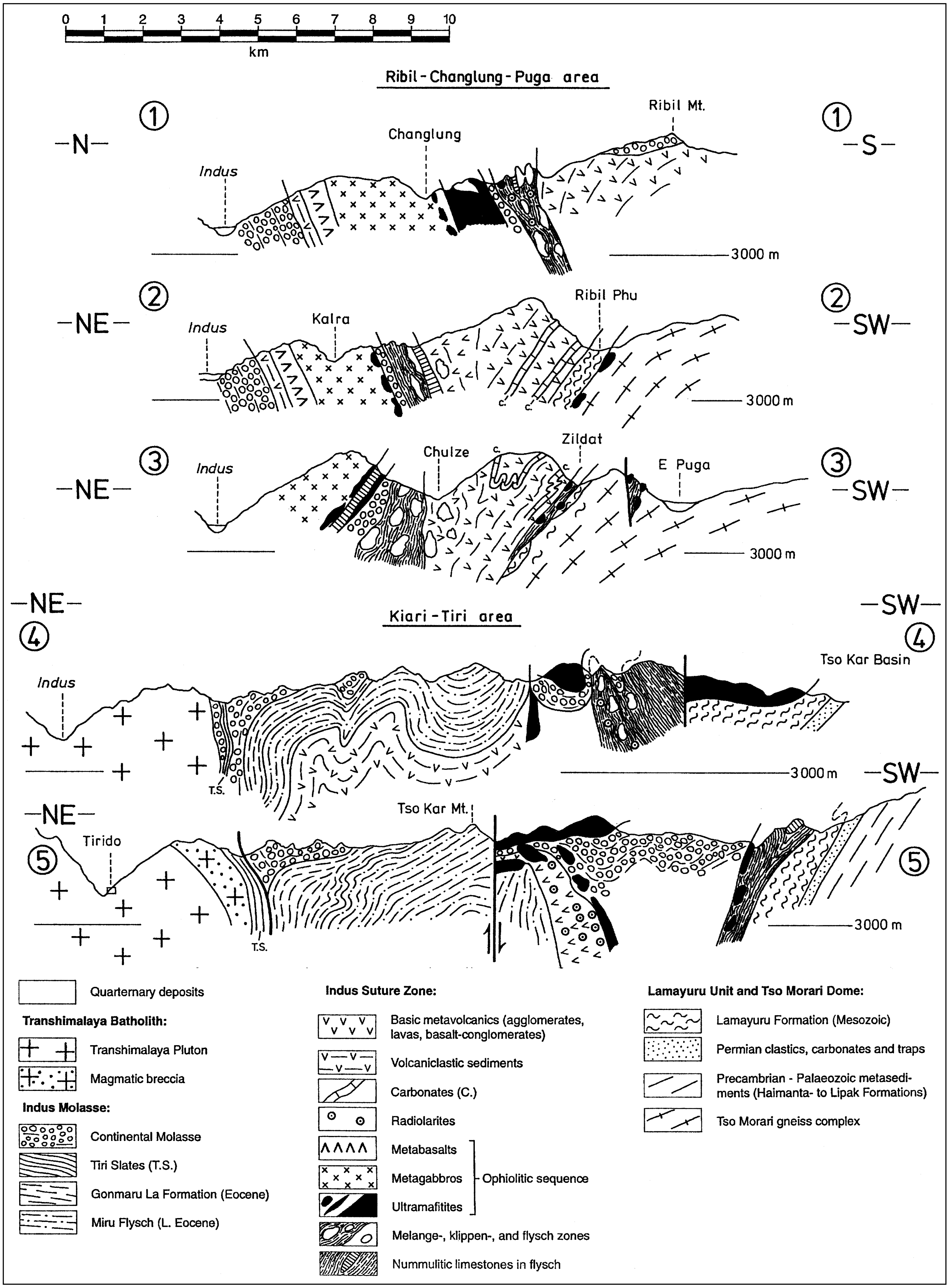
(Text-Figs. 1, 3)

In western Ladakh the Lamayuru Zone is a distinctive tectonic unit separated in the S by a thrust from the Tethyan Zone of Zanskar and by an ophiolitic melange from the Dras-Nindam Unit in the north. East of the Zanskar River the Lamayuru Unit of the Markha Valley interfingers with the Mesozoic sediments of Zanskar (FUCHS, 1986), which documents the transition of the basin and slope sediments into the shelf series. The Tso Morari Dome plunges towards the NW in the Nimaling region and there the Lamayuru Zone bifurcates. The main branch continues straight to the Rumtse area and the northern Tso Kar basin. Probably the Lamayuru Formation of this belt comprises the whole of the Mesozoic as in western Ladakh. The southern branch represents the major part of the Triassic up to the base of the Kioto Limestone (FUCHS, 1986). Traced towards the S the stratigraphic range of the Lamayuru Formation is further reduced comprising the Noric only (FUCHS & LINNER, 1995). Thus the slope facies of Lamayuru type is gradually replaced by shelf carbonates towards the south. The Lamayuru Formation of the Morari Lake belongs to the southern belt and seems to be mainly Triassic. As in the southern flank, the Lamayuru Formation of the northern limb of the Tso Morari Dome is in stratigraphic contact with the underlying Permian.

The northern delimitation of the Lamayuru Zone is tectonic. It can be traced from the klippen of Omlung – Hankar, Lato, Rumtse to the area N of Shingbuk La. SE of Rumtse the lineament is marked by small lenses of basalt, and serpentinite. NE of Shingbuk La the Lamayuru Formation is succeeded by Cretaceous clastic flysch with a few foraminiferal marl beds, and nummulitic limestones at the top.

The marls contain abundant planktonic and rare benthic foraminifera. Strong recrystallization makes identification problematic. One sample (95/19u) seems to belong to the late *Dicarinella asymetrica* Zone or earliest *Globotruncanita elevata* Zone (latest Santonian or earliest Campanian). Another sample yielded a possible *Globotruncana ventricosa* and *G. orientalis*, which indicate a minimum age of mid Campanian. There are also reworked planktonics from *Dicarinella concavata* and/or *Dicarinella asymetrica* Zones (Coniacian–Santonian). The nummulitic limestone contains large benthic foraminifera (common stellate and granulate *Nummulites*, rare *Assilina*, discocyclinids, *Operculina*). Few small benthic and planktonic foraminifera (reworked globotruncanids [dark] and very rare *Morozovella* sp. and *Acarinina* sp.). The evolutionary stage of *Nummulites* and *Assilina* suggests an Early Eocene age (possibly mid Early Eocene). This age is consistent with the presence of morozovellids and acarininids.

The occurrence of serpentinite klippen N of this Cretaceous–Eocene series make it probable that these beds still belong to the Lamayuru Zone. This would mean that the Lamayuru Formation is stratigraphically followed by Cretaceous–Eocene series. This agrees with the views of SINHA & UPADHYAY (1993), but we see the young series as part of the tectonic Lamayuru Unit and not as a portion of the Lamayuru Formation.



Text-Fig. 3.
Sections across the Indus Suture Zone.
Sections ① – ③: Ribil – Changlung – Puga areas; sections ④ – ⑤: Kiari – Tiri area.

From the upper Tiri Valley to the western slopes of the Tso Kar basin normal faults complicate the geology. The flysch and klippen belt E of Thratsang La probably is the continuation of the Cretaceous flysch NE of Shingbuk La (see above). It also adjoins the Lamayuru rocks in the N. A large ultramafitite body is partially resting on the Lamayuru Formation, and Tertiary continental molasse transgressed on all rock series thus making the situation even more complex (Text-Fig. 4, see chapter 4.1 and 4.2).

NE of the Tso Kar basin the Lamayuru Formation continues towards the E as a wide belt. It is underlain by the Permian Karzok Formation and thus is part of the northern limb of the Tso Morari Dome.

Due to restrictions we did not follow the Lamayuru Zone for the next 30 km towards the east. We found it again in the Kalra Valley at Sumdo and Ribil Phu, but changed in several respects. First its thickness is much reduced. Further the Lamayuru rocks are not part of a sedimentary succession. They directly overlie the Tso Morari Gneiss complex and there is no well-defined boundary to the latter. The dark calcareous phyllites and micaschists are intercalated with the garnet micaschists of the gneiss complex. Whereas the Lamayuru Formation generally shows greenschist metamorphism it reaches amphibolite facies in the Kalra Valley. A lenticular serpentinite body W of Ribil Phu indicates tectonic complications. The Lamayuru rocks and the Tso Morari Gneiss complex suffered at least the last phases of Alpine regional metamorphism together.

The Lamayuru Zone continues towards the SE in the mountains S of the Ribil Valley as a small (100–200 m), but distinct band. It is underlain by much deformed micaschists and tectonically overlain by a thick volcanic complex of agglomeratic slates with sporadic intercalations of schistose pelagic limestones.

4. The Indus Suture Zone

(Text-Figs. 1, 3)

From the Ganda La area in the NW to Miru in the SE the Indus Molasse shows rather simple structure. There is a central anticline of the Eocene Miru Flysch striking from Jurutse to Miru. NE and SW of this anticline we find synclines of terrestrial, coarse-grained post-Eocene molasse (Hemis Conglomerates, Nurla Formation, etc.). Between the marine and continental sequence the bright red Gonmaru La Formation marks the change brought about by continent/continent collision (GARZANTI & VAN HAVER, 1988). Generally the Gonmaru La Formation shows thick development in the northern limb and is reduced or missing in the southern limb of the anticline.

E of Rumtse NW axial plunge can be observed, which determines the geology of the region investigated in the course of our 1995 expedition. Towards the SE lower elements of the Suture Zone become exposed.

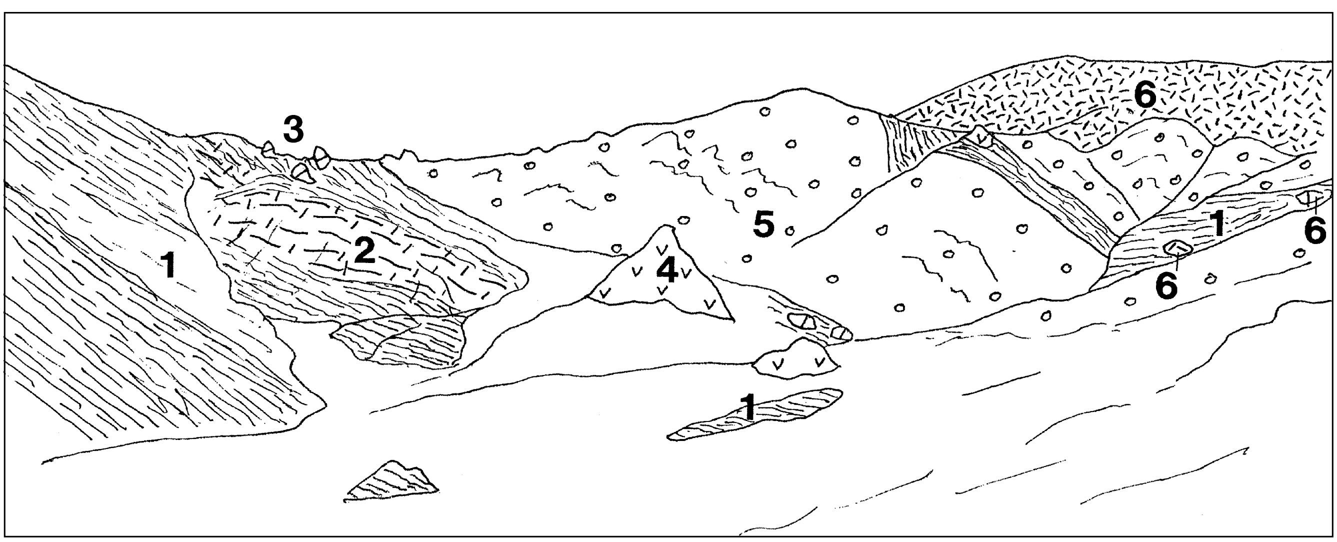
4.1. The Tiri Section

Ascending the Tiri Valley from the Indus Valley we are still in the Ladakh (Transhimalaya) Batholith, which is composed of porphyric granite with lenticular bodies and dikes of diorite and gabbro. The uppermost 500 m of the pluton consist of a magmatic breccia: well-rounded components of hornblende granite, diorite, and gabbro are embedded in a fine-grained porphyritic matrix.

The boundary between the pluton and the adjoining slates is sharp, but not tectonic. The latter consist of dark, finely laminated slates and subordinate fine-grained, grey sandstones with breccia layers. In the Khatpa Thanbo Phu, this formation is interstratified with the Continental Molasse, which transgresses on the pluton. Obviously it represents a lacustrine facies in the fluvial deposits. We suggest the term Tiri Slates for the formation.

At the Tiri village the vertical Tiri Slates border the Gonmaru La Formation, higher up varicoloured Continental Molasse overlies the Gonmaru La Formation. Probably the southern boundary of the Tiri Slates is tectonic.

The Gonmaru La Formation is stratigraphically underlain by a thick development of Miru Flysch. The latter is composed of bleaching dark slates with layers of silt- and sandstone and sporadic impure limestone beds. In the south-westernmost part of the flysch, which is probably youngest, conglomerates are interstratified. In carbonate



Text-Fig. 4.
The area W of Kiari La, view towards the N and NW.
Cretaceous flysch (1) with marl zones (2) passes into melange containing blocks of limestone (3), basic volcanics (4), and serpentinite (6). Terrestrial molasse (5) transgressed flysch and melange and was overthrust by a large mass of ultramafitite (6). The whole complex was folded in the course of later tectonic phases.

or sandstone matrix the conglomerates contain rounded and angular components of green slate, sandstone, serpentinite, radiolarite, and quartz up to dm-sizes. These beds may indicate the approach of a thrustsheet from the south. In the orographically right side of the valley steeply dipping Miru Flysch with conglomerates is in tectonic contact with serpentinite conglomerate containing only few boulders of peridotite and quartzite. This conglomerate (20–50 m thick) is associated with small slivers of radiolarite, flysch, and carbonates. Then follow radiolarites, basic volcanics and flysch a few tens of meters thick, but attaining approximately 1000 m further to the SW. Then follow small or large lenticular bodies of serpentinite and terrestrial conglomeratic molasse 20 to 30 m thick. The latter is overlain by a monomict ultramafitite conglomerate (15 m) where peridotite overlies, respectively a polymict, mud-supported conglomerate with dark, slaty matrix where slivers of flysch overlie. Then follows the northern edge of the ultramafitite thrustsheet NE of Thratsang La (Text-Fig. 1).

The observed tectonic succession suggests that a metabasalt-radiolarite-flysch complex was thrust onto the Miru Flysch from the S putting an end to the marine flysch sedimentation. Then terrestrial molasse transgressed and after that ultramafitite thrustsheets were emplaced on the molasse.

If we continue the section up the Tiri Valley we cross the already mentioned complex of basalts, matrix supported basalt breccias, conglomeratic flysch, and lenses of radiolarite. The beds are vertical and attain approximately 1000 m thickness. We suspect that this complex may represent parts of an island arc, which shall be cleared by geochemical analyses. Serpentinite bodies are frequent along the boundaries of the above named complex.

In the pass regions of Thratsang La and Kiameri La Continental Molasse ("Kargil Formation" [THAKUR & VIRDI, 1979]) has large extension. The thick-bedded series consists of unsorted, but well-rounded conglomerates, sandstones, and impure pelites with plant imprints; sediment colours are red-brown, grey, and green. The molasse transgresses on the melange zone E of Thratsang La. The boundaries against the metabasite complex in the N, the Lamayuru Zone in the SW, and the flysch E of Shingbuk La are reactivated in late tectonic phases as indicated by the serpentinite and basalt lenses along this lineament.

The Cretaceous flysch and nummulitic limestones E of Shingbuk La may represent the youngest formations of the Lamayuru Unit or form a separate tectonic unit. The serpentinite lenses immediately N of the named flysch support the view that the flysch belongs also stratigraphically to the Lamayuru Zone.

E of Thratsang La a normal fault terminates the molasse against a serpentinite mass, flysch and a melange zone. E of this fault the serpentinite rests on Lamayuru rocks and borders the Cretaceous flysch along an E–W striking fault (Text-Fig. 1).

This flysch consists of predominating slates, sandstones, varicoloured foraminiferal marls and limestones and chert (ca. 400 m). The northernmost carbonate band is a calcareous breccia with small to large clasts of limestone with rare to abundant calcitized radiolarians, rare clasts of pelletiferous sparite containing rare small benthic foraminifera, and abundant shallow-water oncoids and very rare ooids inbetween clasts; further few echinoderm fragments, very rare small benthic foraminifera, both agglutinated and calcitic, fragments of calcareous algae (probably solenoporacean *Parachaetetes*) and one *Protopeneroplis*?.

From a carbonate band in the central part of the flysch a sample of dark red micrite yielded very abundant planktonic foraminifera and rare small calcitic benthic foraminifera. The well-diversified planktonic fauna seems to belong to the top part of the *Globotruncana aegyptiaca* Zone (which now is latest Campanian). Another sample taken further S yielded an assemblage very close to the above sample. One specimen close to *Gansserina gansseri*, however, points to a slightly younger age.

A strongly recrystallized, grey carbonate rock close to the southern boundary of the flysch is very rich in planktonic foraminifera. The well diversified fauna seems to belong to the base of the *Gansserina gansseri* Zone, very close or coincident with the base of the Maestrichtian. The fact that the samples seem progressively younging from N to S suggests tectonic inversion.

Towards the N the flysch passes into a melange (ca. 300 m) consisting of lenses of chert, radiolarite, limestone, sandstone, and basalt in schistose flysch matrix; in the latter there are also bands of pelagic foraminiferal marls. A sample of light grey marl is extremely rich in partially recrystallized planktonic foraminifera and very rare small benthic foraminifera. The planktonic assemblage is very mixed with Upper Albian, Cenomanian, Coniacian–Santonian, and Maestrichtian taxa; one specimen is possibly belonging to *Acarinina*. The youngest Cretaceous planktonics are attributable to the upper part of the *G. gansseri* Zone or to the transition to the *Contusotruncana contusa* Zone, about mid Maestrichtian in age, whereas *Acarinina* may indicate a possible Early Eocene age. A dark, marly shale yielded less abundant, poorly preserved planktonic foraminifera and very rare small benthic foraminifera. The planktonic fauna is mixed with Upper Albian up to at least Campanian. The mixed faunas in our view indicate canibalization in the accretionary wedge.

Melange and flysch are transgressed by the Tertiary molasse, and the whole complex was intricately folded in a later tectonic phase (Text-Fig. 4, 7). Due to this folding the molasse beds locally overlie the ultramafitite thrustsheet (NE of Thratsang La), though this mass was originally emplaced on top of the Tertiaries.

4.2. The Kiari Section

(Text-Fig. 1, 3)

The eastern continuation of the units described in the last chapter were studied in the Kiari La – Khatpa Thanbo section. The flysch and melange are overlapped by the molasse towards the east. Thus the molasse comes in contact with the Lamayuru Zone.

In the N the molasse overlies thick vertical lenses of ultramafitite conglomerate and a complex of volcaniclastic sediments. The conglomerate is composed of unsorted, coarse boulders of peridotite, serpentinite and basalt in a matrix of fine serpentinite breccia. Some of the peridotite boulders exhibit a bright red surface; this alteration has not affected the matrix.

The well-bedded volcaniclastic series consists of a thick alternation of fine-grained, grey sandstones and green, grey, and dark, silty slates, light green and purple tuffs, and sporadic pyroclastic layers. Fine laminations, ripple-cross laminations and convolute bedding are common. A marly shale in the volcaniclastics yielded poorly preserved radiolarians and very rare ghosts of planktonic foraminifera; one possible *Praeglobotruncana stephani* and one *Rotalipora greenhornensis* point to an age not older than the mid Cenomanian.

This volcaniclastic series passes upwards into the Miru Flysch by decrease in sand- and volcanogenic content and increasing pelites. We draw the stratigraphic boundary with a thick conglomerate bed composed of boulders of quartz, carbonates, and volcanics, matrix supported in a sandstone groundmass. From this transition zone a sample yielded an apparently homogeneous fauna pointing to the *Rotalipora cushmani* Zone, *Dicarinella algeriana* Subzone (late Middle to Late Cenomanian). Another sample from the base of the Miru Flysch contains very abundant recrystallized radiolarians concentrated in layers, and very rare and small planktonic foraminifera. One *Hedbergella planispira*, one *Globigerinelloides bollii* and one double keeled globotruncanid indicate an age not older than Turonian. Hitherto the Miru Flysch was regarded as Early Eocene in age. The above determinations show that the formation comprises also the Upper Cretaceous. That means that the underlying volcaniclastics are mid Cretaceous.

Volcaniclastics and Miru Flysch are folded along axes plunging NW at an angle of 30–40°. The Miru Flysch builds up the range between the Tiri and Khatpa Thanbo Valleys and due to the axial plunge it does not reach the orographically right slope of the Khatpa Thanbo Phu. Almost all of the eastern side of the valley is formed by the volcaniclastic formation. The succession Miru Flysch, Gonmaru La Formation and Continental Molasse crosses the valley in its lower part. The thickness of these formations is reduced and they are mainly overturned. The Continental Molasse is followed by a vertical brownish weathering sequence of grey, fine-grained sandstones, siltstones, and laminated slates with sporadic layers of impure carbonate and matrix supported, polymict conglomerate. This formation seems to join up with the Tiri Slates to the NW (see chapter 4.1.). But in the Khatpa Thanbo Valley a transgression horizon (20–30 m) forms the contact of the formation with the Ladakh Pluton. The granite is reworked to m-sized blocks embedded in green arkoses and sandstones of the molasse.

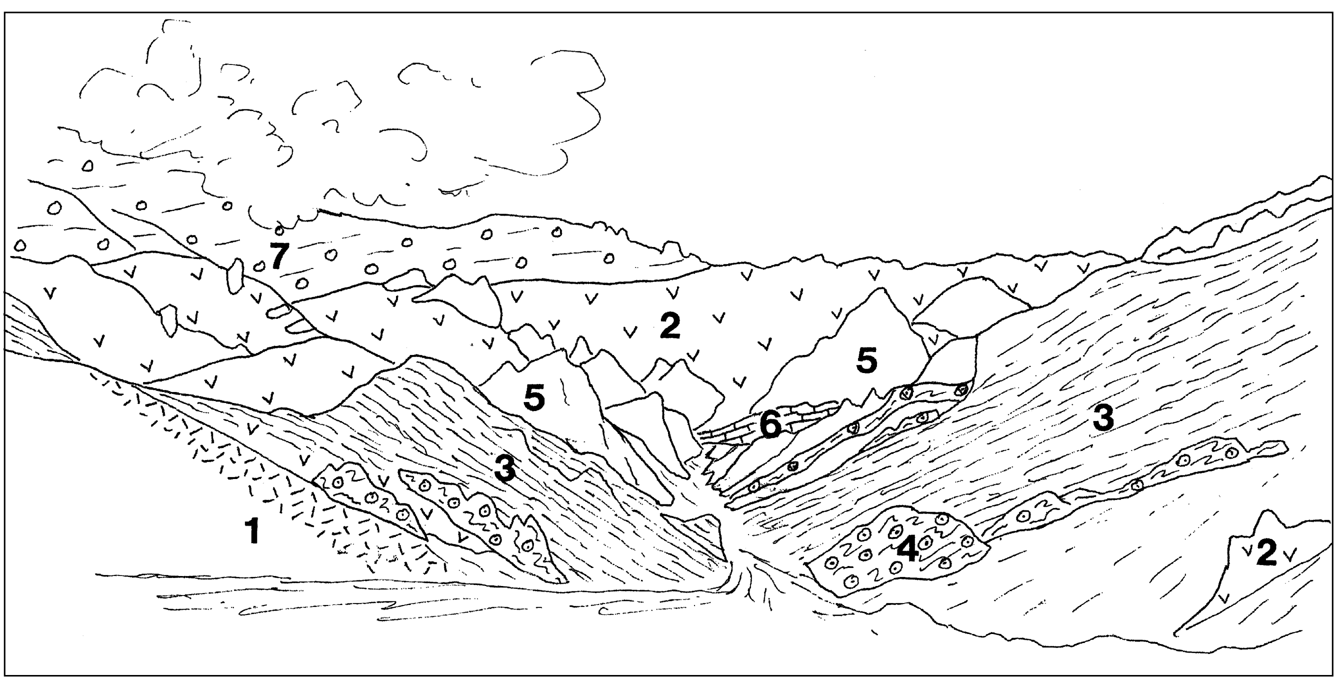
The Tiri Slates may represent a lacustrine basin facies in the braided river facies of the Continental Molasse. Whereas in the region down the Indus at Basgo or Karu older formations of the Indus Molasse transgress the Ladakh Pluton (FRANK et al., 1977; GARZANTI & VAN HAVER, 1988), younger terrestrial molasse overlaps the pluton at Kiari.

4.3. The Kalra Section

The next region investigated by us is about 30 km to the southeast. In the lowest course of the Kalra River, W of Mahe, varicoloured Continental Molasse borders an ophiolitic sequence along a steep tectonic boundary. The ophiolitic succession obviously is overturned to the N: Next to the Indus Molasse we find 150–200 m of brownish weathering, grey, hard sandstones and splintery slates. There are also polymict breccia and conglomerate layers. From this lithology and the map of THAKUR & VIRDI (1979) it is probable that this sedimentary series correlates to the volcaniclastic formation of the Khatpa Thanbo Phu (see chapter 4.2).

Then follow 800–1000 m thick basalts with pillow lavas and vesicular types. The basic volcanics are succeeded by a 1000–1500 m thick gabbro complex. It is composed of coarse- to fine-grained gabbros of various shades and gabbroic pegmatites. The gabbros are frequently layered and also magmatic breccias occur. Towards the southern boundary of the gabbro complex small serpentinite bodies are found. Along the boundary a 100–200 m band of serpentinite with occasional peridotite can be traced. Gabbroic dikes penetrate the ultramafitites.

The described SSW-dipping succession represents an inverted ophiolite sequence, a slab of oceanic crust.



Text-Fig. 5.
Upper Changlung Valley, view towards the south.
A melange of serpentinite (1), metabasalts (2), flysch (3), radiolarites (4) and carbonates (5) contains also lenses of Early Tertiary series (6). Terrestrial molasse (7) of the Ribil Mountain transgresses the melange zone.

Above the serpentinites of the ophiolite complex described above we find a highly complicated melange zone (Text-Fig. 5). In the southern flank of the Changlung Valley this zone is approximately 1000–1500 m thick. Flysch consisting of grey, blocky sandstones, conglomerates, and light grey to green silty slates, and volcanics (flows, agglomerates, and tuffs) form the groundmass of the melange. In this matrix lenses of serpentinite, red, grey, and green radiolarite and chert, frequently associated with red slates and pink limestone, are embedded. Conspicuous thick bands and klippes of white and grey crystalline limestone are prevalent in the upper part of the melange. They generally consist of grey to white recrystallized, rather massive limestones. Fossiliferous carbonates with remains of gastropods, bivalves and echinoids, crinoids, small benthic foraminifera, and ostracods gave no indication of the age. These massive limestones are frequently accompanied by cherty limestone and red marls. They are extremly rich in planktonic foraminifera and show few common benthic foraminifera, mainly agglutinants and possible *Nuttalides*. The planktonic fauna is extremely mixed: very rare possible Aptian specimens, very abundant Upper Albian to mid Cenomanian forms, and much rarer Santonian to Lower Campanian elements; one doubtful *Morozovella* may indicate even an Eocene age. The oldest elements of this mixed fauna give the minimum age of the massive, crystalline carbonate coated by the red limestone. This supports the correlation of the thick carbonate bands with the Khalsi Limestone.

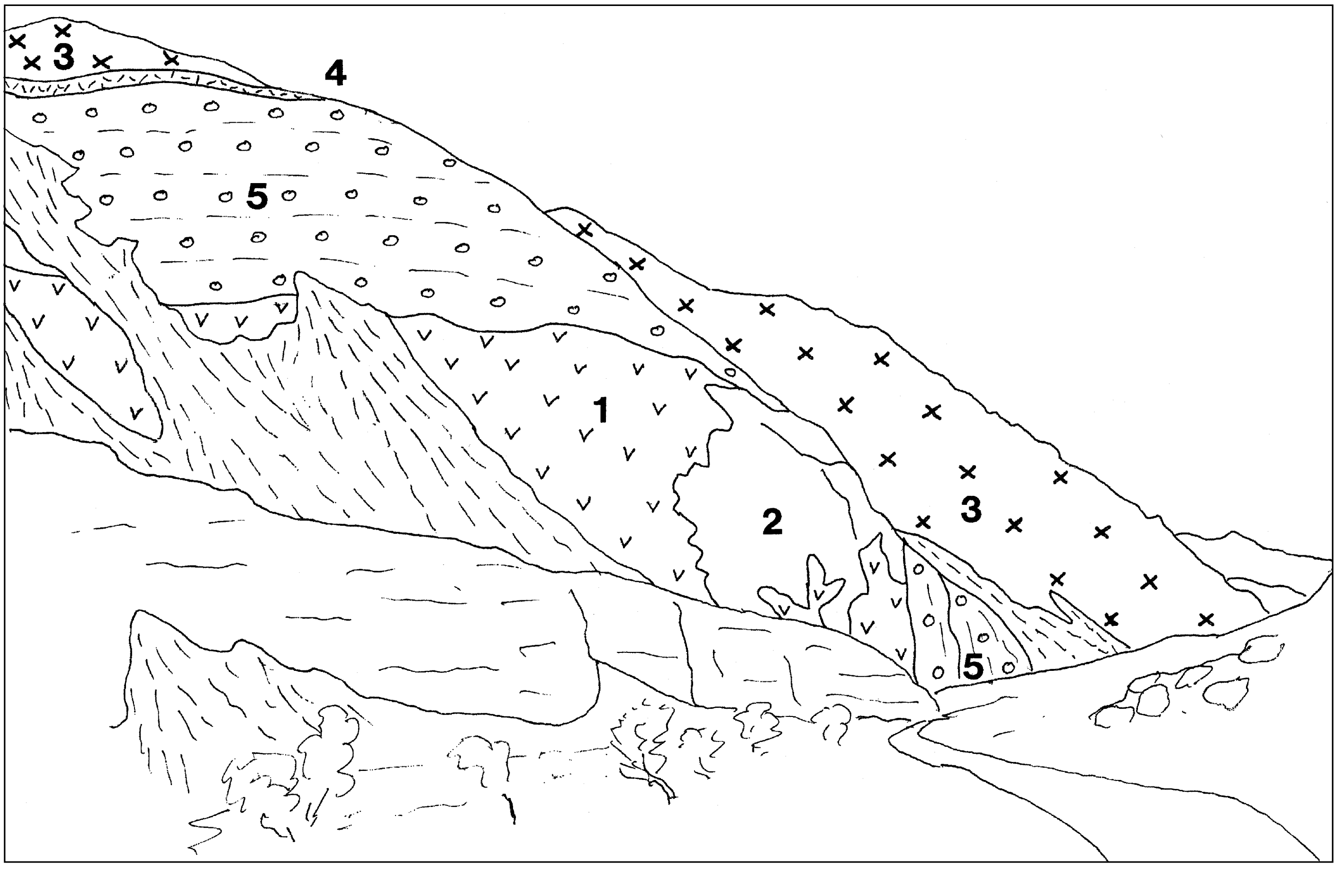
A red limestone block enclosed in basalt yielded common echinoderm fragments, rare mollusks, very rare small benthic and planktonic foraminifera; benthics include *Lenticulina* and a rotaliform; one planktonic specimen may be a globotruncanid. The age is probably not older than Coniacian–Santonian.

A sample of red limestone in the flysch shows few ghosts of radiolarians, very rare planktonic and few benthic foraminifera (lagenids, agglutinants and one specimen possibly close to *Amphistegina*). The planktonic species seem to belong to the Late Albian and Coniacian to possibly Campanian age; one doubtful *Morozovella* may indicate Eocene age.

In contact with the basaltic rocks the sediments occasionally show reaction rims. In this mixed complex there are also lenses of limestones, marls, and grey slates, associated with soft, earthy, platy sandstones.

All the limestone samples show breccia structure with clasts of different origin, oncoids, rare ooids, echinoderm and *Inoceramus* fragments etc. in a matrix rich in planktonic foraminifera. The assemblage is a mixture of species from several Cretaceous zones, in one case Cenomanian to at least Campanian; in another sample Late Albian (*Rotalipora appenninica* Zone) to at least Campanian, rare specimens may even belong to the Aptian; a third sample of Late Albian to at least Campanian age. Very rare occurrence of *Morozovella* or acarininids in these samples points to an Early Eocene age.

Whereas these beds are an integrated part of the melange, terrestrial local molasse composed of red, grey, and green, unsorted conglomerates, sandstones, and silty slates transgressed the whole complex. This can be observed in the upper Changlung Valley. Later tectonic phases, however, led to imbrication of melange and molasse beds.



Text-Fig. 6.
The Chulze-Kalra junction, view downstream.
Basaltic lavas and agglomerates (1) enclose limestone klippe (2). Local molasse (5) overlies and is succeeded by serpentinite (4) and gabbros (3) of the ophiolite sequence.

SW of the melange an approximately 2000 m thick basic volcanic complex follows. Near the boundary limestone bands and lenses are also embedded in the basaltic lavas and agglomerates.

Where the melange zone crosses the Kalra Valley, the gabbro with small serpentinite bodies is directly overlain by the molasse (orographically right side, Text-Fig. 6). The conglomerates are unsorted and contain angular and rounded components derived from all the adjoining units. The molasse is sandwiched between gabbro, flysch, and the basalts with lenses of crystalline carbonate. A large body of light crystalline carbonate is overlain by brownish weathering, grey, platy shales and impure limestones rich in fossil detritus. These grey, strongly crystalline limestones contain clasts of shallow-water components, gastropods, possibly corals, large solenoporaceans, echinoderm fragments, and very rare benthic foraminifera. Few outlines may belong to Cretaceous planktonic foraminifera. The above series is followed by the thick metabasalt mass, with embedded crystalline limestone lenses in the lower part.

In the orographically left flank of the Kalra Valley the molasse transgresses on a complex of flysch, basalt flows and agglomerates and embedded limestone klippes (Text-Fig. 6). An old weathering surface a few dm thick was observed on some of the limestones. On this side of the valley the series dip towards the N and thus are overlain by the gabbros and serpentinites.

Also up the Chulze Valley, a tributary of the Kalra Valley, the dip is steep and varies between southwest and northeast. Between the vertical molasse conglomerates and the gabbro complex we found a thin serpentinite lamella and 20–30 m platy, grey, earthy shales and carbonates with m-sized sandstone lenses. The carbonates contain fine serpentinite detritus. These beds are followed by a serpentinite conglomerate and then by the gabbros. The thin-section of a carbonate shows the strong recrystallization. There are large mollusks (rare gastropods and pelecypods), a recrystallized clast possibly with radiolarians, chert fragments, phosphatic and/or volcanic grains. The fossils give no age indication.

Between the described area and Sumdo the 2000 m thick volcanic complex crosses the Kalra Valley. It is composed of vesicular lavas, agglomeratic slates, pyroclastic breccias, and tuffs. The volcanics contain a few bands of light, varicoloured marls and limestones. Lenses of conglomerates with components of varicoloured limestones, cherts, volcanic slates etc. are rather rare. We think that this volcanic complex may represent an island arc.

In the Zildat Valley N of Sumdo THAKUR & VIRDI (1979) reported an interesting melange with blueschists. But their "Zildat Ophiolitic Melange" contains also the volcanic complex described above. In our view the melange is only 50–100 m thick and is composed of much deformed carbonate schists, light-coloured marble, green to blue-grey schistose volcanics, lenses of serpentinite, garnet phyllites and even gneiss. The melange separates the metavolcanics from Lamayuru respectively the Tso Morari Gneiss complex. The melange appears to occur in lenses, because the hangingwall volcanic complex in some places comes in immediate contact with Lamayuru or gneisses (e.g. Ribil Phu, up the Zildat Valley). Zildat Melange was possibly brought into the Tso Morari Gneiss complex along an E–W striking normal fault W of Sumdo.

5. Discussion and Conclusions

The Tso Morari Dome is a large anticlinorium in the northern edge of the Indian Continent like the Gurla Mandata in SW Tibet (HEIM & GANSSER, 1939; GANSSER, 1964). In the Markha Valley the dome plunges axially towards the NW (THAKUR & VIRDI, 1979; BAUD et al., 1982). There it can be shown that the sedimentary succession of Zanskar makes up the mantle of the dome. The Mesozoic formations show the change from the shelf to slope and basin facies in the NE (FUCHS, 1986). Followed towards the SE along the axis of the dome the older formations and finally the core of the dome are exposed (THAKUR & VIRDI, 1979).

The grade of metamorphism increases gradually from greenschist facies in the NW to amphibolite facies in the southeast. The Tso Morari Gneiss (Puga Formation), a granitic complex, forms the core of the dome; its boundary against the metasediments is relatively sharp.

In the metasediments as well as in the crystallines we find distorted basic dikes in great number. They are dolerites in the sedimentary sequence and are related to the Panjal Trap (LINNER & FUCHS, 1993). In the Tso Morari Gneiss there are garnet amphibolites, eclogite-amphibolites, and eclogites (BERTHELSEN, 1953; GUILLOT et al., 1995). According to the last authors the eclogites indicate a burial of about 55 km depth. From the fact that the eclogites occur all over the gneiss complex it is to be excluded that they were emplaced along tectonic lineaments. So the whole complex must have been subsided.

The metasediments of the western Tso Morari Dome exhibit well-preserved sedimentary structures (FUCHS, 1986; STUTZ, 1988). They show progressive metamorphism from greenschist to amphibolite facies (LINNER & FUCHS, 1993; COLCHEN et al., 1994). Thus it seems that there is a continuous metamorphic zonation in the dome from northwest to southeast. Contrary in the Tso Morari area the Tso Morari crystalline borders against greenschist metamorphic metasediments of the Karzok Syncline. There are no brittle faults between the crystalline and the metasediments. How to understand this hiatus in metamorphic grade between the core and the metasediments in the Tso Morari area? An explanation would be that the high-pressure metamorphism was Early Palaeozoic at the latest and the major part of the sedimentary succession was deposited after that. Against this view it may be argued that for comparable eclogites in the Kaghan Valley (POGNANTE & SPENCER, 1991) an age of 49±6 Ma was obtained (TONARINI et al., 1993). Further it is probable that all the basic lenses correlate with the Permian Panjal Trap (LINNER & FUCHS, 1993; COLCHEN et al., 1994; GUILLOT et al., 1995). In this case the metamorphism should be Alpine and there must be a ductile, extensional shear zone as suggested by GUILLOT et al. (1995) between the Tso Morari Gneiss complex and the metasediments of the Karzok Syncline in the south. Possibly this problem is clarified by the petrological evaluation and age dating of the sample material.

The sedimentary development of the Tso Morari Dome is in some connection with the above problem. In the Nimaling area the SW-flank of the dome is formed by a complete Precambrian–Eocene succession (FUCHS, 1986). The NE-flank is composed of Precambrian to Jurassic formations (FUCHS & LINNER, 1995). Also in the area Shingbuk La – Tso Kar the Palaeozoic–Mesozoic sequence seems complete. The Karzok Syncline, however, shows relatively thin Precambrian–Early Palaeozoic series and consists mainly of the Permian Karzok Formation and Lamayuru Formation (here mainly Triassic). The rich development of Panjal Volcanics and the missing of Mid-Palaeozoic series suggest that Permian rifting led to the basin, in which the Permo-Triassic series were deposited. It was a basin with epicontinental shallow facies in the Permian followed by deeper basin facies in the Triassic (Lamayuru). The Permian rifting is indicated by the Panjal Volcanism, gabbros, serpentinites and chromite in the Tso Morari area. Possibly this rifting is responsible for the deep subsidence of the core of the dome during Alpine orogenesis: The connection of the northern edge with the rest of the Indian Continent was weakened. At the collision with the island arc (Late Cretaceous) it broke off and was deeply subsided. The continent/continent collision in the Early Eocene led to the uplift of the continental sliver.

The uplift of the Tso Morari Dome affected also the Indus Suture Zone adjoining to the north. The Indus Molasse, which can be traced as a wide belt from western Ladakh to the Tiri Valley, becomes rather narrow E thereof. This is caused by an axial plunge towards the north-west. The molasse formations strike out into the air and Suture Zone units become exposed, which are hidden below the Indus Molasse to the west. THAKUR & VIRDI (1979) found a rich development of ophiolites and melanges N and NE of the Tso Morari region. From their map it appears that these ophiolite zones pinch out in direction to Rumtse. Actually they plunge beneath the molasse.

The tectonic style of the molasse is entirely different from that of the underlying Suture Zone units. The molasse exhibits tight, but harmonic folding, contrasting to the underlying slabs of oceanic crust and wedges of volcanic complexes separated by melange zones. These complicated structures were transgressed by terrestrial local molasse ("Kargil Formation" [THAKUR & VIRDI, 1979]). These overlapping series are folded and sandwiched along tectonic lineaments in the course of late tectonic phases. In some places ultramafitite bodies are found resting on the molasse. The interference of sedimentation and tectonics allows to discern a series of tectonic phases. This will be dealt with later.

The Lamayuru Zone is a continuous belt from the Suru area to Ribil Phu N of Tso Morari. The Lamayuru Formation represents the Mesozoic portion of the NE-flank of the Tso Morari Dome. It was deposited on the slope of the Indian Continent and in the basin N thereof. The Lamayuru Zone is demarcated in the NE by a tectonic lineament. The latter can be traced from the klippen of Omlung (BAUD et al., 1982; FUCHS, 1986) to Rumtse (LINNER & FUCHS, 1993; FUCHS & LINNER, 1995). From there the lineament does not strike to the Tiri Valley, but passes S of Kiameri La to the area E of Shingbuk La. It is marked by small lenses of serpentinite and sheared basalt. East of Shingbuk La an accretion wedge of Cretaceous flysch and nummulitic limestone is found along this lineament. In the N local molasse borders this suture zone and documents the young reactivation of the latter.

East of Thratsang La a N–S trending fault caused a N-displacement of the Lamayuru Zone and the accretion wedge. Here the flysch passes into a melange zone, the continuation of the above lineament (Text-Fig. 4). Flysch and melange were transgressed by terrestrial, local molasse and folded together in a later phase. Finally a large ultramafitite mass was emplaced on top of the molasse.

In the Sumdo area the Lamayuru Unit is very much reduced and welded with the Tso Morari Crystalline. We explain this fact as tectonic reduction of the NE-flank of the Tso Morari Dome and that both units suffered strong Alpine metamorphism.

The Zildat Melange separates the Lamayuru and crystallines from the overlying thick basic volcanic sequence. It represents the continuation of the Rumtse – Shingbuk La lineament.

THAKUR & VIRDI (1979) took the mentioned volcanics as part of their Zildat Ophiolitic Melange. In our view it is a separate volcanic complex, consisting mainly of basalts and agglomerates. Other volcanic complexes composed of volcaniclastic sediments are in the Kiari area, and of basalts, basaltic breccias, and radiolarites in the Tiri Valley. We suspect that these various volcanic complexes represent different parts of a deformed island arc. ROBERTSON & DEGNAN (1994) described a variety of facies in the Dras – Nindam Unit of western Ladakh. We think that the volcanic complexes in the Indus Suture Zone N of the Tso Morari Dome may correspond to this unit.

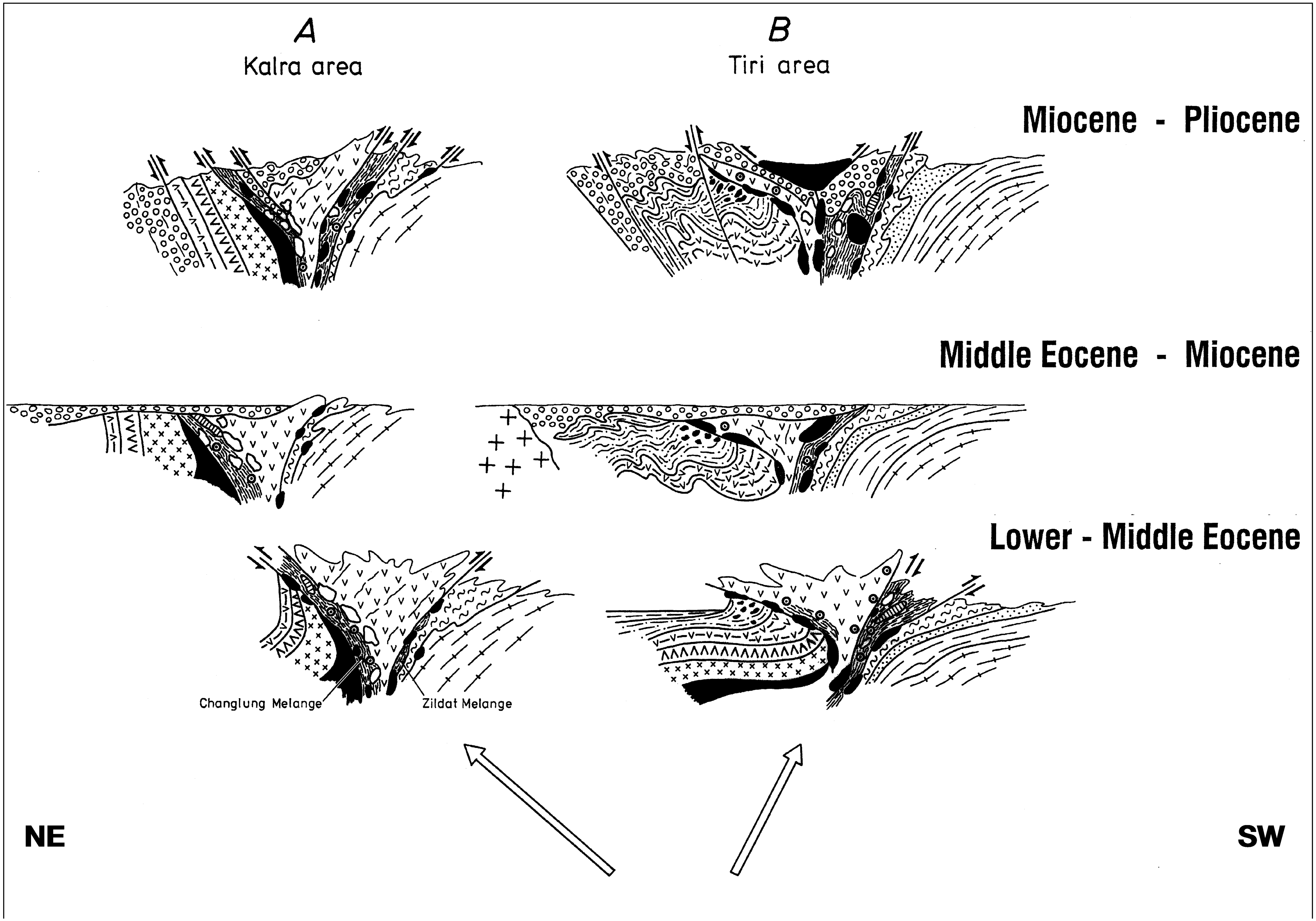
In the Tiri Valley the basalt breccias and cherts border against the Miru Flysch from the south. Serpentinite conglomerates are found along this lineament. Polymict conglomerates in the southernmost portion of the Miru Flysch document that a thrustsheet approached the flysch from the S and finally put an end to flysch sedimentation. The volcanic complex was thrust onto the Miru Flysch. These are transgressed by local molasse, which in turn is overthrust by a large ultramafitite mass NE of Thratsang La. This situation reminds of the Markha Valley N of Chaluk and Skiu (FUCHS, 1986). There isolated thrustsheets rest on the Dras – Nindam Unit and are connected by the Skiu Conglomerate horizon. The Chilling Molasse overlaps the above units. Later other serpentinite masses were emplaced on top of the molasse.

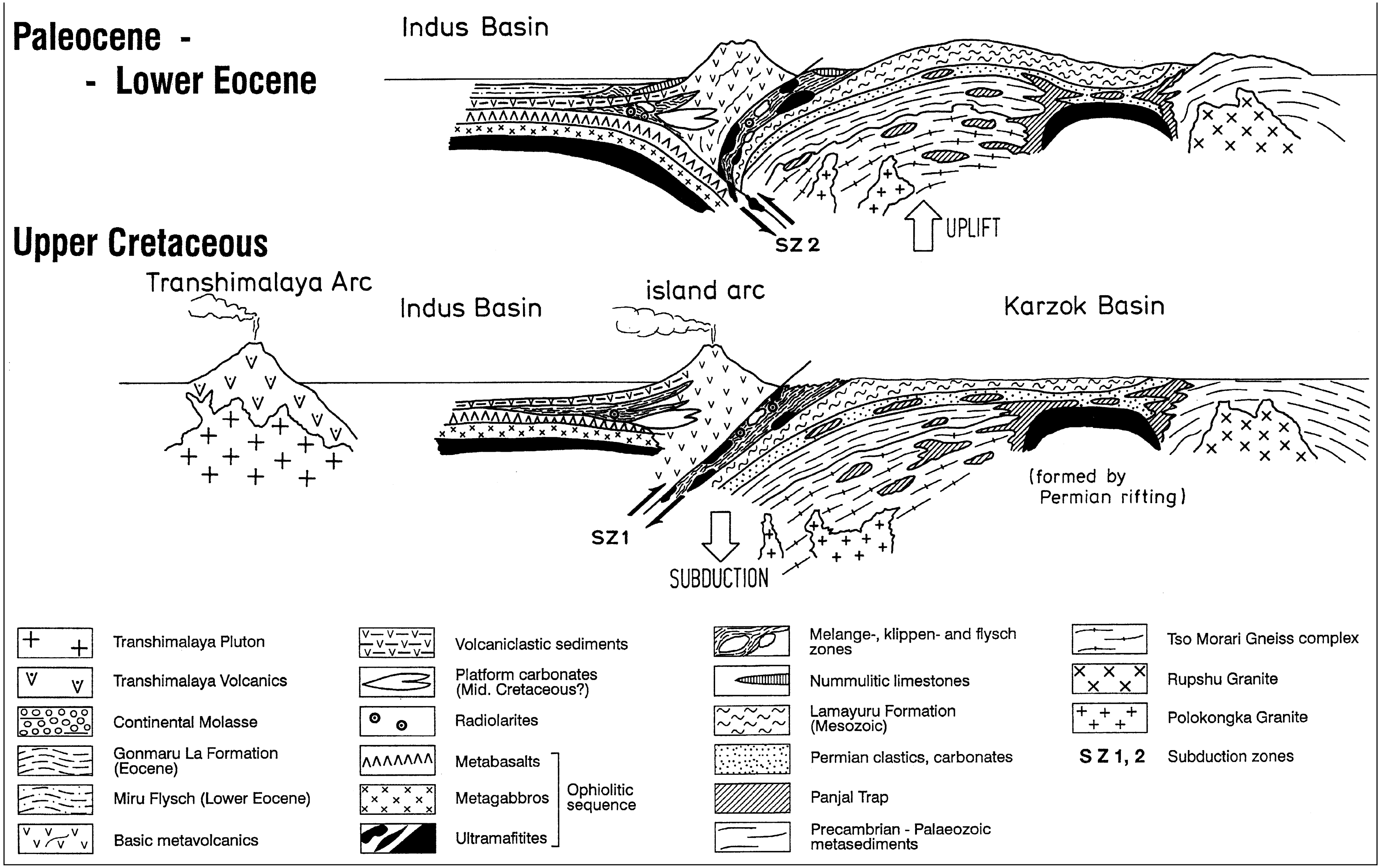
East of the Tiri Valley the Miru Flysch rests stratigraphically on the volcaniclastic sediments of the volcanic complex. We explain these as the northern slope deposits of an island arc extending into the Indus Basin (in the sense of GARZANTI & VAN HAVER, 1988). The peridotite conglomerates E of Kiari La mark a tectonic lineament reactivated after the deposition of the local molasse. We expect that the central and southern parts of the island arc complex may be squeezed off along this tectonic plane.

Due to the NW axial plunge the succession Miru Flysch, Gonmaru La Formation, and Continental Molasse is confined to a narrow overturned belt in the Indus Valley at Kiari.

Also in the lower Kalra Valley the Indus Molasse is overturned along its southern boundary W of Mahe, which is tectonic. Then follow strongly sheared volcaniclastic sandstones and pelites, which probably join up with the thick volcaniclastic succession of the Khatpa Thanbo Phu (compare the map of THAKUR & VIRDI, 1979). These sediments are succeeded by an inverted ophiolite sequence consisting of basalts, gabbros and serpentinites at the top. This slab of oceanic crust is a tectonic element missing in the described sections to the west. Obviously it plunges towards the NW beneath the volcaniclastic sediment complex of the Kiari region.

The above ophiolite sequence is separated from the volcanic complex in the S by a conspicuous melange zone (Text-Fig. 5, 6). Like the ophiolite this melange does not continue to the Kiari and Tiri region. Generally the melange


A
Kalra area
B
Tiri area
Miocene - Pliocene
Middle Eocene - Miocene
Lower - Middle Eocene
Changlung Melange
Zildat Melange
NE
SW



Text-Fig. 7.
The Development of the Suture Zone in the Tiri–Kalra region in cartoon
Upper Cretaceous: The northern edge of the Indian Continent collides with an island arc. The Tso Morari Block, partly separated by Permian rifting, is deeply subsided. The Indus Basin separates the island arc from the Andean-type Transhimalaya Arc (active margin of Asia). The island arc volcanics are interlayered with Mid-Cretaceous? carbonates, flysch, and radiolarites, which overlie oceanic crust.
Paleocene–Lower Eocene: After the island arc was attached to India a S-heading subduction zone becomes active N of the island arc, where the Indus Basin is consumed. The Tso Morari Block is uplifted.
Lower–Middle Eocene: The continent/continent collision causes strong deformation of the island arc: Along the reactivated melange zone (SZ 1) it overrides the Tso Morari Block in the S and along the Changlung Melange (SZ 2) it overthrusts the remains of the Indus Basin in the N. Due to the NW axial plunge the Kalra and Tiri areas respectively show what happened in higher and deeper levels of the lithosphere (column A and B). Ophiolite pebbles in the southern parts of the Miru Flysch, and the Gonmaru La red beds signal the tectonic event.
Middle Eocene?–Miocene: Continental molasse transgresses the Suture Zone and Ladakh Batholith.
Miocene–Pliocene: Final compression reactivates older tectonic planes and leads to the emplacement of ultramafitite thrust masses on top of local terrestrial molasse; the latter is folded and imbricated.

dips towards the SW, only E of the Chulze Valley steep NE-dip was observed (Text-Fig. 6). The melange consists of limestone bands and klippen, basalts, radiolarites, and flysch. Also Tertiary beds are part of the melange. Terrestrial local molasse of younger age ("Lyang Molasse" [THAKUR & VIRDI, 1979]) transgressed the melange zone, but in the course of later deformational events it was sandwiched within the melange. In its marginal portions the volcanic complex contains limestone bands and blocks possibly corresponding with the Khalsi Limestone. These limestones were partly incorporated in the adjacent melange. We think that the volcanic complex was thrust onto the ophiolite slab to the N. The internal structure of the volcanic complex, which generally dips NE, is discordant to the SW-dipping melange zone. This and the imbricated molasse indicate a late deformation of the melange.

Finally we try to reconstruct the evolution of the Suture zone on the basis of the new observations. The lineament demarcating the Lamayuru Zone in the NE is the northern boundary of the Indian Plate. In the investigated area it can be traced from Rumtse to Sumdo (Zildat). Serpentinite, basalts, flysch, and melange mark a subduction zone (SZ 1), which was active up to the end of the Cretaceous, when the island arc was attached to the northern edge of the Indian Continent. The volcanic complexes were attached to India. They may represent strongly deformed and squeezed parts of an island arc and oceanic islands. Therefore we find different volcanic sequences when followed along the strike (lavas, basalt breccias, volcaniclastic sediments, etc.). The deformation of the volcanic sequences caused thrusting towards the SW. Then subduction was taken up by a SW-dipping subduction zone (SZ 2) at the northern foot of the island arc. It appears that the floor of the Indus Basin was consumed there. This basin separated the island arc from the Andean-type magmatic arc forming the active margin of the Asian Continent. We do not think that the Indus Basin was a small forearc basin (Text-Fig. 10 in GARZANTI & VAN HAVER, 1988). We envisage a wider ocean basin between island arc and the Asian Continent. The floor of the Indus Basin consisted at least in part of oceanic crust, as documented by the ophiolite sequence of the lower Kalra Valley. The volcanic complex contains a probably Mid Cretaceous carbonate succession, which later was incorporated in a tectonic melange with volcanics, flysch, and radiolarites.

The subduction along the younger subduction zone (SZ 2) came to an end by the India/Asia collision in the Early Eocene. Along the Changlung Melange the deformed volcanic complex was thrust towards the NE onto an overturned fragment of oceanic crust, a relic of the floor of the Indus Basin. This event is indicated by serpentinite detritus in possibly Tertiary beds in the Chulze Valley. Similarly polymict conglomerates in the southernmost portions of the Miru Flysch (Tiri area) signal the approaching of a thrustsheet composed of volcanic material.

The overthrusting of the volcanic complex onto the southern part of the Miru Flysch caused the change from flysch to red bed sedimentation in the remaining basin (Gonmaru La Fm.). Therefore the Gonmaru La red beds overlie only the northern parts of the Miru Flysch.

The subduction of the Indus Basin and the collisional deformation caused the rapid uplift of the Tso Morari Dome from deep burial and in connection the NW axial plunge in the dome and the Indus Suture Zone. Therefore post-deformational denudation eroded to lower levels in the E (Kalra Valley) than in the W (Tiri Valley).

The post-Early Eocene Continental Molasse of the remaining Indus Basin transgressed also the already deformed parts of the Suture Zone (volcanic complex, thrustsheets, and melanges). Later tectonic phases led to folding of the transgressive molasse and to its imbrication. The emplacement of ultramafitite masses on top of the molasse marks a rather late phase. The provenance of these ultramafitites is an interesting question. Probably they are derived from nearby lineaments. All these lineaments are reactivated and it is likely that the ophiolites were squeezed out of these lineaments in the course of reactivation.

According to the map of THAKUR & VIRDI (1979) the ophiolite becomes very thick towards the southeast. Also there it is transgressed by local molasse. This shows that towards the SE not only the southern elements of the Suture Zone, but also northern units were uplifted in an earlier phase. After extensive erosion the Continental Molasse transgressed on the whole deformed complex.

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