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The geology of Western Zanskar

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With 18 Figures and 6 Tables (= Beilagen 1-6)
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Schlüsselwörter
NW-Himalaya
Ladakh
W-Zanskar
Stratigraphy
Tectonics
Evolution

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Abstract

Based on the work of my 1976 and 1980 expeditions a geological map of western Zanskar (Ladakh, India) is presented. The structural units of the Zanskar-Indus region exhibit individual stratigraphy, which allows to reconstruct the facies distribution. The tectonic evolution of the NW-Himalaya is very well documented in the Mesozoic to Lower Eocene sequence of Zanskar.

Zusammenfassung

Die Arbeiten im Zuge meiner Expeditionen 1976 und 1980 ermöglichten die Erstellung der geologischen Karte des westlichen Zanskar-Gebietes in Ladakh (Indien). Die tektonischen Einheiten der Zanskar-Indus-Region zeigen unterschiedliche stratigraphische Entwicklung, die die Rekonstruktion der ursprünglichen Faziesverteilung erlaubt. Aus der mesozoisch-alttertiären Schichtfolge Zanskars läßt sich das tektonische Geschehen während der Himalaya-Gebirgsbildung sehr gut ablesen.

Die Tibet-Zone besitzt von der Trias bis in den M. Jura karbonatische Schelffazies. Danach zeigt ein Wechsel von sandig-flyschoiden, pelagisch- und benthonisch-kalkigen Formationen epirogene Unruhe (Malm – O. Paleozän). Bunte siltige Schiefer schließen die Schichtfolge ab (Eozän?). Die Nördliche Zanskar-Einheit stimmt bis in die Mittelkreide mit der Tibet-Zone überein zeigt aber dann eine pelagische Schwellenfazies (Campan). Auf diese greift im Maastricht vom N her die Lamayuru-Beckenfazies über (Subduktion der nördlichen Teile des Schelfs). Im O.Paleozän zeigt benthonische Kalkfazies auch hier ein Seichterwerden an. Die Schichtfolge schließt mit untereozänen Schiefern. Die Lamayuru-Einheit ist durch eine z. T. flyschartige, z. T. kalkige, euxinische Beckenfazies charakterisiert, welche das gesamte Mesozoikum umfaßt. Ehemalige Verzahnungen mit der Schelffazies wurden später klippenartig zerlegt.

Die Rusi La-Zone ist durch Flysch und Kieselkalke, vermutlich kretazischen Alters, und gleichzeitigen alkalischen Vulkanismus geprägt. Die Dras-Einheit zeigt hingegen den für Inselbögen typischen Basaltvulkanismus mit gleichzeitiger Flyschsedimentation (Ob. Jura – Kreide – Alttertiär?).

Zwischen diesen Einheiten kennzeichnen ophiolithische Melangezonen, mit submarinen Vulkaniten, Mantelgesteinen, Tiefseesedimenten, exotischen Kalken und Flysch große Bewegungsflächen.

Die Indus-Molasse (Eozän-Miozän) entstand in einem größtenteils kontinentalen Becken. Sie transgredierte über Gesteinen der Dras-Einheit und dem im N eingedrungenen Ladakh-Batholithen (O. Kreide – Oligozän).

Die tektonische Entwicklung ist durch das Schließen der Tethys während der Kreide und des Alttertiärs geprägt. Der Indische Kontinent mit dem Zanskar-Schelf und dem nördlich anschließenden Lamayuru-Trog näherte sich dem Dras-Inselbogen, der über einer Subduktionszone entstand. Ende der Kreide kam es zur Deformation der Rest-Tethys. Es entstanden die ophiolithischen Melangezonen, Mantelgesteine wurden durch Obduktion emporgebracht und die tektonischen Großeinheiten wurden primär angelegt. Die Kollision zwischen Indien und dem Dras-Inselbogen an der Wende Paleozän-Eozän führte zum SW-gerichteten Deckenbau (Spongtang-Deckscholle). Dadurch wurde im Bereich der Nördlichen Zanskar-Einheit die jüngere Schichtfolge z. T. abgeschert und im Stirnbereich der Decken angereichert. Die endgültige Verschmelzung Indiens mit Asien am Beginn des Oligozäns hatte eine Periode starker Einengung zur Folge. Es entstand der steile, fächerförmige Faltenbau Nord-Zanskars, die N-Überkippung der gesamten Wurzelzone und das Auffahren der Nördlichen Zanskar-Einheit über die Tibet-Zone. Z. T. an alten Bewegungsflächen entwickelten sich die NE-gerichteten „Gegenüberschiebungen". Da an diesen noch miozäne Schichten der Indus-Molasse überfahren werden, scheint ein miozänes Alter dieser Überschiebungen gesichert (gleich alt wie Deckenbewegungen des Niederen Himalaya!). An dem Lineament, das Nördliche Zanskar-Einheit und Tibet-Zone trennt, kam es zu diapirartigem Aufdringen des noch unter Bedingungen der Regionalmetamorphose befindlichen, und daher mobilen Kristallins. Dabei wurden die bereits nicht mehr aktiven Gegenüberschiebungen gefaltet. Eine Zone mit Quertektonik (Schuppung, Brüche) ist von Kargil bis Kishtwar im Niederen Himalaya zu verfolgen. Es wird vermutet, daß jüngste Bewegungen im Quartär ein bereits entwickeltes Relief gestört haben.

1. Introduction

In 1976 when I started to work in Ladakh, much geological work was in progress along the Kargil-Leh road; the interior parts of Zanskar, however, were geologically very little known. Almost all the information goes back to LYDEKKER (1883), who made the first traverses, and LA TOUCHE (1888), who located the occurrence of nummulitic limestones in central Zanskar. The participants of the Himalayan Geology Seminar 1976 in New Delhi received series of xeroxed papers containing also some brief reports about the work of the Geological Survey of India in central and eastern Zanskar (JOSHI & ARORA, SINGH et al., SRIKANTIA & BHARGAVA). NANDA & SINGH (1976) deal with the geology of southern Zanskar.

The large outcrop of volcanic rocks reported by LYDEKKER (1883, p. 116) from the central parts of the Tibetan Zone attracted my special interest. I made a traverse from Lamayuru to Spongtang and returned trough the Shillakong Valley. In Spongtang I found not only the peridotites and Dras Volcanics but also flysch and the black shale complex of the Lamayuru-Mulbekh Zone. So it became evident, that the Spongtang area is composed of an outlier of thrust sheets derived from the Indus Zone. After the discovery of the Spongtang Klippe (FUCHS, 1977, 1979) the area was visited respectively dealt with by ANDRIEUX et al (1977), BASSOULLET et al (1978 a, b, c, 1980), FRANK et al. (1977, personal comm.), STERNE (1979), ANDREWS–SPEED & BROOKFIELD (1982), KELEMEN & SONNENFELD (1981) and others. METZELTIN & NICORA (1977) made the Kangi-Rangdum traverse apparently in the same year as I. GAETANI et al. (1980) made detailed stratigraphical studies in the Upper Cretaceous-Paleocene sequence of the Tibetan Zone.

I summarised my observations in the 1977 and 1979 reports, but due to the unfossiliferous nature of several formations and the complex tectonics much uncertainty remained concerning stratigraphy, facies distribution and tectonics. The aim of my two month's expedition in summer 1980 was to solve these problems and to study the southern parts of the Spongtang Outlier. I took the following route (Fig. 1): Suru Valley – Rangdum – Spanboth Chu (Tib. Valley) – Pukdum La (Tib. Pass) – Diwing – Oma Chu – Kesi La – Lingshet – Singhe La – Photaksar – Photak La – Diwing – Chulung La – Kong – Kangi – Mezik La – Wakha Chu – Mulbekh – Wakha Chu (SW branch) – Itchu La – Phulungma – Bartu – Rusi La – Lomba – Arju La – Chaskor – Kargil. This criss-crossing of western Zanskar along with my former traverses enabled me to give a geological map of this region (Pl. 1). ERTS-satellite imagery and my panorama photos helped in filling the gaps between my traverses. The only remaining gaps are SE of Rangdum and in the upper Mulbekh Chu.

The above survey, new fossil finds and stratigraphic studies by BASSOULLET et al. (1978 b) and GAETANI et al. (1980) removed most of the uncertainties mentioned above, making it possible to present a fair picture of the geology of western Zanskar.

Fig. 1

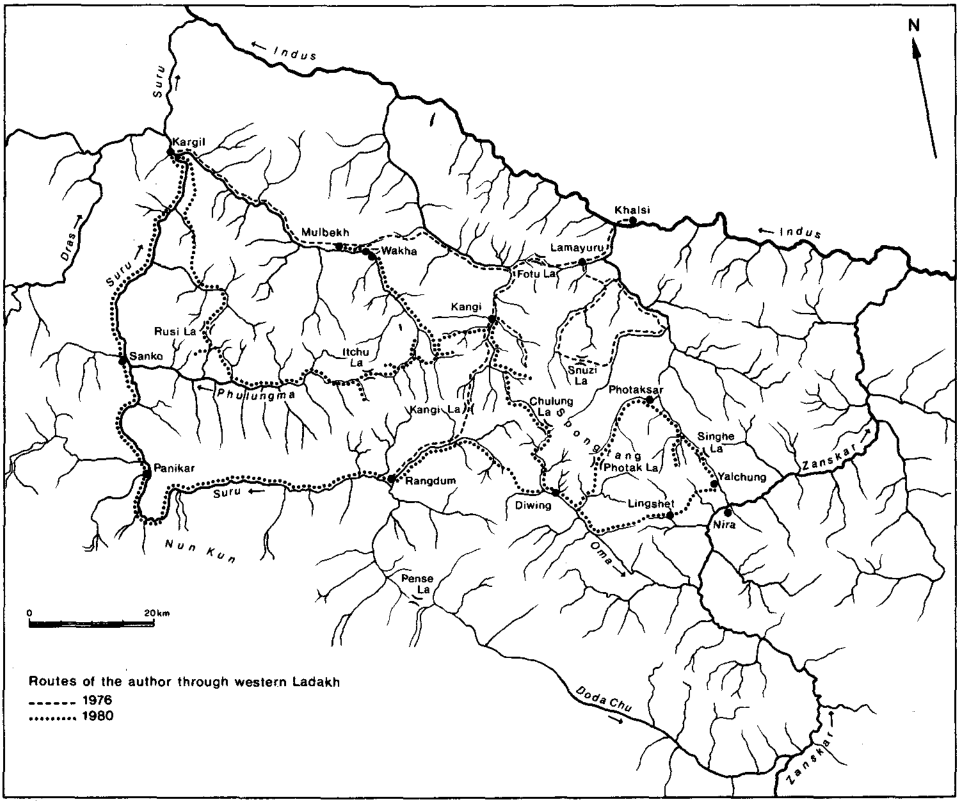

Fig. 1: Sketch map of western Zanskar showing the routes of the author.

2. Stratigraphy

The tectonic units are discerned not only by structural features, but also by their different stratigraphic-facial development. Therefore the stratigraphic successions are described in order of individual tectonic units, beginning with the southern (lower) units and going through to the northern (upper) ones.

2.1. Stratigraphy of the Tibetan Zone

Succeeding the Central Crystalline we find the fossiliferous and rather complete Palaeozoic to Early Cenozoic deposits of the Tethys. S of the Great Himalaya these sedimentaries build up the Synclinoria of Kashmir and Chamba and a few smaller occurrences. The sedimentary belt N of the Great Himalaya is known as the Tibetan Zone, which is connected with the southern synclinoria via Lahoul (upper Chandra Valley) and the Zoji La area of Kashmir.

South-western Zanskar belongs to the Tibetan Zone. The lower portions of the stratigraphic column, comprising Palaeozoics and Triassics, are metamorphosed and have become part of the Crystalline. The younger parts, the Cretaceous – Early Tertiary formations, form extensive outcrops in the western Zanskar Synclinorium. Thus in western Zanskar the rich Palaeozoic sequence of SE-Zanskar (NANDA & SINGH, 1976) is missing.

2.1.1. Crystalline

The Suru Valley from Sanko upstream to Rangdum is composed of high-grade metamorphic rocks, migmatites and granitoids (Suru Formation in SINGH et al, 1976, NANDA & SINGH, 1976, a. o.). The mica schists and paragneisses of the Panikar – Nun Kun – Chilung Pass area contain garnet, kyanite and staurolite. Marble (± calcsilicates) and calc-mica schist form conspicuous folds in this typical amphibolite facies assemblage. Amphibolites, partly garnetiferous, accompany the carbonate bands. Followed to the W from the Chilung Pass area the carbonates pass into the Triassic series of Zoji La, the amphibolites into the Panjal Trap (FUCHS, 1977, 1979). This connection is already shown by LYDEKKER's map (1883).

Upstream the Suru in its E-W course the content of granite-gneiss and migmatites increases. Pegmatites contain tourmaline, mica, garnet, and in one intance also beryl.

Further upstream towards Rangdum the grade of alteration decreases. The gneisses and mica schists pass into phyllitic rocks. The marbles and calc-mica schists are recognised as metamorphosed Triassics, the greenschists as altered Panjal Trap.

The passage zone between the Crystalline and the Tibetan Zone was also observed in the Phulungma Valley: The core of the Itchu Anticline consists of mica schists to phyllitic mica schists with subordinate layers of gneiss and amphibolite. They are succeeded by dark phyllites and bright green phyllitic chlorite schists (Panjal Trap?). The black phyllites contain layers of blue metamorphosed limestone, calc-mica schist, and graphite quartzite.

Above this probably Permo-Carboniferous series (Sanko Formation, NANDA & SINGH 1976) follows the thick carbonate sequence of the Trias. The lower portion of it is altered to calc-mica schist.

Thus there is a transition from the Crystalline to the sedimentary sequence of the Tibetan Zone, respectively the Kashmir Synclinorium. This is a general experience all along the Himalaya, but here the front of metamophism reached extraordinarily high into the Tibetan succession. The formations older than the Panjal Trap are no more identifiable.

NANDA & SINGH (1976) take this gradation as „apparent", because they found a conglomerate between their Suru Formation and the succeeding Phe Formation. Therefore they regard the crystallines as an old basement. Locally the contact may be disturbed. BAUD et al (1982) take the succession of Zanskar as allochthonous, thrust onto the Crystalline. It appears that further work is needed to clear this controversy in south-eastern Zanskar.

HONEGGER et al. (1981) give details about the Crystalline of the Suru area and its age, to which I refer.

2.1.2. Panjal Trap

The Panjal Trap was observed merely in the hill of Rangdum Gompa (tib. monastery) and in the outcrops NW and SE thereof. The light to dark green schistose trap still shows sporadic amygdales. Greenish chloritic phyllites alternate with the trap, which weathers to coarse blocks.

Boulders of agglomeratic slate and sandstones found E of Shergandik in the Phulungma Valley are probably derived from the north-western continuation of the volcanic series.

According to SINGH et al. (1976) and NANDA & SINGH (1976) the metavolcanic series extend from Rangdum south-eastwards to the Zanskar Valley and to the Lingti Valley, where they are replaced by a shale-limestone facies. These authors termed the formation Ralakung Volcanics in upper Zanskar Valley. According to them the volcanism started with Upper Carboniferous outbursts producing agglomerates, which were succeeded by Lower to Middle Permian lava flows. Intertrappean limestones yielded fossils of Zewan affinity (lower Middle Permian). The composition is essentially of a tholeiitic basalt with spilitic variation. On the basis of their detailed studies SINGH et al. also correlate the Zanskar volcanics to the Panjal Volcanic Series of Kashmir. According to HONEGGER et al. (1981) the volcanics have alkaline trend and show affinity to Mid-Ocean Ridge Tholeiite.

2.1.3. Permo-Triassic

The Panjal Trap of the Rangdum section is overlain by a 100 – 150 m alternation of dark blue schistose limestones, calc schists and black phyllites exhibiting brown weathering colour (FUCHS, 1979). In absence of fossils it is difficult to decide whether this metamorphosed series represents the Middle to Upper Permian only or also lower portions of the Triassic. JOSHI & ARORA (1976) describe calcareous sandstones overlying the volcanics of eastern Zanskar, then follow carbonaceous shales with thin limestone bands. This Permian series is poor in fossils in the Zanskar Valley, but highly fossiliferous towards the SE (Lingti Valley).

2.1.4. The Banded Triassic Series

The conspicuously banded series, which builds up the mountains N and NE of Rangdum, represents the Triassic. The thickness of the folded succession is estimated a 500 m. The lower part of it (100–120 m) is a thick-bedded alternation of light to dark grey limestone and light dolomite. Then comes a band of cream to light brown cellular dolomite, 50–70 m thick. It is succeeded by an alternation of light grey or blue limestone, dark calc schist, dark phyllite and light coloured dolomite. This sequence, 300–350 m thick, still contains some beds of cellular dolomite. Intraformational breccias, lenticular and current bedding, as well as shell beds underline the shallow-water origin of the series. The whole sequence is recrystallised and shows phyllitic metamorphism and thus the fossils are undeterminable. NANDA & SINGH (1976, p. 376) report a series of Triassic fossils from their Zangla Formation, which correlates with the beds described above.

The Triassic series of the Rangdum area resembles very much that of the Zoji La regarding its composition and the grade of alteration. I tried to recognise the lithounits of the Spiti Trias, which I had studied in 1978, but found no similarity.

In the Spanboth Valley I found blocks of green coarse-grained diabase, which seem to be derived from dikes in the Triassic.

2.1.5. Quartzite Series and Kioto Limestone

The Quartzite Series (Up. Noric? – Rhaetic, 70–80 m) is characterised by white, grey, brown, or dark quartzites and carbonate quartzites; in the lower portion there are also beds of dark grey, sandy, or silty argillite. The upper part of the formation consists of an alternation of light, partly cellular dolomite, dark limestone and calc schist resembling the banded Triassics below. There are also breccia and arenaceous layers interbedded. The top of the Quartzite Series is formed by a conspicuous band of light dolomite, 8 m thick. Corals, crinoids and shell layers indicate deposition in shallow water, the fossils, however, are undeterminable.

The Kioto Limestone (350–400 m) contrasts in the scenery by its dark colour with the predominantly light Quartzite Series and the light-dark banded Triassic sequence. The thick-bedded formation is made up mainly of blue and grey limestone with thin argillaceous layers. Oolites and intraformational breccias show that the sedimentation occurred in agitated shallow water. In a fallen block I found *Lithiotis*, a leading fossil of the Kioto Limestone. I assume that the formation, which is rather constant throughout the Himalaya (FUCHS, 1967), comprises the Rhaetic to Middle Dogger also in south-western Zanskar.

2.1.6. Upper Dogger

The Kioto Limestone is overlain by a conspicuous ochre weathering band, 7–10 m thick, composed of a medium grey, current-bedded carbonate sandstone and grey to blue-grey arenaceous limestone. Reworking is indicated by fragments of limestone contained in certain layers of the thick-to thin-bedded series. Crinoids and sections of recrystallised coarse shells were observed.

2.1.7. Spiti Shales

The Upper Jurassic – Lower Cretaceous formation is only 15 m thick in the section along the Spanboth Valley. It consists of black fissile shales and silty slates showing bleaching weathering colours. According to KELEMEN & SONNENFELD (1981) the Spiti Shales form a constant horizon in the Zanskar Valley region.

2.1.8. Giumal Sandstone

In the scenery the Giumal Sandstone is easily identified by its thick-bedded, brown weathering arenites and the black to dark grey argillite intercalations. It forms the best marker horizon in false colour ERTS imagery.

The formation is 150–200 m, occasionally 250 m thick and consists of medium to coarse-grained quartzite, greywacke and sandstone showing white, grey, green (glauconitic!) or dark grey to black colours; the thick-bedded, brown weathering arenites are irregularly interbedded with dark grey to black micaceous silty or sandy slates. Breccia layers in the arenites contain components up to 1 cm size.

The sandstones and greywackes commonly are ill-sorted and the grains are predominantly angular. The matrix is siliceous, carbonate, ferruginous or in a few cases phosphoritic. Some sandstones also contain coaly matter or phosphoritic nodules. KELEMEN & SONNENFELD (1981) observed graded beds, flute casts, and cross-bedding in the Giumal Sandstone.

The rare fossiliferous layers yielded crinoids, belemnites, and bivalves. The poor preservation does not allow determination. From the fossils found in the type area in Spiti (SPITZ, 1914) and the fossiliferous beds under- und overlying, an Upper Neocomian age of the Giumal Sandstone is generally accepted (PASCOE, 1959, GUPTA, 1975).

KELEMEN & SONNENFELD (1981) report of Giumal Sandstone alternating with limestone, this repetition however, is tectonic in my view.

2.1.9. Chikkim Limestone

The Giumal Sandstone – Chikkim Limestone boundary is very clear on satellite pictures by the contrast from brown to light, almost white colour; the Chikkim Limestone however, shares this light colour with the succeeding Kangi La Flysch and the bleaching shales of the Lamayuru Formation. In the landscape the Chikkim Limestone forms a hard resistant band of 30 to 50 m thickness (Fig. 2 on Pl. 3). Tectonically it may swell up to 100 m or be reduced to 20 m. The thickness of 1000 m reported by KELEMEN & SONNENFELD (1981) certainly is the product of tectonic repetition.

The formation is predominantly thick-bedded and shows light weathering colour. It is composed of very light to medium grey, rarely blue, dense limestone. Depending on the grade and type of tectonisation the rocks may be flasery, schistose, or occasionally rich in veinlets of calcite. The lower part of the series, up to 20 m thick, may be developed as a bluish nodular limestone containing wavy shale laminae. KELEMEN & SONNENFELD (1981) record algal mats and stromatolites.

At the top the content of carbonate decreases and the rock becomes silty and thus passes into the Kangi La Flysch without a hiatus.

The Chikkim Limestone is a typical pelagic sediment free of sand or silt and crowded by foraminiferas, which, however, are mostly recrystallised. Dr. R. OBERHAUSER, Geol. B.-A. Vienna, kindly made the following determinations:

Sample 80/7 from lower, nodular part of the formation near Chumse Tajok – Oma Chu junction, yielded *Oligostegina* sp., 80/6 near top (tectonic complication possible) yielded plenty, but ill-preserved Globotruncanas of probably Cenomanian to Turonian age. Samples 80/9 and 10, from upper boundary, Chumse Tajok, contain:
Pseudotextularia cf. *elegans*
Globotruncana sp. (types with one and two keels)

These foraminiferas along with *Globotruncana* ex gr. *lapparenti* (see FUCHS 1979, p. 520) suggest a Cenomanian to Campanian age of the formation, which is in agreement with KOHLI & SASTRI (1956).

Sporadic belemnites and the remains of an ammonite were undeterminable.

2.1.10. Kangi La Flysch

Above the steep rock faces of the relatively thin band of the Chikkim Limestone and below the rough morphology of the overlying Spanboth Limestone the terrain is ochre coloured and shows soft geomorphological forms (Fig. 2 on Pl. 3). It is composed of an argillaceous – silty – arenaceous series named the Kangi La Flysch by FUCHS (1977). Due to the folding of the Kangi La area the thickness was overestimated at 1000 m. GAETANI et al. (1980) regard it to be approximately 400 m only. After my recent survey I estimate the thickness at 400–600 m. The Kangi La Flysch consists of grey, green and dark slates, sandy and silty slates and marls and argillaceous or carbonate sandstones, all weathering in rusty colour. The sandstones contain quartz, muscovite, felspar partly replaced by carbonate, and tourmaline (GAETANI et al., 1980). The matrix is mainly carbonate. The s-planes of the rocks are frequently irregular and uneven; transversal shearing is not rare. Fucoids and *Zoophycus* are often observed. Black concretions are common. The succession is thin-to thick-bedded and shows poor cyclicity. Turbiditic structures also are scanty (GAETANI et al., 1980). Therefore there may be dispute whether the term „Flysch" is justified. One thing, however, is certain from the character of the formation, that it was triggered by one of the early phases of the Himalayan orogenesis.

Apart from hieroglyphs no fossils were found in the Kangi La Flysch, but its age can be deduced from the under- and overlying formations. The passage beds from the Chikkim Limestone to the Kangi La Flysch suggest a Campanian age (80/9 and 10) and the fossiliferous basal beds of the succeeding Spanboth Limestone are Maestrichtian. So the Kangi La Flysch is predominantly Campanian to Lower Maestrichtian. The Chikkim Shales,the youngest beds of Spiti, are exposed in a thickness of 50 m only. They show similar lithology and are regarded Lower Maestrichtian from their microfauna (GUPTA, 1975).

Towards the top of the Kangi La Flysch the content of silt and sand increases in certain areas(e.g. S of Kesi La). There are even beds of quartzitic sandstone interbedded with the silt- and sandstones and thus the boundary to the basal beds of the Spanboth Limestone, which are rich in arenites, is not sharp. In the Spanboth Chu GAETANI et al. (1980) describe silty marls, densely burrowed mainly of the Zoophycus type, as unit 1 of the Maestrichtian-Paleocene limestone series. I regard them as passage beds forming the top of the Kangi La Flysch.

2.1.11. Spanboth Limestone

The Kangi La Flysch is succeeded by an approximately 300 m thick limestone formation of Maestrichtian to Paleocene age. In the Spanboth Valley GAETANI et al. (1980) studied the petrography and the rich fossil content of the formation in much detail; therfore I name this series the Spanboth Limestone. It is surprising that the said authors do not mention the mixed arenaceous-calcareous beds, which make up the lowest 20–80 m of the formation. Probably these beds are not represented in the Spanboth Valley and occur further N and E indicating a change of facies.

The basal unit consists of a thick- to thin-bedded alternation of current-bedded white, grey, green quartzites and carbonate quartzites rich in burrows, green-grey sand- and siltstones, impure, sandy limestones, blue, partly nodular limestones and green to black silty argillites. The series weathers in rusty colour. The arenites are rather resistant and disintegrate in coarse blocks. Fossils are abundant in these beds: Foraminiferas, corals, bryozoa, gastropods, bivalves and crinoids. From the few samples taken the following determinations are given:
Omphalocyclus macroporus LAMARCK (76/35)
Omphalocyclus sp. (80/24)
Heterohelix sp. (76/36)
? Siderolites sp. (76/36; 80/24)
Siderolites calcitrapoides LAMARCK (80/36)
? Globotruncana sp. (76/37)

The samples of 1976 are determinations by Dr. M. SCHMID (Geol. B.-A.) and listed in FUCHS (1979 p. 521), whereas the samples of 1980 were kindly examined by Dr. R. OBERHAUSER, Geol. B.-A., Vienna.

A large gastropod was kindly determined by Director Dr. H. KOLLMANN (Naturhistorisches Museum, Vienna) as *Campanile ganesha* (NOETLING) (80/36).

By kind determination of Dr. A. DHONDT (Bruxelles) a lumachelle (Fig. 3) yielded:
Neithea regularis (SCHLOTHEIM)
Plicatula foliacea (NOETLING)
Chlamys or *Mimachlamys* sp. (indet.)

From the bivalves an Upper Campanian age can not be excluded, but the species of Campanile seems to occur in the Maestrichtian only. This age is also supported by the foraminiferas.

Above the basal unit a well-bedded complex follows, composed of dark blue to grey limestones with a few light coloured dolomitic beds, dark to grey marls, and one horizon of white quartz arenite. Some of the limestones contain black chert or balls of white calcite or gypsum. The occurrence of sulphur appears to be related with the latter mineral.

This sequence was subdivided into several lithounits by GAETANI et al. (1980). They discern five faunal assemblages in the succession abounding in fossils: Benthonic

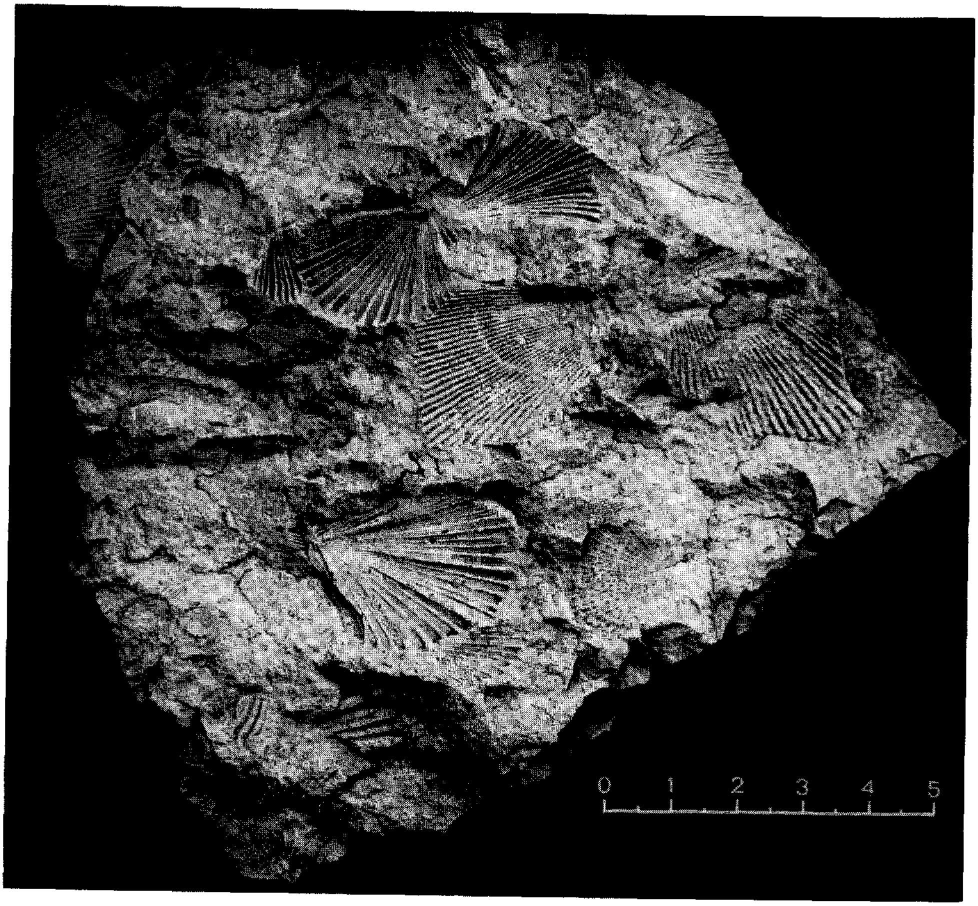

Fig. 3: Lumachelle from the basal arenaceous beds of the Spanboth Limestone; orogr. left side of the Chulung Valley.

foraminiferas, algae, corals and molluscs. The lower three assemblages are Late Maestrichtian, the upper two are Paleocene.

R. OBERHAUSER identified in my samples:
80/25: *Omphalocyclus macroporus* LAMARCK and in
80/5 and 5 a (upper part of the formation):

Robulus sp.
Alveolinids
Rotaliids
arenaceous tests

large foraminiferas of *Sorites* type suggesting probable Paleocene age
80/23, a sample taken from the topmost bed of the Spanboth Limestone, was kindly examined by Prof. Dr. L. HOTTINGER (Palaeont. Inst. Univ. Basle, CH):

Dasycladacea
Glomalveolina cf. sp. 1 in HOTTINGER (1971, pl. I fig. E)
Lockhartia conditi or tipperi
Orbitolites sp.

This faunula suggests Middle Ilerdian (Upper Paleocene) age.

These determinations substantiate the observation of the Italian geologists that the succession does not extend into the Eocene*).

The fossiliferous typical shelf deposits are overlain by a varicoloured silty argillaceous formation, the youngest beds of the Tibetan Zone of Zanskar.

2.1.12. Chulung La Slates

Above the blue, thick-bedded Spanboth Limestones the purple and green Chulung La Slates are very conspicuous. The formation is named after the Pass, where the schistose rocks are exposed in a thickness of serveral hundred meters. This, however, is not the original thickness, because the emplacement of the Spongtang Outlier sheared off the younger formations at its base and enriched them in front of the klippe (Pl. 1, 2).

The formation commences with a few meters of dark grey slates, succeeded by green, partly laminated slates (10–15 m) and a thick series of purple and green slates, siltites and impure fine-grained sandstones. In the litharenites GAETANI et al (1980) indentified "abundant well-sorted small quartz grains, rarer white mica, tourmaline, very altered feldspar, altered iron oxides. Autigenic carbonates in grains and in large dots" (p. 136). Current bedding, ripple cross-laminations, graded bedding, clay gall breccias and cm-sized sandstone fillings in the underlying layer etc. are structures indicating rapid sedimentation in an agitated environment. Cleavage oblique to the sedimentary s-planes is very common.

In the Spanboth syncline I found a green fine breccia, which seems to be formed by reworking of a marly layer. In the above area the rocks of the formation exhibit relatively strong alteration. Blastesis of chlorite and clinozoisite is observed. Thus it is not surprising that rare remains of microfossils are generally indeterminable. In one slide a *Globigerina* could be identified, which may be reworked. From the character of the formation I infer that the scarcity of fossils is primary and that the series is non-marine. Regarding the age it merely can be said that the Culung La Slates are of post-Paleocene, probably of Lower Eocene age. They mark the end of sedimentation in the Tibetan Zone. The above age is suggested by the following observation: N of the Tibetan Zone in the frontal parts of the Northern Zanskar Unit purple and green slates occur together with the foraminiferal Kong

*) GAETANI et al. (1980, p. 130) argue against the term „Nummulitic Limestone" used in my preliminary report 1977, but they overlooked in that paper that in footnotes I had revised that term after having received the first determinations of my samples. In my 1979-report I designated the limestones to Maestrichtian but was not aware that the upper part, from which I had no samples, reached into the Paleocene.

Slates of Lower Eocene age. They fill a squeezed syncline in the Paleocene Lingshet Limestones. The outcrop, high up in the orographic right slope of the lower Chulung Valley, unfortunately, was not studied. Facial interfingering of Kong- and Chulung La Slates, however, is very likely.

2.2. Stratigraphy of the Northern Zanskar Unit (N. Z. U.)

The northern parts of the Zanskar Synclinorium were most difficult to understand and therefore opinions about the stratigraphy and tectonics of that region were rather divergent (BASSOULLET et al. 1978 a, 1980; FUCHS, 1977, 1979). The Campanian fauna found by BASSOULLET et al. (1978 b) in the "multicoloured series" now named the Shillakong Formation, the determination of my 1980-samples by R. OBERHAUSER and my recent survey of western Zanskar show the area in a new light: Successions hitherto regarded to belong to different tectonic units turned out to form one stratigraphic sequence. The Triassic-Jurassic part resembles that of the Tibetan Zone, whereas the Cretaceous to Eocene portion exhibits individual features.

Structurally the Northern Zanskar Unit is parautochthonous, marginally overriding the Tibetan Zone in the S.

2.2.1. Triassic-Jurassic Carbonates

The rugged mountains of northern Zanskar are composed of much disturbed steeply dipping to vertical carbonates. The varicoloured Shillakong Formation (Campanian) is dealt with in chapter 2.2.3., the rest of the carbonates being of Triassic-Jurassic age is described here.

There is a thin-, predominantly thick-bedded complex of grey, blue, locally black limestones and light dolomites; part of the dolomites is of secondary origin. Compared to the Triassic series of the Tibetan Zone argillites are much more subordinate. They occur as a few and rather thin layers. Generally the rocks are strongly recrystallised and often show schistose and flasery structure. The whole complex seems to reach 1000 m thickness and comprises the main part of the Triassic as well as the Upper Triassic to Mid-Jurassic Kioto Limestone.

S of Baltikar, in the Lomba Valley, conspicuous green horizons a few tens of meters thick were observed in the basal portion of the carbonates. In the field I took them as tuffites, which is confirmed by the microscopic examination, kindly done by Dr. A. DAURER (Geol. B.-A., Vienna):

Sample 80/41 exhibits a deformed homaeoblastic carbonate aggregate with quartz, chlorite and albite. Carbonate (71 vol.%) shows deformed twin lamellae; chlorite (12 vol.%), dark green-violet interference colours (Mg-Fe chlorite), partially radial growth; quartz (5 vol.%); albite (5 vol.%) round grains; white mica (5 vol.%) larger, mostly deformed plates, and recrystallisation aggregates intergrown with chlorite?, ore and graphites (2 vol.%) very fine-grained and therefore difficult to distinguish, together with limonite forming lenticular aggregates parallel to s.

Thus the green horizons consist of carbonate with a distinct tuffaceous influence.

In the rather uniform mass of carbonates the Kioto Limestone is ill-defined. Separation is possible, where the Quartzite-Series forming the base of the Kioto Limestone is represented. This series consists of green grey, white quartzites, carbonate quartzites, impure micaceous sandstones, green-grey silty argillites, and blue limestones. The Kioto Limestone is easily identified, where shell beds occur, containing *Megalodon, Dicerocardium* or *Lithiotis* (FUCHS, 1979, fig. 4–7, p. 526). Other fossils like corals, bryozoa, brachiopods, gastropods, pelecypods (FUCHS, 1979, p. 526) and crinoids stress the benthonic nature of the limestone. Frequent oolites, intraformational breccias and current-bedding in arenaceous limestones indicate shallow-water deposition.

From SW of the village Honupatta FUCHS (1979) reported Dogger represented by ochre weathering arenaceous-calcareous beds a few meters thick.

2.2.2. Jurassic – lower Upper Cretaceous

In the steeply folded carbonates of northern Zanskar black silty argillites occur in narrow zones. In absence of fossils I pointed out the ambiguity whether they are Spiti Shales (Up. Jurassic – Lower Neocomian) or overthrust parts of the Lamayuru Unit (1969). Now there is a third possibility that the black slates represent the Maestrichtian portion of the Lamayuru Formation, which overlies the multicoloured Campanian limestones stratigraphically. So each case has to be considered separately. The black argillites SW of Honupatta, which seem to occur in a stratigraphic succession, probably are Spiti Shales, whereas those NE of that village forming a syncline in the Shillakong Formation appear to be Upper Cretaceous. Recently BROOKFIELD & WESTERMANN (1982) report about a berriasellid, *? Kilianella*, which BROOKFIELD found in the area SW of Honupatta. The fossil proves a Valanginian age, which is in agreement with Spiti Shale. In both branches of the Wakha Chu a few meters up to 15 m black slates overlie the Triassic-Jurassic limestones and are succeeded by Giumal Sandstone; thus with some safety they may be regarded as Spiti Shales.

In most sections the Giumal Sandstone overlies directly the carbonates. The Spiti Shales either may be missing primarily or are tectonically squeezed out; their thickness, however, was definitely small.

The Giumal Sandstone (Upper Neocomian) exhibits the same rock types as in the Tibetan Zone, its thickness, however, is rather variable. In the upper Wakha Chu – Phulungma area 30 to 80 m is an average, but locally the thickness may exceed 100 m. In the lower Wakha Chu, however, the formation dwindles down to a few meters. Probably this is a sedimentary reduction. Tectonics also may be responsible, for it is proved that there was intensive shearing above the Triassic-Jurassic carbonate complex. Thus the Giumal Sandstone was torn out to form lenticular bodies of 10 to 50 m thickness N of Kangi. The fine – to medium-grained green sandstones and dark phyllitc slates of this occurrence were described as flysch by FUCHS (1979).

Mapping of the Wakha Chu and upper Phulungma showed that these rocks occur stratigraphically between the Triassic-Jurassic carbonates and the Chikkim Limestone or directly below the Shillakong Formation, where the Chikkim Limestone is missing. Also the pinching out of the Chikkim Limestone is due to the strong deformation (shearing) above and below the Giumal Sandstone.

The Chikkim Limestone (Cenomanian-Campanian) occurs as light grey to bluegrey dense limestone often showing rusty weathering. Sporadic fragments of belemnites were found. In the area around Itchu La the formation is 20–50 m thick or may be reduced entirely. In the lower course of the Wakha Chu I did not observe this limestone between Giumal Sandstone and the succeeding Shillakong Formation.

2.2.3. Shillakong Formation

This multicoloured formation is the most characteristic series of the Northern Zanskar Unit. (Fig. 4, 5 on Pl. 3). I introduce the term Shillakong Formation, because the series is typically developed in the valley of this name. Further the name has been made popular by BASSOULLET et al (1978 a, b, 1980). Their term „serie de la Shillakong", however, comprises also other formations.

The formation consists of an alternation of white, grey, blue, cream, red, and green limestones, some being dolomitic, and red, purple, green slates, phyllites, and calc schists. This varicoloured series is banded in a dm- to m-rhythm and also shows major cycles up to tens of meters thick. The rocks generally exhibit phyllitic metamorphism and the fine-grained carbonates have recrystallised during deformation. Transversal cleavage is common.

I assumed a Triassic age from the apparent superposition of the Kioto Limestone near Honupatta (FUCHS 1977, p. 223). BASSOULLET et al. (1978 b) discovered an Upper Campanian microfauna in the formation S of Fotu La. This important fossil find is evidence of the presence of an Upper Campanian horizon, but it is derived from a much deformed belt and thus can not give the precise stratigraphic range of the formation. From its superposition on Chikkim Limestone and the fact that it is succeeded by Lamayuru Formation yielding Maestrichtian microfossils, the Campanian age is well-established. This implies that the pelagic formation, which is almost free of terrigeneous detritus and represents a „couches rouges" facies, is roughly of the same age as the Kangi La Flysch S of thereof. Thus the Shillakong Formation was deposited on a sill separating the Kangi La basin in the S from the Lamayuru trough in the N (Pl. 2 A). The Shillakong Formation is several hundred meters thick in the range SW of the Lamayuru belt. Its limestones also occur in form of klippes in the Lamayuru Formation. Therefore it may be concluded that the Campanian limestones of the sill were interfingering with the basin facies N thereof, or portions of it slipped into the adjoining trough. Towards the SW the thickness dwindles down to a band of 20 to 30 m (e. g. upper Phulungma).

KELEMEN & SONNENFELD (1981) report that the multicoloured limestones (Shillakong Formation) grade into the Giumal Sandstone, Chikkim Limestone and even the dark argillites of the Kangi-Photaksar belt. I am rather sceptic regrading these passages, particularly those of Upper Zanskar where the Shillakong Formation should pass laterally into Giumal Sandstone and Chikkim Limestone of the Tibetan Zone. In my view these formations come in touch along a tectonic plane separating the Tibetan Zone from the Northern Zanskar Unit. The contacts between the Shillakong Formation and the black argillites of the Lamayuru Formation I found always to be sharp. However it is quite likely that the upper portions of the Chikkim Limestone are replaced by the Shillakong

Formation. In the Northern Zanskar Unit the thickness of the Chikkim Limestone decreases towards the N, whereas the overlying Shillakong Formation increases from a few tens to several hundred meters.

2.2.4. Lamayuru Formation (Maestrichtian portion).

The Spongtang Outlier in Central Zanskar is surrounded in the W, N, and SE by a wide belt of dark argillites. They form relatively low terrain with soft scenery (Fig. 6 on Pl. 3). A series of passes like Singhe La, Sirsir La, Snuzi La, and Kesi La are found in that belt and villages like Lingshet, Photaksar, and Kangi could develop there. From work in the Spongtang-Shillakong area I regarded these black argillites as Lamayuru Unit forming part of the outlier. Recent mapping of the Lingshet area and the region Kong-Wakha Chu-Phulungma revealed that the major part of this black shale complex is parautochthonous. They form one stratigraphic sequence with the Shillakong Formation just described and the succeeding Paleo-Eocene beds. Only the black argillites overlying the Eocene series seem to represent an outlier of the Lamayuru Unit. Where the separating Tertiary formations are missing, distinction between allochthonous and parautochthonous Lamayuru Formation is almost impossible.

The rocks are dark grey to black slates and silty slates often exhibiting oblique cleavage. Locally the argillites are altered to phyllites. On the surface of the bleaching argillites sometimes foraminiferas can be recognised by means of the lens. In certain zones subordinate blue marly or calcareous, partly nodular layers or thin, rusty weathering, fine-grained, impure, micaceous sandstones may be interbedded with the slates. Black concretions are not rare. Under the microscope the argillites show flasery or lenticular structure; sedimentary lamination was not observed and seems to be non-typical. Tests of formaminiferas are frequent but ill-preserved. Dr. R. OBERHAUSER (Geol. B.-A. Vienna) kindly identified:

Globotruncana stuarti (LAP.) (80/ 15,)
Globotruncana arca (CUSHMAN) (80/ 11,)
Globotruncana sp. (80/ 12, 17, 33)
Pseudotextularia sp. (80/ 11)
Globigerina cf. *bulloides* (80/ 15)
Globigerina (?) (80/ 33)

Besides these fossils shell fragments were observed but are rather rare. The microfauna indicates Upper Campanian – Maestrichtian age. From the fact that the underlying Shillakong Formation has yielded an Upper Campanian fauna (BASSOULLET et al., 1978 b) the Lamayuru Formation of the Northern Zanskar Unit seems to be mainly Maestrichtian.

It is quite likely that the Lamayuru Formation reaches up into the Early Tertiary; there is, however, no fossil evidence.

NE of Kesi La the upper boundary of the Lamayuru Formation was examined (from top to bottom):

- Quartzite Series (base of Paleocene Lingshet Lms.): rusty weathering, dark quartzites with ferruginous layer at the base.
- Dark sandy slates – schistose sandstones, rusty weathering (6 m).

- Black sandy slates – sandstones (containing black concretions) interbedded with dark, nodular, mostly impure limestone (20–30 m).
- Grey, green, white quartzite, ferruginous weathering (2 m)
- Black silty slates (badly exposed)

This section shows increasing arenaceous influx towards the top of the Lamayuru Formation which points to a regression. The ferruginous layer at the base of the quartzite series may indicate a gap.

The dark pigmented silty argillites of the Lamayuru Formation succeeding the Shillakong Formation mark an abrupt change in facies. Apparently the Campanian sill subsided in the Maestrichtian and was overlapped by the Lamayuru basin facies from the N (Pl. 2 A, B).

There is also a marked facies difference between the Lamayuru Formation of the Northern Zanskar Unit and Maestrichtian portion of the Spanboth Limestone of the Tibetan Zone. According to Dr. R. OBERHAUSER the contrast between the basin facies and benthonic shelf facies is also obvious from the comparison of the coeval foraminiferal faunas.

KELEMEN & SONNENFELD (1981) regard the dark argillites of the Kangi – Photaksar – Lingshet belt as continuation of the Kangi La Flysch. The age of the latter formation, however, is Campanian to Lower Maestrichtian, whereas the Lamayuru Formation is post-Upper Campanian. Thus the two formations are not equivalent, but the highest portions of the Kangi La Flysch are contemporaneous with the lower part of the Maestrichtian Lamayuru Formation. This may explain the difficulties in demarcating the lithologically similar formations in the Kong area. Former passages are not entirely destroyed there by the disturbances along the Tibetan Zone – Northern Zanskar Unit boundary: in the lower Chulung Valley the uppermost Kangi La Flysch (Tibetan Zone) is coloured dark (30–40 m). The Lamayuru Formation of the Kong-Wakha region (N. Z. U.) contains zones lithologically similar to the Kangi La Flysch.

It is difficult to estimate the original thickness of the Lamayuru Formation of the Northern Zanskar Unit. Certainly it measures up to 1000 m in some sections, but intercalated Shillakong Formation (Fig. 7, 8 on Pl. 3,4) or Lingshet Limestone are proof of the intensive internal tectonisation of the formation. This is easily explained from its position below the Spongtang Outlier.

2.2.5. Lingshet Limestone (Fig. 7, 8, on Pl. 3, 4)

In undisturbed sections the formation commences with rusty weathering quartzite beds, generally 20 to 40 m thick. The quartzites are thick-bedded and of white, green, grey and brown colour. There are sandstones, carbonate quartzites, sandy limestones, and brown, grey, and dark, silty slates interbedded. Burrows are frequent. Oolitic iron ore found in the highly disturbed zone of the lower Chulung Valley appears to be derived from this ferruginous Early Tertiary horizon. A specimen, not found in situ, was kindly examined by Dr. R. FISCHER (Mineralogical Instiute of the University of Vienna):

The diffractometric examination of the powder showed haematite and chamosite (thuringite) in approximately equal amounts, quartz is very subordinate.

Under the ore microscope three kinds of ooids may be discerned:

a. Concentric ooids around a non-ore nucleus

b. Ooids around a core of haematite, which is sometimes fragmental. This nucleus is surrounded by concentric shells of fine-grained haematite or non-ore minerals. Some ooids consist of practically pure haematite, whereas in others haematite is subordinate.

c. Ooids containing fragments of earlier ooids. The radius of these former ooids is predominantly larger than that of the unbroken ooids. The structure of the „new" ooids appears undisturbed by the fragments enclosed. Fragments of earlier ooids are found also in the matrix.

Pyrite is found in the matrix but in very subordinate quantity. This mineral was never observed in the ooids. The pyrite grains may be well-preserved, but with a marginal rim of limonite, or may be entirely replaced by limonite (pseudomorphs). Limonite is observed only in connection with pyrite.

The above examination shows that the ferruginous beds were deposited in an agitated and well-aerated environment.

It is possible that the arenaceous-ferruginous beds indicate a hiatus between the Lamayuru Formation and the Lingshet Limestone, which however is not proved.

Upwards these beds pass into blue, dark grey to blackish, partly cherty limestones, which are mostly nodular and interstratified with dark silty slates. Indeterminable fossil debris of crinoids, corals, pelecypods, and gastropods indicates shallow-water origin.

It follows a thick-bedded to massive sequence of blue to black limestone and light grey to cream dolomitic limestone. The rocks are partly cherty, oolitic and contain stromatolitic layers (LLH-C type) and intraformational breccias. Shrinkage cracks filled by calcite are not rare. Commonly, but not always, the rocks are rich in fossils:

Foraminiferas (up to 3 cm size), corals, bryozoa, brachiopoda, pelecypoda, and crinoids. Prof. Dr. L. HOTTINGER (Palaeontol. Inst., University Basle, CH) kindly gave the following determinations of the foraminiferas:

80/13 A, B:	*Alveolina (Glomalveolina) lepidula* SCHWAGER
	Alveolina ilerdensis HOTT.
	Alveolina sp. ex gr. *elipsoidalis*
	Lockhartia haimei (DAVIES)
	Orbitolites ex gr. *complanatus* LK.
	Orbitolites cf. *minimus* HENSON
	Nummulites sp.
80/13 C, D:	*Alveolina* ex gr. *elipsoidalis*
	Nummulites sp.
	Assilina sp.
	Operculina cf. *canalifera A.*
	Lockhartia sp.
80/16:	*Orbitolites* ex gr. *minimus* HENSON
	Orbitolites ex gr. *complanatus* LK.
	Alveolina (Glomalveolina) lepidula SCHWAGER
	Alveolina cf. sp. 1 in HOTTINGER, 1971, pl. I, fig. E
	Alveolina cf. *ilerdensis* HOTT.
	Alveolina aff. *pasticillata* n. sp. in HOTTINGER, 1971, pl. III, fig. A, B

These faunas from the Lingshet-Singhe La area suggest Middle Ilerdian (Up Paleocene) age.

80/22 (S of Photak La): *Globigerina* indet.
Truncorotalia indet. – Paleo-Eocene

80/27 (lower Chulung Valley):
Orbitolites gr. *minimus* HENSON
Rotalia aff. *trochidiformis*
Lockhartia haimei
Lockhartia conica altispira SMOUT
Rotalia hensoni SMOUT
Up. Paleocene-L. Eocene indet.

80/28: indeterminable Miliolids, Spirolinas
Glomalveolina cf. *lepidula*

80/30: *Rotalia* ex. gr. *trochidiformis*
Operculina jiwani (DAVIES)
L. Ilerdian (Up. Paleocene)

80/27–28, 30 from the southernmost limestone of the lower Chulung Valley are in ascending order, 30 from the topmost portion.

From these determinations by L. HOTTINGER follows an Upper Paleocene age of the Lingshet Limestone. Thus its stratigraphic range is much more limited than that of the Upper Maestrichtian – Upper Paleocene Spanboth Limestone. Though I do not follow KELEMEN & SONNENFELD (1981) equating the two limestone formations, I agree that they were continuous before their tectonic separation. The benthonic limestone deposition started in the Upper Maestrichtian in the S and spread to the N reaching Northern Zanskar in the Upper Paleocene. Still within the Paleocene the limestone sedimentation ended. In the S it was followed by the Chulung La Slates, in the N by the Kong Slates to be described next.

After a first report of nummulites from Zanskar by THOMSON (cit. LA TOUCHE, 1888) LA TOUCHE rediscovered the Eocene beds in the Singhe La area. From his description, no doubt, they are identical with the Lingshet Limestone.

The strong deformation at the base of the Spongtang Outlier entirely squeezed out the formation in the Photaksar – Snuzi La area. W of Lingshet, however, its thickness swells up to several hundred meters. The original thickness of the carbonates overlying the quartzite beds seems to be about 100 m.

2.2.6. Kong Slates

The Lingshet Limestone is succeeded by cream, light grey to greenish slates, schistose marls and limestones with a few beds of blue grey limestone. The rocks abound in large foraminiferas recognisable for the naked eye. Ostreas and snails were also observed. These beds pass into medium to dark grey bleaching slates, which are laminated, partly graded. In contrast to the bleaching slates of the Lamayuru Formation sandy and silty layers seem to be absent. The thickness of the calcareous-argillaceous series overlying the Lingshet Limestone varies around 100 m. It is not always easy to separate the slate series from the overthrust slates of the Lamayuru Unit and they may be mistaken, when seen from afar.

Fossils predominantly occur in the lower portion of the formation.

Prof. Dr. L. HOTTINGER (Palaeont. Inst., Univ. Basle, CH) kindly examined my samples:

80/31 (close to the base of the Kong Slates, Chulung Valley):
„*Assilinas*"
Nummulites sp.
probably Lower Eocene

80/32: *Assilina daviesi* var. *nammalensis* GILL (1953)
Assilina granulosa + *daviesi* in GILL (1953)
Nummulites sp.
Alveolina sp.
Ilerdian (Up. Paleocene)

80/34: *Operculina escheri* HOTT. (ex gr. *O. canalifera)*
Nummulites cf. *bombitus* HOTT. (ex gr. *N. spirectypus*)
Lower Eocene

80/35: Small *Nummulites* and *Assilinas*.

These determinations along with those referred by METZELTIN & NICORA (1977,. p. 807–809) and G. FUCHS (1979, p. 522) indicate that the Kong Slates are mainly Lower Eocene, the sedimentation, however, may have commenced already in the Upper Paleocene.

As the fossils are derived from the lower parts of the formation the higher portion may be somewhat younger. The Eocene series, the youngest beds of the Northern Zanskar Unit, are evidence that the Spongtang Outlier was overthrust after the Lower Eocene and not pre-Maestrichtian as inferred by ANDREWS-SPEED & BROOKFIELD (1982) and BROOKFIELD & REYNOLDS (1981 a, b).

2.3. The Lamayuru Unit

The much disturbed tectonic unit consists of a thick complex of dark slates and phyllites in certain zones alternating with thin-bedded flyschoid impure sand- and siltstones or bluish marls and limestones. This characteristic lithounit representing a basin facies was called the Lamayuru Formation and I refer to the description on p. 517–519 in FUCHS (1979).

The terms „Lamayuru Flysch" (GANSSER, 1976) and „Flysch Zone" (HONEGGER et al., 1981) are not used here, because only a part of the formation exhibits flysch character. The latter name may easily be confused with the Cretaceous flysch of the Dras Unit or Indus Flysch (s. s., GANSSER, 1976).

Rare fossils proved a Triassic-Jurassic age and after the Maestrichtian fossil finds in the Lamayuru Formation of the Northern Zanskar Unit and the interfingering with the Shillakong Formation (Campanian) it is rather probable that the eugeosynclinal facies persisted into the Upper Cretaceous. Along the terminating ophiolite zones various klippes of limestone (e. g. BASSOULLET et al. 1978 c), radiolarite or serpentinite are found within the Lamayuru complex, however only klippes of Kioto Limestones type (DE TERRA, 1935; FRANK et al., 1977; FUCHS, 1979; BASSOULLET et al, 1981) and Shillakong Formation occur throughout the Lamayuru Unit (FUCHS, 1979). These rocks, typical of the Northern Zanskar Unit adjoining in the S, either were interfingering with the eugeosynclinal facies or slumped into the basin. Anyhow they show that the Lamayuru basin was adjacent in the N to the Zanskar shelf.

BASSOULLET et al (1981) studied the limestone intercalations and distinguish three types: 1) olistolites (sedimentary klippes) or olistolite breccias 2) grainstones resedimented grain by grain at the outer border of the shelf 3) „grain flows" deposited in the flysch. Later these sedimentary intercalations were tectonically broken. New fossil finds in the above limestones prove that the Lamayuru-Formation comprises Middle Triassic to Middle Jurassic parts. Thus the careful studies of the French workers agree very well with my views (FUCHS, 1977, p. 222, 227; 1979 p. 518).

In the recent scenery the rigid limestone klippes stand out as cliffs from the soft predominantly argillaceous rocks of the Lamayuru Formation.

SRIKANTIA & RAZDAN (1979, 1980) took the Kangi-Photaksar belt of mainly Maestrichtian Lamayuru Formation als Spiti Shales and Giumal Sandstone, the Lamayuru-Mulbekh zone as Kuling Formation (Permian). They refer to the Permian fossils found by TEWARI & PANDE (1970) which, however, are derived from a klippe. On the other hand the Mesozoic fossils found by FRANK et al. (1977) and FUCHS (1977, 1979) are not from „Lilang limestone bands", but from the Lamayuru Formation itself. Like SHAH et al. (1976) SRIKANTIA & RAZDAN (1979, 1980) regard the Lamayuru Zone and the limestones of Northern Zanskar as one stratigraphic sequence neglecting the thrust contact of the formations.

As already mentioned my 1980 survey has shown that most of the Lamayuru Formation in the Spongtang area belongs to the Northern Zanskar Unit. Only the Lamayuru Formation overlying the Lingshet Limestone represents the Lamayuru Unit. It is not always easy to distinguisch these Lamayuru argillites from Kong Slates of the topmost portions of the Northern Zanskar Unit. In the same way separation is difficult where the Lingshet Limestones are squeezed out and Lamayuru Formations of the two tectonic units join each other (e. g. Photaksar-Kangi).

The (?) *Prograyiceras* of Callovian-Oxfordian age reported by BROOKFIELD & WESTERMANN (1982) seems to be derived from the allochthonous Lamayuru Formation of the Spongtang area.

Apart from a chloritic carbonate bed observed at Lamayuru, which probably represents a tuffite (FUCHS, 1979, p. 517), I did not find volcanic rocks associated with the Lamayuru Formation. HONEGGER et al. (1981), however, describe „Triassic volcanics", which according to them are related with the Lamayuru Formation („Flysch Zone") of the Sanko region. Based on field observation in the area S of Rusi La I regarded these metavolcanic rocks as belonging to the Dras Unit. The chemical-mineralogical examination by HONEGGER et al. (1981) however, showed that these alkali-basalts to alkali-rhyolites, a type known from many oceanic islands and some continental rift valleys, are distinct from the Dras Volcanics, which are indicative of an island arc. I do not follow the named authors because:

a. The Triassic age of the volcanics may be contested, as the Lamayuru Formation comprises not only the Triassic, but reaches higher up, most probably into the Upper Cretaceous. The volcanics in question (Rusi La) are very distant from the Triassic fossil localities at Lamayuru. The volcanic rocks associated with the exotic Permian and Scythian carbonates (BASSOULLET, 1978 c) just prove that they are post-Scythian, but do not document „Triassic age". Further these carbonates and volcanics occur as a block in the ophiolitic melange zone terminating the Lamayuru Unit in the N and thus do not belong to the latter.

b. The greenish flysch sediments associated with the volcanics S of Rusi La are lithologically quite different from the rocks of the Lamayuru Formation. They resemble the flysch associated with the Dras Volcanics and are of a type unknown from the Lamayuru Unit. Furthermore it is a characteristic feature of the Lamayuru Formation to be free of volcanics. Serpentinites in the marginal parts belong to the ophiolitic melanges terminating the Lamayuru Unit in the N and S.

In view of these field observations along with the petrochemical data recorded by HONEGGER et al. (1981) the referred volcanic belt probably represents an individual unit (Rusi La Zone), which has to be separated from the Lamayuru – as well as from the Dras Unit.

2.4. The Dras Unit

In the type area (WADIA, 1934) and eastwards towards Lamayuru volcanic rocks predominate in the Dras Unit. Further east the volcanics gradually become replaced by flysch (GANSSER, 1976; FRANK et al., 1977). In the Spongtang Klippe the Dras Unit is composed of volcanics and flysch (FUCHS, 1977, 1979). Other sedimentary rocks associated with the volcanics are synchronous marls, limestones and radiolarian cherts and exotic carbonate blocks.

The volcanics form massive or irregulary stratified, rusty rock faces disintegrating to coarse blocks (Fig. 9 on Pl. 4). Fresh, the rocks are mostly green or red and comprise flows of fine-grained or dense basalt and diabase, often in form of pillow lava and amygdaloid lava, porphyrite, medium-to coarse-grained doleritic, dioritic, gabbroic rocks, volcanic breccias, agglomerates and tuffs. The phenocrysts of the porphyric rocks pyroxene, hornblende, and plagioclase are mostly transformed due to the greenschist metamorphism, which the whole complex has undergone. Besides basalts also andesitic and dacitic rocks occur, which however are subordinate (HONEGGER et al., 1981). According to these authors petrographic and petrochemical data indicate that the Dras Volcanics formed an island arc.

The flysch consists of brownish weathering, green, grey, fine to coarse-grained sandstones, which may pass into breccias, greenish siltstones, dark grey, green, purple slates and phyllites. Frequently these rocks are alternating in a cyclic way. Graded lamination, flute casts, load convolutions, and hieroglyphs stress the flysch character. There is no sharp line between flysch and volcanics because many of the sandstones are made up of reworked volcanic material or are contaminated by tuffaceous substance. In breccias also volcanic material is found in form of clasts as well as in the matrix.

N of Photak La breccias become very coarse and build up a good portion of the flysch-volcanic series. This complex is best termed „wildflysch": In the unsorted brecciaceous zones the rock fragments may attain sizes of several meters. Ultimately also the light-coloured limestone klippe, building up the conspicuous peak NE of Photak La and having almost km-dimension, represents a component in this wildflysch (Fig. 10 on Pl. 4). From this klippe the light grey, cream to pink, dense limestones seem to be derived, which are found as boulders embedded in the breccias of the wildflysch (Fig. 11). Unfortunately no good sample could be extracted from these fossiliferous rocks. They contain large stems of crinoids, single corals, snails, ammonoids and sections of brachiopod or pelecypod shells. From my description Dr. L. KRYSTYN (Palaeont. Inst. Univ. Vienna) supposed these limestones to be of Permian age. The limestone, which appears almost unstratified, certainly

Fig. 11: Wildflysch N of Photak La: A m-sized exotic block of cream to pink, dense limestone containing large crinoid stems and sections of brachiopods, corals, and cephalopods is embedded in brecciaceous flysch matrix (right side).

was formed in a benthonic environment. As an exotic block it slumped into the mobile Cretaceous trough, in which the wildflysch and volcanics were formed. Besides the above limestone the following components are found: Reworked carbonate breccias, cherts, sandstones, and argillites. The rock fragments are irregularly embedded in an argillaceous-arenaceous groundmass.

Carbonate rocks are found not merely as blocks but also interstratified in the flysch. They are dense marls and limestones of grey, cream, and red colour, reminiscent of the „couches rouges" of the Alps. The carbonates are frequently schistose. In sample 80/14, a red cherty marl, Dr. R. OBERHAUSER (Geol. B.-A., Vienna) kindly determined small globigerinas and heterohelicids suggesting Middle to Upper Cretaceous age. 80/18 yielded sphaerical fossils, probably large radiolaria, and very fine-grained indeterminable detritus of microfossils.

The dense carbonates grade into fine-clastic limestones, carbonate breccias, carbonate sandstones etc. by increasing contamination with clastic and volcanic matter. These rocks yielded double-carinated globotruncanas pointing to Upper Turonian – Santonian age (80/19, det. R. OBERHAUSER). Sample 80/21 contains single and double-carinated globotruncanas; among the ill-preserved fossils *Globotruncana stuarti* (LAP.) was detected, suggesting Maestrichtian age.

Similarly the Mid-Cretaceous Khalsi Limestone is interbedded with volcanic layers of the Indus Flysch (FUCHS, 1979, p. 516). Boulders of Orbitolina limestone I found enclosed in agglomerates of the Dras Volcanics of Arju La (SE of Kargil).

Red and green bright coloured cherts are frequently associated with the volcanics and flysch.

HONEGGER et al. (1981) report on radiolarian cherts yielding Callovian to Tithonian age near Dras.

Considering all these indications a Jurassic to Upper Cretaceous age of the Indus Flysch – Dras Volcanic complex is proved, which may reach into the Paleogene. K/Ar whole rock ages of 77.5 ± 1 m. y. for the Dras Volcanics were obtained by K. K. SHARMA et al. (1978) and fit well with the age suggested above.

2.5. The Rusi La Zone

In the Rusi La region the dark coloured Lamayuru Formation is underlain by a brown weathering, greenish flysch-volcanic complex, which in analogy to the Lamayuru area, I have mapped as Dras Unit. Recently HONEGGER et al. (1981) demonstrate that these volcanics are petrochemically distinct from those of the Dras Unit. They comprise alkali-basalts to alkali-rhyolites, basic to intermediate types being dominant. This volcanic suite is known from many oceanic islands and a few continental rift valleys. Accepting the discrimination from Dras Volcanics, I do not agree with HONEGGER et al., who speak of the „Triassic Volcanism" and regard it as part of the Lamayuru Unit (their „Flysch Zone"). From the fact that comparable volcanics are generally missing in the Lamayuru Formation and from the lithology of the associated flysch I am convinced that the volcanics are not related with the Lamayuru Unit. Though no fossils could be obtained from my samples, I suppose a Cretaceous age for the bulk of the Rusi La Zone and a palaeogeographic position S of the Dras island arc and N of the Lamayuru trough.

The fine- to coarse-grained volcanites form irregular flows tens of meters thick.

The microscopic examination of a sample kindly done by Dr. A. DAURER (Geol. B.-A., Vienna) reveals the metamorphism the rock has undergone:

The fabric is heteroblastic, slightly lenticular around aggregates of albite. Chlorite (37 vol.%, estim.) with light green to brown interference colours (Mg-Fe-chlorite); quartz (25 vol.%); albite (7 vol.%) almost idiomorphous, slender crystals, slightly filled by sericite and epidote; ore (1 vol.%). The rock reminds of epi-metamorphic hyaloclastic tuffs from ophiolites of the Alps (Engadiner Window, Idalpe).

The volcanics are interstratified with light green to dark grey phyllites and thin-bedded arenaceous slates and sandstones. The rocks frequently show graded bedding, flute casts, and hieroglyphs. The series, which directly underlies the Lamayuru Unit, contains carbonate bodies up to 50 m thick and disrupted to klippen. They consist of grey to cream cherty limestone interlayered with rusty weathering detrital and arenaceous limestone and light to dark grey slate in a cm- to dm-rhythm (Fig. 12). Like the surrounding series the banded limestone exhibits much small scale folding and flasery-lenticular structures. At the contact intermingling with volcanic material can be observed indicating contemporaneous origin.

Fig. 12: Banded limestone with cherty and arenaceous layers. The limestone has not yielded fossils, the volcanic flows of the Rusi La Zone, however, show magmatic contacts to the carbonates; SSW of Rusi La.

Underlying these carbonates I observed the following rock assemblage: (Fig. 10 on Pl. 4): red, purple, and green slates to phyllites, green and purple schistose effusiva, agglomerates und tuffs, fine-clastic carbonate breccias, impure flasery limestones mainly as lenticularbodies. This multicoloured association of sedimentary and volcanic rocks is quite distinct from the sombre-coloured Lamayuru Formation.

2.6. The Peridotites and Ophiolitic Melanges

Ophiolitic melanges (GANSSER, 1974) separate the major stratigraphic-structural units of the Indus Zone. They mark very much tectonised zones made up of ultramafic rocks, mainly serpentinites, basaltic lavas and pyroclastics, gabbros, ophicalcite, flyschoid shales and sandstones, radiolarian cherts, quartzites and blocks of Permian-Mesozoic carbonate rocks of a facies unknown from the adjacent Himalayan zones. TEWARI & PANDE (1970) and BASSOULLET et al. (1978 c) record Permian respectively Scythian ages of limestone blocks; S. K. SHAH & M. L. SHARMA (1977) and HONEGGER et al. (1981) found Upper Cretaceous microfaunas in cherts respectively limestones of the Mulbekh-Dras ophiolite zone. The basaltic rocks show tholeiitic affinities characteristic of mid-ocean ridges (HONEGGER et al.

1981). Blue schists, indicating high-pressure/low temperature conditions, are occasionally found in these belts (KUMAR, S. 1978; VIRDI, 1981; DESIO & SHAMS, 1980). According to GANSSER (1974) the melanges are produced by the obduction of oceanic crust of basins, which were obliterated during the collision and subduction of continental plates. Though there is dispute on that problem, the mantle material within the melanges indicates that they definitely mark deep reaching and very important structural planes.

It appears that the ophiolitic melanges are most characteristic in the root zone, the Indus Suture belt, and are less pronounced in the frontal portions of the Spongtang Klippe.

The highest parts of the Spongtang Outlier consist of masses of peridotite, mainly harzburgites. The coarse-grained, dark green rocks disintegrate to round, rusty weathering blocks. Occasionally dioritic dikes may penetrate the peridotite. BASSOULLET et al. (1980) record about the occurrence of chrome bearing dunites, besides harzburgite, pyroxenites, gabbros, and diabase dikes. Regarding the petrography of the peridotitic masses I refer to the detailed studies of HONEGGER et al. (1981) and KELEMEN & SONNENFELD (1981).

2.7. The Indus Molasse

It is the merit of A. P. TEWARI (1964) to recognise the Indus Molasse as an entity, which is separated from the Indus Flysch and Dras Volcanics by a thrust. The Indus Molasse consists mainly of thick-bedded conglomerates, sandstones, and sandy argillites, frequently of bright purple, green, and beige colours. It was deposited in a continental basin after the first Himalayan nappe movements. In the N the Indus Molasse transgresses on the Ladakh batholith (TEWARI, 1964; GANSSER, 1976). Most of the pebble content is derived from the reworked Ladakh Intrusives. FRANK et al. (1977), SRIKANTIA & RAZDAN (1979, 1980), BROOKFIELD & REYNOLDS (1981 a, b), BROOKFIELD (1981) give a detailed review on the Indus Molasse belt, to which I refer.

In the Lomba Valley, S of Kargil, the Indus Molasse is found sandwiched between Dras Volcanics. It is excellently exposed around Chaskor and in the gorge between Lomba and Patambis. Inspite of the scale tectonics the transgressive contacts of the Indus Molasse on the Dras Volcanics are locally preserved. They are unconformable and the basal conglomeratic beds are made up almost exclusively of reworked Dras Volcanics (W of Lomba). The boulders and pebbles (cm- to m-sizes) are sub- to well-rounded but ill-sorted. In higher portions of the conglomerate complex purple arenaceous argillites and sandstones are interbedded.

From these observations follows that the Indus Molasse is younger than the Dras Volcanics and post-dates their first deformation.

SRIKANTIA & RAZDAN (1979, 1980) take the Chaskor-Lomba occurrence as a window of the Indus Molasse (their „Indus Group") framed by Dras Volcanics. They are right regarding the superposition of overthrust Dras rocks, but overlook the unconformable transgressive contacts of the molasse on underlying Dras Volcanics.

My recent survey of Zanskar proves that the units making up the Spongtang Outlier took their present position after the sedimentation of the underlying Lower Eocene formations of the Northern Zanskar Unit. These nappe movements most probably initiated the molasse deposition. LYDEKKER (1883) and DAINELLI (1934) on the other hand mention intercalations of nummulitic limestones in the molasse. Recently BROOKFIELD (1981) made a traverse E of the Zanskar River, where DAINELLI has described his Eocene rocks, and found a Lower to Middle Eocene series deposited in marginal marine to freshwater environment (Unit III, member 1) which passes up into shelf facies. These beds are succeeded by thick flysch containing thin nummulitic limestones (member 2). The flysch is unconformably overlain by coarse-clastic series of the Indus Molasse. My interpretation of BROOKFIELD's observations is that the Eocene flysch represents a lower stage in the trough of the Indus Molasse, probably formed in the central portions. It is succeeded unconformably by the youger typical molassic stages.

It may be inferred that BROOKFIELD's Unit III member 1 marks the beginning of the Indus Molasse. In central portions of the basin, however, deposition still was of flysch type. After a youger tectonic phase molasse type sedimentation spread over the whole basin.

Limestone pebbles in the conglomerates are Lower Eocene, Paleocene, Upper Cretaceous and older (BECKMANN in FRANK et al., 1977, p. 99). From the fact that the molasse transgresses on the Ladakh Intrusives their age is of great importance.

HONEGGER et al. (1981) interprete their U/Pb results of 103 ± 3 m.y. as the formation of the magma. Intrusion ages of 80 ± 3 m.y. for the Somau granodiorite and 60 ± 10 m.y. for the granites of Shey Gompa indicate composite intrusion. K. K. SHARMA, et al. (1978) obtained an age of 27,8 ± 0,6 m.y. (Up. Oligocene) by K/Ar whole rock method for the porphyritic granites in the core of the Ladakh Pluton. Kailas intrusives and volcanics yielded a well-defined isochrone of 38,8 ± 2 m.y. (HONEGGER et al., 1981). Thus at least some portion of the molasse must be Oligocene or younger. TEWARI (1964, p. 47–48), considering the few fossil references and structural aspects, concludes that the Indus Molasse is post-Eocene, possibly post-Middle Miocene.

In view of all these facts and arguments the Indus Molasse seems to commence in the Eocene and reach into the Miocene. Probably it started after the Eocene nappe tectonics of the Indus-Zanskar region and came to an end by the Mid-Miocene nappe movements of the Lesser Himalayas, which produced the „counterthrusts" in the Ladakh-Tibetan area.

3. Tectonics

The following structural units are discerned:

The Tibetan Zone, an autochthonous unit showing gradational contacts to the underlying Central Crystalline. The Northern Zanskar Unit formed the northern portions of the Zanskar shelf and thus was continuous with the Tibetan Zone. The unit became parautochthonous, overthrusting the Tibetan Zone marginally from the N. The Lamayuru Unit composed of continental slope- to eugeosynclinal sediments was dragged to the S onto the units of Zanskar by the overthrusting nappes. The Rusi La Zone represents a wedge between the Lamayuru Unit and the Dras Unit, which consists of Dras Volcanics and Cretaceous flysch. As shown by the Spongtang Outlier the Dras Unit and the succeeding peridotite masses were thrust to the SW in form of nappes. The boundaries of the structural units of the Indus Zone are frequently marked by ophiolitic melanges. After the nappe movements directed SW, the whole pile of units was overturned towards the NE by later compression in the Indus Zone.

3.1. The Tibetan Zone

The unit is characterised by open folds, which are upright or directed towards the SW. These folds are described starting in the SW with the passage zone to the Crystalline: The metamorphosed Triassic carbonates, crossing the Suru Valley just W of Zulidok, represent a syncline. Towards SE this syncline crosses the Sang Po Valley about 7 km S of Rangdum.

An anticline composed of Palaeozoic rocks is exposed in the slope N of Zulidok. S of the Suru Valley a stock of porphyric granite intruded into the core of this anticline.

After a syncline of Triassic carbonates another anticline follows; Panjal Trap makes up the core, building the monastery hill of Rangdum. All the fold elements mentioned strike NW-SE. The prevailing north-eastern dip indicates SW-directed fold movements (Pl. 1, 2, [6–8]).

The Kioto Limestone NE of Rangdum marks a syncline, which is just one of several megafolds observable in the Mesozoic carbonate series N and E of Rangdum (FUCHS, 1979, Fig. 3 on Pl. 5).

In the Cretaceous series of the Spanboth Valley the bright coloured Chulung La Slates form the core of a large syncline. The SW-limb of this syncline shows conspicuous folding in the orographic right flank of the Spanboth Valley. The NE-limb also is deformed by minor folds: The Spanboth Limestones branching off from the main syncline in the valley leading to the Pukdum La represent a minor syncline. Towards the NW the synclines end due to axial rise. But also towards the SE the older formations only can be followed.

An anticline composed of Kangi La Flysch strikes from the southern slopes of the Kangi Pass region to the Pukdum La and crosses the upper Oma Chu. There the core of the anticline consists of intricately folded Giumal Sandstone.

NE of this anticline the Spanboth Limestone of the Kangi La forms a much folded syncline. The limestone formation ends in the mountains W of the Oma Chu and the syncline is indicated in that valley by Kangi La Flysch (Fig. 2, on Pl. 3). Further SE Chikkim Limestone surrounded by a thick development of Giumal Sandstone marks the utmost extension of the syncline. In the Oma Chu area too the folds are strictly directed SW (Pl. 1, 2).

At Diwing an anticline of Giumal Sandstone follows the course of the Oma Chu. Towards the W this anticline is indicated by Kangi La Flysch separating synclines of Spanboth Limestone.

The area N of Diwing and towards the Chulung Pass represents a structural depression: The Chulung La Slates, the youngest formation, fill several SW vergent synclines, separated from each other by anticlines of Spanboth Limestone. The most pronounced of these synclines is that of Chulung La, which can be followed SE to the Chumse Tajok Valley leading to the Kesi La. Near the junction of that valley with the Oma Chu folding and imbrication leads to repetitions of Chikkim Limestone and Giumal Sandstone, which were mistaken by KELEMEN & SONNENFELD (1981) for stratigraphic repetitions.

A glance on the map (Pl. 1) shows that the folds built by the Cretaceous series strike NW-SE and are slightly oblique to the Triassic belt of the south-western limb of the Zanskar Synclinorium. Further the area Spanboth – Pukdum La – Chulung La represents an axial depression. I infer that both, the slightly aberrant strike and the axial depression, are related with the emplacement of the Spongtang Outlier. The axial depression either is responsible that the oulier was preserved from erosion there or is the effect of the emplacement of the Spongtang Klippe.

The northern boundary of the Tibetan Zone is rather complicated. The geological map clearly shows that there must be a structural line terminating the Tibetan Zone in the N: various formations and different structural units come in touch with each other. Regionally the strike in the adjoining units is rather divergent. There is also much distortion; nevertheless it is not always easy to locate the tectonic contact, as can be seen from the following description:

At the village Itchu a marked anticline composed of the Crystalline crosses the Phulungma Valley (Pl. 1). To the W and the N these Crystallines are overlain by the Triassic-Jurassic carbonates of the N. Z. U.; E of the Itchu structural high these carbonates are folded together with their Cretaceous cover. The folds show a strict E-W strike and are overturned to the N (Fig. 4, 5 on Pl. 3; Pl. 2). The Triassic-Jurassic carbonate series, which strike from Rangdum towards the NW to the Phulungma Valley and overlie the Itchu Crystallines in the E, no doubt belong to the Tibetan Zone. Thus the Triassic-Jurassic carbonates of this zone are in contact with those of the N. Z. U. I suppose that the boundary between these structural units is located in the disturbed zone crossing the Phulungma Valley W of its marked N-convex bow (Pl. 1). There, the rather horizontal carbonates of the N. Z. U. are underlain by a zone of intricate folding, which strikes NW-SE and shows NE dip at medium angles.

Further E in the upper Wakha Chu the folds of the frontal portion of the N. Z. U. strike E-W and are directed N, whereas all the folds of the Tibetan Zone show NW-SE strike and SW-vergency (Pl. 1, 2). Thus a structural disconformity between these units is obvious. But the Maestrichtian Lamayuru Formation of the N. Z. U. contains portions lithologically rather similar to the Kangi La Flysch and therfore it is certainly not easy to locate the tectonic boundary. This is to be sought N of the drainage divide between the Wakha Chu and the Suru. I have not crossed this range except on my 1976 traverse over the Kangi La.

In the upper Kangi Valley (Kong area) the Cretaceous-Eocene formations of the N. Z. U. are steeply folded (Fig. 13 on Pl. 5). Their contact to the Kangi La Flysch of the Tibetan Zone appears disturbed . The southernmost of the Paleocene Limestones (samples 80/27–28,30) crossing the lower course of the Chulung Valley, however, is linked with the Tibetan Zone. Followed SE this limestone overlies stratigraphically the Kangi La Flysch with a dark band inbetween and is succeeded by the Chulung La Slates. No doubt, the limestone belongs to the Tibetan Zone there. In the Chulung section mentioned above the limestone is followed in the N by a syncline composed of Lower Eocene Kong Slates typical of N. Z. U. and Chulung La Slates characteristic for the Tibetan Zone. This limestone therefore has a position between N. Z. U. and Tibetan Zone in respect of facies as well as tectonically. These observations seem to substantiate the concept of KELEMEN & SONNENFELD (1981), who correlate the Lamayuru Formation of the Kangi-Photaksar belt with the Kangi La Flysch, the Spanboth Limestones with the Lingshet Limestone. I agree that the named formations once were continuous, but their fossil content clearly shows that their stratigraphic range is different. A shifting of facies is indicated, which is dealt in chapter 4. Tectonics brought more distant portions of the formations in juxta-position and thus accentuated facies and age differences. Therefore I discern the N. Z. U. and Tibetan Zone. But as shown by the Chulung section the horizontal displacement is not too large, because a connecting link is still preserved there between the two units. The tectonic plane at the base of the southernmost Lingshet Limestone observed in the Kangi La section (FUCHS, 1977, 1979) loses its importance in the Chulung Valley. The more active structural plane seems to follow the syncline N of the named limestone (Pl. 1, 2, [7, 8]).

N of Chulung La the N. Z. U. and the Lamayuru Unit are squeezed out or overlapped by the Dras Unit of the Spongtang Outlier. Multicoloured slates and volcanics come in touch with the Chulung La Slates. Furter SE in the region of the Photak La the Lamayuru Unit and N. Z. U. are exposed again. It is obvious there that the multicoloured flysch of the Dras Unit is a separate unit unrelated with the similarly coloured Chulung La Slates of the Tibetan Zone. KELEMEN & SONNENFELD (1981) mistake the red slates of the Photak La (= Flysch) with the red slates (Chulung La Slates) overlying the limestones of Kangi La (= Spanboth Limestone). The Lingshet Limestone is stratigraphically followed by the Lower Eocene Kong Slates and then come overthrust Lamayuru Unit and the multicoloured series of the Dras Flysch (Fig. 10 on Pl. 4).

The N. Z. U. consisting of much folded Lingshet Limestone and Lamayuru Formation comes in contact with Chulung La Slates, Spanboth Limestone, and Kangi La Flysch of the Tibetan Zone. Pl. 1 clearly shows that there is a tectonic contact between the Tibetan Zone and N. Z. U. south of Photak La. From there to the Zanskar Valley Kangi La Flysch and Lamayuru Formation border each other. Similar lithologies make it difficult to locate the tectonic boundary exactly. KELEMEN & SONNENFELD (1981) report that the Giumal Sandstone and Chikkim Limestone of the lower Oma Chu pass into the multicoloured limestones (Shillakong Formation). From my experience with the Tibetan Zone-N. Z. U. contact I suppose that the Giumal Sandstone and Chikkim Limestone end along a tectonic plane and instead of these formations of the Tibetan Zone the multicoloured limestones are found in the N. Z. U. Thus I opine that there is a tectonic juxtaposition and not a facial replacement.

3.2. The Northern Zanskar Unit (N. Z. U.)

This unit comprises the carbonate belt building up the rugged mountains of northern Zanskar and the Cretaceous to Eocene sedimentary series framing the Spongtang Outlier. The N. Z. U., once continuous with the Tibetan Zone, is now sheared off and overrides this zone marginally. Thus its southern frontal portions are parautochthonous (FUCHS, 1981, Pl. 1, section 1). The Cretaceous-Eocene sequence of the N. Z. U. is mostly sheared off from its base in the N and is enriched in the S, in the frontal parts of the unit. It is a characteristic that compression post-dating the SW-directed nappe tectonics deformed the northern parts of the N. Z. U. into tight vertical folds. Along its northern and western margins the N. Z. U. overrides the adjoining Lamayuru Unit ("Zanskar Thrust", FRANK et al., 1977). FUCHS (1977) regads this thrust and other counterthrusts as the product of younger compression, which has led to the inversion of the entire Indus Zone.

The Triassic-Jurassic carbonates of the N. Z. U. are connected with the Itchu Crystallines by gradational contacts. Conspicuous green horizons built of chloritic rocks and metamorphosed dark argillaceous – calcareous series in the upper parts of the Crystalline probably represent the Panjal Trap and Upper Palaeozoic to Lower Triassic beds. The Triassic-Jurassic carbonates also show varying grade of alteration (up to greenschist facies).

Crystallines and Mesozoic rocks are folded together as observable in the flanks N of the Phulungma Valley. A syncline reaches the bottom of the valley and can be followed into the slopes S of the village Shergandik. According to HONEGGER et al (1981) the syncline continues further towards the W.

The vast mountaineous terrain between the Phulungma Valley and the Mulbekh depression and E of Rusi La consists mainly of Triassic-Jurassic carbonates. This region is almost unexplored. From binocular observation gentle dip towards the central parts of this carbonate platform predominates. Locally, however, horizontal or vertical folds also are observed.

All along their margins the Zanskar carbonates overlie the dark Lamayuru Formation with tectonic contacts. SW of Baltikar an outlier of the carbonate mass rests on the Lamayuru Unit.

S of Wakha the Shillakong Formation overrides the Lamayuru Unit dipping S at medium to steep angles. A syncline of dark Lamayuru rocks may either stratigraphically follow as Maestrichtian series on the Campanian Shillakong Formation or form an outlier of the Lamayuru Unit. Upstream the Wakha Chu the Triassic-Jurassic carbonates are exposed in a small N-vergent anticline. They are mantled by a few meters of Giumal Sandstone. Further upstream another anticline brings up the Triassic-Jurassics. In the rock faces overtowering the valley of Mulbekh in the S, Triassic-Jurassic carbonates and bands of Giumal Sandstone overlie the Shillakong Formation. These rocks are continuous with the folds overturned to the N observable in the Wakha Chu gorge. In the rock faces of this gorge W of the river, Shillakong Formation builds the core of a syncline with NW-SE axis.

The Triassic-Jurassic carbonate series are gently dipping to horizontal. In a local anticline they are much disturbed by intricate folding. Quartzitic rocks in the core of this anticline seem to represent the Quartzite Series; shell beds contain ill-preserved specimens of *Dicerocardium* or *Megalodon*, corals, and other fossil debris.

S of the bifurcation of the Wakha Valley the Triassic-Jurassic carbonates dip SSE at medium angles and are succeeded by a few meters of Spiti Shales, thick development of Giumal Sandstone, very thin Chikkim Limestone, Shillakong Formation, and several hundred meters of Lamayuru Formation. The Lower Tertiary Lingshet Limestone is preserved in the syncline of the uppermost Wakha Chu, which may be followed to the ridge NW of Itchu La (Fig. 4, 5 on Pl. 3).

The Cretaceous-Eocene succession of the upper Wakha Chu is more or less in stratigraphic connection with the Triassic-Jurassic carbonates. Further E this connection is disturbed more and more.

The whole pile of formations is isoclinally folded, dipping S at medium angles (Pl. 1, 2 [5,6] Fig. 4, 5, on Pl. 3). Thus there is a marked vergency towards the N in the upper Wakha Chu-Phulungma area. Due to axial rise towards the W the synclines end and strike into the air in the upper Phulungma Valley. SSW-lineations crossing the regional E-W strike are observed in Kioto Limestone of the western branch of the Wakha Chu. Probably the cross axes are younger.

In the eastern branch of the Wakha Chu and particularly in the Kangi Valley the younger formations gain in areal extent due to axial plunge towards the E. Followed E the S-dipping isoclinal folds become vertical und finally dipping N (Pl. 1, 2 [7, 8]). The conspicuous folds of the upper Kangi Valley are composed of Lamayuru Formation, Lingshet Limestone and the Lower Eocene Kong Slates (Pl. 1, 2, Fig. 13). In my 1977 and 1979 papers I have mistaken the limestones for Kioto Limestone. After my visit to the Lingshet Limestones of the type locality, which abound in fossils, I found fossils also in the poorly fossiliferous Kong occurrence. SRIKANTIA & RAZDAN (1979, 1980) recognised the Eocene age of these beds (their Kanji Group), but regarded the Lamayuru Formation (Maestrichtian) as Spiti Shales-Giumal Sandstone.

S of Kangi it is questionable whether there exists Lamayuru Unit or not and the separation of Lamayuru Formation of this unit from that of N. Z. U. is problematic. In the upper tributary reaching the Kong cirque from ENE, however, Kong Slates are tectonically overlain by Lamayuru Unit (Fig. 14 on Pl. 5). This unit appears to overlap the folds of the N. Z. U. disconformably and both units finally are squeezed out in the Chulung La area.

Concerning the northern parts of the N. Z. U. in the Kangi-, Shillakong-, and Yapola Valleys I refer to my 1977 and 1979 papers and KELEMEN & SONNENFELD (1981). The boudined bodies of flyschoid sandstones, siltstones, and argillites N of Kangi I have taken as flysch. Seen along with the observations in the Wakha Chu I am certain now about their being Giumal Sandstone. Their position near the Kioto Limestone – Shillakong Formation boundary is stratigraphic. From the nature of this occurrence it is clear, however, that the post-Jurassic series are sheared off from their base. Thus there and further E the upper boundary of the Triassic-Jurassic carbonates was transformed to a tectonic horizon (Kangi-Naerung Fault, KELEMEN & SONNENFELD, 1981). In the Shillakong section the Shillakong Formation overlies directly the Kioto Limestone without remains of the Giumal Sandstone. In the Spongtang section a thin band of dark argillites between Kioto-Limestone and Shillakong Formation may represent Spiti Shale or Lamayuru Formation squeezed along the zone of disturbance. Due to inversion this plane dips steeply NE. KELEMEN & SONNENFELD (1981) found a broad zone of black shales between Kioto Limestone and the Shillakong Formation in the Machu-Photaksar section. They noted an extreme angular unconformity between the two units and term this zone of disturbance the Kangi-Naerung (Nira) Fault. At Nira these authors observed disrupted and dismembered Giumal Sandstone along this fault. This occurrence resembles closely to the Giumal Sandstones N of Kangi.

From these observations it is probable that the contacts between Kioto Limestone and Shillakong Formation are largely tectonised, also in the northern portions of the carbonate belt.

The stratigraphic boundary between the Campanian Shillakong Formation and the Maestrichtian Lamayuru Formation also is frequently tectonised. Serpentinite bodies near this boundary are observed E of Snuzi La and N of Sirsir La (FUCHS, 1979; KELEMEN & SONNENFELD, 1981). KELEMEN & SONNENFELD regard these serpentinites as outliers derived from the Spongtang Allochthon. As it may be, the ultramafics do not indicate an ophiolitic zone, but show that some movements occurred along the stratigraphic boundary.

Regarding the order of the sequence it is evident that the Lamayuru Formation is higher than the Shillakong Formation. This is shown by the fact that the Lamayuru Formation forms synclines (e. g. Kangi, W of Snuzi La, N of Singhe La) and builds up high terrain, whereas the Shillakong rocks come from below and are exposed predominantly in valleys (E and W of Snuzi La) (see FUCHS 1977, 1979; KELEMEN & SONNENFELD, 1981). From Kangi to the Shillakong Valley the Shillakong rocks steeply dip SSW beneath the Lamayuru Formation and come up again in anticlines (Pl. 1, 2 [7]). E of the Shillakong Valley the boundary is vertical or overturned dipping NE. This and the NE-dipping schistosity of the Shillakong Formation brought BASSOULLET et al. (1977, 1978 a, 1980 a) to the view that the carbonate belt of northern Zanskar was an outlier of a higher nappe overriding the Lamayuru rocks. It can be observed that the Shillakong Formation is tightly folded with shear planes dipping NE, the folded sedimentary bands, however, plunge beneath the Lamayuru Formation in the SW. The latter formation too shows the NE-dipping or vertical schistosity, which is transverse to the gently S-dipping ophiolitic melange and Dras Volcanics overlying (Fig. 6 on Pl. 3).

I put arguments against the opinion of BASSOULLET et al. (FUCHS 1979, p. 530). The superposition of the Lamayuru Formation on Shillakong Formation is evident particularly in the Linghet-Zanskar area (see below, and KELEMEN & SONNENFELD 1981).

N of the Spongtang Outlier Lamayuru Formation represents the youngest beds of the N. Z. U. The highest portions of the dark argillite belt, higher than sporadic klippes of quartzites, carbonate rocks and serpentinites are probably belonging to the Lamayuru Unit.

W of Singhe La the Lingshet Limestones appear again and we find a rich development of the Cretaceous-Lower Eocene formations of the N. Z. U. in the Singhe La – Lingshet area (Fig. 6–9, 15–17 on Pl. 3–6). The first report on these youngest beds of Zanskar is given by LA TOUCHE (1888). The Lamayuru Formation of Singhe La is overlain by highly contorted and folded Lingshet Limestones. At the pass it can be observed that these limestones form a syncline, the northern limb of which is overturned towards the SW (Fig. 15 on Pl. 5). The basal quartzitic beds of the limestone series are lain into several folds overturned to the SW (scale of the folds: tens of meters). These beds dip NE as the Lamayuru and Shillakong rocks do (Pl. 1, 2 [12], Fig. 15 on Pl. 5).

Between the much folded Lingshet Limestone and the Dras Volcanics of the Spongtang Outlier there is a zone of dark argillites. This band is composed of Kong Slates following stratigraphically on the Lingshet Limestone and of rocks of the Lamayuru Unit dragged onto the N. Z. U. by the overthrust nappes. The separation is somewhat problematic and needs detailed study.

NW of Yalchung the limestones turn to the SW and build up the precipices above the villages Goma and Lingshet (Fig. 7, 8, 16, 17 on Pl. 3–6). They are predominantly horizontal or gently dipping, but locally the limestone band is intensely folded. The axis of these folds is partly directed WSW, thus being transverse to the regional NW-SE strike (e. g. W of Goma, N of Lingshet). A broad band of Kong Slates fills the core of a WSW-ENE trending syncline in the limestones above Lingshet (Fig. 16, 17 on Pl. 6). These transverse folds are related with the eastern edge of the Spongtang Outlier. The cross-folding probably follows the shape of the allochthonous mass.

The Lingshet Limestones are underlain by a thick development of Lamayuru Formation, which builds up the morphologically soft terrain E and S of Lingshet. There is steep detail folding in the area around Kesi La, but generally the dip of the schistosity is NE at medium angles. This implies that the schistosity is transverse, because the extent of the formation suggests a rather horizontal position. The dark argillites have this transverse schistosity in common with the multicoloured rocks of the underlying Shillakong Formation. These beds are exposed in SW vergent anticlines SE of Lingshet and E of Stumpata Goma (Fig. 7, 8 on Pl. 3, 4). Around the latter village the relations are somewhat disturbed: The Shillakong rocks forming the core of the anticline end in the flank E of the village. They are in direct abnormal contact with overlying quartzites and carbonates, probably belonging to the Lingshet Limestone. The surrounding Lamayuru argillites contain several klippes of similar limestones and Shillakong Limestone (Fig. 7 on Pl. 3). These block-shaped occurrences represent sheared off wedges, anti- and synforms and thus indicate intense internal deformation of the Lamayuru Formation, which in absence of characteristic horizons is difficult to note.

KELEMEN & SONNENFELD (1981) attended a trip by boat down the Zanskar River. In course of this adventure they explored the geology of the Zanskar gorge, which can not be reached on foot. Their investigations along with the described geology of the Lingshet area leave no doubt that the Shillakong Formation underlies the Lamayuru rocks and that the Shillakong Formation of the Zanskar area continues via Singhe La, Photaksar, Kangi to the NW to the Wakha Chu. Therefore it is proved that inspite of NE-dipping schistosity the carbonate belt of northern Zanskar is a lower element than the Lamayuru argillite zone (Kangi-Photaksar) (Pl. 1, 2). This is unequivocal evidence against the view of BASSOULLET et al. regarding their allochthonous Shillakong Unit (1977, 1978) respectively „nappe du Zanskar“ (1980 a).

If we follow the N. Z. U. around the south-eastern edge of the Spongtang allochthonous mass towards the W we find again reduction: The thick development of Lingshet Limestone in the type area is disrupted to several thin bands in a matrix of Lamayuru Formation (S of Photak La) (Fig. 10, 18 on Pl. 4, 6). SW of Photak La this series is deformed in megafolds (Pl. 1, 2 [10]). Further W the N. Z. U. ends and the overthrust Dras Unit overlaps the lower units coming in contact with Chulung La Slates of the northernmost syncline of the Tibetan Zone.

The boundary of the Tibetan Zone and N. Z. U. is problematic in the area between Lingshet and the lower Oma Chu. The Kangi La Flysch and Maestrichtian Lamayuru Formation are in juxtaposition. These formations are much deformed and the lithological contrast is low. Therefore KELEMEN & SONNENFELD (1981) take them as one unit. From the stratigraphic and structural reasons already given I accept a tectonic boundary also there. In the traverse from the Chumse Tajok Valley (Barmi Valley of KELEMEN & SONNENFELD) to Lingshet I would place the tectonic boundary near Kesi La.

3.3. The Lamayuru Unit

Between the carbonate belt of northern Zanskar and the Dras Volcanics-Flysch Zone there is a zone of dark argillites with calcareous and silty-sandy interstratifications (Lamayuru Formation). Larger bodies of Triassic-Jurassic limestones and Shillakong Formation occur as blocks in this series. Marginally serpentinites and exotic blocks occur related with the terminating ophiolitic melange zones. SHAH et al. (1976), SHARMA & KUMAR (1978) and others regard this zone as part of the Tethyan (Tibetan) Zone of Zanskar. GANSSER (1976), FRANK et al. (1977) named this zone the Lamayuru Flysch, whereas FUCHS (1977, 1979) and BASSOULLET (1978 a, 1980 a) term it the Lamayuru Unit. I use this name for the tectonical unit; the lithounit Lamayuru Formation is not restricted to the Lamayuru Unit, but occurs also in the N. Z. U. adjoining in the S.

In the type area the unit shows much internal folding. The s-planes generally dip SW at medium to vertical angles. Serpentinites and exotic blocks are found near the margins. They are derived from the terminating thrust planes and ophiolitic melanges. In the SW the carbonate belt of northern Zanskar overrides the Lamayuru Unit, which overthrusts the Dras Unit in the NE. These relations to the adjoining zones remain constant if we follow the Lamayuru Unit towards the W via Fotu La – Bodhkarbu – Namika La – Wakha – Mulbekh – Shergal. In this region the strike gradually becomes E-W and towards Baltikar SW. Dipping SE beneath the Zanskar carbonates the black argillites zone may be followed to the ridge E of Rusi La. Always underlying the carbonates, dipping E at medium angles, the Lamayuru Unit continues to Bangbar and Bartu in the Phulungma (Sanko) Valley. Due to increasing grade of metamorphism in that region the rocks are generally black phyllites. They are intricately folded and dip NE around Bangbar. Towards the S the s-planes become vertical and finally dip steeply S near Bartu. Thus the Lamayuru phyllites form an anticline, in the core of which rocks of the underlying Rusi La Zone are exposed (Pl. 1, 2). I have not followed the Lamayuru rocks further W, but according to HONEGGER et al (1981) they continue to Sanko and to the region S of Dras.

Thus the structures of the Phulungma-Sanko Valley are very much complicated: The counterthrusts directed N, which are younger than the S-directed nappe tectonics, are deformed there in steep folds. This seems to be related with the Ichtu crystalline dome and the convergence of the Tibetan Zone and N. Z. U. The complicated polyphase tectonics of this region, which are important for the understanding of the orogenic mechanism, shall be discussed in chapter 4.

In the Spongtang area the Lamayuru Unit is found underlying the ophiolitic melange at the base of the Dras Unit. As already noted it is sometimes difficult to separate the unit from similar formations of the N. Z. U.

3.4. The Rusi La Zone

In the Rusi La area the dark argillaceous series of the Lamayuru Unit are underlain by green und grey volcanic and flyschoid series weathering in rusty colours. In the lower portions purple slates and breccias and cherty limestones are associated with the volcanics.

SHARMA & KUMAR (1978) regard the volcanics S of Rusi La as Panjal Trap. From field evidence I took this series as Dras Unit like NANDA & SINGH (1976) and SRIKANTIA & RAZDAN (1979, 1980). HONEGGER et al. (1981) show that from petrochemical reasons, however, the Rusi La and Dras Volcanics are principally different. In consequence the Rusi La Zone, in my view, has to be regarded as a separate entity.

Structurally the rocks of the Rusi La Zone dip E to NE south of Rusi La, towards the Sanko Valley the dip changes to SSE indicating an anticlinal structure. The multicoloured beds and limestones are exposed in the core of the anticline, which affects the rocks of the Rusi La Zone and the Lamayuru Unit as well. HONEGGER followed the Rusi La Zone east towards Mulbekh. Detailed petrochemical studies might show that upper portions of the Dras Unit actually belong to the Rusi La Zone. To the W an extension of the Rusi La Zone beyond Sanko is recorded by HONEGGER et al. (1981, fig. 2).

3.5. The Dras Unit and Peridotites

The Dras Unit consists predominantly of volcanics in the type area, towards the E (Lamayuru) Cretaceous flysch becomes important. Ophiolitic melanges mark the tectonic boundaries against the Lamayuru Unit, respectively Rusi La Zone (HONEGGER, pers. comm.) in the S, and the Indus Molasse in the N. But there are ophiolitic melange zones within the Dras Unit also, e. g. S of Khalsi, where the Indus Flysch s. s. (GANSSER, 1976; FUCHS 1977, 1979) is separated from the Dras Volcanics-Flysch. Apart from the internal disturbance evident from such ophiolitic melanges, intense folding shows the deformation of the Dras Unit.

The dip of the beds is predominantly SW or S and the direction of the movements is NE or N. This, however, is the effect of younger structural phases, because the Spongtang Outlier documents that the earlier nappe movements were directed S (FUCHS, 1977).

In the Patambis-Chaskor area the Dras Unit is imbricated with the Indus Molasse. The latter transgressed and reworked the volcanics of the Dras Unit. Later movements, which apparently were directed W and NW, led to the wedge structures. Smaller bodies of serpentinite are not rare near the tectonic contacts of the Dras Unit overriding the Indus Molasse. In the Valley of Chaskor an additional wedge of Dras Volcanics protrudes into the Indus Molasse. The latter is sandwiched between the stratigraphically underlying and the overthrust Dras rocks (Pl. 1, 2 [2, 3]). SRIKANTIA & RAZDAN (1980) regard the Indus Molasse of the Patambis area and the granitoid intrusion of Longtse as a tectonic window. Like FRANK et al. (1977) and HONEGGER et al. (1981) I take the granitoid as an intrusion of the Ladakh Intrusive complex into the Dras Unit. The Indus Molasse transgressed on already deformed Dras Unit, like it overlies the Ladakh Batholith unconformably in the N and was imbricated with the Dras Unit by later tectonic phases.

The Dras Unit not only forms a broad and continuous belt along the upper Indus Valley and from the Suru area westwards to the Nanga Parbat spur, but builds up a large volume of the Spongtang Outlier. There flysch and volcanics of the Dras Unit overlie black argillites of the Lamayuru Unit or, where they are missing, even rocks of the Tibetan Zone. N of Chulung La the Dras Unit seems to be imbricated with rocks of the Lamayuru Unit.

The base of the Dras Unit is of ophiolitic melange type: we find thin slices of various carbonate rocks, radiolarites, jaspillites and serpentinites (nappe ophiolitique, BASSOULLET et al. 1980 a, b). The contact to the underlying series is frequently unconformable, e. g. S of Photaksar, where the schistosity of the underlying slates is vertical or steeply dipping NNE, whereas the Dras rocks show gentle dip towards the S. Generally the Dras rocks dip towards the center of the allochthonous mass, at a low angle in the W, N and E, at low to medium angles in the south. KELEMEN & SONNENFELD (1981) point to the fact that their „Spongtang Allochthon“ forms a complex group of isolated blocks and contest my view that the Dras Volcanics and flysch form a continuous unit underlying the peridotites. They are right, inasmuch, as the Dras Unit is inhomogeneous: there is the huge volcanic mass S of Photaksar, sedimentaries predominate around Photak La, N of this pass the wildflysch represents a breccia of gigantic dimensions and there are mixed volcanic-sedimentary series. The multicoloured slates of Photak La being part of the flysch were mistaken by KELEMEN & SONNENFELD (1981) as Chulung La Slates. The primary inhomogeneities probably were accentuated in the course of the tectonic transport. But the different lithologic series all belong to the Dras Unit, which no doubt underlies the peridotites. These form a huge fla lying mass building up the high mountains of Spongtang and W of Photaksar. The Dras Unit and peridotites are separated by ophiolitic melange indicating a thrust zone. In the section Photaksar – Photak La the central parts of the allochthonous mass are folded. In a syncline the ophiolitic melange at the base of the peridotites reaches the bottom of the valley, crosses it and strikes towards the SE to a smaller peridotite mass NNW of Lingshet.

4. Palaeogeography and the structural development of Zanskar (Pl. 2, A, B)

From the present position of the tectonic units and the lithologic character of the successions the palaeogeography may be reconstructed:

The Zanskar Synclinorium is composed of the Tibetan Zone and the N. Z. U. Both formed a shelf at the northern margin of the Indian continent. The tuffite layers in the Triassic of Baltikar excepted, the development is non-volcanic. The sediments of the shelf interfinger with the monotonous sequence of the Lamayuru Unit deposited on the continental slope and in a basin N thereof. Flyschoid and euxinic conditions predominated. This facies belt also is characteristically non-volcanic. Our knowledge about the ocean N of the Lamayuru trough is meagre. Some information is given by the composition of the ophiolitic melanges: There was volcanic oceanic crust and there were Permian and Mesozoic fossiliferous limestones deposited in warm shallow water. We must be aware that these rocks may belong to different facies belts, microcontinents (HONEGGER et al., 1981) etc. and have been mixed up in the ophiolitic melanges.

The Panjal Trap, the oldest identifiable formation of western Zanskar, may represent final basic to intermediate volcanism after a Hercynian disturbance or indicates rifting, the opening of the Mesozoic Tethys (ANDREWS–SPEED & BROOKFIELD, 1982; HONEGGER et al., 1981; SEARLE, 1981). The Triassic-Jurassic carbonates of the Tibetan Zone and N.Z. U. were deposited in shallow water almost undisturbed by tectonics. The Quartzite Series found in the whole Tibetan Zone and in the Kashmir Synclinorium appears to reflect an epirogenetic event in the Rhaetic. Probably due to climatic conditions reefs did not develop.

The Spiti Shales (Malm-Neocomian), indicating a short phase of deepening, are rather subordinate in Zanskar. The Giumal Sandstone (Up. Neocomian) signals a marked change in the conditions of sedimentation brought about by a first, probably epirogenetic phase of the Himalayan orogenesis. The arenaceous-argillaceous flyschoid material, which was deposited after long times of carbonate sedimentation, is derived from the S (Himalayan Ridge, FUCHS, 1967). This is shown by the decreasing thickness of the formation if followed northwards.

The Giumal Sandstone was not found in the Lamayuru Unit, but some of its sandy and silty zones may correlate with the Giumal Sandstone. We have to face the problem where the clastic non-carbonate material of the Lamayuru Formation is derived from. I suppose, that like the Kioto Limestone and Shillakong Formation slumped into the Lamayuru basin or were intertonguing with the Triassic to Cretaceous Lamayuru Formation, the clastic influx also predominantly is of southern provenance. On the Zanskar shelf, however, the Quartzite Series and the Giumal Sandstone are the only clastic horizons, documenting clastic influx from the S.

N of the Lamayuru basin the Dras Volcanics formed in an island arc associated with flysch (FRANK et al., 1977; KLOOTWIJK et al., 1979; ANDREWS-SPEED & BROOKFIELD, 1982; BROOKFIELD & REYNOLDS, 1981 a, b; KELEMEN & SONNENFELD, 1981 a. o.). According to HONEGGER et al. (1981) the volcanics commenced in the Upper Jurassic, because they are interbedded with radiolarian cherts of this age. The main mass, however, is Cretaceous probably reaching into the Early Tertiary. Besides the prevailing flysch shallow-water limestones (Astor-Deosai, Khalsi, Mid-Cretaceous) also are associated with the Dras Volcanics. This island arc formed N of a subduction zone active from Upper Jurassic to Eocene times. We do not know the original distance of this subduction zone from the Lamayuru basin. The Rusi La Zone with its alkaline volcanism typical of seamounts and oceanic islands (HONEGGER et al., 1981) had a position between the Lamayuru trough and the Dras Volcanic arc.

The continued subduction of oceanic crust resulted in anatexis and the production of enormous intrusive masses of basic, predominantly intermediate to acid composition – the Ladakh and Transhimalayan plutons N of the Indus Suture Zone; further N intermediate to acid extrusives are found (POWELL & CONAGHAN, 1973, 1975; FRANK et al., 1977; ANDREWS-SPEED & BROOKFIELD, 1982; HONEGGER et al., 1981, a. o.). HONEGGER et al. (1981) got U-Pb ages on zircons of 103 ± 3 m. y. interpreted as the time of magma formation; Rb/Sr age of muscovite (biotite) of the Somau granodiorite gives a cooling age immediately after intrusion 80 ± 3 m. y. This rock intruded Dras Volcanics as does the syenite dated 82 ± 6 m. y. by BROOKFIELD & REYNOLDS (1981 a, b); granite samples of Shey Gompa yielded an intrusion age of 60 ± 10 m. y. and K/Ar biotite ages of 45–50 m. y. The latter data concur with those recorded by DESIO et al. (1964). BROOKFIELD & REYNOLDS (1981 a, b) record mineral ages of 39 and 42 m. y. and regard the Ladakh Intrusives Eocene to Oligocene. SHARMA et al. (1978) report K/Ar ages of 27,8 ± 0,6 m. y. from pink porphyritic granite, a very late intrusion in the composite magmatic complex. Obviously the intrusive activity spans from Upper Cretaceous to Oligocene.

After the first disturbance at the northern margin of the Indian continent resulting in the deposition of the Giumal Sandstone, pelagic foraminiferal limestones of Cenomanian to Campanian age were formed. This Chikkim Limestone is free of sandy or silty material and indicates sedimentation under quiet conditions. In the N. Z. U. the higher parts of the Chikkim Limestone may be replaced by multicoloured pelagic limestones and argillites of the Shillakong Formation (Pl. 2 A). In the S the Chikkim Limestone is succeeded by the Kangi La Flysch. The formation documents increased terrigeneous influx in the Campanian-Lower Maestrichtian. This material is derived from the S, because the Campanian Shillakong Formation of the N. Z. U. is free of such contamination. It probably formed on a sill not reached by the silty material of the Kangi La basin in the S and Lamayuru trough in the N.

The pelagic Shillakong Formation of the N. Z. U. is overlapped by Maestrichtian argillites in Lamayuru basin facies. These dark series correlate with the upper part of the Kangi La Flysch in the S. Regarding this correspondence KELEMEN & SONNENFELD (1981) are right, but there is no stratigraphic equivalence of the two formations (Pl. 2 A). The increasing extension of the Lamayuru basin facies overstepping the Shillakong sill and getting connection with the Kangi La basin documents a general downward movement of the Zanskar shelf. This, in my view, is related with the subduction along the Indus Suture. Thus the Zanskar shelf seems to have approached the subduction zone in the Maestrichtian;

the closing of the Tethys ocean was far advanced. In accordance with other ophiolite belts and observations from the Dras Unit BROOKFIELD & REYNOLDS (1981), M. SEARL (pers. comm. and 1981) argue for a Late Cretaceous emplacement of the ophiolitic melanges of the Indus Zone. It is suggestive that the deformation of the remaining Tethys floor started at that time. Separated by ophiolitic melange zones the principal tectonic units were pre-formed under submarine conditions.

In the Upper Maestrichtian the silty to arenaceous sedimentation of the Kangi La Flysch stopped and the benthonic Spanboth Limenstones prove a marked shallowing in the Tibetan Zone. In the N. Z. U. the silty and euxinic Lamayuru sedimentation persisted. With the Upper Paleocene the benthonic carbonate sedimentation extended from the S to the N. Z. U. The Lingshet Limestones show arenitic beds at their base like the Spanboth Limestones, but they yielded Upper Paleocene ages only, whereas the Spanboth Limestones commence in the Upper Maestrichtian. The development of shallow-water limestones gradually shifting northwards indicates a rise of the northern edge of the Indian continent. This probably was caused by some resistance against further northward drift. Thus I see the facies changes on the Zanskar shelf related with the beginning deformation of the Tethys floor.

The Spanboth-Lingshet Limestone sedimentation ends in the Upper Paleocene. The Lower Eocene Kong Slates of the N. Z. U. are still marine, whereas the Chulung La Slates of the Tibetan Zone in the S seem to represent a silty fresh-water facies. Again we find terrigeneous influences from the S. Both formations named are the youngest beds of the Zanskar Synclinorium. It appears that their deposition was immediately followed by the nappe movements. KLOOTWIJK et al. (1979) and KLOOTWIJK (1980) – based on palaeomagnetic data – come to the result that the initial collision between India and the Ladakh magmatic arc was in Late Paleocene – Early Eocene times. This event caused the already pre-formed tectonic units of the Indus Suture Zone to be thrust towards the SW: The Dras island arc was deformed to the Dras Unit and was thrust onto the Zanskar Synclinorium; at the base of this nappe the Lamayuru Unit also was dragged to the SW. The peridotite masses seem to be derived from ophiolite zones within the Dras Unit (e. g. S of Khalsi) or terminating this unit in the N.

KELEMEN & SONNENFELD (1981) assume a first phase of folding (Late Cretaceous) prior to the deposition of the Lingshet Limestones, a second phase affecting also these limestones, and the emplacement of the Spongtang Allochthon in a third tectonic phase (after the folding of the Lower Eocene beds). I explain the observable differences in tectonic style in another way: The Cretaceous to Lower Eocene sequence seems to be complete in the Zanskar Synclinorium. If there is a gap below the quartzitic beds of the Spanboth or Lingshet Limestones, it was not of the same age and thus the result of epirogenetic movements. The latter also caused the facies changes shifting with time. The assumption of a phase producing tight isoclinal folds requires a marked unconformity beneath the succeeding beds, which is nowhere observed. Inspite of the beginning deformation of the Indus basin in the Upper Cretaceous, the Zanskar platform remained undisturbed by folding.

Differences in tectonic style are partly due to different mechanical properties of the formations or to their position in the orogene.

The first phase (post-Lower Eocene) produced the open SW-vergent folds of the Tibetan Zone. In the N. Z. U. the tectonic forces were stronger leading to tight isoclinal folds directed SW. This is the effect of the overthrusting Spongtang Nappes. Under their influence the Cretaceous - Lower Eocene sequence of the N. Z. U. was partly sheared off from the Triassic-Jurassic carbonate platform. The Lamayuru argillites probably played a great part in these decollement tectonics. It is not surprising that the type of folding is different below and above this shaly mass (e. g. at Lingshet). Below there are isoclinal SW-vergent folds, the band of Lingshet Limestone above is rather horizontal with occasional intricate folding, partly along WSW-axes (Pl. 1, 2 [12, 13]); Fig. 7, 8, 16, 17 on Pl. 3–6). This limestone band seems to have slipped on the Lamayuru Formation and moved independently also from the overlying argillites (Kong Slates, Lamayuru Unit). Thus the sheared off younger formations of the N. Z. U. formed a lubricant for the Spongtang Nappes.

The above tectonic event is immediately subsequent to the initial collision of the Indian continent and the Ladakh magmatic arc in the Late Paleocene – Lower Eocene deduced from palaeomagnetic studies (KLOOTWIJK et al, 1979; KLOOTWIJK, 1980). After the merging with the Ladakh magmatic arc the Indian continent moved about 10° latitude northwards in the interval between 55 and 38 m. y. before the present.

The post-Lower Eocene phase initiated the molasse stage of the Indus basin lasting from the Eocene into the Miocene. The fact that Indus Molasse trangresses on Dras Volcanics and reworks them is evidence that the molasse is younger than the Dras Volcanic – Flysch stage. SRIKANTIA & RAZDAN (1979, 1980) have assumed penecontemporaneous sedimentation in two parallel basins (Indus Group, Sangeluma Group).

The Indus Molasse was deposited in a remnant basin between the Ladakh batholith and the roots of the Dras Unit, transgressing on both sides. The sedimentation was predominantly of fresh-water type in a continental basin. Recent studies by BROOKFIELD (1981) show that there are also marine beds in the sequence: E of the Zanskar BROOKFIELD found a thick flysch sequence containing nummulitic limestones (member 2 of his Unit III). The Lower to Middle Eocene beds at the base of this flysch (member 1) already described by DAINELLI (1933–34) represent marginal marine to fresh-water environments. Because of these beds I interpret the flysch as marine ingression in the continental molasse basin, probably in its deeper parts, and not as a continuation of the Dras Flysch.

In my view the Indus Molasse commenced in the Eocene and lasted into the Miocene as shown by fresh-water fossils (SAHNI & BHATNAGAR, 1962, cit. by TEWARI, 1964 and GUPTA & KUMAR, 1975).

After these considerations on the Indus Molasse I continue to describe the structural history of Zanskar.

In a second tectonic phase the Indus Zone was subdued to intense compression. The root zone of the nappes was steepened and finally overturned to the NE (FUCHS, 1977, 1979). The northern marginal parts of Zanskar were deformed to tight upright isoclinal folds in the area between the Kangi and Yapola Valleys. The beds are vertical in the central parts of that fold belt, dip steeply SW in the N, and NE in the S (Pl. 1, 2). thus the most compressed parts (e. g. in the Shillakong and Yapola sections) show fan structure. KELEMEN & SONNENFELD (1981) termed this zone the Honupatta Anticlinorium. The decollement structure of the N. Z. U. related with the overthrusting Spongtang Nappes is deformed by these folds. It appears that parallel with the Honupatta Anticlinorium the Spongtang Synclinorium was formed. The limb connecting these structures is overturned ot the SW (Spongtang, Photaksar, Singhe La, Zanskar Valley).

The Kangi-Naerung Fault (KELEMEN & SONNENFELD, 1981) is a very complex structure: First there was the decollement of the post-Jurassic beds of the N. Z. U. caused by the Spongtang Nappes. Then this movement plane was folded and overturned towards the SW (see above). This SW-vergency probably was still active even in Quaternary times disturbing the already developed relief. Fig. 6 (on Pl. 3) shows the discrepancy between the rugged rock faces NE of the Kangi-Yalchung line and the relatively mature landscape of central Zanskar.

It is significant that the Honupatta Anticlinorium is tightestly folded and faulted N of the Spongtang Outlier. Towards the E in the section along the Zanskar River (KELEMEN & SONNENFELD, 1981) the fan structure of the anticlinorium is still recognisable, but the fold belt is wider and not so compressed. Going to the W the section of the Wakha Gorge shows no fan structure, all the folds are N-vergent and not so tight. Between the Wakha River and the Rusi La the Triassic-Jurassic carbonates dip at prevailingly low angles. There are some recumbent folds, steeply folded beds occur only locally (Pl. 1, 2). The area is partly unexplored but it is certain that the tectonic style is quite unlike the intensely compressed zone N of the Spongtang Outlier.

It is very much suggestive that the Spongtang Klippe formed the south-western abutment, against which the northern carbonate belt was pressed. This infers that the original extent of the Spongtang Outlier was not much larger than the present one: from the Zanskar River to the Kangi Valley. This means that there was not a continuous Flysch-Volcanics nappe and peridotite nappe from Ladakh to SW-Tibet. There are so many analogies between the Spongtang area and the region described by GANSSER (in HEIM & GANSSER, 1939). GANSSER (1976, 1980), FRANK et al (1977), FUCHS (1979, 1981), KELEMEN & SONNENFELD (1981) and others pointed to these great similarities. There exists no doubt that the main lithologic-tectonic units continue from Ladakh to Tibet along the Indus Suture zone. This however does not imply that the thrust sheets derived from that root zone were continuous. The folding along WSW-axes observed at Lingshet probably is parallel to the original eastern edge of the allochthonous mass. Thus the crossfolding follows the shape of this mass, it is determined by its form and does not necessitate the assumption of a different folding phase.

Another argument for a limited extent of the Spongtang Nappes is the fact that the Cretaceous-Eocene sequence of the N. Z. U. is sheared off from its base along the Kangi-Yalchung line; W and SE thereof the normal succession is preserved. If it were the Spongtang Nappes, which have caused this decollement, again a limited extent of the thrust mass may be deduced. Finally the erosion of a volcanics-flysch-peridotite thrust sheet continuous from SW-Tibet to Ladakh should be indicated in the boulder spectra of the Indus Molasse and younger deposits, which however is not substantiated.

In an advanced stage of folding phase 2, which produced the Honupatta Anticlinorium and Spongtang Synclinorium, thrusts are formed: along the S- and SW-dipping Zanskar Thrust the Honupatta Anticlinorium overrides the Lamayuru Unit; the latter overthrusts the Dras Unit, and this one in turn is moved onto the Indus Molasse. Thus the whole sequence of tectonic units in the root zone becomes inverted. The older thrust planes and ophiolitic melange zones are reactivated to NE- and N-vergent counterthrusts.

I think that conform with the fan-structure of northern Zanskar also SW-directed thrusts developed. The movement plane separating the N. Z. U. and the Tibetan Zone probably was formed then. The displacement along this thrust seems to be moderate, in the order of a few km only (FUCHS, 1981, Pl. 1, section 1). This is inferred from the fact that in the Kong area, though disturbed, facies passages between the N. Z. U. and the Tibetan Zone still can be observed.

The N. Z. U. exhibits SW-vergent isoclinal folding E of the Spongtang Outlier, W of it there are tight upright folds, and further W all the folds are isoclinal and directed N (Pl. 1, 2). The tectonic style of the N. Z. U. and the Tibetan Zone is disconformous all along their boundary. This is apparent from different strike direction as well as different style of folding.

The change in the vergency of the movements observed in the N. Z. U. mentioned above is a very much interesting feature. It is significant, inasmuch as it shows how far the N. Z. U. became allochthonous in the N. In the Lamayuru area the Zanskar Thrust is steep and it seems that only the SW-dipping parts N of the central vertical zone of the Honupatta Anticlinorium are allochthonous. In the Wakha Chu region all the isoclinally folded beds dip S at medium angles (N-vergency). Not far from there in the Rusi La area the counterthrusts can be followed towards the S into the Sanko Valley. Thus the vergency of folding seems related to the distance the counterthrusts can be followed back to the S, that means to the allochthony of northern Zanskar. In consequence it may be expected that the root of the Zanskar Thrust follows roughly the line Sanko Valley – S Itchu La – Shopa La – S of Kangi – central part of Shillakong Gorge – Honupatta. Thus the allochthonous portion of northern Zanskar is much wider in the W. This difference within the mapped area may be explained in the way that the north-western spur of Zanskar moved as platform over the zones adjacent to the N, whereas in the E more space was consumed by the strong internal deformation of the Honupatta Anticlinorium.

The timing of the second tectonic phase of Zanskar is not as easy as the dating of the first phase: The Indus Molasse containing Miocene beds is overridden by the Dras Unit along counterthrusts and shows N-vergent structures. This on one hand suggests a connection with the post-Lower Miocene nappe tectonics along the Main Central Thrust and other thrusts of the Lesser Himalaya. On the other hand based on palaeomagnetic data MOLNAR & TAPPONNIER (1975), KLOOTWIJK et al (1979) proposed the final intimate collision between India and Asia to have taken place 38 m. y. ago. If the second compressive phase is correlated with this event it was active over a rather long period from the beginning of the Oligocene up to the Middle Miocene. Probably the compression first resulted in steep and tight folding of northern Zanskar and of the root zone of the nappes. Later, when no further folding was possible the N-vergent counterthrusts and the S-directed thrust of the N. Z. U. became active. Then the Indus Molasse was deformed and overthrust from the south.

It is very likely that in course of the second folding phase the Spongtang Klippe too slipped further SW. The unconformable contact with various overthrust units along its south-western frontal parts and the disharmonic tectonics with the Lamayuru Formation near Photaksar may be due to such younger and independent movements of the outlier.

A third phase of folding is indicated in the Sanko – Rusi La – Phulungma area – a very complicated region: The map (Pl. 1) clearly shows that the different tectonic zones converge there and come very close to each other: From the SE the Central Crystalline and connected series of the Tibetan Zone strike to the Itchu Anticline. From the E the folded frontal portions of the N. Z. U. strike towards Itchu. The carbonates N of the Itchu Crystalline belong to the N. Z. U. and pass into the metamorphicum. They overlie tectonically in turn the Lamayuru Unit, Rusi La Zone, Dras Unit, which strike S into the

Sanko Valley, where they turn to the W. N of Bartu this tectonic sequence is deformed in upright megafolds along E-W trending axis. This observation shows that, when the counterthrusts were already dead, they themselves were folded in a late tectonic phase.

The folding occurs close to a deep-seated rupture. This line appears to follow the E-W striking northern margin of the Central Crystalline S of the Sanko River; towards the E it continues in the tectonic plane separating the N. Z. U. and the Tibetan Zone.

The Itchu crystallines, which are connected by gradational contacts with both the N. Z. U. and the Tibetan Zone, form a conspicuous anticline at Itchu. I explain this structure as a diapiric fold. The metamorphic complex still in a mobile state intruded along the deep-seated movement plane. The uplift of plastic and hot material along the rupture led to intensive folding with the surrounding beds (e. g. folds N and W of Itchu). The already inactive counterthrusts also were folded there. For the dating of this event the age determinations and studies of the metamorphism by HONEGGER et al (1981) are of great interest. From the Sanko Dome, which has a position comparable to the Itchu Anticline (see their Fig. 14), biotite and a phengite yielded K/Ar ages of 21,5 respectively 26 m. y. therefore „a somewhat earlier cooling of this northernmost frontal part of the Suru Crystalline in comparison to its center“ is assumed. We may infer that the Crystalline remained in a mobile state also somewhat after these cooling ages, but it appears to be reasonable that the diapiric tectonics of Itchu still occurred in the Miocene.

Not far from the complex structure described above a N-S-lineament is indicated which, however, is not explored in detail. This Kargil-Kishtwar Lineament must be seen in connection with the Lesser Himalaya: At Kishtwar the Chenab (Chandra) River makes a sharp bend to the S. There the window of Chail Nappes framed by the Central Crystalline is terminated to the W by a fault (FUCHS, 1975; 1981, Pl. 1). The Kashmir side is down thrown. HONEGGER's mappings of the Warwan region (SW of Nun Kun) show a pronounced N-S-strike of the crystallines and synclines of Kashmir sedimentaries (HONEGGER et al. 1981, Fig. 2). In that zone we find the marked bend of the Suru River. The Suru takes an E-W course and bends abruptly N in the area NW of Nun-Kun. Downstream the Suru the Indus Molasse, wedged between Dras Volcanics, exhibits N-S-strike. This direction of the molasse band is not only the result of erosion of the pile of thrust sheets plunging E. There appears to be also a strong component of movement towards the W (Pl. 2 [1, 2,]). At Kargil the outcrops of Ladakh Intrusives reach further S west of the Suru River. Thus the Kargil-Kishtwar Lineament crosses the Lesser and High Himalayas. It appears that the eastern Chamba-Zanskar block was lifted and moved against the western Kashmir block.

5. Conclusions

In the previous chapters the great importance of Zanskar for the understanding of the evolution of the Indus Zone was shown. Particularly the Cretaceous-Eocene sequence is a key for the dating of orogenic events at the northern edge of the Indian continent and in the Tethys. Studies of the structural units found in Zanskar give more information about the tectonic development of the Indus Suture Zone than work in that zone itself, because from the squeezed and inverted units of the Indus Valley the nature and direction of earlier movements hardly can be deduced.

The evolution of Zanskar and adjoining regions may be summarised: In the Mesozoic Zanskar was a shelf attached to the Indian continent. N of this shelf monotonous series were deposited in the Lamayuru basin. Subduction of oceanic crust during Upper Jurassic to Eocene times led to the formation of the Dras island arc with basic to intermediate volcanism and flysch; N of it anatectic melts intruded forming the huge Ladakh batholith (Upper Cretaceous to Oligocene).

On the Zanskar shelf the Giumal Sandstone and Kangi La Flysch signal first epirogenetic movements along the margin of the Indian continent in the Upper Neocomian respectively Upper Campanian. In the Maestrichtian the transgression of Lamayuru facies indicates downward movement of the northern portions of the shelf by subduction. At the same time the floor of the closing Tethys was deformed – ophiolites and the melanges formed by obduction. The principal structural units, Lamayuru Unit, Rusi La Zone, Dras Unit and peridotite masses were pre-formed. The Upper Maestrichtian Spanboth Limestone shows shallowing in the S of the shelf propagating to the N in Upper Paleocene times (Lingshet Limestone).

After the Lower Eocene (Kong Slates) the nappes from the Indus Zone (Lamayuru Unit, Dras Unit, peridotites) were thrust onto the Zanskar shelf.

This was the first folding phase of Zanskar. The northern parts overridden by the nappes show stronger deformation (isoclinal SW-vergent folds) than the southern ones. Partially the Cretaceous-Tertiary formations were sheared off from their base. This event is related with the initial collision between India and the Dras island arc (KLOOTWIJK et al, 1979). In the remaining basin N of the Dras belt the Indus Molasse was deposited in Eocene to Miocene times. In part sedimentation was marine (e. g. Eocene flysch, BROOKFIELD, 1981), predominantly it was continental and fresh-water. The molasse transgresses on the Dras Unit as well as on the Ladakh Intrusives.

The final collision between India and Eurasia at the beginning of the Oligocene (MOLNAR & TAPPONNIER, 1975; KLOOTWIJK et al., 1979) initiated further deformation. Northern Zanskar was tightly folded and got fan structure (Honupatta Anticlinorium), the Spongtang area became a syncline. Continued compression led to northward inversion of the root zone, and the counterthrusts were activated. The N. Z. U. was formed and moved marginally onto the Tibetan Zone along a NE-dipping plane. The tectonics along the counterthrusts deformed the Indus Molasse and put an end to the molasse stage. Since the youngest beds of the Indus Molasse are Miocene, this compressional phase is correlated with the post-Lower Miocene nappe tectonics of the Lesser Himalaya.

The Palaeozoic sequence and partly even the Mesozoic formations were metamorphosed in western Zanskar, and were incorporated into the Crystalline. In the Miocene regional metamorphism was still active and the Crystalline was in a mobile state. Along the deep-seated fault separating the N. Z. U. and Tibetan Zone the Crystallines intruded forming the diapiric fold of Itchu. Related with this event the counterthrusts, which apparently were already inactive, were folded near the named rupture.

Probably younger a lineament crosses the Himalaya from Kargil to the Chenäb in the Lesser Himalaya. Along this line the Zanskar-Chamba block seems to have moved towards the WNW onto the Kashmir block. The wedge structures of the Indus Molasse of Patambis and the fault terminating the Kishtwar Window in the W are tests of these transverse tectonics.

If we compare the rather mature morphology of the Spongtang heights with the precipices towards the Oma Chu or the rugged carbonate belt of northern Zanskar, it appears that Quaternary tectonics disturbed a relief already formed. Particularly the Kangi-Photaksar furrow and the carbonate range NE of it suggest a very youg accentuation of morphologic differences, which are not fully explained by the difference in material. JAROS & KALVODA (1978) documented the existence of a series of Quaternary relief thrusts in Nepal, which, in my view, are not restricted to that part of the Himalaya. However, special studies are needed to demonstrate the existence of such sub-recent tectonics.

Though the present studies in Zanskar are still of reconnaissance type a varied and complex geological history is documented. Much more information can be expected from further work in that remote and rather inaccessible region.

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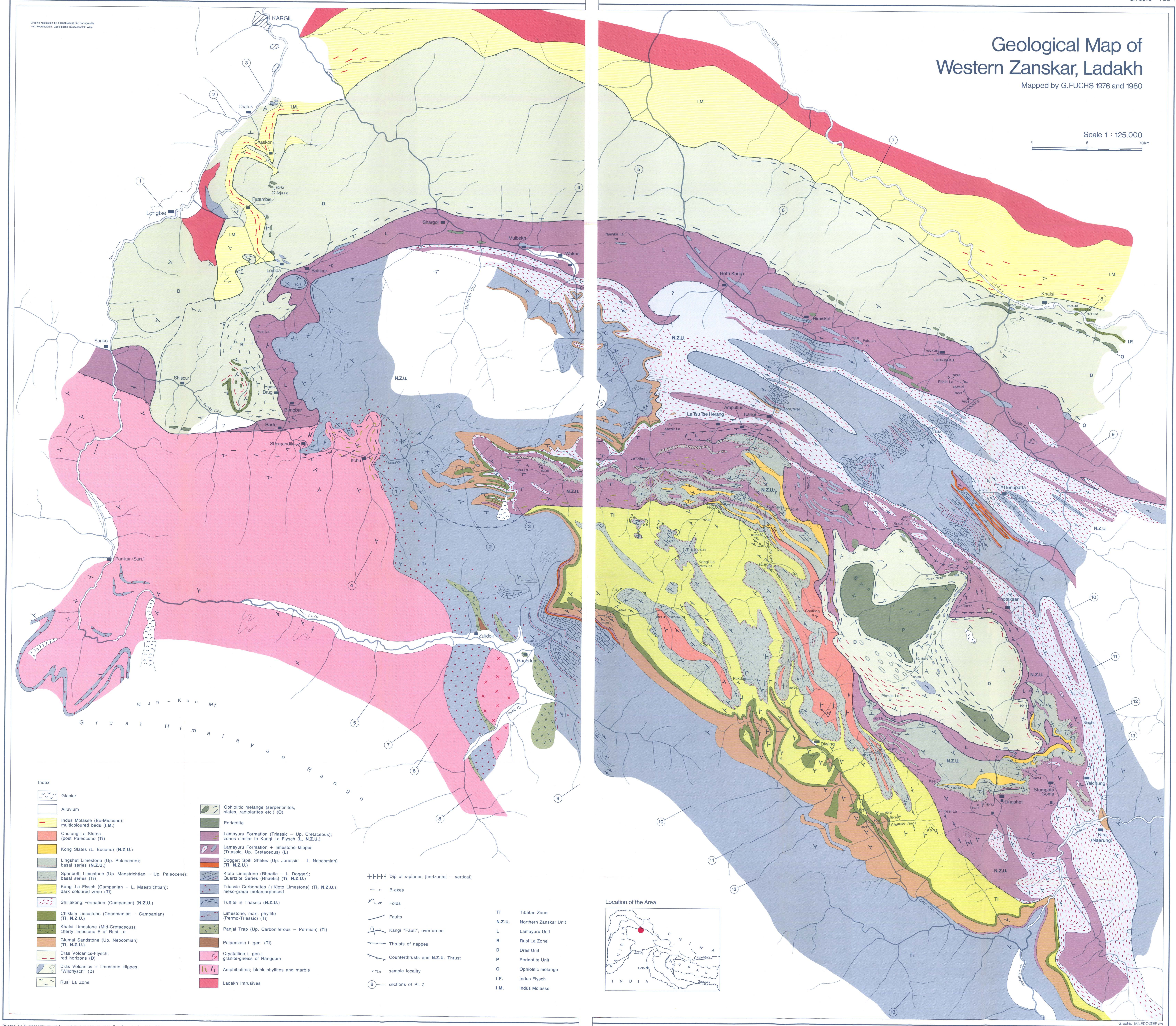

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Jahrbuch der Geologischen Bundesanstalt, 125. Band, 1982 – Beilage 2
G. FUCHS – Plate 2

Geological Sections across Western Zanskar (Ladakh, India) G. FUCHS, 1980

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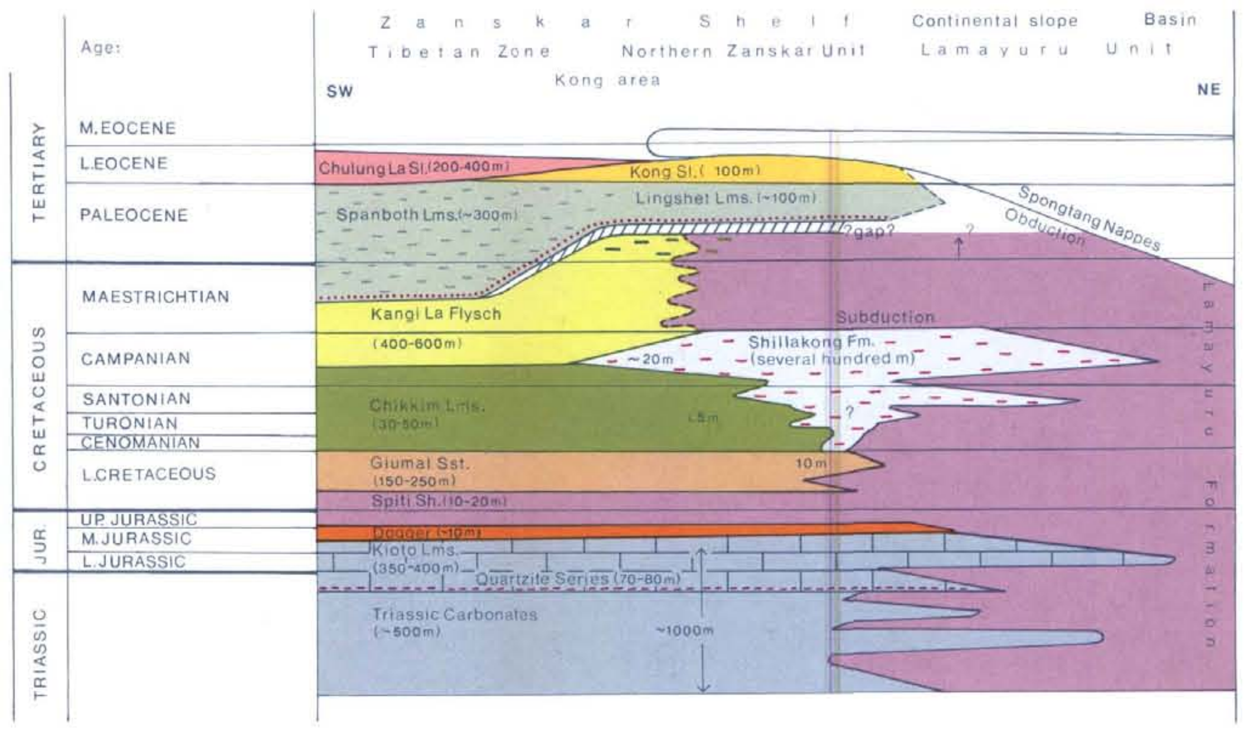
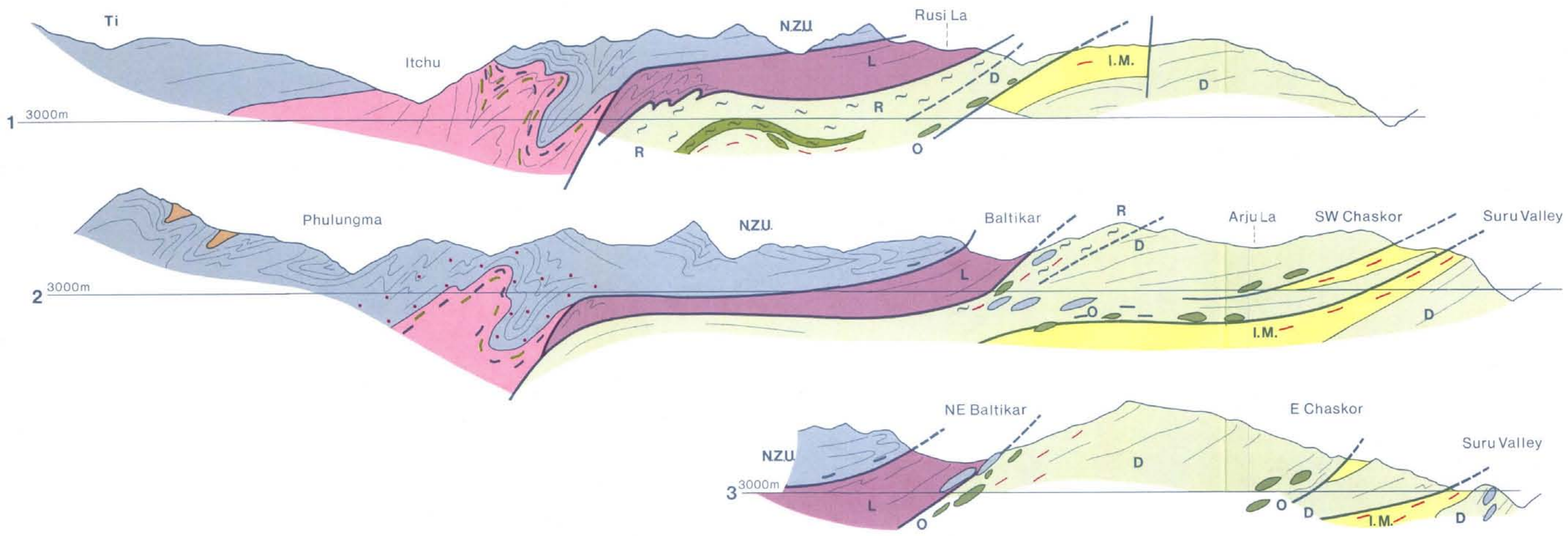
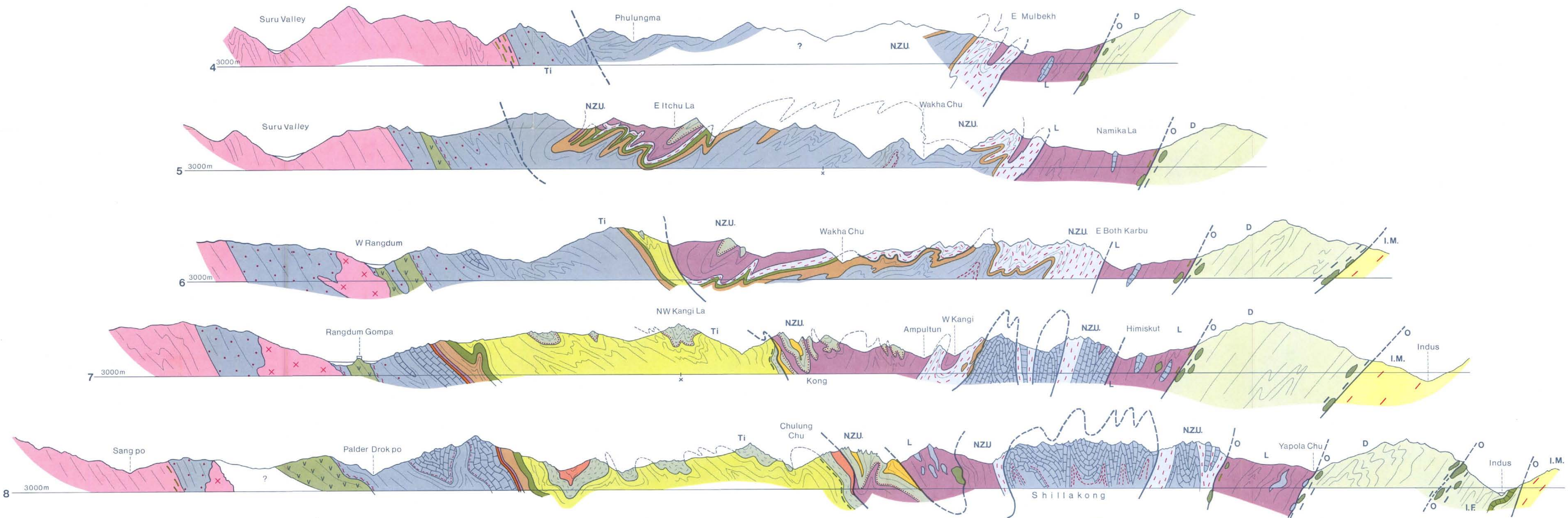
Facies Scheme of the Mesozoic Succession of Zanskar **A**

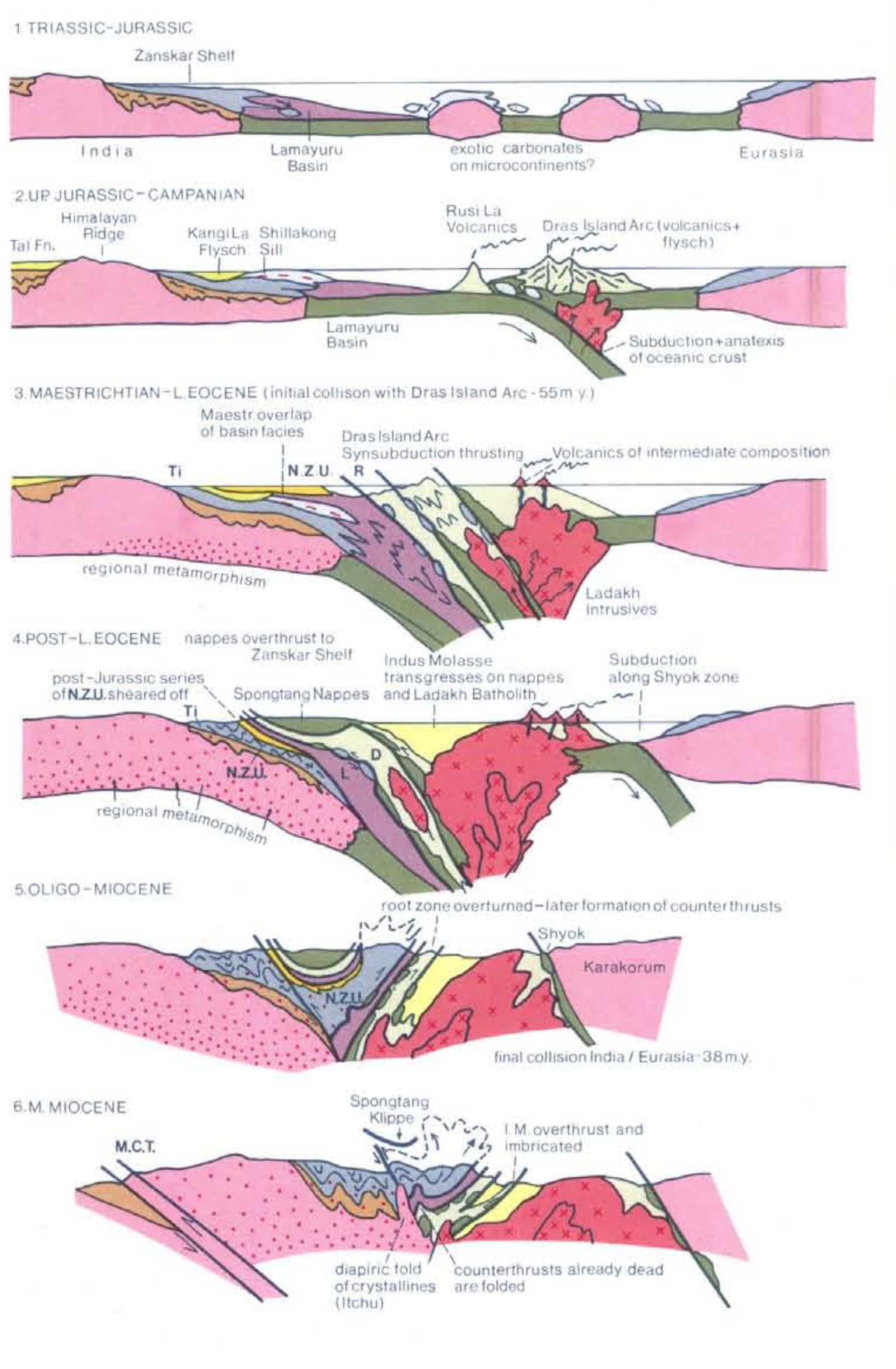


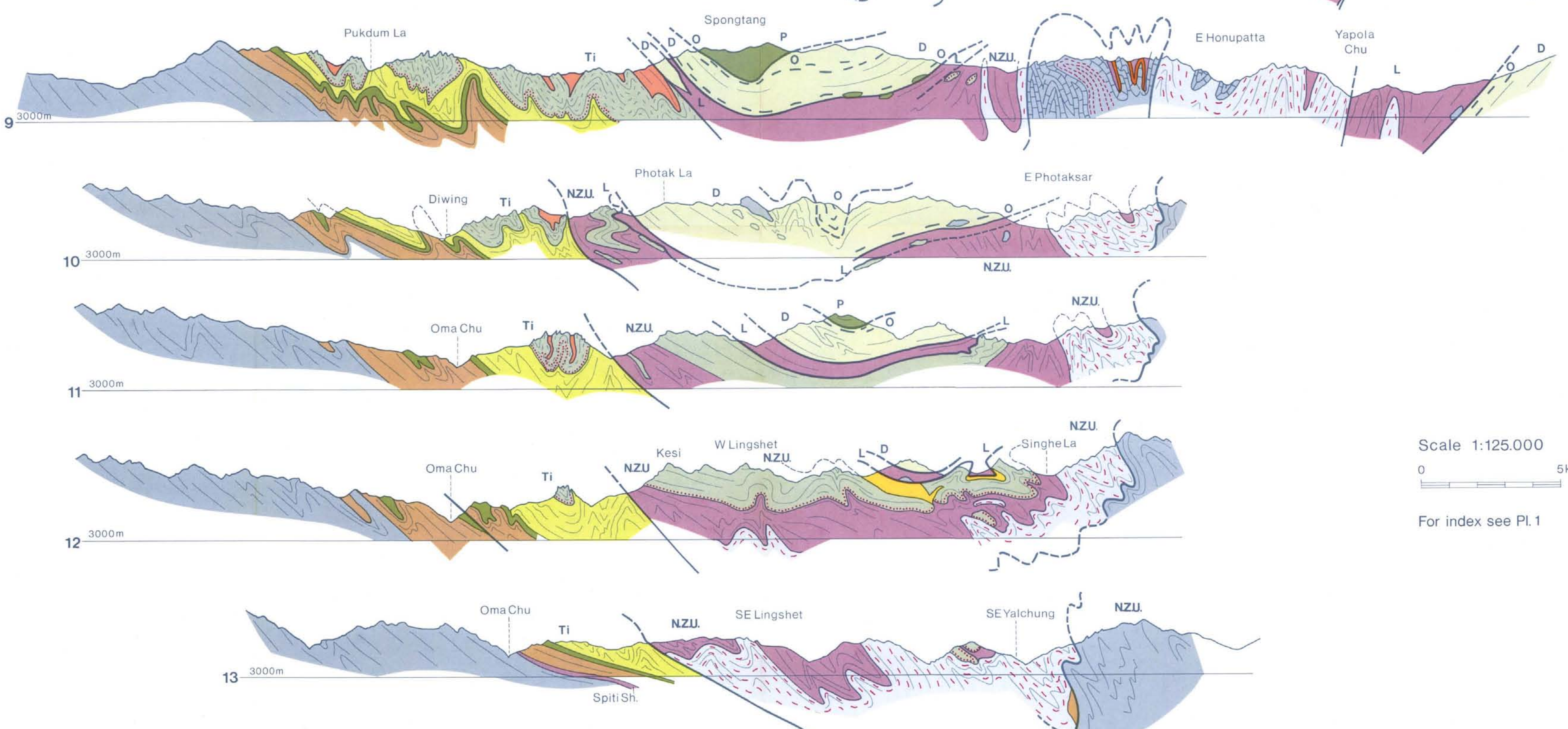




The Evolution of Zanskar and the Indus Zone **B**

(Schematic sketch based on literature and own interpretation)





Scale 1:125.000

0 5km

For index see Pl. 1

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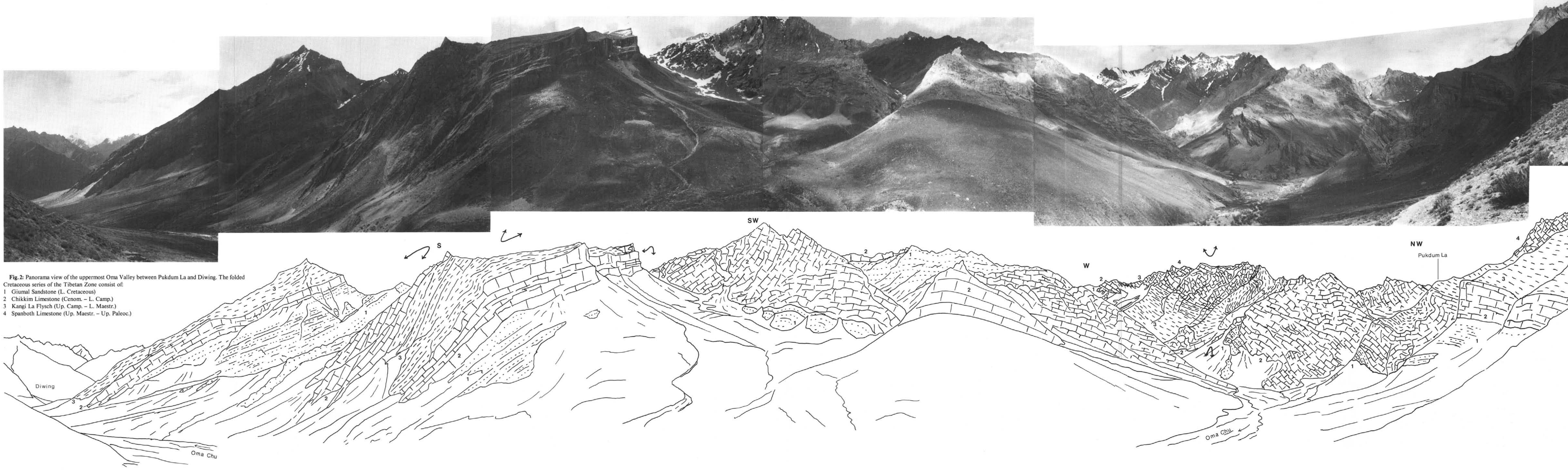


Fig. 2: Panorama view of the uppermost Oma Valley between Pukdum La and Diwing. The folded Cretaceous series of the Tibetan Zone consist of:
1 Giumal Sandstone (L. Cretaceous)
2 Chikkim Limestone (Cenom. – L. Camp.)
3 Kangi La Flysch (Up. Camp. – L. Maestr.)
4 Spanboth Limestone (Up. Maestr. – Up. Paleoc.)

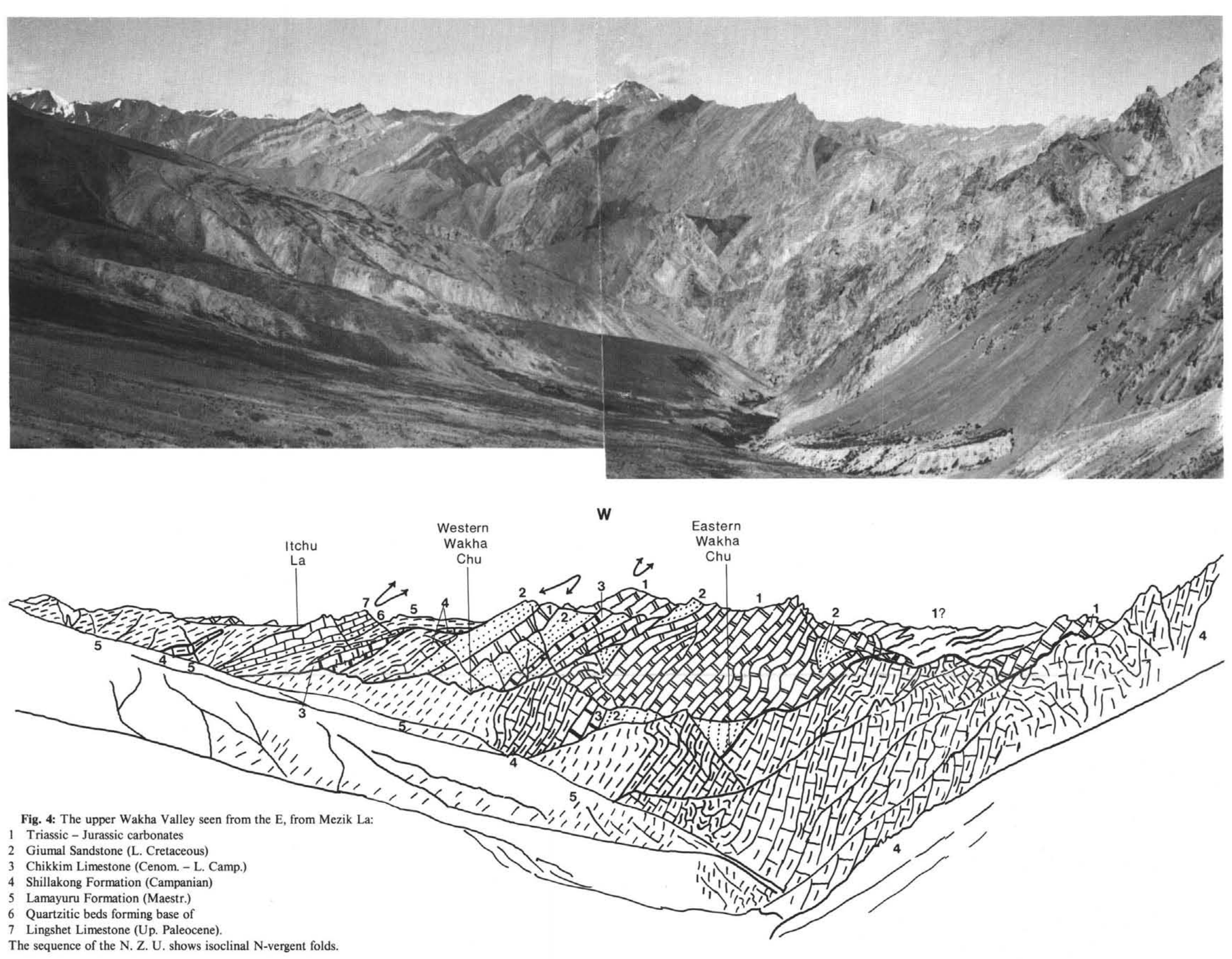


Fig. 4: The upper Wakha Valley seen from the E, from Mezik La:
1 Triassic – Jurassic carbonates
2 Giumal Sandstone (L. Cretaceous)
3 Chikkim Limestone (Cenom. – L. Camp.)
4 Shillakong Formation (Campanian)
5 Lamayuru Formation (Maestr.)
6 Quartzitic beds forming base of
7 Lingshet Limestone (Up. Paleocene).
The sequence of the N. Z. U. shows isoclinal N-vergent folds.

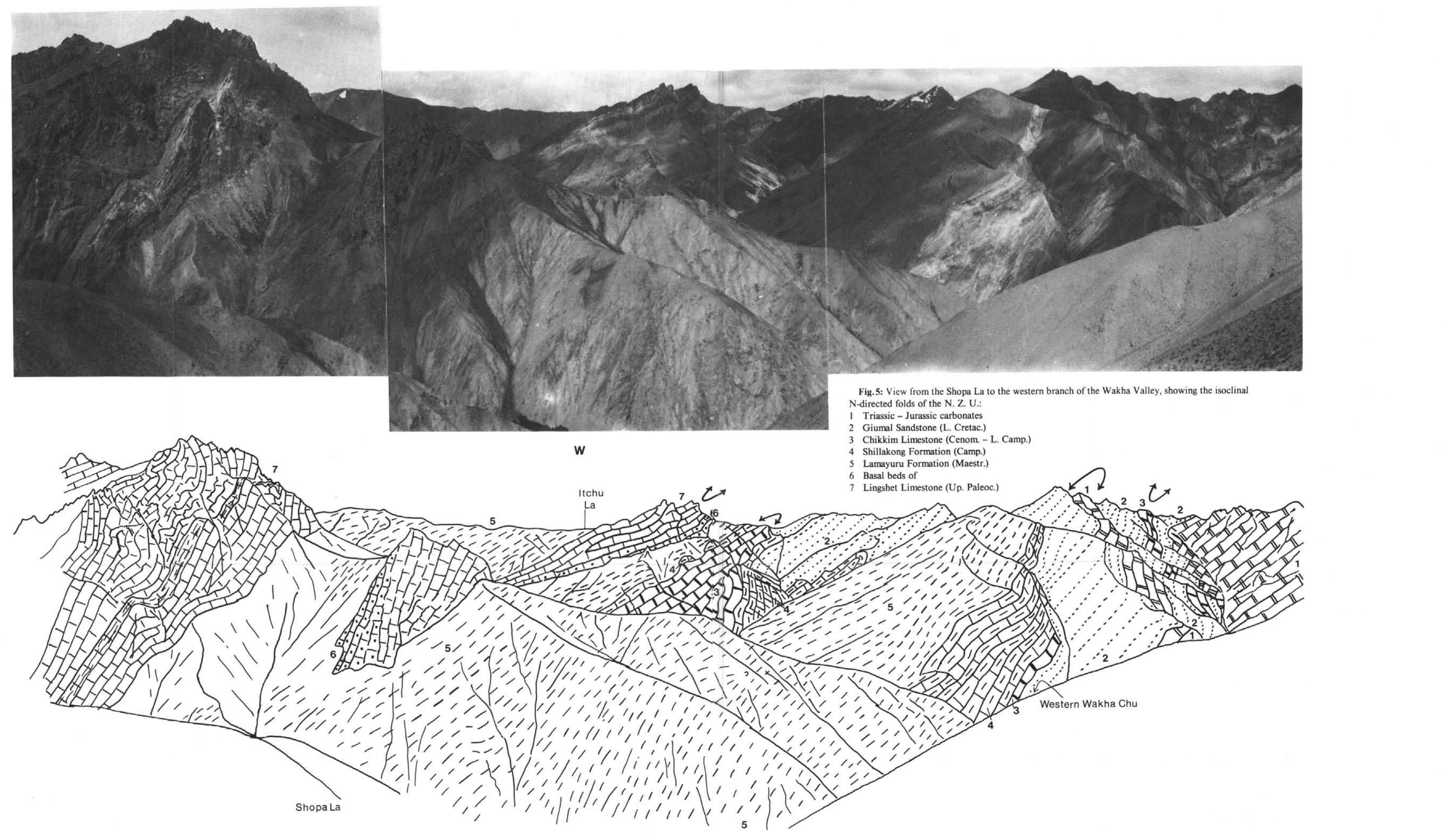


Fig. 5: View from the Shopa La to the western branch of the Wakha Valley, showing the isoclinal N-directed folds of the N. Z. U.:
1 Triassic – Jurassic carbonates
2 Giumal Sandstone (L. Cretac.)
3 Chikkim Limestone (Cenom. – L. Camp.)
4 Shillakong Formation (Camp.)
5 Lamayuru Formation (Maestr.)
6 Basal beds of
7 Lingshet Limestone (Up. Paleoc.)

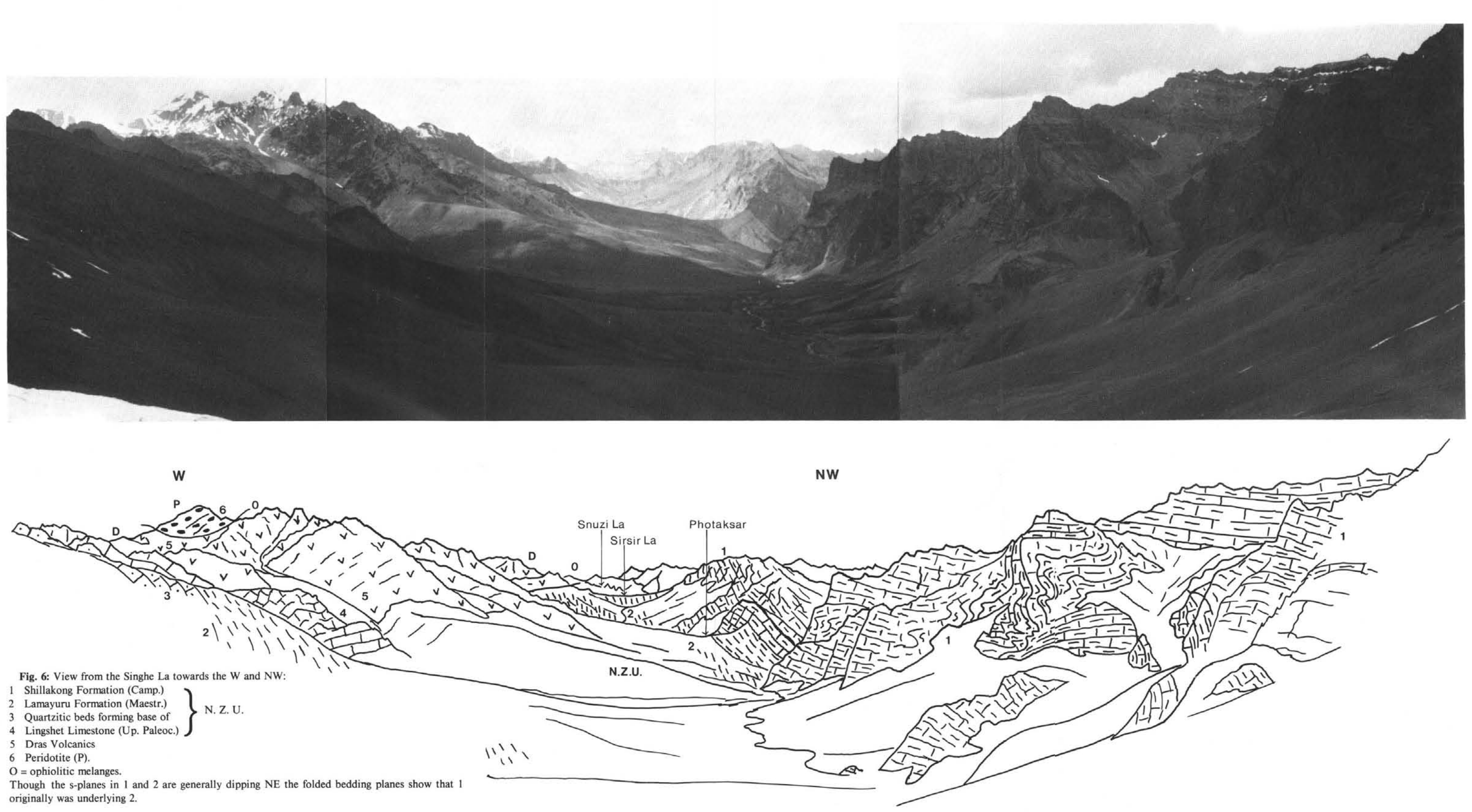


Fig. 6: View from the Singhe La towards the W and NW:
1 Shillakong Formation (Camp.)
2 Lamayuru Formation (Maestr.)
3 Quartzitic beds forming base of
4 Lingshet Limestone (Up. Paleoc.) } N. Z. U.
5 Dras Volcanics
6 Peridotite (P).
O = ophiolitic melanges.
Though the s-planes in 1 and 2 are generally dipping NE the folded bedding planes show that 1 originally was underlying 2.

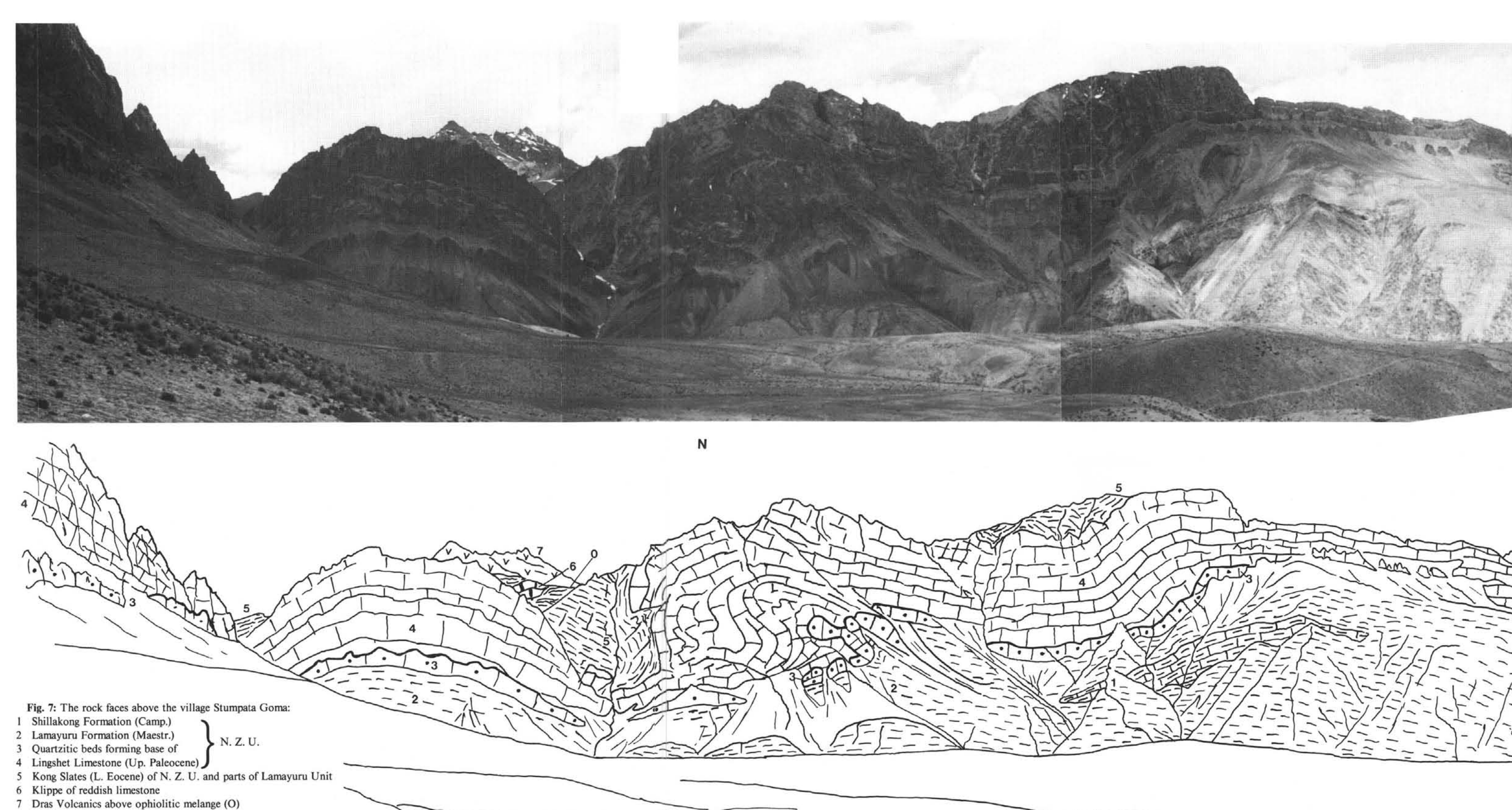


Fig. 7: The rock faces above the village Stumpata Goma:
1 Shillakong Formation (Camp.)
2 Lamayuru Formation (Maestr.)
3 Quartzitic beds forming base of
4 Lingshet Limestone (Up. Paleocene) } N. Z. U.
5 Kong Slates (L. Eocene) of N. Z. U. and parts of Lamayuru Unit
6 Klippe of reddish limestone
7 Dras Volcanics above ophiolitic melange (O)

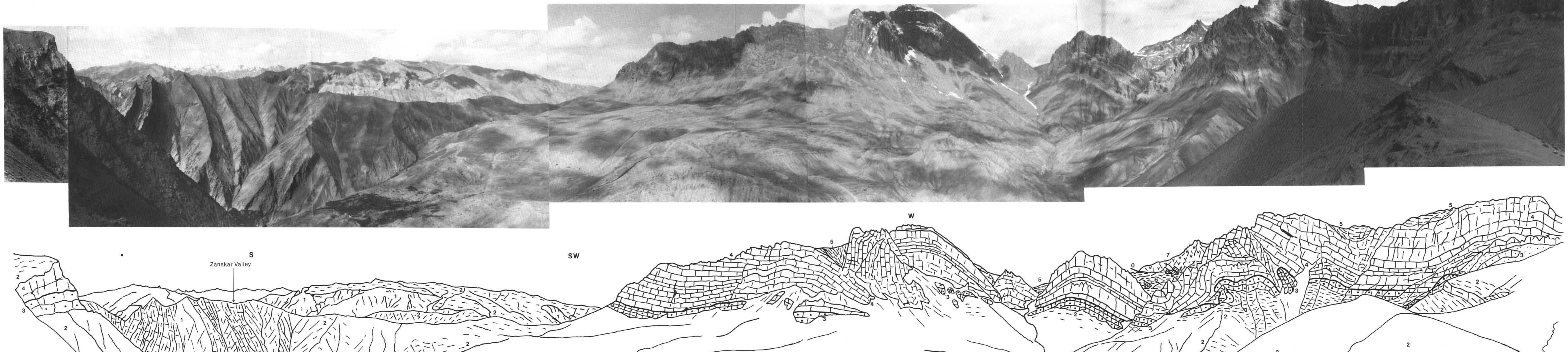


Fig. 8: Panorama view from the small pass E of the village Stumpata Goma:

1 Shillakong Formation (Camp.) } N. Z. U.
2 Lamayuru Formation (Maestr.) } N. Z. U.
3 Quartzitic beds forming the base of } N. Z. U.
4 Lingshet Limestone (Up. Paleocene) } N. Z. U.
5 Kong Slates (L. Eocene) of N. Z. U. plus parts of Lamayuru Unit
6 Limestone Klippes
7 Dras Volcanics above ophiolitic melange (O); Dras Unit.

The axes of the folds in the Lingshet Limestone strike W to WSW thus being transverse to the regional NW – SE strike. Note the Shillakong Formation brought up in the core of anticlines from beneath the Lamayuru Formation (looking to the SSW).

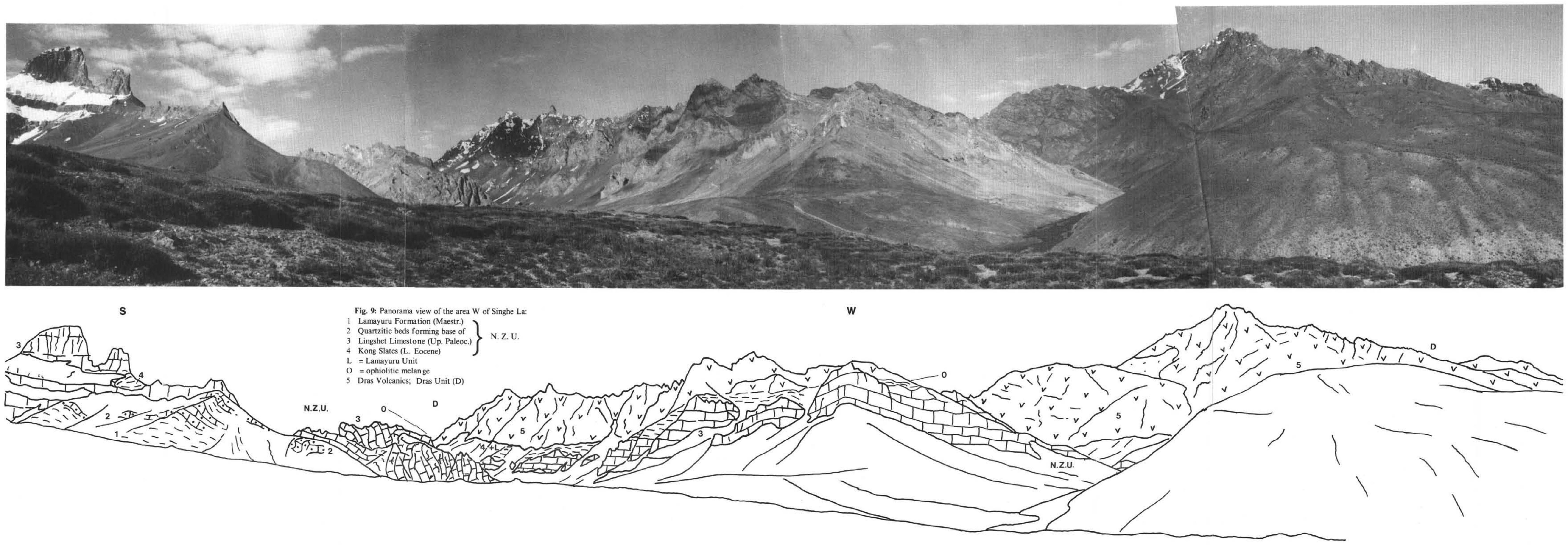


Fig. 9: Panorama view of the area W of Singhe La:

1 Lamayuru Formation (Maestr.) } N. Z. U.
2 Quartzitic beds forming base of } N. Z. U.
3 Lingshet Limestone (Up. Paleoc.) } N. Z. U.
4 Kong Slates (L. Eocene) } N. Z. U.
L = Lamayuru Unit
O = ophiolitic melange
5 Dras Volcanics; Dras Unit (D)

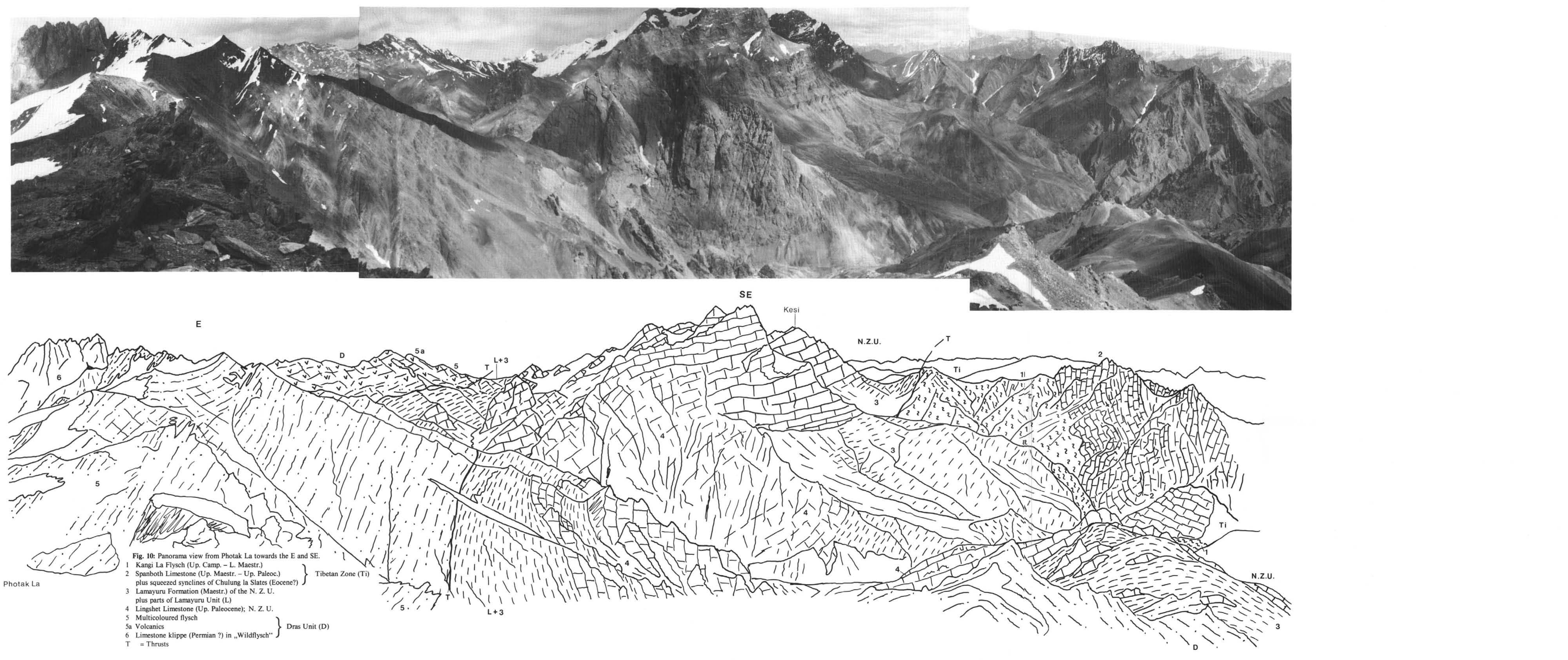
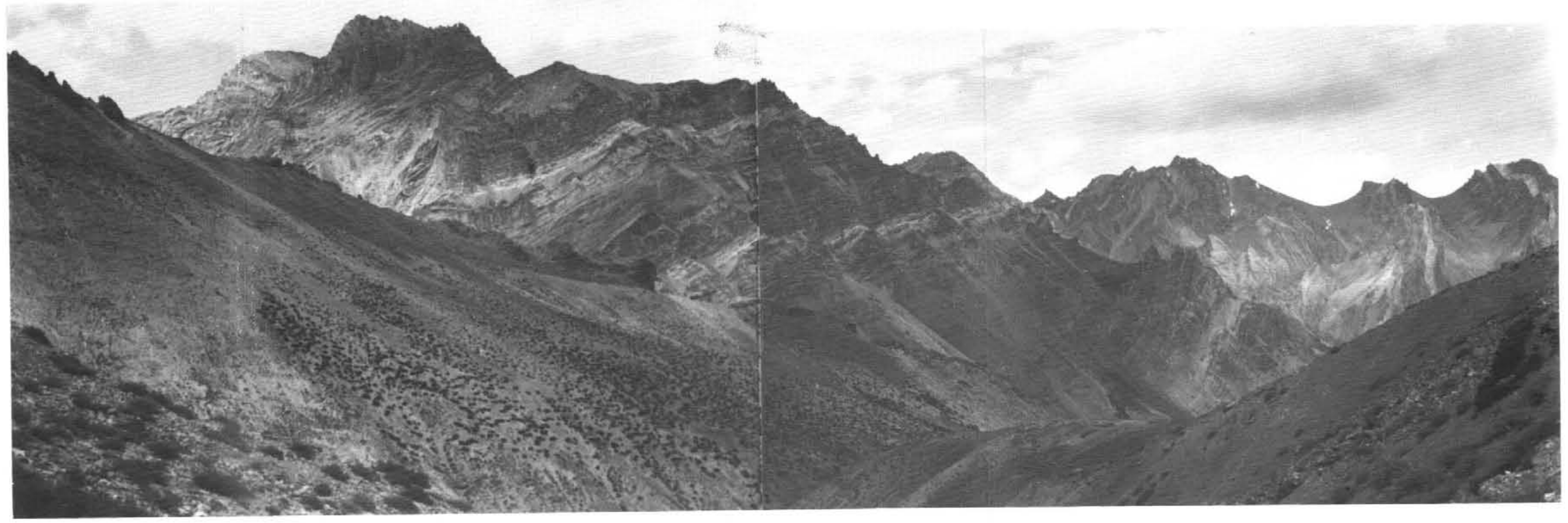


Fig. 10: Panorama view from Photak La towards the E and SE.

1 Kangi La Flysch (Up. Camp. – L. Maestr.) } Tibetan Zone (Ti)
2 Spanboth Limestone (Up. Maestr. – Up. Paleoc.) plus squeezed synclines of Chulung la Slates (Eocene?) } Tibetan Zone (Ti)
3 Lamayuru Formation (Maestr.) of the N. Z. U. plus parts of Lamayuru Unit (L)
4 Lingshet Limestone (Up. Paleocene); N. Z. U.
5 Multicoloured flysch } Dras Unit (D)
5a Volcanics } Dras Unit (D)
6 Limestone klippe (Permian ?) in „Wildflysch“ } Dras Unit (D)
T = Thrusts



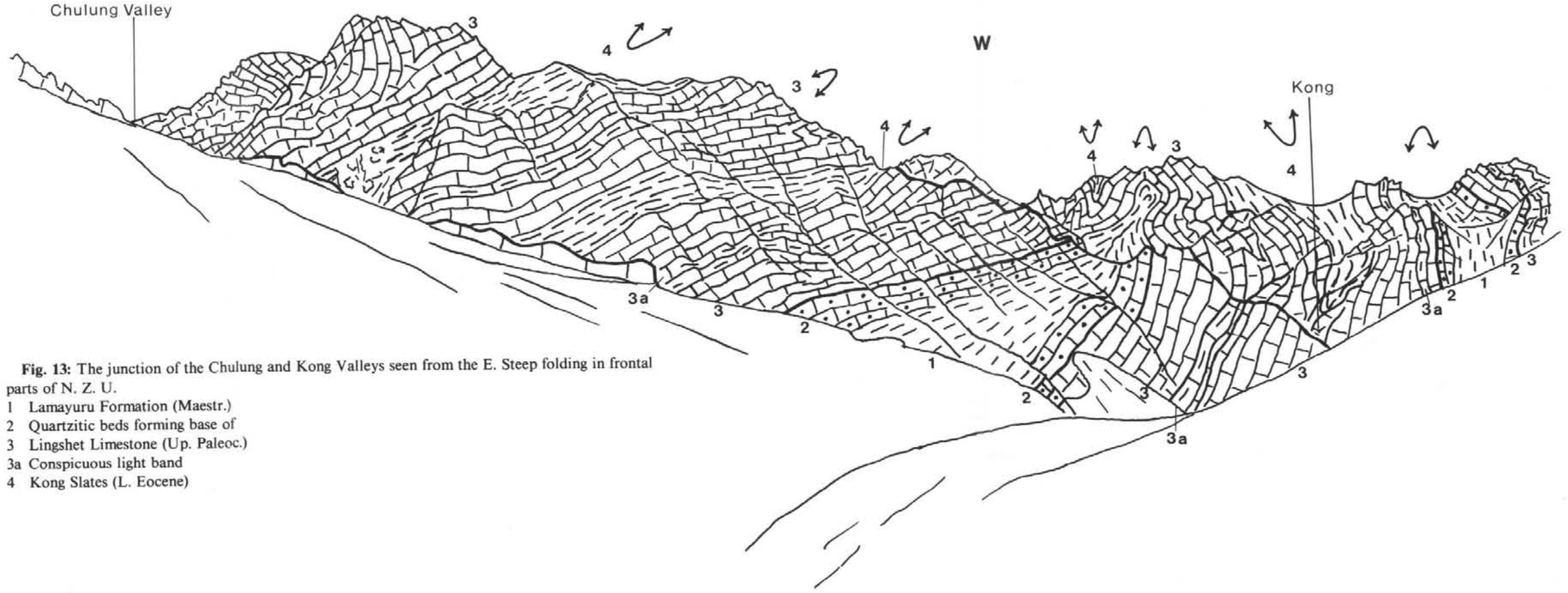
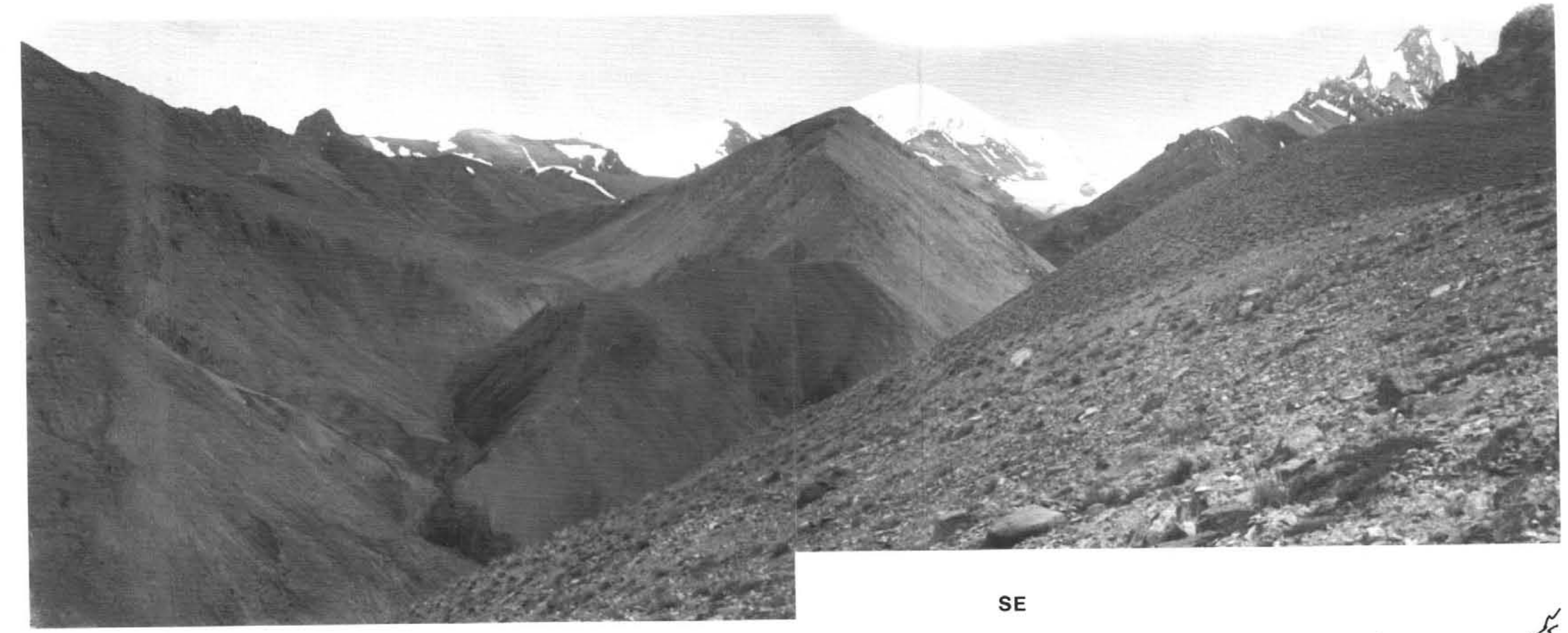


Fig. 13: The junction of the Chulung and Kong Valleys seen from the E. Steep folding in frontal parts of N. Z. U.
1 Lamayuru Formation (Maestr.)
2 Quartzitic beds forming base of
3 Lingshet Limestone (Up. Paleoc.)
3a Conspicuous light band
4 Kong Slates (L. Eocene)



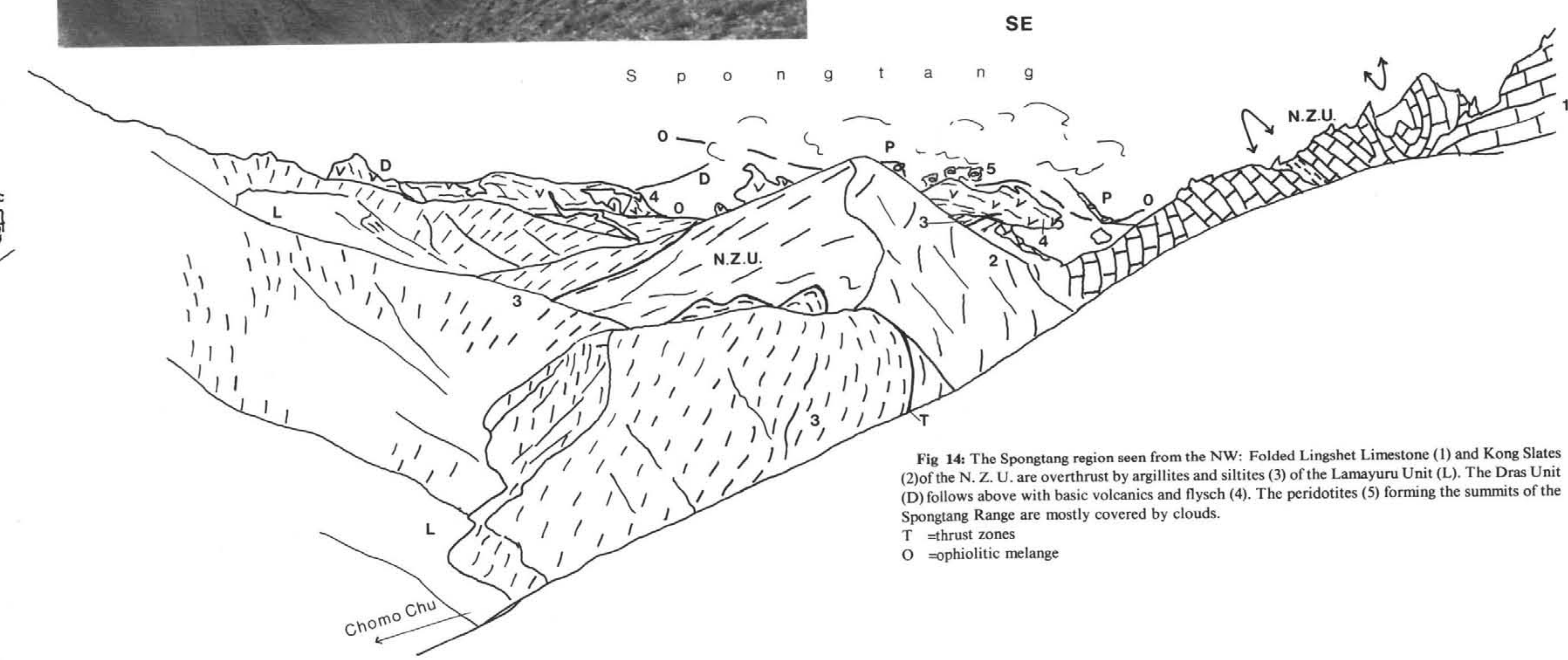


Fig 14: The Spongtang region seen from the NW: Folded Lingshet Limestone (1) and Kong Slates (2)of the N. Z. U. are overthrust by argillites and siltites (3) of the Lamayuru Unit (L). The Dras Unit (D) follows above with basic volcanics and flysch (4). The peridotites (5) forming the summits of the Spongtang Range are mostly covered by clouds.
T =thrust zones
O =ophiolitic melange

Fig. 15: The Singhe La seen from the SE showing folds overturned towards the S:
1 Shillakong Formation (Camp.)
2 Lamayuru Formation (Maestr.)
3 Basal beds of
4 Lingshet Limestone (Up. Paleoc.)
5 Kong Slates (L. Eocene)
All formations belong to the N. Z. U.

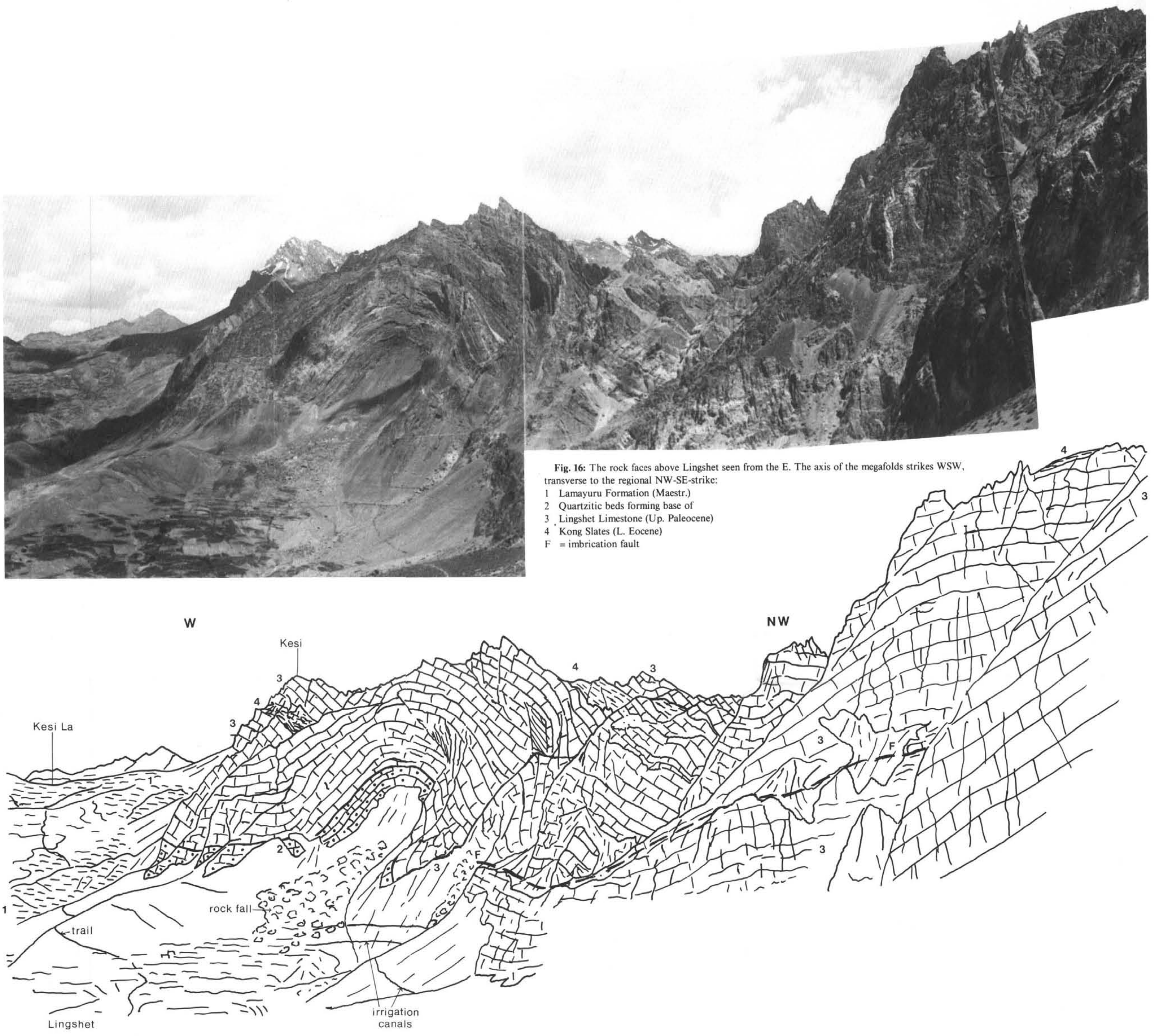


Fig. 16: The rock faces above Lingshet seen from the E. The axis of the megafolds strikes WSW, transverse to the regional NW-SE-strike:
1 Lamayuru Formation (Maestr.)
2 Quartzitic beds forming base of
3 Lingshet Limestone (Up. Paleocene)
4 Kong Slates (L. Eocene)
F = imbrication fault

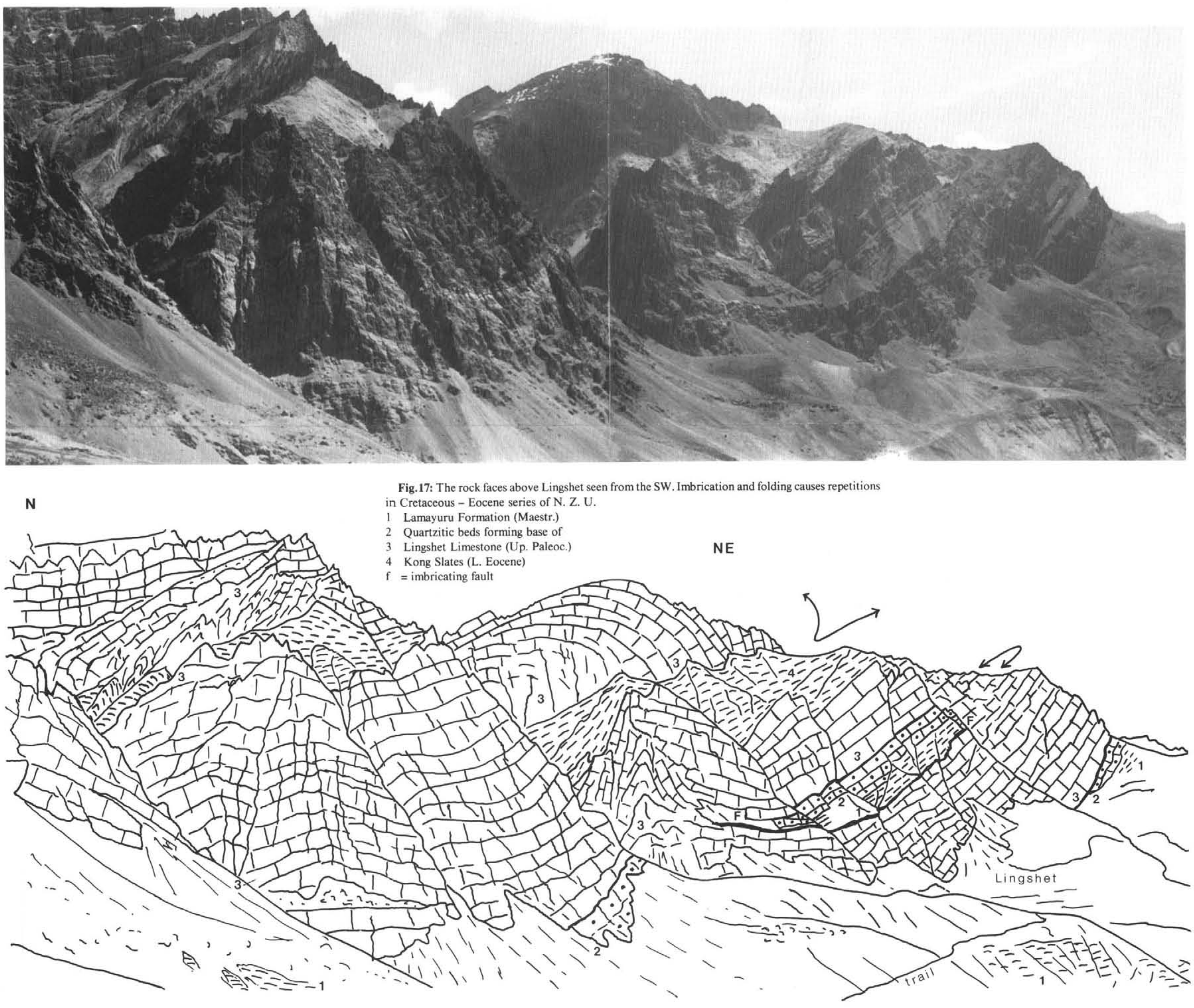


Fig. 17: The rock faces above Lingshet seen from the SW. Imbrication and folding causes repetitions in Cretaceous – Eocene series of N. Z. U.
1 Lamayuru Formation (Maestr.)
2 Quartzitic beds forming base of
3 Lingshet Limestone (Up. Paleoc.)
4 Kong Slates (L. Eocene)
f = imbricating fault

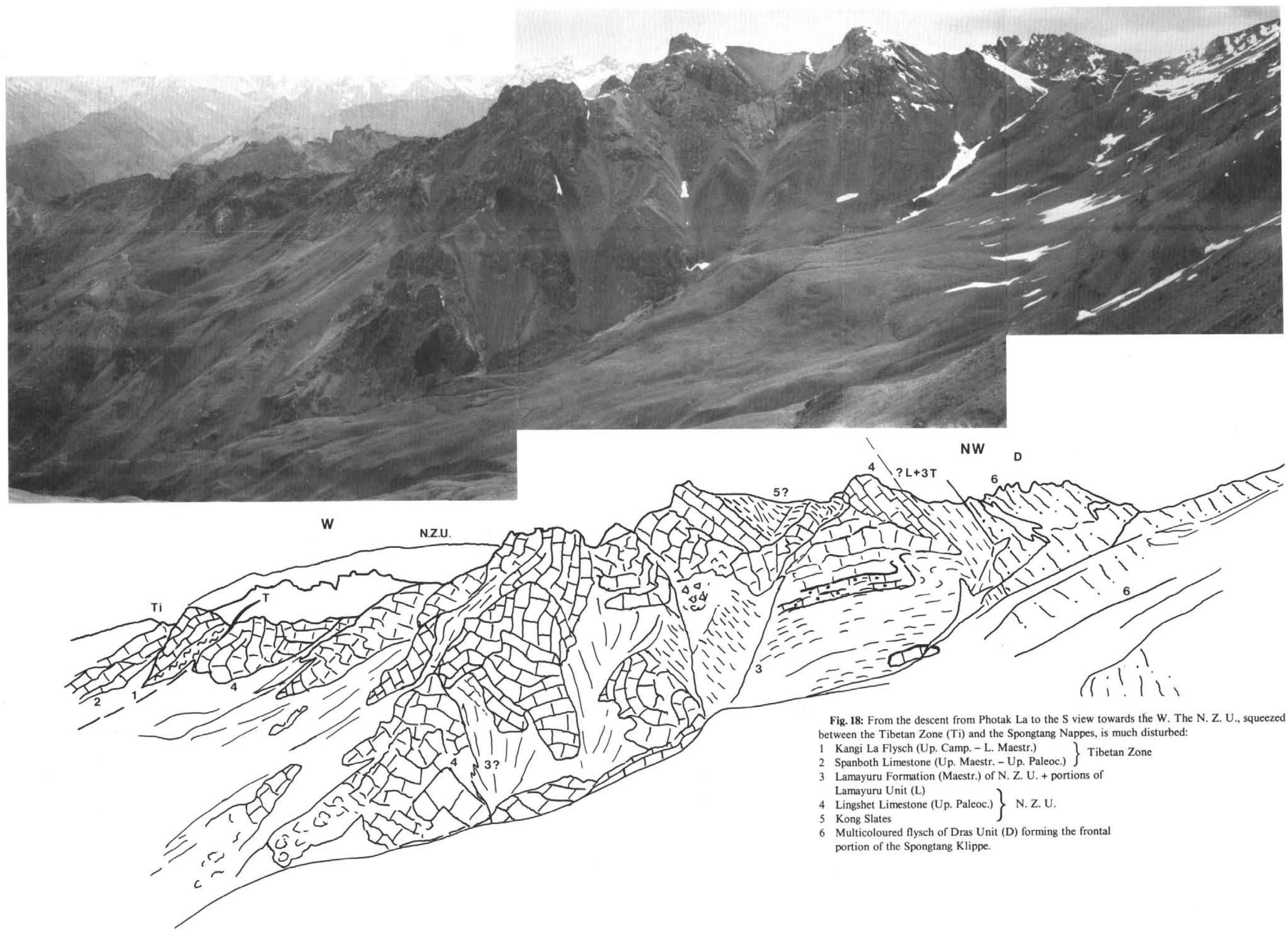


Fig. 18: From the descent from Photak La to the S view towards the W. The N. Z. U., squeezed between the Tibetan Zone (Ti) and the Spongtang Nappes, is much disturbed:
1 Kangi La Flysch (Up. Camp. – L. Maestr.)
2 Spanboth Limestone (Up. Maestr. – Up. Paleoc.) } Tibetan Zone
3 Lamayuru Formation (Maestr.) of N. Z. U. + portions of Lamayuru Unit (L)
4 Lingshet Limestone (Up. Paleoc.) } N. Z. U.
5 Kong Slates
6 Multicoloured flysch of Dras Unit (D) forming the frontal portion of the Spongtang Klippe.

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