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Geological Traverse Across the Western Himalaya – a Contribution to the Geology of Eastern Ladakh, Lahul, and Chamba

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15 Text-Figures, 4 Tables, 1 Plate (in pocket)

India
W-Himalaya
Ladakh
Lahul
Chamba
Regional Geology
Tectonics
Petrology

Contents

Geologisches Querprofil durch den westlichen Himalaya - ein Beitrag zur Geologie von Ost-Ladakh, Lahul und Chamba

Zusammenfassung

Ein Querprofil durch den westlichen Himalaya wird im Bereich Ost-Ladakh – Lahul – Chamba vom Industal bis zu den Fußhügeln bei Dharamsala beschrieben.

1) Die Indus-Molasse zeigt die Schichtfolge: mariner Flysch (U. Eozän), rote Schiefer und wenige Sandsteine (post-Unter-Eozän), grobklastische terrestrische Molasse (Eozän–Miozän). Die Molassezone ist in zwei große Synklinalen und eine trennende Antiklinale gelegt.
2) An der Indus-Sutur stoßen die Indus-Molasse und die Lamayuru-Zone scharf aufeinander. Von der dazwischen zu erwartenden Dras-Nindam-Zone und Ophiolithischen Melange treten nur verquetschte Linsen auf.
3) Eine Antiklinale in der Lamayuru-Zone zeigt deren stratigraphischen Untergrund, es ist ein Paläozoikum in der Ausbildung wie in Zanskar. Eine scharfe Abtrennung der Lamayuru-Zone von der Schichtfolge des Nimaling-Domes und des Zanskar-Schelfes ist nicht möglich, da die Becken- und Kontinentalhang-Folge allmählich in die Schelf-Folge übergeht.
4) Die in die Literatur eingegangene Ophiolith-Deckscholle im oberen Zaratal existiert nicht.
5) Die Schichtfolge des Nimaling-Domes zeigt: Phe Fm. (Präkambrium), Karsha Fm. (Kambrium), Karbonat-Dunkle-Schiefer-Vergesellschaftung und Quarzit-Arkosekomplexe, die einander faziell vertreten (Devon?), Karbonate (U. Karbon), Tilloide bzw. Metabasite (Perm) und Mesozoikum, teils in Lamayuru-, teils in Schelf-Fazies. Eine Gegenüberschiebung teilt den Nimaling-Dom in zwei Blöcke. Sie bringt die ordovizischen Granite empor, die in den tieferen Teil der Phe Fm. intrudiert sind.
6) Die Metamorphose ist im Nimaling-Dom nicht gleichmäßig entwickelt – sie reicht von der Grünschiefer- bis in die unterste Amphibolitfazies. Auf unserer Route unterscheiden wir in den Metapeliten drei Mineralzonen. Die Granatzone zeigt die höchsten Bedingungen mit T = 470–490°C und P = 3–4 kbar. Das Alter der ersten prograden Regionalmetamorphose ist alpidisch.

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7) Der Zanskar-Schelf zeigt vorwiegend SW-vergenten Falten- und Schuppenbau. Besonders die Marang La-Überschiebung ist von Bedeutung, da an ihr ein Faziessprung festzustellen ist. Die Existenz einer „Nimaling-Tsarap-Decke“ (STECK et al., 1993) wird widerlegt. Auch ist die Anzahl der Schuppen in dieser Arbeit übertrieben.
8) Die Sarchu-Scherzone hat noch in der Spätphase der Regionalmetamorphose eingesetzt und steht mit einer ersten Heraushebungsphase des Gebirges und gravitativen Absetzbewegungen in Zusammenhang. In den angrenzenden Gesteinspaketen kam es zu NE-vergenten Schleppfaltungen in km-Dimensionen. Die letzten Scherbewegungen führten zu kräftiger Kataklase entlang der Störung.
9) In Lahul sind die Sedimentzonen von Zanskar, Spiti und Chamba in direkter Verbindung. Das Zentral-Kristallin ist infolge einer Achsendepression verborgen.
10) Zur Klärung der Geologie von Chamba wurden Arbeiten im Chandra-Tal durchgeführt und das Profil Chobia-Paß – Barmaur – Kuarsi – Dharamsala aufgenommen. Die glazigenen Manjir-Konglomerate sind innig mit den präkambrischen Haimantas verbunden, weshalb wir uns der Ansicht von GRASEMANN (1993) anschließen, daß auch die Tilloide proterozoisch sind. Damit ist die Sedimentfolge von Chamba präkambrisch bis kambrisch, mit Ausnahme der permo-mesozoischen Serien der Tandi- und Kalhel-Mulden.
11) In der Stirn der Kristallin-Decke, zu der das Chamba-Synklinorium gehört, sitzt ein großer Granitkörper (Dhauladhar Granit). Die Serien des Niederen Himalaya sind stark reduziert und auf einen schmalen Streifen zwischen der Kristallin-Decke und der Tertiär-Zone beschränkt. Die Zone ist stark gestört und z.T. invers. Die schroffe Südflanke der Dhauladhar-Kette spricht für eine sehr junge und kräftige Heraushebung gegenüber den Fußhügeln. Damit in Zusammenhang steht wohl die bekannt große Seismizität der Region.

Abstract

We describe a geological traverse across the western Himalaya from the Indus Valley through eastern Ladakh, Lahul, and Chamba to the foothills of Dharamsala.

1) The Indus Molasse shows the succession: marine flysch (Lower Eocene), red pelites with few intercalations of sandstone (post-Lower Eocene) and coarse-clastic continental molasse (Eocene–Miocene). Structurally the Indus Molasse exhibits two large synclines separated by the Miru anticline.
2) The Indus Suture Zone (I.S.Z.) sensu lato comprises the Ladakh Batholith (magmatic arc of the active margin of Asia), the Dras-Nindam Unit (island arc and fore arc basin), ophiolitic melanges, the Lamayuru Zone (continental slope deposits of the passive margin of India), and molasse series deposited after collision. The I.S.Z. sensu stricto is the suture between the continents. Along the I.S.Z. sensu stricto the Indus Molasse borders tectonically the Lamayuru Zone. The Dras-Nindam Zone and ophiolitic melanges are mostly squeezed and occur as lenses and klippen.
3) In the Lamayuru Zone the basement of the Mesozoic Lamayuru Formation is exposed in an anticline: Palaeozoic formations in a development like in the adjoining Nimaling Dome and in Zanskar. There are no sharp boundaries between the sequences of the Lamayuru Zone, the Nimaling Dome and the Zanskar Shelf, because the Mesozoic basin and continental rise series pass into the shelf series in the S.
4) The ophiolite klippe in the upper Zara Valley reported in literature is not existing.
5) The Nimaling Dome is composed of the succession: Phe Fm. (Precambrian), Karsha Fm. (Cambrian), carbonates and quartzite-arkose complexes facially replacing each other (Devonian?), carbonates (Lower Carboniferous), tilloids respectively metabasics (Permian) and Mesozoics, partly in Lamayuru partly in shelf facies. A counterthrust divides the Nimaling Dome into two blocks and brings up the Ordovician granites intruded in the Phe Formation, which form the core of the dome.
6) The metamorphism is not homogeneous in the Nimaling Dome. It ranges from greenschist facies into amphibolite facies, increasing towards the ESE. On our route we discerned three mineral zones in the metapelites. The garnet zone indicates the highest grade with T = 470–490° C and P = 3–4 kbar. The age of this first prograde regional metamorphism is Alpine.
7) The Zanskar Shelf is deformed by folding and imbrications, predominantly directed SW. The Marang La Thrust is of importance, because there occurs a marked change in facies. The “Nimaling-Tsarap Nappe“ proposed by STECK et al. (1993) is abandoned, because it is a schuppen belt, the number of imbrications actually is much less than suggested by the above authors.
8) The Sarchu Shear Zone became active during a late stage of regional metamorphism. It is related to a first phase of upheaval with gravitational detachment movements. Adjoining to the shear zone NE directed drag folds developed in km-dimensions. The last down-through along the shear zone caused strong cataclasis.
9) In Lahul the sedimentary zones of Zanskar, Spiti and Chamba are connected. The Central Crystalline is hidden due to an axial depression.
10) To clarify the geology of Chamba we worked in the Chandra Valley and along the route Chobia Pass – Barmaur – Kuarsi – Dharamsala. The glacigeneous Manjir Conglomerates are intimately connected with the Precambrian Haimantas. Therefore we agree with GRASEMANN (1993) who takes them as Proterozoic. This implies that the sucession of Chamba is mainly Precambrian–Cambrian, except the Permo–Mesozoic series of the Tandi and Kalhel Synclines.
11) There is a large granite intrusion (Dhauladhar Granite) in the frontal portions of the Crystalline Nappe, of which the Chamba Synclinorium is part. The units of the Lesser Himalaya are confined to a narrow zone between the Crystalline Nappe and the Tertiary Belt. The zone is much disturbed and partly inverted. The steep southern face of the Dhauladhar Range indicates strong and young uplift. This seems to be a cause of the high seismicity of the region.

1. Introduction

Almost two decades have passed since Ladakh was opened to tourism. By the work of many expeditions the geology of western and central Ladakh is well-known now. Though the Manali–Leh road provides good access to eastern Ladakh, for political reasons – the proximity of the Tibetan Border – the region remained closed to non-Indians for many years. When the Manali–Leh road was opened for foreigners a few years back, the team of the Lausanne University made a first transect; recently their results were published.

In summer 1992 we made a geological traverse across the western Himalaya along the route Upshi – Rumtse – Taglang La – Sangtha – Marang La – Sarchu – Bara Lacha La - Kyelong – Chobia Pass – Barmaur – Kuarsi – Dharamsala. Work along that route should give answer to a series of problems of Himalayan Geology:

1) Which units are found along the Indus Suture Zone in that section?
2) What is the relation of the Lamayuru Zone to the Nimaling-Tso Morari Dome and to the shelf series of the Zanskar Synclinorium?
3) What is the stratigraphy and metamorphism of the Nimaling Dome?
4) Are there nappe structures in the Nimaling-Zanskar Region (BAUD et al., 1982; STUTZ & STECK, 1986; STUTZ,

1988; a.o.) or just fold and imbricate structures (FUCHS, 1986)?

5) What are the relations of the Sarchu Shear Zone to the adjoining rock units?
6) How is the geology of Lahul connected with Zanskar, Spiti, and Chamba?
7) In Chamba the Manjir Conglomerates are a major problem: Are they correlative to the Po- and Agglomeratic Slate Formations of Upper Palaeozoic age as suggested from the Sach Pass–Kalhel section (FUCHS, 1975), or are they Proterozoic as proposed by recent observations of the team FRANK – GRASEMANN, who found the conglomerates underlie Haimantas? To clarify this problem we undertook a joint excursion in the Chandra Valley. Further we made the Chobia Pass – Barmaur – Dharamsala traverse to solve the above problem.
8) At Dharamsala the relations of Crystalline Nappe, Lesser Himalayan units, and Tertiary Zone are of great interest. What about the great thrust planes MCT and MBT?

In the following we shall present our observations and shall discuss the above problems beginning in the N.

2. The Indus Molasse

At Upshi the boundary between the Ladakh (Transhimalaya) Batholith is hidden below the Indus Alluvium and the large fans of tributary streams. Upstream the intrusives build up hills also on the orographically left side of the Indus Valley (Text-Fig. 1). There the basal portions of the overlying Indus Molasse are of bright purple to red colour and are predominantly pelitic. These beds occur also S of the Upshi bridge, but ill-exposed. They are red-brown shales containing 2–4 m bands of light weathering sandstones and arkoses, some of them are fine-conglomeratic. The red series is strongly sheared. These red beds correspond with the “folded red beds of Basgo type” which FRANK et al. (1977, Text-Fig. 4, p. 95) report from W of Upshi. They found a steep thrust separating these beds from the succeeding Hemis Conglomerates. Such a thrust is rather probable from different type of folding, but not exposed in our section.

Above the red beds a thick-bedded series follows consisting of greenish conglomerates, red and green sandstones, and red slates. The components (up to 30 cm sizes) of the coarse clastics are sandstone, slate, radiolarite, quartz, basic to acid plutonic rocks, and volcanics. They are angular to well-rounded. Cyclic units show thickness up to 50 m. The ratio of sandstones and conglomerates to pelites varies between 60 : 40 and 70 : 30. This coarse-clastic complex corresponds with the Hemis Conglomerates (FRANK et al., 1977).

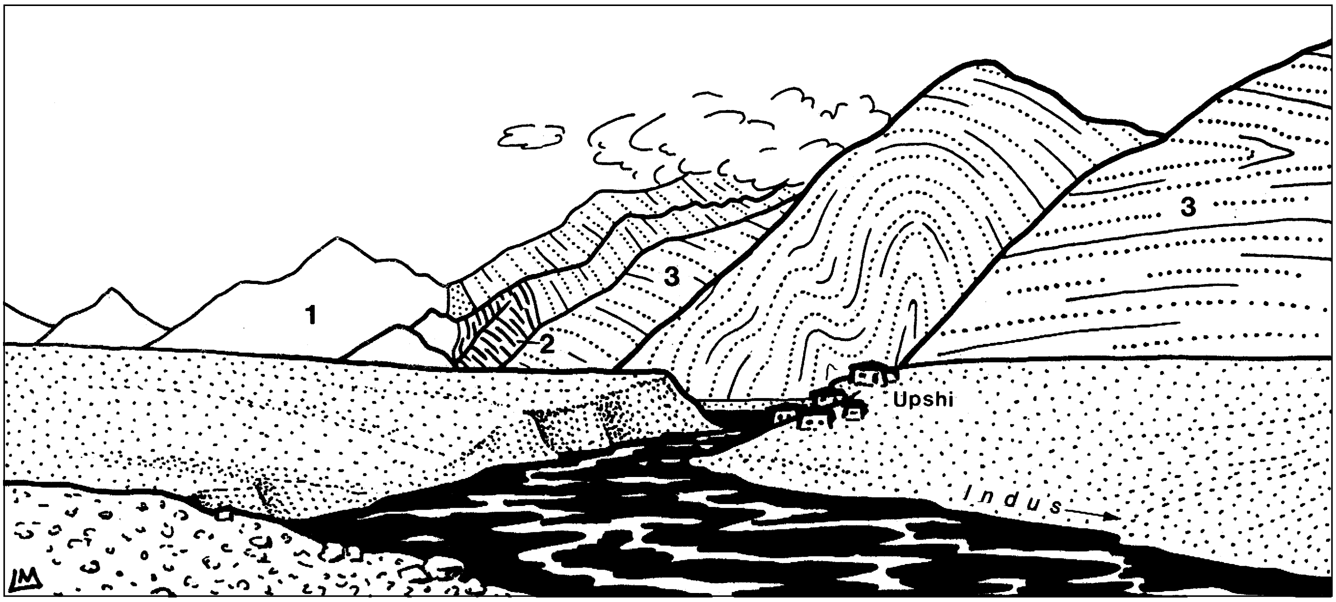
Where the road leaves the Indus and enters the gorge at Upshi the above sequence exhibits conspicuous folds. Generally the series dips SW at steep angles.

Towards the S, where tributaries join the main stream, the sequence becomes rich in red and green argillites. They are estimated to make up 70 % of the succession, the rest consists of green and grey, partly arkosic sandstones.

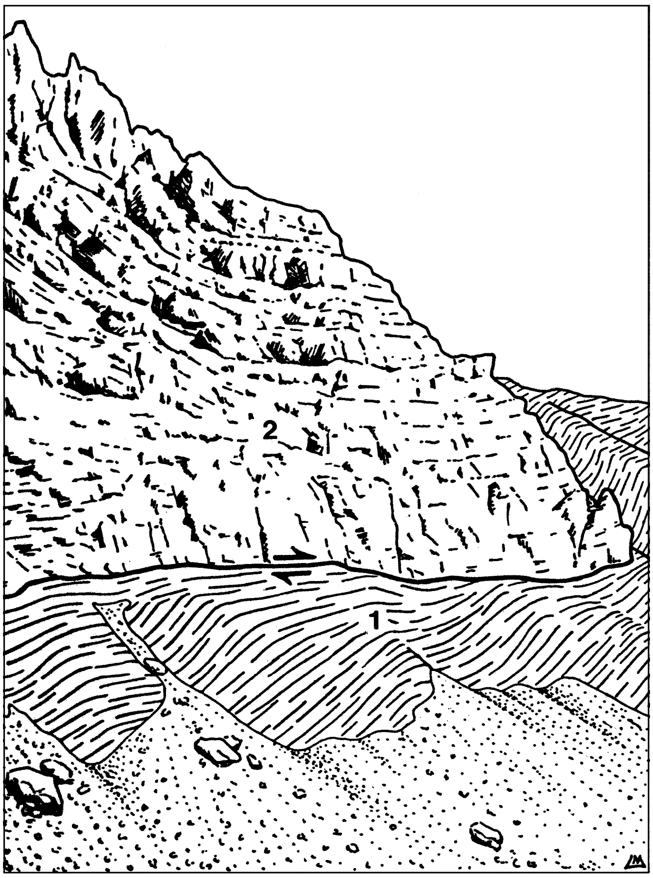
After the junction the arenite content increases again, but conglomerates remain sporadic. This series forms a big syncline (Pl. 1) which correlates to the Hemis Syncline of STECK et al., 1993, Text-Fig. 6). In the core of which these authors show their Variegated Molasse, which corresponds to our molasse series succeeding the Hemis Conglomerates at the junction of the tributaries mentioned above.

Approximately 3 km N of Miru the coarse clastic formation is underlain by thick red pelites. The contact is disturbed due to different mechanical properties of the two rock units (Text-Fig. 2). The red pelites contain thin beds of silt- and sandstone. Ripple marks, desiccation cracks, cross bedding, and raindrop imprints are frequent. The series is about 700 m thick and dips steeply towards NNE. STECK et al. (1993) described these beds as Sumdo Red Molasse. Close to Miru 10–20 m thick, pure, fine-grained, green sandstones are interstratified with the red pelites. This about 300 m thick series is steeply folded.

At Miru the red formation is underlain by highly deformed, beige weathering, grey to dark grey shales with layers of sandstone and marl. This Formation correlates to the Chogdo Flysch (STECK et al., 1993).



Text-Fig. 1.
The Indus Valley upstream of Upshi, view towards the SE.
1 = Rocks of the Ladakh Pluton; 2 = Red pelites of the Indus Molasse; 3 = Coarse continental molasse.



Text-Fig. 2.
The contact of the Gonmaru La Formation (1) and the young continental molasse (Nurla Formation) (2).
About 3 km N of the village Miru; view from the road towards the E (the orographic right side of the valley).
Due to very different mechanical properties of the two formations the stratigraphic boundary is locally sheared.

The section resembles the Ganda La traverse: The flyschoid series of Miru forming an anticline corresponds with the Jurutse Flysch (BROOKFIELD & ANDREWS-SPEED, 1984; FUCHS, 1986, p. 404–405). The Eocene flysch is overlain by red argillaceous series at Rumbok and then by the Rumbok Molasse (BROOKFIELD & ANDREWS-SPEED, 1984) composed of thick-bedded conglomerates, sandstones, and shales. The present experience from the Miru section requires a reinterpretation of the Ganda La section. Following previous authors FUCHS (1986, p. 404) accepted the red pelites of Rumbok as older than the flysch. This implies complicated relations: The Rumbok Molasse overlies the red pelites either on a structural plane (BAUD et al., 1982) or transgresses on the folded red pelites – Jurutse Flysch sequence (BROOKFIELD & ANDREWS-SPEED, 1984; FUCHS, 1986, p. 405, Pl. 3). The fact that the sections of Rumbok and Miru are practically identical suggests that the succession Jurutse Flysch – red pelites – Rumbok Molasse is primary. This agrees also with the concept of GARZANTI & VAN HAVER (1988). According to them the red beds (Gonmaru La Fm.) mark the change from the marine flysch stage (Tar Fm. to Urucha Marl) to the continental molasse (Nurla Fm. including the Hemis Cgl.).

S of Miru the flysch is overlain by SW dipping red pelites, which are only 20–50 m thick. They are overlain by a thick alternation of thick-bedded conglomerates, green sandstones, and red and green shales. The well-rounded components of the coarse clastics are quartz, quartzite, chert, and sandstones. Boulders of magmatic provenance are rare. In the section to the west STECK et al. (1993) described these beds as Stock Molasse. The rocks dip steeply SSW, then towards Lato, they are vertical or dip steeply towards the NE. At Lato close to the I.S.Z. bright red shales are exposed again (Gongmaru La Red Mudstones [STECK et al., 1993]). Due to their position near this lineament these beds are much squeezed.

Review

The Indus Molasse Zone shows a central anticline, where the marine Jurutse Flysch (Eocene) is exposed. Red argillaceous beds (Gonmaru La Fm.) indicate the end of marine sedimentation and a halt after the end of the Early Eocene before thick and coarse clastics were deposited in a continental basin (comp. GARZANTI & VAN HAVER, 1988). The freshwater molasse forms the two wide synclinal belts N and S of the central anticline.

3. The Indus Suture Zone (I.S.Z.)

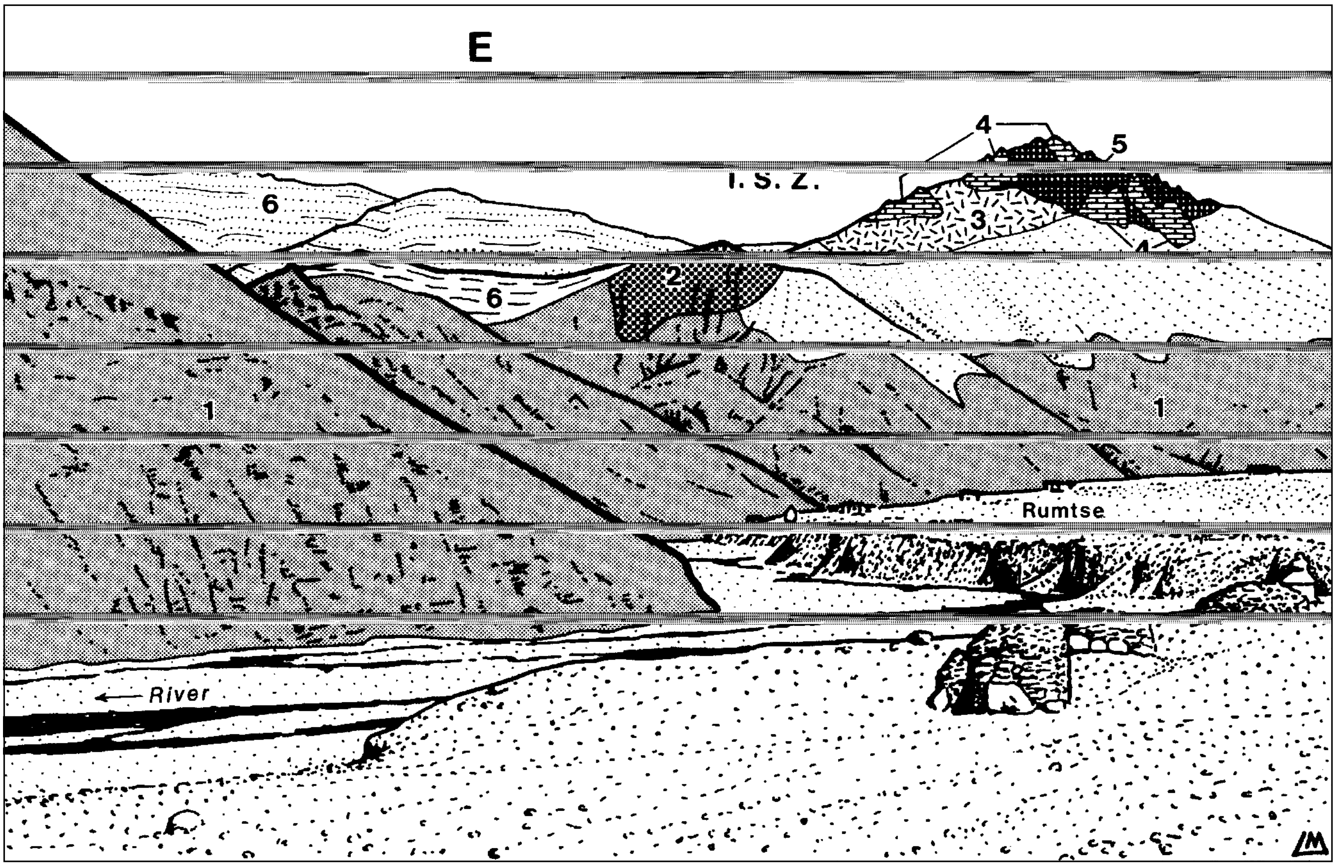
NW of Lato the Dras-Nindam- and the Ophiolitic Melange Zones are completely squeezed out. There the Indus Molasse is in direct contact with the Lamayuru Zone. E of Lato lenticular sandstones and shales (about 20 m), blocks of orange weathering carbonates and of serpentinite (about 3 m) are mixed up in a vertical, approximately 70 m thick shear zone. They represent the remains of the highly reduced Dras-Nindam (?) and Ophiolitic Melange Zones.

Further E another klippe builds up the mountain ESE of Rumtse (Text-Fig. 3). At the ascent from the WNW on the ridge varicoloured conglomerates, sandstones and shales of the Indus Molasse border schistose rocks of the Lamayuru Formation, separated by only 2 m of greenish mylonite. To the E a lens of serpentinite several tens of meters thick is exposed at the I.S.Z. (Text-Fig. 4).

Upridge sheared flyschoid sandstones and slates follow with blocks of light spathic carbonates. In the sandstones the components are angular and ill-sorted. Quartz, carbonate, plagioclase and volcanic clasts were cemented with quartz. The carbonates contain brown weathering, rounded to subangular fragments of volcanic material. The lapilli have sizes of a few mm to 1 cm. They consist of glass, feldspars, and amygdules in a vitrophyric groundmass, aphanitic rocks, and fine- to coarse porphyric rocks. The plagioclase laths and needles frequently exhibit fluxion structure. The volcanic components are often surrounded by a thin rim of columnar carbonate cement and scarce green chlorite. Such columnar cements are common in mixed meteoric/marine phreatic environments. The carbonate matrix is sparitic with few fragments of micritic carbonate containing small undeterminable shells. In the sparite Dr. R. OBERHAUSER (Geol. B.-A., Vienna) kindly determined small gastropods and benthic forams (Valvulinids, Bolivinids?). The age is open, but the fossils indicate a shallow marine environment. Contemporaneously there was active intermediate to basic volcanism producing the pyroclastic rocks.

The carbonates and pyroclastics are associated with fine- to medium-grained flyschoid sandstones and dark to medium grey phyllitic slates. The carbonates are interbedded or form lenticular blocks in flysch.

The peak of the mountain is composed of light to dark grey limestones intruded by dark, dense to fine-grained basalts, green and purple agglomeratic or tuffaceous shales, and subordinate flysch. The blocky medium-



Text-Fig. 3.
The Indus Suture Zone E of Rumtse, view towards the E.
1 = Lamayuru Zone; 2 = Serpentinite; 3 = Flysch; 4 = Light-coloured carbonates; 5 = Basic volcanics; 6 = Indus Molasse; I.S.Z. = Indus Suture Zone.

grained carbonates are contact-metamorphosed by the surrounding basaltic rocks.

The basalts are altered. In thin-section the groundmass of fine-grained amphibole, feldspar, quartz, and opaque minerals contains only few phenocrysts. The latter are pseudomorphs of plagioclase with minor amounts of amphibole and opaque minerals. Additionally there are some phenocrysts of apatite and magnetite. Veins of quartz and calcite are the last manifestations of alteration.

Similar veins cut through the inhomogeneous agglomeratic shales. Lava fragments, lapilli, and crystal fragments are embedded in a chaotic way in a dark matrix. The latter is rich in fine-grained opaque minerals. Zoned plagioclase phenocrysts are frequent in the vitrophyric groundmass of the lapilli or lava fragments. The partly resorbed crystal fragments are prevailingly plagioclase. A second typical phenocryst is anorthoclase suggesting fractionated basalts as source of the agglomeratic shales.

The geochemistry (Tab. 1) points to highly fractionated members of an alkali basalt suite. In the total alkali (Na_2O+K_2O) versus silica diagramm (COX et al., 1979) the porphyric basalt plots in the mugearite field and the agglomeratic shales in the benmoreite field. The volcanics have high and variable contents of the incompatible trace elements Zr and Nb, but constant Nb/Zr-ratios. Thus the basalt and the agglomeratic shales seem to derive from more fractionated members of the same alkali basalt suite (WILSON, 1989).

Two different Triassic basalt suites are described from the Tibetan Kiogar-Amlang La region (HONEGGER et al., 1982). The volcanics of the klippe ESE Rumtse represent the fractionated part of the alkali basalt – hawaiite – mugearite – benmoreite suite. Similar klippes in the I.S.Z. are in the Markha Valley S of Leh (BAUD et al., 1982; FUCHS, 1984, 1986).

According to THAKUR & VIRDI (1979) the I.S.Z. rock units become more important towards the SE. They discerned the Zildat Ophiolitic Melanges, ultramafics, and the Nidar Ophiolite belt. The patches of Kargil Formation found by the above authors on the ophiolitic rocks correlate to the Chilling Molasse (FUCHS, 1986) respectively the Liuqu Conglomerates of Tibet (BURG, 1983). These molasse series were deposited after the first strong deformation phase of the I.S.Z.

4. The Lamayuru Zone and its Relation to the Nimaling Dome

South of the Indus Molasse, after crossing the I.S.Z., we find wide, geomorphologically soft terrain built up by the Lamayuru Formation. All the hills S of Lato and Rumtse consist of this series. The Lamayuru Formation is characterized by dark grey to black silty slates, partly phyllitic, and marls with layers of impure, fine-grained sandstone and blue limestones. There are also tens to hundred meters thick zones of fine-olistolithic, blue limestone, occasionally yielding crinoids.

Due to sulphide content the dark carbonaceous Lamayuru Formation shows efflorescences and is bleaching on weathered surfaces. This causes the Lamayuru belt to appear as a light band on satellite imagery.

The Lamayuru Formation suggests sedimentation in an euxinic, turbiditic environment. The calcareous flysch se-

Table 1.
Chemical composition of basites from eastern Ladakh and of one mafic sill from Chamba (E Kuarsi).

Sample	RU - 4	RU - 6	RU - 7	RU - 8	TS - 9	DB - 24	ZA - 37	ZA - 46	ZA - 48	SA - 53	KU - 105
Lithology	alkali basalt	agglomeratic shale	agglomeratic shale	tuffaceous shale	chlorite schist	mafic dike	mafic dike	Chl - Ep - schist	Ep - schist	mafic dike	mafic sill
Location	E Rumtse	E Rumtse	E Rumtse	E Rumtse	Tsakenama	Debring	NE Jakang	NE Jakang	NE Jakang	N Sangtha	E Kuarsi
SiO_2	54.60	65.85	62.47	37.29	47.86	48.69	49.68	46.95	46.90	48.49	47.59
TiO_2	1.91	0.86	0.82	3.50	2.60	2.58	2.52	1.28	1.56	2.18	1.35
Al_2O_3	17.85	16.29	15.59	14.93	14.05	14.75	13.51	17.17	17.03	14.92	16.51
FeOtot	7.40	4.14	6.78	12.21	11.71	12.49	12.88	12.37	11.50	14.42	11.54
MnO	0.07	0.16	0.06	0.11	0.15	0.21	0.18	0.21	0.17	0.23	0.19
MgO	1.11	0.60	2.11	6.64	9.88	5.79	5.82	7.29	5.63	4.95	7.49
CaO	3.11	1.53	1.37	9.61	4.61	9.92	7.69	6.40	13.21	9.40	9.44
Na_2O	3.13	4.84	3.29	1.39	1.91	3.00	2.71	3.79	0.42	2.33	1.94
K_2O	6.29	3.77	4.69	1.73	1.18	0.84	1.82	0.08	0.02	1.03	0.73
P_2O_5	0.85	0.21	0.21	0.52	0.65	0.23	0.32	0.19	0.28	0.45	0.17
LOI	2.87	1.89	2.54	11.84	5.02	1.27	2.41	3.13	2.79	1.14	2.58
Total	99.20	100.12	99.93	99.78	99.62	99.78	99.54	98.86	99.51	99.53	99.54
V	175	62	84	473	357	534	409	297	346	393	212
Cr	<10	<10	24	508	166	150	92	49	237	77	89
Co	<10	<10	10	36	51	42	45	50	46	44	51
Ni	<10	<10	13	142	114	79	69	18	54	50	122
Cu	<10	<10	<10	34	48	149	165	<10	82	88	53
Zn	204	61	184	118	137	105	132	117	90	143	90
Ga	20	15	25	14	15	13	16	16	14	16	11
Rb	78	44	65	40	23	28	56	<5	<5	35	42
Sr	52	73	85	362	110	397	189	331	290	212	250
Y	41	35	75	28	24	23	36	36	48	45	28
Zr	529	609	1304	279	296	119	216	175	141	234	112
Nb	150	139	287	45	77	10	18	5	8	21	9
Ba	665	453	328	164	96	56	159	46	10	303	120
Pb	<10	<10	<10	<10	<10	12	22	<10	<10	<10	46
Major elements (wt %); Traces (ppm)											

diments were deposited along a passive continental margin on the slope and in the adjoining basin (FRANK et al., 1977; FUCHS, 1977b, 1979, 1986; BASSOULLET et al., 1981; BROOKFIELD & ANDREWS-SPEED, 1984). The carbonates interbedded with this basin facies yielded fossils indicating a shallow water source. BASSOULLET et al. (1981) proved the olistolithic nature of some of these limestone intercalations and envisaged various mechanisms by which material from the shelf slumped into the basin. Particularly the Kioto Limestone is a source of olistoliths. Also the Upper Cretaceous Shillakong (Fotu La) Limestones are interfingering with the Lamayuru rocks, therefore FUCHS (1977b, 1979, 1986) proposed that the younger portions of the Lamayuru Formation are of Cretaceous age. From the fossils reported a Triassic–Jurassic age is well-documented (FRANK et al., 1977; FUCHS, 1979; BASSOULLET et al., 1981; BROOKFIELD & WESTERMANN, 1982). Recently SINHA & UPADHYAY (1993, p. 61–62) proposed an age range even to the Eocene. They found thin calcareous bands in the Lamayuru Formation rich in Alveolinas, Nummulites, and Miliolids. As this horizon is just near the contact to the Ophiolitic Melange Zone we think that the Tertiary rocks also might be a schuppe in the Lamayuru Formation.

The stratigraphic range is largest in the Lamayuru Zone, that means between the I.S.Z. and the Nimaling Dome, towards the S it decreases because of intertonguing with the carbonates of the Zanskar Shelf. The basin facies is more and more replaced by shallow-water series. It persists farthest towards the S in the Norian, the Upper Jurassic (Spiti Shales) and Maestrichtian (Goma Shales). There exists no sharp boundary between the Lamayuru Unit and the Zanskar Synclinorium in eastern Zanskar (FUCHS, 1986). In this region also the contact to the Ophiolitic Melange Zone (I.S.Z.) in the N seems to be primary (FUCHS, 1986): Within the Lamayuru belt the carbonate content of the series decreases towards the N. The areno-pelitic schists accepted by STUTZ (1988) as Permian "Lutchungse Formation" probably correspond at least in part to the non-carbonate flysch of FUCHS (1986). This implies that the rocks in discussion are much younger than Permian.

Though volcanism is generally absent from the Lamayuru Formation, there is basic volcanism active close to the Ophiolitic Melange Zone (FUCHS, 1986, p. 417). In the course of our 1992 campaign we found tuffaceous shales in one locality immediately S of the klippe mountain E of Rumtse. Thus the position of the tuffaceous rock is also close to the Ophiolitic Melange Zone. Under the microscope the tuffaceous shale shows fine- to medium-grained clasts of carbonates, quartzites, and plagioclase crystal fragments embedded in a chlorite-leucoxene groundmass. While the quartzites are well-rounded, the carbonate clasts are resorbed and recrystallized. The

Table 2.
Mineral assemblages of mafic rocks from the Nimaling Dome.

No.	Mineral assemblage	Lithology	Location	Sample
1	Chl - Bt - Ep - Ab - Qtz - Cal ± Czo Acc.: Ilm, Ttn	chlorite schist	Tsakenama	TS - 9
2	Hbl - Bt - Chl - Ep - Pl - Qtz ± Czo Acc.: Ilm, Ttn, Ap	metamorphic mafic dike	Debring	DB - 24
3	Hbl - Bt - Chl - Ep - Pl - Qtz - Cal Acc.: Mag, Ttn	metamorphic mafic dike	Zara Valley (NE Jakang)	ZA - 37
4	Chl - Ep - Hb - Bt - Pl - Qtz ± Czo Acc.: Mag, Ttn, Ap	Chl - Ep - schist (Panjal Trap)	Zara Valley (NE Jakang)	ZA - 46
5	Ep - Chl - Hb - Bt - Pl - Qtz ± Czo Acc.: Mag, Ttn	Ep - schist (Panjal Trap)	Zara Valley (NE Jakang)	ZA - 48
	Symbols of minerals after KRETZ (1983)			

trace elements (Tab. 1) point to detrital influence from tholeiitic basalts.

In our section the Mesozoic Lamayuru Formation described above is exposed in a belt about 4.5 km wide. The series is strongly deformed, the dip is generally N to NE at 50 to 80°.

At a place called Tsakenama the calcareous flysch is underlain by a conspicuous band (about 30 m) of green chlorite schists with thin layers of light yellowish arkose schists. The fine- to medium-grained chlorite schists show a greenschist facies assemblage (Tab. 2, No. 1). The pseudomorphs after coarse-grained amphibole consist of green biotite and fine-grained sphene. The geochemistry of the schist (Tab. 1) indicates a basic composition with relatively high values of potassium and magnesium, and low calcium. This agrees well with the dominance of chlorite and biotite and the lack of amphibole in this greenschist facies assemblage. The high TiO_2 and P_2O_5 contents and the trace elements suggest a significant amount of basaltic tuff in the educt material of the chlorite schists.

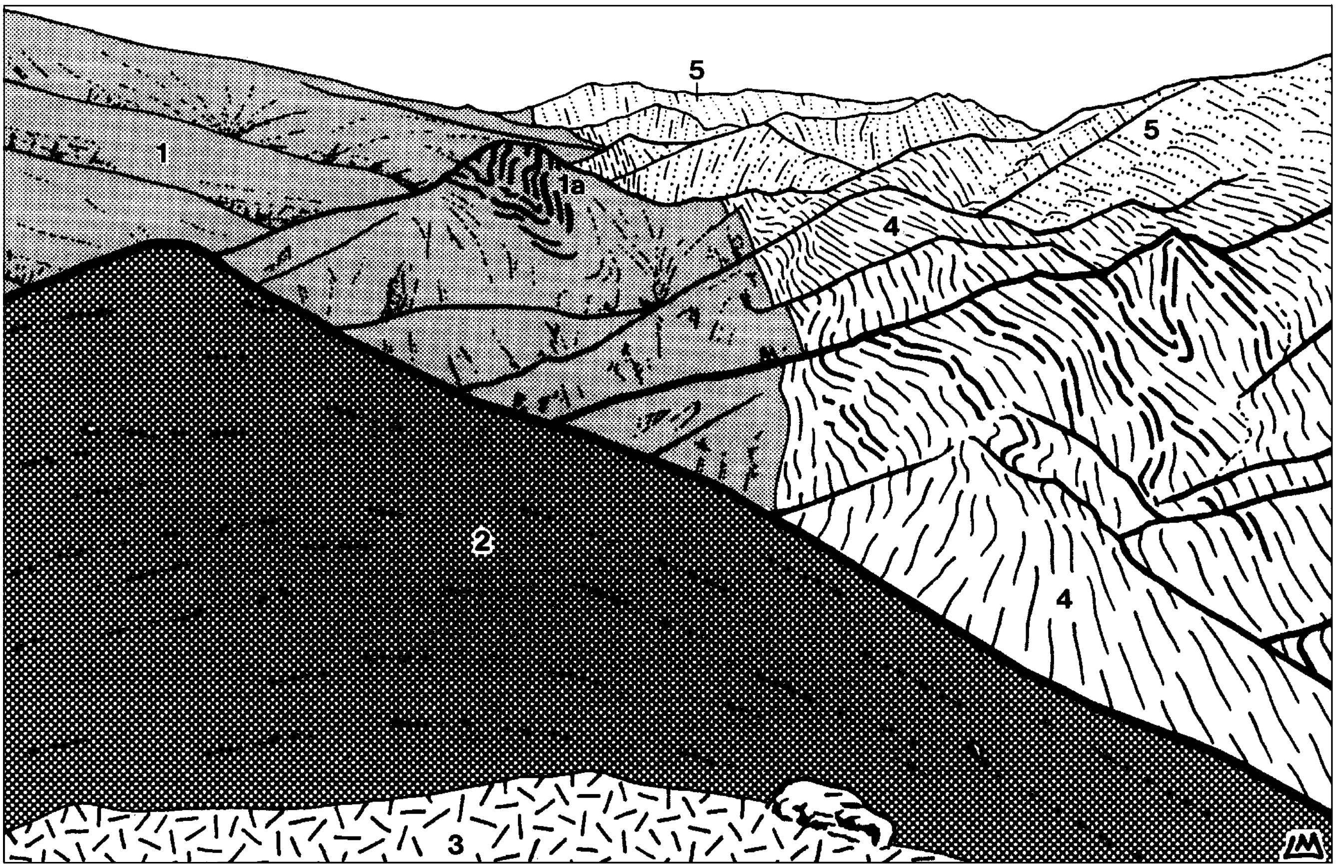
We think that the chlorite schists are tuffites representing the Panjal volcanic event, which is consistent with our geochemical data. STUTZ (1988, p. 43) mentioned chlorite schists interbedded in the Kuling Formation at the NW end of the Nimaling Dome. There the Permian age of the beds accompanying the chlorite schists is documented by fossils, which supports our proposed correlation with the Panjal Trap.

Below the conspicuous green horizon follows a series about 600 m thick of dark blue to light grey or cream coloured marbles interbedded with frequently dark coloured calcschists to calc-micaschists. In these carbonates the crystallinity is increased compared to the overlying Lamayuru Formation. Several samples of the carbonates were taken for conodont examination, but proved to be sterile.

Where a tributary joins the main valley from the SSW (Shagrot encamping ground) phyllitic micaschists, quartzites, and huge blocks of dark brown weathering dolomite come up beneath the carbonate series and form the core of an anticline. Sporadically we found metamorphic iron oolite. This series is composed of light greenish-grey, thick-bedded phyllitic micaschists interlayered with sericite quartzite. The rocks exhibit even s-planes. The assemblage of the phyllitic micaschists (Tab. 3, No. 1) contains chlorite as index mineral. Therefore this area is part

Table 3.
Mineral assemblages of metapelites from the Nimaling Dome.

No.	Mineral assemblage	Lithology	Location	Sample
1	Chl - Ms - Pl - Qtz Acc.: Tur, Zrn, Ap, o. m.	phyllitic schist (Karsha Fm.)	Shagrot	SH - 12
2	Chl - Ms - Qtz - Mag Acc.: Tur, Ap, o. m.	quartzphyllite (Kuling Fm)	S Taglang La	TL - 21
3	Bt - Chl - Ms - Ab - Cal - Qtz Acc.: Tur, Aln, Zrn, Ap, o. m.	phyllitic micaschist (Haimanta Fm.)	Debring	DB - 22
4	Bt - Chl - Ms - Pl - Qtz Acc.: Tur, Aln, Zrn, Ap, o. m.	phyllitic psammite-schist (Haimanta Fm.)	Debring	DB - 23
5	Grt - Bt - Chl - Ms - Ab - Cal - Qtz Acc.: Aln, Tur, Zrn, Ap, Ilm	phyllitic micaschist (Haimanta Fm.)	Debring Plain (NE Zara knee)	DB - 27
6	Bt - Chl - Ms - Pl - Qtz Acc.: Tur, Aln, Zrn, Ap, Cal, o. m.	phyllitic micaschist (Haimanta Fm.)	Zara Valley (SW Debring)	ZA - 43
7	Bt - Chl - Ms - Ab - Cal - Qtz Acc.: Tur, Zrn, o. m.	phyllitic schist	Zara Valley (SW Debring)	ZA - 35
8	Chl - Ms - Pl - Qtz Acc.: Tur, Zrn, Ap, o. m.	phyllitic schist (Phe Fm.)	SW Jakang	SA - 54
	Symbols of minerals after KRETZ (1983)			o. m. = opaque minerals



Text-Fig. 4.
The Indus Suture Zone seen from the klippe E Rumtse towards the NW.
1 = Lamayuru Zone; 1a = Olistolithic carbonates; 2 = Serpentinite; 3 = Float of flysch and light-coloured carbonates; 4 = Indus Molasse, predominantly red; 5 = Indus Molasse, coarse-clastic continental deposits.

of the chlorite zone. The metamorphic zonation of the Nimaling Dome will be described below in more detail. The lenses of dolomite, tens of meters thick, consist of medium grey, resistant, massive dolomite weathering in characteristical rusty colours and disintegrating to big blocks. The lithology of the formation is typical for the Parahio or Karsha Formation of Cambrian age. Thus we think that the carbonates outcropping between the Karsha Formation and the chlorite schist band were deposited in the Ordovician–Permian period; similar rocks are known particularly from the Devonian–Carboniferous.

The anticline of Karsha Formation plunges towards the W. Walking upstream towards Taglang La we again come into the overlying carbonate series. The boundary to the Karsha Formation appears to be somewhat tectonized. In the SW-flank of the anticline the carbonate series is richer in dark, carbonaceous, schistose rocks than in the NE-limb.

At the ascent on the mule-track to Taglang La the above carbonates are overlain by a conspicuous, light-coloured band, which builds up the peak N of Taglang La. This band consists of platy to thick-bedded, light green-grey, white crystalline limestones and quartzites weathering in yellow to cream colours. This light and resistant band can be traced from the S to Taglang La but ends NW of the pass. Further NW a lenticular body of the Taglang La carbonates and quartzites rests on the dark carbonates (from the talus and by binocular observation, see Pl. 1).

The outcrop relations of the Taglang La rocks suggest that they occur in the core of a syncline and therefore do not reach the bottom of the valleys and topographically lower terrain. Therefore we accept in Pl. 1 that the dark carbonates and pelites overlying the light Taglang La rocks represent the inverted SW-limb of a syncline and not stratigraphically succeeding Lamayuru Formation.

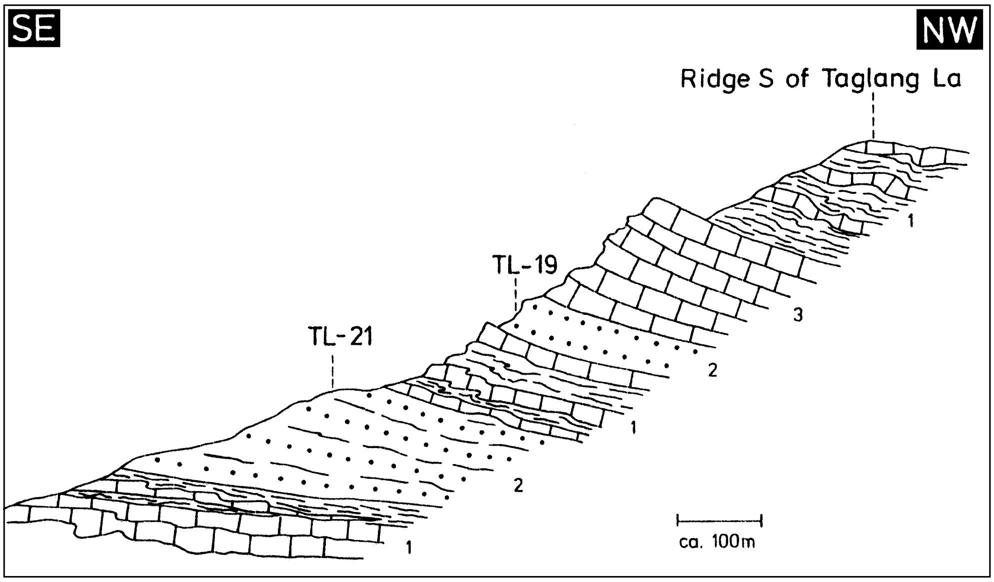
Concerning the age of the Taglang La rocks G. Fuchs stresses the resemblance of the lithology with the Permian series of Nimaling ("Fil d'Ariane", Stutz & Steck, 1986; Fuchs, 1986; Kuling Formation, Stutz, 1988).

The locality LK-660 where Virdi et al. (1978) found their Permian fossils appears to be situated in the dark carbonates and pelites and not in the light band of Taglang La. Therefore we are aware that not only the Taglang La rocks, but also the upper portions of the dark carbonates and pelites may represent the Permian. Our samples have yielded no conodonts.

On the descent from Taglang La to the SSE along the mule track we observed the section (Text-Fig. 5):

(7) The ridge SW of the pass consists of dark phyllites and carbonates. They rest on
(6) light Permian marbles of Taglang La (about 150 m)
(5) cross-bedded, brown to grey arkose-quartzites and platy, white to greenish, fine-grained quartzites showing fine needles of tourmaline on s (40–50 m)
(4) crystalline limestone (about 6 m)
(3) dark grey to black calcschists with sandy layers (about 100 m)
(2) platy, white to light grey quartzites, psammite schists, arkose schists, and quartz phyllites (about 200 m). At the base passage by alternation with black schists into
(1) dark schists and schistose carbonates.

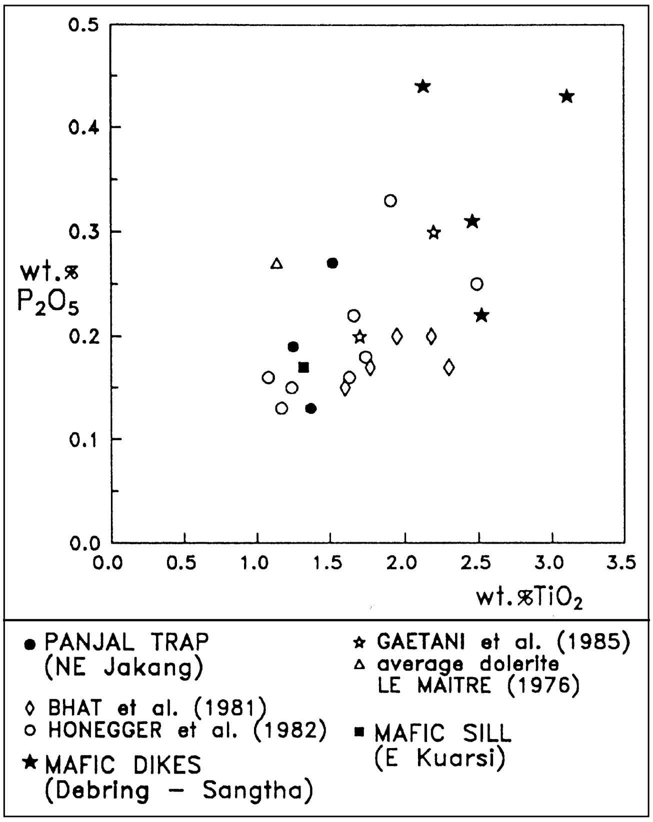
Text-Fig. 5.
The section on descent from the Taglang La towards the SE in direction to Debring.
1= Carbonates and dark, phyllitic pelites; 2 = Quartzites, metaarkoses and psammite schists; 3 = Light-coloured crystalline carbonates of Taglang La (Permian?).



From the foot of the Taglang La to the Debring camping ground both slopes of the valley are built of platy quartzites and arkosic schists. In a tributary from the NE the quartzites appear to be underlain by carbonates exposed in the bottom of the side valley.

Comparing the sections N and S of Taglang La the dissimilarities are obvious. Though we find the same rock types, quartzite and metaarkose intercalations are important in the S. All observations indicate that the successions are stratigraphic and we envisage major facies intertonguing below the light carbonates of Taglang La. The dark carbonate-pelite facies is partly replaced by light terrigeneous clastics towards the S and SE.

At Debring camping ground the quartzites abut against Phe (Haimanta) Series (Precambrian–Cambrian) in the orographic right slope of the valley. The boundary seems to be a steep fault. In the N side of the valley the quartzites overlie the Haimantas. These form a wide anticline composed of dirty green-grey, silty to sandy slates, phyllitic micaschists and metasiltstones. The rocks exhibit fine sedimentary laminations characteristic for the Phe- and Haimanta Formations. The Karsha Formation with its rusty weathering dolomite bodies is missing in the Debring area.



Text-Fig. 6.
P_2O_5 versus TiO_2 diagram of the Panjal Trap and mafic dikes in the Nimaling Dome, and one mafic sill from Chamba (E of Kuarsi), compared with data from literature.

Between the Haimantas and the overlying quartzites black phyllitic schists and lenses of light carbonates were observed N of the Debring Plain.

In the Haimantas and the quartzite series mafic dikes are not rare. They are metamorphosed to amphibolites. The assemblage (Tab. 2, No. 2) contains fine-prismatic, bluish-green hornblende intergrown with olivegreen biotite and chlorite. Medium-grained hornblende shows a pale core rich in inclusions. Clinozoisite also with fine-grained inclusions shows a rim of epidote. Epidote occurs also as fine aggregates. Magnetite or ilmenite are abundant, the latter is frequently surrounded by sphene.

The chemical composition (Tab. 1) of the amphibolites points to dolerites as educt material (Text-Fig. 6). The compositions are similar to the Panjal Trap basaltic dikes cutting the Karsha Formation as described by GAETANI et al. (1986).

The metasediments of the Tso Morari Dome exhibit increasing metamorphism towards the core (THAKUR, 1983). We recognized a metamorphic zonation in the metapelites of the Nimaling Dome between Shagrot N of Taglang La and the plains S of Debring. The metamorphism increases towards the SE. Three zones can be distinguished characterized by the index minerals chlorite, biotite, and garnet.

Chlorite occurs in the phyllitic micaschists of Shagrot and in the quartz phyllites of Taglang La (Tab. 3, No. 1, 2). Therefore the chlorite zone covers the region NW of Taglang La and the adjacent area SE of the pass. Whereas in the arkose schists associated with the basic horizon of Tsakenama no biotite occurs, in the arkose schists S of Taglang La – still in the chlorite zone – the first appearance of biotite was observed (Text-Fig. 5, TL-19). Thus biotite is stable under lower metamorphic conditions due to a higher potassium content of the arkose schists.

Close to Debring nodular blasts of plagioclase appear in the green-grey phyllitic micaschists of the Haimanta Formation. In thin-section eye-shaped albite blasts occur in a fine-grained matrix of quartz, calcite, albite, chlorite, muscovite, and some biotite (Tab. 3, No. 3). A small amount of calcite seems to be typical for the pelites of the Haimantas of this area. Phyllitic psammite-schists without calcite contain small blasts of plagioclase and medium-grained biotite growing across the foliation (Tab. 3, No. 4). Thus we enter the biotite zone at Debring.

The plagioclase and biotite porphyroblasts increase in size and frequency from Debring to the SE. Approximately 6 km SSE of Debring garnet porphyroblasts up to 5 mm appear in green phyllitic micaschists (Tab. 3, No. 5). Biotite blasts are of the same size and plagioclase blasts are still found. Towards the upper course of the Zara Valley garnet soon disappears, thus we only touched the NW rim of the garnet zone and left it in SSW direction.

Under the microscope the garnet porphyroblasts are poikiloblastic and extended parallel to the foliation. Fine-grained quartz, albite, and ilmenite inclusions are arranged in lines parallel to the external foliation. Biotite porphyroblasts parallel or across the foliation contain very fine-grained opaque inclusions also parallel to the external S_1. Therefore the biotite and garnet blasts grow postdeformative in respect to the main foliation (S_1). In contrast the albite blasts show sigmoidal inclusion trails, thus they are syn- to post-deformative. The fine-grained groundmass is grano- to lepidoblastic. It is built up by layers rich in polygonal quartz with some albite and calcite and bands of muscovite, biotite, and some chlorite. Accessories are ilmenite, zoned tourmaline, and zoned allanite. A crenulation cleavage (S_2) cuts across the foliation (S_1). This deformation was rather late because the fine-grained micas did not recrystallize.

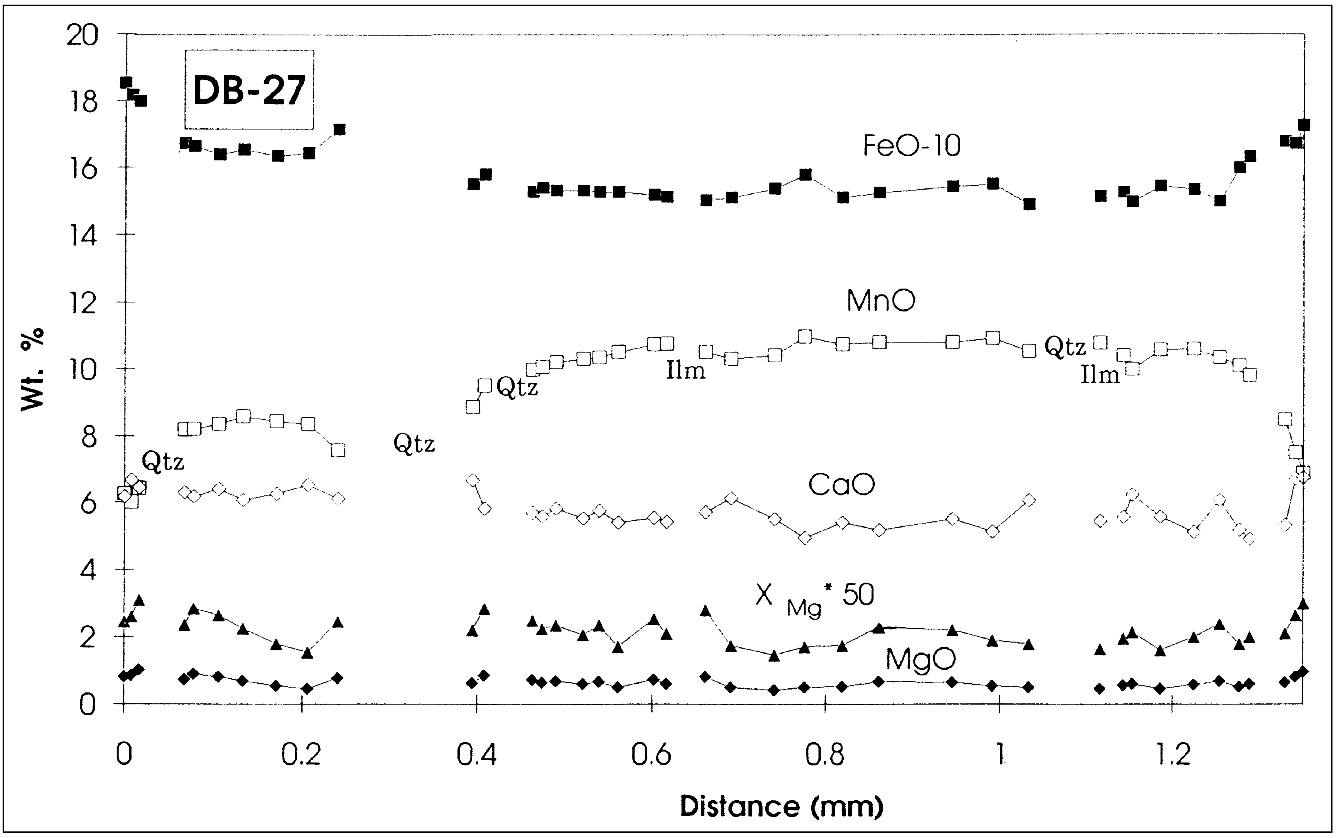
The compositions of the coexisting mineral phases in the sample DB-27 (Tab. 4) were determined on a SEMQ-ARL electron microprobe. Operating conditions were 15 kV accelerating voltage and 20 nA sample current on Cr-Ni-steel and data correction procedures were by online ZAF-program (ARMSTRONG, 1988).

Garnets (60 mol % alm, 20 mol % sps, 17 mol % grs, 3 mol % pyr) show a relatively flat element distribution: A cross profile (Text-Fig. 7) exhibits a slightly bell-shaped Mn profile with compensating bowl-shaped Fe profile. This zoning pattern is commonly observed in primarily low to medium grade regionally metamorphosed rocks. Biotite blasts, fine-grained biotites in the groundmass and even the biotites in contact with garnet have the same composition. They are annite-rich (x_{Mg} = 0.36) with 1.7 wt.-% TiO_2 and a vacancy in the octahedral site of about 0.15. The fine-grained chlorites have also a constant iron-rich (x_{Mg} = 0.39) composition. Phengitic muscovite (3.2 Si per formula unit) contains 9 mol % paragonite. Pure albites occur as blasts, fine-grained in the groundmass, and as inclusions in garnet. Calcites are impure with about 4 mol % ankerite, 2 mol % rhodochrosite, and 1.5 mol % magnesite. Ilmenites contain a pyrophanite component of about 10 mol %.

Table 4.
Representative microprobe analysis of the coexisting mineral phases of the sample DB-27.

	Garnet rim of blast	Biotite blast	Muscovite	Chlorite		Albite blast		Calcite
SiO_2	36.72	35.34	46.51	24.85		68.90		n.a.
TiO_2	0.10	1.61	0.21	0.08		-		n.a.
Al_2O_3	20.90	18.51	32.42	22.71		19.16		n.a.
FeO tot	26.38	22.46	2.07	30.65		0.07		2.68
MnO	8.35	0.13	0.05	0.27		-		1.11
MgO	0.82	7.20	0.63	10.87		-		0.77
CaO	6.40	-	-	-		-		51.47
Na_2O	-	0.09	0.63	-		11.89		n.a.
K_2O	-	8.89	10.05	-		-		n.a.
CO_2	n.a.	n.a.	n.a.	n.a.		n.a.		43.56
Total	99.67	94.23	92.57	89.43		100.02		99.59
Si	2.980	2.753	3.190	2.635	Si	3.008	Fe	0.038
Al IV	0.020	1.247	0.810	1.365	Al	0.986	Mn	0.016
Al VI	1.979	0.452	1.811	1.473	Fe	0.003	Mg	0.019
Ti	0.006	0.094	0.011	0.006	Mn	-	Ca	0.927
Fe tot	1.790	1.463	0.119	2.718	Mg	-	Total	1.000
Mn	0.574	0.009	0.003	0.024	Ca	-		
Mg	0.100	0.836	0.064	1.718	Na	1.006		
Ca	0.556	-	-	-	K	-		
Na	-	0.014	0.084	-	Total	5.000		
K	-	0.883	0.879	-				
Total	8.005	7.752	6.970	9.940			n.a. = not analyzed	

Structural formulae have been calculated on the basis of :
12 O for garnet; 11 O for biotite and muscovite; 14 O for chlorite; 8 O for albite;
3 O for calcite and CO2 - saturation.



Text-Fig. 7.
Cross profile through a garnet porphyroblast elongated in s.
Despite of the flat element distribution a slightly bell-shaped Mn profile with compensating bowl-shaped Fe profile is recognized.

The composition of the ferromagnesian mineral phases and the phase relations are shown in the AFM-diagramm (Text-Fig. 8; THOMPSON, 1957). The coexisting mineral phases garnet, biotite, and chlorite are connected with tie-lines. The triangle formed by the tie-lines points to the continuous reaction

$$Chl + Ms + Qtz = Grt + Bt + H_2O \qquad (1).$$

With increasing temperature the three-phase association becomes more Mg-rich, until chlorite disappears (THOMPSON, 1976). In the sample DB-27 chlorite still exists, but the whole rock composition is very close to the tie-line garnet-biotite. So the sample is close to the chlorite-out isograde. Albite blasts are also formed by muscovite decomposition. Albite is produced from the paragonite component by the reaction

$$Chl + pg + Qtz = Grt + Ab + H_2O \qquad (2).$$

Another possible reaction to form albite is

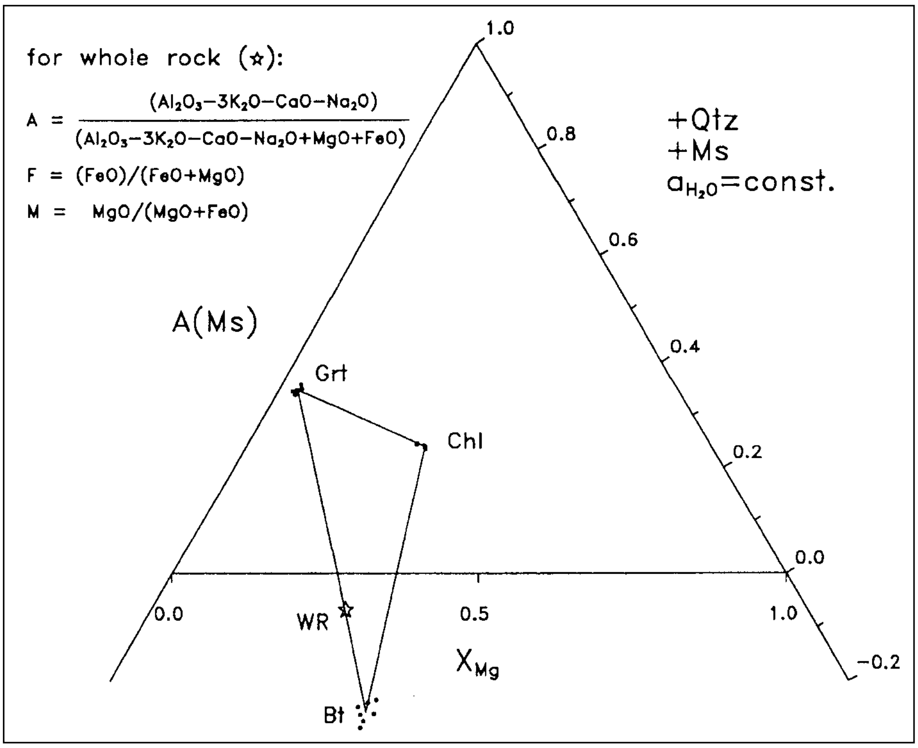
$$cal + pg + Qtz = grs + Ab + H_2O + CO_2 \qquad (3)$$

where calcite instead of chlorite is consumed. This reaction also produces the grossularite component of the garnets.

These reactions and the Fe-Mg cation exchange reaction between garnet and biotite

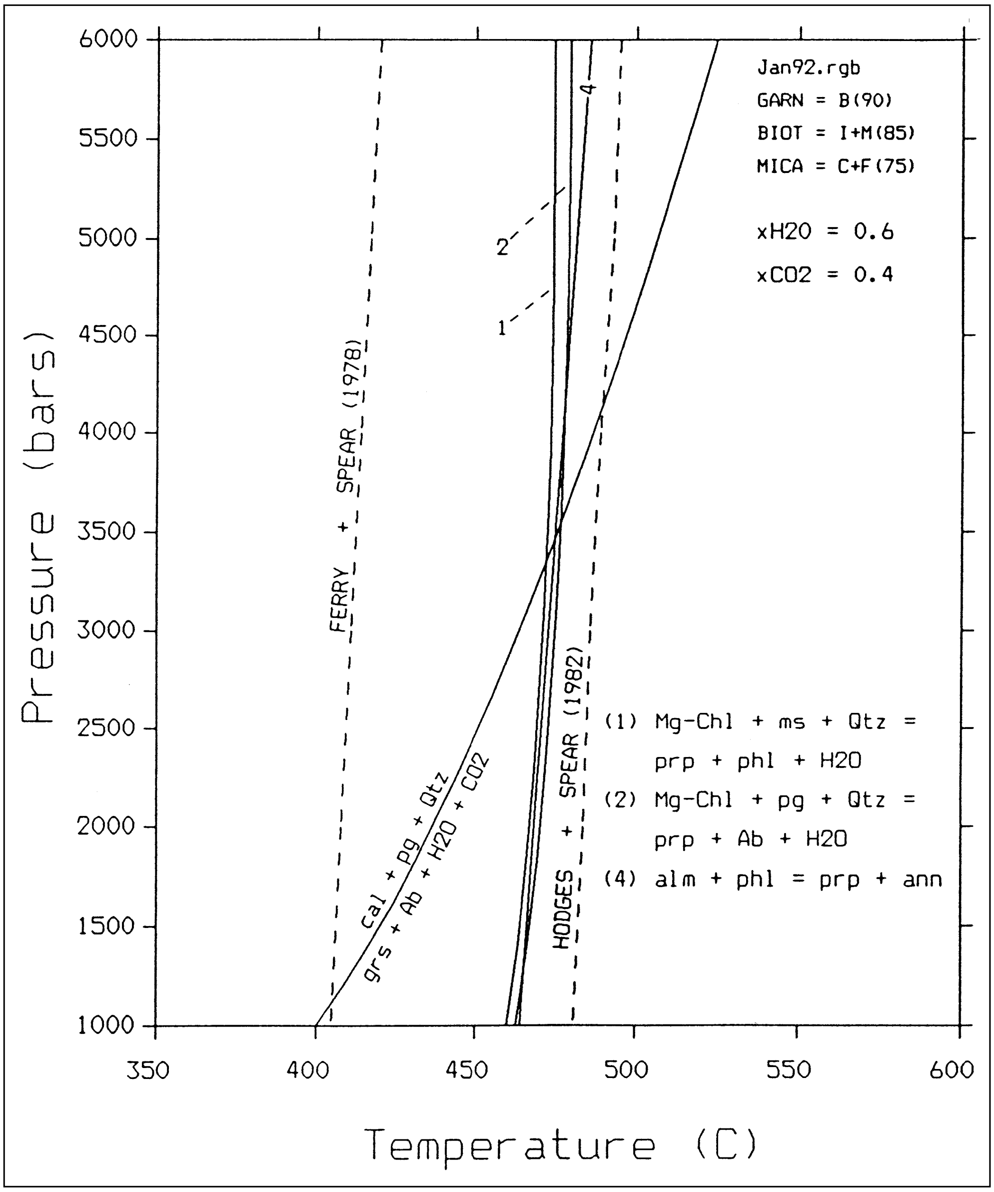
$$alm + phl = prp + ann \qquad (4)$$

were calculated with the internally consistent data-set of BERMAN (1988) (Text-Fig. 9). Following



Text-Fig. 8.
AFM-diagram of the ferromagnesian mineral phases of the sample DB-27 to show their composition and phase relations (discussed in the text).

Text-Fig. 9.
P–T diagram of the sample DB-27 (discussed in the text).
Symbols of minerals after KRETZ (1983).



mixing-models for the mixing properties were applied: garnet (BERMAN, 1990), biotite (INDARES & MARTIGNOLE, 1985), muscovite (CHATTERJEE & FROESE, 1975), chlorite (ideal), and calcite (ideal). For comparison two empirical calibrations of the garnet-biotite thermometer (FERRY & SPEAR, 1978; HODGES & SPEAR, 1982) were used to determine the temperature. At a pressure of 3.5 kbar the calculated temperatures are 410°C (F & S), 490°C (H & S), and 475°C (B). The low temperature obtained from the FERRY & SPEAR-calibration seems to be due to the grossularite component (17 mol %) of the garnet. The influence of the grossularite component is considered by HODGES & SPEAR. The temperature from this calibration is close to the temperature obtained with the data of BERMAN.

The water activity can be estimated from the dehydration reactions (1 + 2) which are responsible for the growth of the garnet and biotite blasts. In a P-X-diagram with fixed temperature (475°C from the garnet-biotite thermometer) the univariant curves of the dehydration reactions (1 + 2) intersect with the garnet-biotite exchange reaction at x_{H_2O} = 0.6 (Text-Fig. 10). The reactions (1)–(3) were calculated based on this mole fraction of water. The dehydration reactions (1 + 2) should give about the same temperature like the garnet-biotite exchange reaction. The pressure was estimated from the dehydration- and decarbonization-reaction (3). The intersection of reaction curve (3) with the garnet-biotite thermometers (from HODGES & SPEAR and BERMAN) is between 3 and 4 kbar (Text-Fig. 9). The metamorphic conditions for the sample DB-27 are 470–490°C, an estimated pressure of 3–4 kbar, and a mole fraction of water of about 0.6. A reduced water activity is expected, because the assemblage of the sample contains calcite (Tab. 3, No. 5).

From the plain of Debring we left the road and turned towards the SW to the Zara Valley. The Zara River first flows in southeastern direction and then turns towards the SW. From that region THAKUR & VIRDI (1979) reported a small outlier of an ophiolitic nappe, which FUCHS (1986, Pl. 1, 2) took over into his map. To investigate this klippe was one of the aims of our traverse. When we found numerous boulders of mafic rocks and light-coloured Upper Cretaceous foraminiferal limestones, we were optimistic to find the outlier. But we soon found out that these rocks are confined to the large areas covered by moraine material. As soon as one comes to outcrops or the normal float on the hill slopes the above rocks are wanting. By our survey we came to the result that the ophiolitic outlier does not exist. Its finders either accepted the glacial material S of Debring as in situ or mistook the metavolcanics NE of Jakang as a klippe. The metavolcanics, however, are definitely a marker horizon (Panjal Trap) in the succession of the region (see below).

The ridges on both sides of the Zara Valley in its NW–SE trend are composed either by Haimantas or the thick quartzites overlying them (pale-green and white, platy quartzites, schistose quartzites, dark-grey phyllites, and metaarkoses). Due to the fault, which we crossed at Debring camping site, there is also a juxtaposition of Haimantas and quartzites in the upper Zara Valley. The upper part of the valley seems to be composed of thick quartzite series overthrust from the S by the Nimaling Granites.

After the knee of the Zara River, where it flows towards the SW, the Haimantas are overlain by a SW dipping series rich in carbonates and then the quartzites follow (Text-

Text-Fig. 10.
P–X_{CO2} diagram of the sample DB-27 (discussed in the text).
Symbols of minerals after KRETZ (1983).

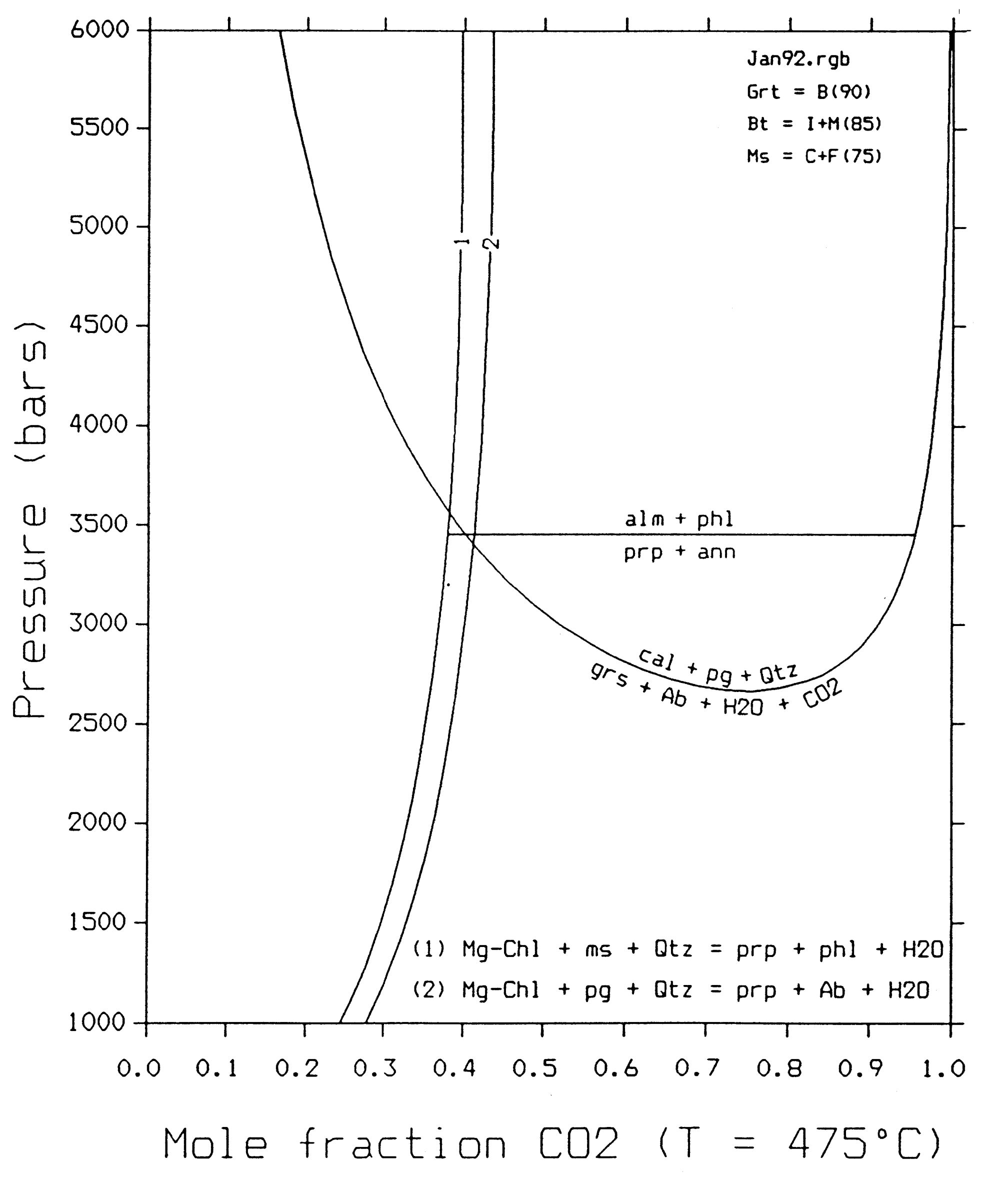


Fig. 11). The section studied on the orographic right side of the Zara Valley shows a passage from the typical Haimanta Formation to the carbonate-pelite series. In a zone, about 400 m thick, the dark grey, partly silty and laminated phyllites contain sporadic thin beds of limestone, but not the brown weathering dolomite lenses characteristic for the Karsha Formation. At the top the carbonate layers increase in a 30 m thick zone (Text-Fig. 12, [2]), which is succeeded by the carbonate series (about 150 m).

A 7 m thick mafic dike crops out in the upper part of the carbonate zone. The homogeneous rock is medium-grained and massive like the mafic dikes of the Debring area. At the contact to the carbonates the dike is very rich in magnetite. Under the microscope no magmatic relics are visible. The metamorphic assemblage is similar to the mafic dikes of Debring (Tab. 2, No. 3). Because of the contact to carbonates the assemblage contains additionally calcite and no clinozoisite. The chemical composition is also similar to the dikes of Debring (Tab. 1, Text-Fig. 6). Thus it is probable that this dike is one of the doleritic feeder dikes of the Panjal Trap.

A transition zone (about 60 m) leads to the quartzites overlying the carbonate sequence: Platy, light coloured carbonates showing ferruginous weathering surface alternate with quartzites or phyllite. Then follow even-bedded, rather pure, light quartzites.

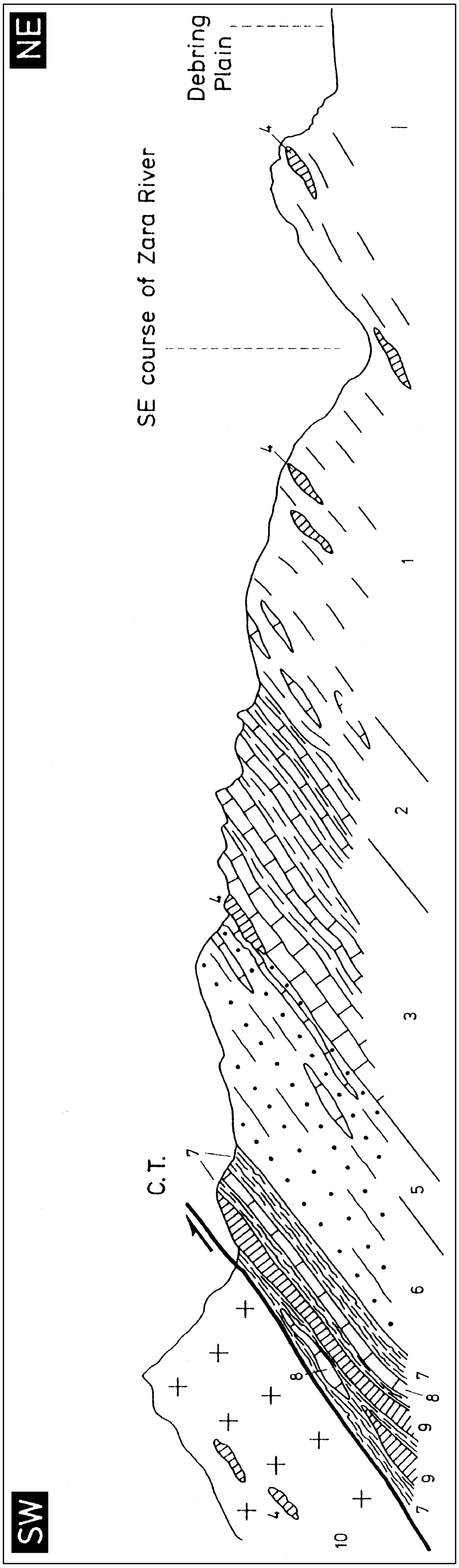
The carbonate zone crosses the Zara Valley towards the ESE as an ochre weathering band. Towards the W it is probably cut out by a fault, because after unexposed terrain Haimantas crop out in a spur (Pl. 1).

The quartzites are approximately 200–300 m thick. They are thin- to thick-bedded, light quartzites interbedded with silvery to green, occasionally dark grey quartz phyllites.

Above the quartzite zone follow about 100 m of dark phyllitic schists containing a 20 m band of brown weathering crystalline carbonates. These rocks are overlain by chlorite-epidote schists, which can be traced through both sides of the Zara Valley as a conspicuous green band. In the orographic right side there comes first a 30 m band of metabasics, then about 50 m of dark, silty phyllitic schists, a lenticular body about 120 m thick of chlorite-amphibole schist, 100–200 m of dark phyllites containing lenses of carbonate, 30–40 m of metabasics (exposed higher up on the slope) and 100–200 m of dark schists. With tectonic contact the above sequence is overridden from the SW by the Nimaling Granites.

Close to the counterthrust there may be tectonic complications, but it is evident that the metabasics are stratigraphically connected with the associated metasedimentaries. The metabasics are schistose, frequently they exhibit epidote-rich schlieren and nodular structures in sizes of several dm. Amygdaloidal cavities occur in compact epidote schists. They seem to be volcanic relic structures like the ophitic textures observable with naked eye.

The mineral assemblages (Tab. 2, No. 4, 5) are the same as in the metamorphosed mafic dikes (Tab. 2, No. 2, 3) reflecting upper greenschist facies conditions. But these schists are dominated by epidote and chlorite instead of hornblende. They also contain biotite, but a very small amount. Ophitic textures are still preserved, but the magmatic minerals are replaced by fine-grained aggregates of chlorite, epidote, and hornblende respectively of quartz and plagioclase. Pseudomorphs after magmatic horn-



Text-Fig. 11.
The ridge W of the Zara Valley gives a section through the Palaeozoic sequence (length of the section approximately 10 km).
1 = Haimanta (Phe) Formation; 2 = Haimanta (Phe) Formation with thin carbonate intercalations; 3 = Metacarbonates and phyllites; 4 = Mafic dikes; 5 = Carbonates alternating with quartzite and schist; 6 = White to greenish quartzites; 7 = Dark phyllites and 8 = Metacarbonates; 9 = Basic volcanics ("Panjal Trap"); 10 = Sheared granite; CT = counterthrust.

blende still show the idiomorphic grain boundaries. Magnetite is a frequent accessory mineral phase.

Major and trace element analyses of the chlorite-epidote schists (Tab. 1) suggest a tholeiitic-subalkaline basaltic composition and compare well with known Panjal Trap volcanics (e.g. Text-Fig. 6).

A comparison of these chlorite-epidote schists with the mafic dikes cutting through the Precambrian and older Palaeozoic formations in the Debring area suggests that the dikes are more fractionated (Tab. 1, Text-Fig. 6).

A similar stratigraphic succession is exposed in the SE-side of the Zara Valley. In the area of the Zara knee the green-grey phyllitic and psammitic schists of the Haimanta Formation are penetrated by mafic dikes. A conspicuous ochre weathering band of marble is found in the first tributary from the SE. The band consists of 7 m platy, white to cream marble and calc micaschist. On the top the carbonates alternate with psammitic schists in dm to m dimension. This carbonate layer is followed by monotonous phyllitic schists. These beds are overlain by the carbonate zone and then by the quartzites. Phyllitic schists with rare carbonate layers occur between the quartzites and the metabasic band. At the base of this band basic schists with fine nodular structure alternate with black phyllites. The metabasic schists are rather homogeneous and show a thickness of about 250 m. The lithological character of the rocks is similar to the metabasics NW of the Zara River.

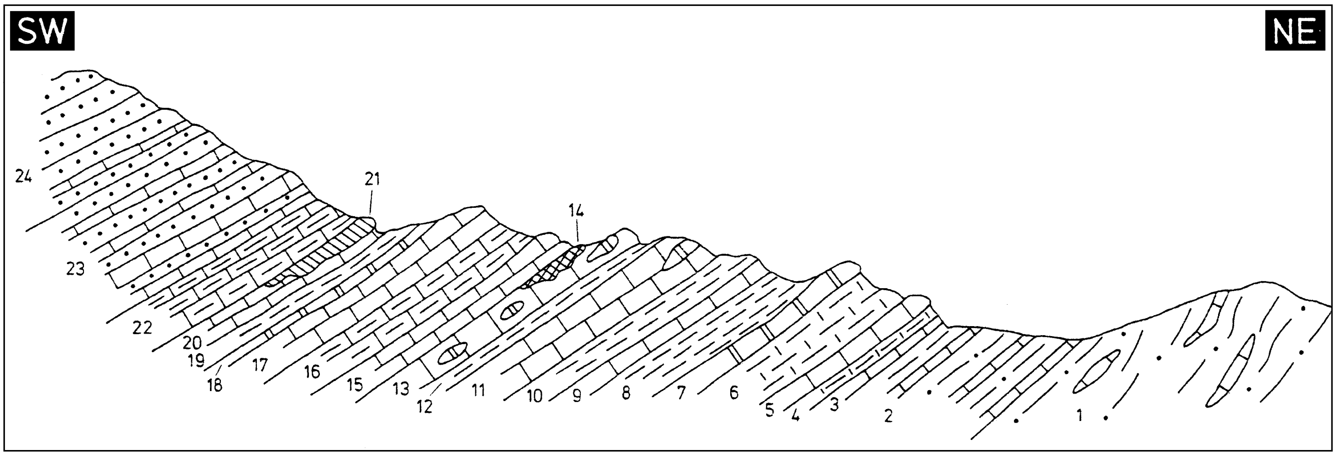
Along the counterthrust the metabasics are overriden by the Nimaling Granite.

In the Zara Valley the biotite zone of the metamorphic zonation can be traced to the SE until the counterthrust. Blasts of biotite occur in the metasediments of the Haimanta Formation (Tab. 3, No. 6). In the succeeding series biotite is found in the mineral assemblage (Tab. 3, No. 7), but not as blasts. Plagioclase blasts show a wider extension towards the SW, however, their size decreases and they become sporadic. In anticipation it may be noted, that the metasediments of the Haimanta and Karsha Formations SW of the counterthrust contain chlorite and no biotite. Thus they clearly belong to the chlorite zone.

As we approach the counterthrust from the NE the crenulation cleavage (S_2) increases until finally penetrative S_2-planes are developed. Also folds in dm-dimensions evolve. It can be observed that along the young s-planes biotite is partially hydrated to chlorite and fine sericite aggregates are developed. Kink bands, younger than the crenulation, occur independent of the distance from the counterthrust.

Regarding the relation of the crystallization to deformation we can summarize: Plagioclase blastesis commences during the formation of the first penetrative foliation (S_1). It continues together with blastesis of biotite and garnet after this deformation. This static crystallization phase is followed by another deformation phase (D2), which is connected with the counterthrust.

A younger penetrative cleavage (S_2) develops only in proximity to the counterthrust. It is accompanied by weak recrystallization only. With increasing distance from the counterthrust towards the NE this deformation – as a crenulation – rapidly fades away. The even younger kink bands are probably the result of lateral NW–SE directed compression.



Text-Fig. 12.
Details of the section shown in Fig. 11 (length of this section approximately 1.5 km).
1 = Dark grey, silty slates with sporadic limestone intercalations (Haimantas); 2 = Dark grey, phyllitic slates with laminae of carbonate (about 30 m); 3 = White, platy marble (3 m); 4 = Calcareous schists (2 m); 5 = Light, platy limestone (5 m); 6 = Calcareous schists (12 m); 7 = Dolomitic limestone (5 m); 8 = Phyllitic schists (12 m); 9 = Light, banded marble (6 m); 10 = Grey phyllites exhibiting fine layering (9 m); 11 = Schistose limestone with a 3 m lens of dolomite (14 m); 12 = Phyllitic schist (1.5 m); 13 = Grey-white, banded limestone containing lenses of dolomite (8 m); 14 = Quartz dike (3 m);15 = Schistose limestone (10 m); 16 = Grey-green calc-micaschists (13 m); 17 = Light grey, thin-bedded limestones with doubtful crinoids (about 15 m); 18 = Grey dolomite (1.5 m); 19 = Grey-green phyllites (2 m) and white and cream schistose limestones (2 m); 20 = Light grey, schistose limestone (about 4 m); 21 = Dike of mafic volcanic rock (described in the text); 22 = Greenish calc-micaschists (about 15 m); 23 = Platy, light carbonates (rusty weathering) interbedded with quartzite and phyllite (60 m); 24 = Passage upwards into light, platy quartzite (60 m).

Discussion

The area crossed between the I.S.Z. and the counterthrust, which duplicates the Nimaling Dome, documents the primary connection of the Lamayuru Zone with the sedimentary zone of Zanskar. The Mesozoic Lamayuru Formation is stratigraphically underlain by the Palaeozoic series of the northern flank of the Nimaling Dome, which is exposed in an anticline bringing up the northern marginal parts of the Zanskar Shelf, like the Gurla Mandata Dome in the Tibetan Zone of SW Tibet (HEIM & GANSSER, 1939). The Lausanne team originally discerned a series of individual “nappes” overthrusting the Nimaling Dome: the “Langtang-”, “Khurnak Nappes ”(STUTZ & STECK, 1986). In a recent paper (STECK et al., 1993), however, the Lamayuru, Nimaling and Zanskar Carbonate Zones are regarded as one large tectonic unit, the “Nimaling-Tsarap Nappe“.

As shown by the Shagrot Anticline the Lamayuru Zone is resting in its southern parts on Palaeozoic formations, in a development characteristic of the Tibetan Zone of Zanskar. Thus Lamayuru is a basin and continental rise facies deposited in the Mesozoic at the northern edge of the Indian Continent.

The Palaeozoic formations are exposed in the anticlines of Shagrot and S of Debring. Whereas in the first anticline the core is formed by the Cambrian Karsha Formation, the latter shows only the Phe (Haimanta) Formation in its oldest parts, the Karsha Formation being missing. This suggests that the Karsha (Parahio) facies with its algal reefs was developed not universally. Apparently it was substituted by Phe facies in deeper water. The sporadic carbonate bands observed in the higher Haimantas may correlate to the algal reefs of the shallow-water Karsha Formation. Thus the mainly Precambrian Phe Formation locally seems to replace in its younger portions the Cambrian Karsha Formation. As shown by BAUD et al. (1984) and GAETANI et al. (1986) the Phe Formation is succeeded by the shallow water reefs of the Karsha Formation and then by the Kurgiakh Formation, which is a typical flyschoid basin facies. Therefore, in case that the Karsha reef facies is not developed, the very similar Phe and Kurgiakh Formations are practically inseparable.

The lithology of these oldest formations is very characteristic. Also the youngest Palaeozoics exhibit a very typical lithology: The light carbonates of Taglang La with associated quartzites and the dark pelites and carbonates correlate with the resembling Kuling Formation of Nimaling, the Permian age of which is documented by fossils (STUTZ, 1988). Further VIRDI et al. (1978) reported Permian fossils also from the Taglang La area.

Other very characteristic rocks are the basic metavolcanics of Tsakenama and immediately N of the counterthrust. With great probability they correlate with the Panjal Traps of southern Zanskar. These volcanics extruded in the Permian (BAUD et al., 1984; GAETANI et al., 1986; a.o.). Thus the Permian age of the Taglang La carbonates and the metavolcanics seems well-established.

The age of the carbonates, pelites, and quartzites occurring between the Karsha respectively Phe Formations and the Permian series seems more doubtful. It is bracketed between Cambrian and Permian. STUTZ (1988) regarded the carbonates as Lower Carboniferous, whereas FUCHS (1986) considered a wider stratigraphic range as possible. From our recent observation of the interfingering quartzite and carbonate facies we favour the view that the major portion is Devonian. This is particularly suggested from the experience from Nepal (FUCHS, 1967, 1977a). There is also the possibility that the oldest carbonates of the series dealt here correspond with the Ordovician–Silurian carbonates of Spiti (HAYDEN, 1904; FUCHS, 1982b; GARZANTI et al., 1993). With great certainty the youngest carbonates underlying the Permian correlate to the Lower Carboniferous Lipak Formation.

According to THAKUR (1983) the metamorphism increases in the Tso Morari Dome towards the SE. In the area crossed we discerned in the metapelites three mineral zones: The chlorite, biotite, and garnet zone. For the garnet zone we determined conditions of T = 470–490°C and p = 3–4 kbar. The zoning of the garnet blasts indicates a first and prograde metamorphic event, which implies a very probable Alpine age of the metamorphism.

The development of the first penetrative schistosity S_1 seems to be caused by the collision of the northern edge of the Indian Continent with Asia. The blastesis of plagioclase respectively of biotite and garnet are late- respectively post-tectonic. This static phase of metamorphism is succeeded by the formation of the Nimaling Dome, finally leading to the counterthrust. Close to this disturbance the S_2 schistosity comes into being, which passes away as a weak crenulation. Kink bands developed in phyllitic schists point to the activity of a late, lateral compression in NW–SE direction. Thus we found crystallization-deformation relations, which are in good agreement with the observations of THAKUR (1983) in the Tso Morari Crystalline and of STUTZ (1988) in the Nimaling region.

5. The Nimaling Dome

From the preceding chapter it is apparent that no sharp boundary is existing between the Nimaling (Tso Morari) Dome and the Lamayuru Zone in the N. In the same way the Nimaling Dome can not be separated from the Zanskar Tethyan Zone in the S. This is explained by the fact that the Nimaling Dome is an anticline exposing the edge of the Zanskar Shelf, where during the Mesozoic passive margin stage the shelf carbonates passed into the continental slope and basin facies. The calcareous flysch of the Lamayuru Zone is Triassic–Jurassic–Cretaceous. In the southern flank of the Nimaling Dome the euxinic Lamayuru facies comprises the Triassic up to the Kioto Limestone (FUCHS, 1986; STUTZ, 1988) and further S it seems to be confined to the Noric only (see below).

Before further discussion we will continue to describe our traverse: Above the counterthrust dipping SW at medium angles there follows a thick body of granite. These coarse-grained granites were described by STUTZ (1988), the age of 460 $\pm$ 8 ma was determined by STUTZ & THÖNI (1987). In the lower parts near the counterthrust the granite is foliated, it becomes more massive towards the top. Though the upper boundary is intrusive, it is prevailingly concordant to the overlying Phe Formation. N of Jakang monastery, however, the granite seems to cut discordantly the SW dipping Phe rocks. The Phe Formation is relatively reduced (about 300–2000 m) and is succeeded by approximately 500 m of Karsha Formation. The rusty weathering dolomite lenses are a conspicuous feature of the landscape N of Sangtha. The dip of the beds steepens within the Karsha Formation. The assemblages of the metapelites in the Phe and Karsha Formation contain no biotite (e.g. Tab. 3, No. 8) and therefore belong to the chlorite zone of the metamorphic zonation.

Like in the northern block of the Nimaling Dome basic dikes, up to 30 m thick, penetrate the granite, the Phe, and Karsha Formations. The dike E of the Zara River, where the local people have built chorten (shrines), mani stones and have fixed prayer flags, is a predominant feature in the scenery. The dark, blocky weathering dolerite shows fine-grained chilled margins and coarse-grained inner portions. There are rare enclosures of phyllitic pelites of the surrounding country rocks in the dolerite.

The central, coarse-grained parts of the dikes are free of foliation. The magmatic texture and the magmatic minerals are prevailingly well-preserved. Coarse-grained brownish amphibole and plagioclase exhibit interstitial, doleritic texture. Further constituents are medium-grained magmatic ilmenite showing lamellae, and accessoric apatite. Autometasomatic alteration has partly replaced the magmatic hornblende into a fine-fibrous aggregate of amphibole and filled the plagioclase with microliths of clinozoisite, albite, and quartz. Around ilmenite we find rims of biotite. Slight metamorphic overprinting is shown by chloritization of fine amphibole, which occurs only along the grain-boundaries of the pseudomorphs. This alteration, however, is faint compared with the mafic dikes NE of the counterthrust. Geochemically the dike resembles the other basic dikes of the Nimaling region (Tab. 1, Text-Fig. 6) and thus could be considered as feeder dike of the Panjal volcanism. It should be noted that we observed the basic dikes only in Precambrian and Palaeozoic formations.

The top of the Karsha Formation is vertical to slightly overturned dipping steeply NE. It is stratigraphically followed by about 7 m of ferruginous weathering, grey, banded, platy limestone. The s-planes are coated with silky phyllite. The limestone band is the very much reduced continuation of the carbonates traced from Nimaling through the SW flank of the Nimaling Dome to Yar La (FUCHS, 1986; STUTZ & STECK, 1986; STUTZ, 1988; STECK et al., 1993). It appears to represent the Lower Carboniferous Lipak Formation.

In the orographic left side of the Zara Valley the limestones are followed by about 50 m of laminated phyllitic rocks and metasandstones. They pass into about 200 m of dark silty and phyllitic schists alternating with impure metasandstones and tilloid conglomerates. The latter exhibit elongated rock fragments of argillite, quartz and black sandstone up to dm-sizes in a groundmass of metasandstone.

Under the microscope the minerals chlorite, muscovite, plagioclase, quartz and magnetite are recognized. This is another indication that the sedimentaries SW of the counterthrust and N of Sangtha belong to the chlorite zone of the Nimaling-Tso Morari Dome. The dark pelitic components and the outer rims of quartz pebbles are enriched in magnetite. This seems to be caused by metasomatosis. Two schistosities are discerned, the younger one being penetrative. The intensity of the latter depends on the proximity to the counterthrust, which shows its genetic connection .

The unsorted, matrix-supported conglomerates resemble the lithology of the Agglomeratic Slates of Kashmir, the Po Formation of Spiti and diamictites of the Damudas of the Lesser Himalaya. A Permo–Upper Carboniferous age is rather probable also for the tilloids in the Zara Valley NE of Sangtha.

In the Sangtha-Lun region the soft schistose Permo–Triassic series are partly removed by erosion and fluviolacustrine sediments accumulated in 100–200 m thicknesses. The young deposits are partly responsible for the geomorphologically soft and wide scenery and terraces in the surroundings of Sangtha. But along deeply eroded streams they show picturesque vertical rock faces, towers, needles, and numerous caves. The deposition of the young sediments is caused by the damming up of the Zara River, when the river had to cut its way across the range composed of resistant Triassic–Jurassic carbonates S of Lun.

Due to the extent of Quaternary sediments the older formations are not well-exposed around Sangtha. We have studied a section across a hill NW of Sangtha. The hill consists of steeply SW dipping dark-grey, silty slates and schistose siltstones with black concretions. In decametric zones these rocks are interbedded with ferruginous weathering, grey to blue limestones. Some of the carbonates yielded fenestellid and other bryozoa, spiriferid brachiopods, and one evolute ammonite. These fossils are undeterminable, but indicate Permian age. Other limestone beds yielded *Kymatites* and *Prionolobus* – both documenting Dienerian (Scythian) age (Univ.-Doz. Dr. L. KRYSTYN kindly determined these ammonites). A band of rusty weathering, grey and blue, platy limestone is rich in ammonites (*Meekoceras* sp., det. L. KRYSTYN) and yielded conodonts. Prof. Dr. H.P. SCHÖNLAUB kindly determined *Neospathodus pakistanensis* SWEET, which indicates Upper Scythian age.

In the area of Sangtha the Upper Permian and Triassic series are lithologically not much different. They mainly consist of dark silty slates to schistose siltstones with subordinate carbonate layers. The latter increase in the Triassic series (e.g. at Sangtha Village), they are scarce in the monotonous Permian siltstones (e.g. S of Sangtha). The Scythian is marked by rusty weathering, platy limestones a few meters thick only.

In the steeply dipping to vertical series around Sangtha the Permian and Triassic rocks are frequently mixed up, which indicates intensive folding and shearing. From the axial plunge of the Khurnak Syncline in the area S of the Yar La it may be inferred that the Permian–Triassic boundary originally was rather flat or gently dipping towards the SW. Obviously it was late compression related with the upheaval of the Nimaling Dome, which has complicated the originally flat stratigraphic boundary by steep folding and shearing.

From our observations the Permian rocks resting on an overturned synform of Triassics reported by STECK et al. (1993, Text-Fig. 11, 15, 18; Pl. 1) seems very unlikely. It probable goes back to the bad outcrops of the region and the tectonic mixing up of Permian and Triassic strata. In our view the syncline of Triassics of Sangtha is followed by an anticline of Permian rocks to the S. All the series are steeply folded and there is no indication of allochthonous Permian rocks in a horizontal position.

Discussion

The Tso Morari Crystalline plunges towards the NW in the Nimaling area, where the anticline was termed the Nimaling Dome by BAUD et al. (1982). These authors envisaged a pile of nappes: the Nimaling Dome overridden by the "Langtang Nappes" and these overthrust by the "Zanskar Nappes". Contrary FUCHS (1986) accepted the above succession as stratigraphic. In this primary sequence it can be shown that the Mesozoic continental rise facies (Lamayuru – Markha) gradationally is replaced towards the SW by the carbonates of the Zanskar Shelf. STUTZ (1988, p. 58 bottom; Text-Fig. 15, p. 72) follows this facies scheme, but keeps to the concept of the existence of "Langtang Nappes". In recent papers the Lausanne team drops the "Langtang Nappes" and proposes the "Nimaling-Tsarap Nappe" (STECK et al., 1993). This is a more or less coherent stratigraphic unit comprising the Lamayuru Zone, Nimaling Dome and Zanskar Carbonate Zone south until S of Sarchu, however the unit is disturbed by numerous imbricate faults. Thus there is agreement now about the stratigraphic coherence of the formations mantling the Nimaling crystalline core.

The updoming of the Nimaling Dome is a late tectonic event. It seems related to the Miocene compression, which ended the Indus Molasse stage by folding and NE directed counterthrusts. Along a counterthrust the granite core and the SW flank of the Nimaling Dome override the folded Palaeozoics of the NE limb.

The "Permian normal fault" proposed by STECK et al. (1993, Pl. 1) in the Nimaling area, in our view, is the continuation of the above counterthrust. Further we doubt that a Permian fault can be identified in this much deformed zone. We do not agree with BAUD et al. (1982), STUTZ & STECK (1986) and STUTZ (1988) who accepted nappe boundaries in that area, but we emphasize that it is the disturbed frontal edge of the Indian Continent which is exposed in the Nimaling Dome. In such a position it is doubtful that a pre-Alpine vertical fault should be still recognizeable. The fact that some pre-Permian formations are missing can be easily explained either as squeezing along the counterthrust or as pre-Permian stratigraphic gap. The latter is documented in many places of the Tibetan Zone.

6. The Zanskar Synclinorium

A boundary between the Nimaling Dome and the Zanskar Synclinorium must be arbitrary. The SW limb of the first is the NE flank of the latter. There is one stratigraphic sequence from the Precambrian series of the Nimaling Dome to the Jurassic–Cretaceous formations of the Zanskar Synclinorium. Tectonically, however, the Khurnak Syncline NW of Sangtha definitely is an element of the Synclinorium and therefore it seems logical to start with this chapter in the area S of Sangtha in the axial continuation of the Khurnak Syncline. Due to this syncline the Permo–Triassic series show such large extent in the Sangtha area (see Pl. 1). They plunge towards the NW under the Kioto Limestone S of Yar La.

Between Sangtha and Lun the steeply folded Permo–Triassic series override Triassic black pelites and limestones along a NE dipping imbricate fault. NE dipping Permian beds are found in juxtaposition to vertical to SW dipping Triassic rocks (see Pl. 1).

The dark, anaerobic, pelite-rich Triassic series of the area Lun-Toze Lungpa/Zara junction contain a thick intercalation of resistant, well-bedded, blue carbonates. They show nodular s-planes and yielded undeterminable corals. This band was not recognized in the Triassics to the N or in the Khurnak Syncline. Thus we think that it indicates the increased interfingering with shallow water carbonates towards the SW. Probably the carbonate band correlates to the "Tropites Limestone" of the area S of the Marang La, which there underlies the Juvavites-Monotis Shales (Noric). Therefore we regard the black silty shales with thin layers of dark sandstones and carbonates between the mentioned carbonate band and the Kioto Limestone as mainly Noric.

In the region around the Toze Lungpa/Zara junction NE-vergent folds are prominent. Further S from the knee of the Zara towards the SW in direction to the Marang La and the Tsarap Valley all the folds are vergent towards the SW. Most of the country is composed of Kioto Limestone. It is noteworthy that the Quartzite Beds at the base of the Kioto Limestone are missing. Carbonate bands a few meters thick in the pelites below the Kioto Limestone apparently mark a vertical transition from the black Noric argillites directly into the Kioto Limestone. In the Khurnak Syncline also the Quartzite Beds are wanting (FUCHS, 1986). We explain this with the outer shelf position of this region. The sands seem to be confined to the central and southern portions of the Zanskar Synclinorium closer to the terrestric source areas of the Indian Continent.

On the ascent to Marang La one has to cross soft black pelites isoclinally intercalated in the NE-dipping Kioto Limestones. The dark series (300–400 m) consists of silty slates with thin layers of blue, nodular limestone and fine-grained sandstone. These rocks are in stratigraphic contact with the Kioto Limestone. From the lithology the shales may be easily mistaken for Spiti Shales. But it is evident that they come from beneath the Kioto Limestone and represent anticlines of the Noric black pelites, which we crossed in the area of the Toze Lungpa (see above).

Between the black pelites and the Kioto Limestone, in inverted position, a few meters of thin-bedded, nodular, dark crinoid limestones are found associated with red coral limestones. It is a frame-structured rock, the coral colonies are still in situ. The thickness of this reef body is about 15 m near the trail and increases to about 40 m in the E-side of the valley. Further upslope the reef body pinches out and the black shales are in direct contact with the Kioto Limestone (Text-Fig. 13).

The stratigraphic sequence euxinic pelites – aerobic coral reef – Kioto Limestone seems to reflect the regression, which is marked by the Quarzite Beds in the inner shelf. The red coral reef facies in the Rhaetic we do not know from any other place in the Himalayas.

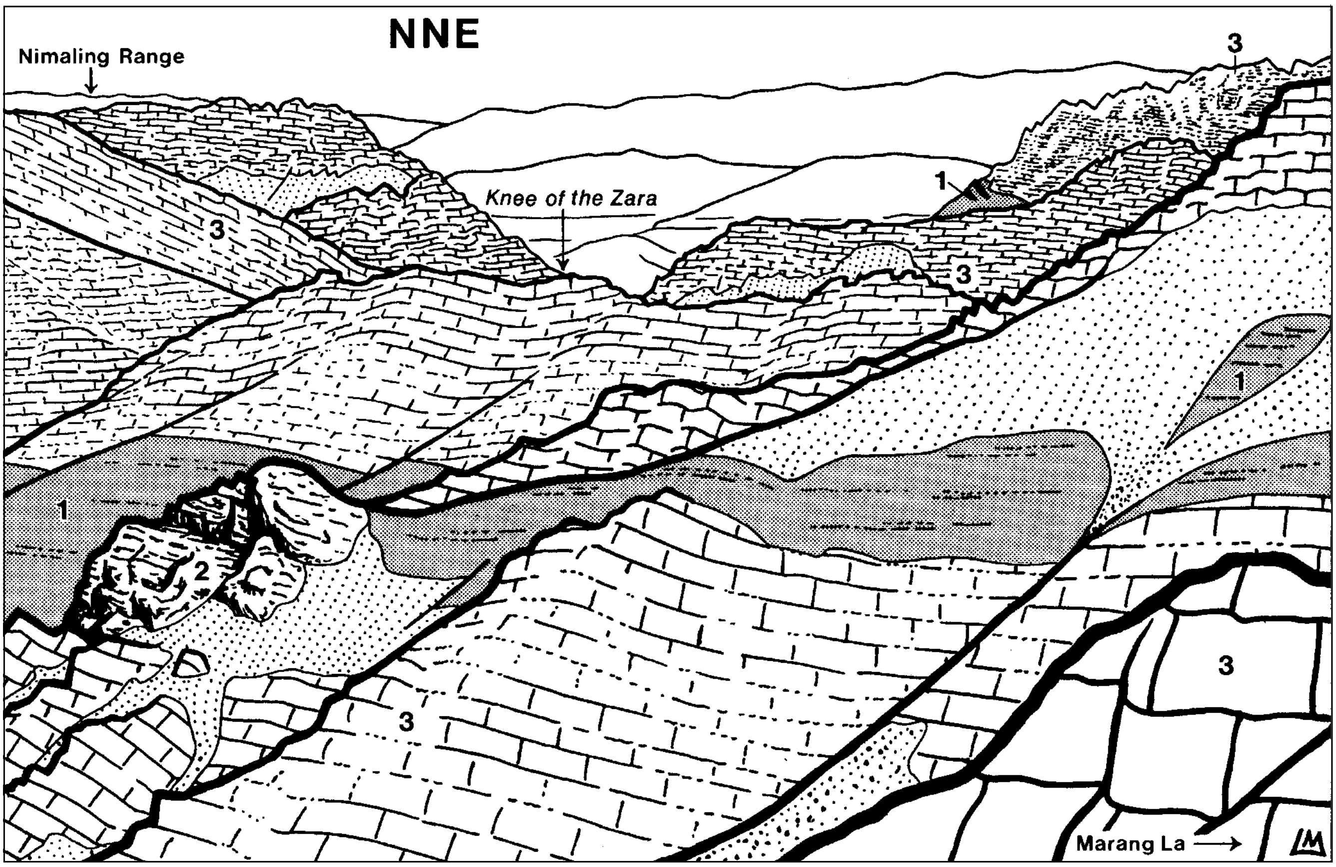
At the last steep ascent to the pass the Kioto Limestone is underlain by much folded dark, platy carbonates and pelites. They again represent the Noric euxinic series, forming the core of an anticline. STECK et al. (1993) mistook these rocks as Spiti Shales in a synclinal position. Immediately S of the Marang La this anticline is truncated by a thrust which brings the dark Noric series respectively the klippes of the Kioto Limestone in contact with underlying Spiti Shales and Ferruginous Oolite (see Pl. 1). These formations are part of the normal stratigraphic succession: Tropites Limestone (HAYDEN, 1904; cf. Zosar Formation [SRIKANTIA et al., 1980]) – Juvavites-Monotis Shales – Quartzite Beds – Kioto Limestone - Ferruginous Oolite – Spiti Shales. This sequence shows the development like in Spiti.

The Tropites Limestone – here devoid of fossils – consists of blue and grey, thick-bedded carbonates. Lithologically it is not dissimilar to the Kioto Limestone, except the missing of *Megalodon* and *Lithiotis* shell beds. Actually the Tropites Limestone was mistaken as Kioto Limestone (STECK et al., 1993, Text-Fig. 18, Pl. 1; SPRING, 1993, map).

But there can be no doubt that the Tropites Limestone is stratigraphically overlain by the grey-green silty shales, siltstones, sandstones, and subordinate blue limestones of the Juvavites-Monotis Shales. They yielded a loose sample with numerous *Spiriferina abichi* OPPEL 1865 (= "*Sp. griesbachi*" BITTNER, 1899) kindly determined by Dr. M. SIBLIK (Geol. Surv. Prague, Czech Rep.). Near the upper contact to the Quartzite Beds we found lumachelles of *Monotis* cf. *salinaria* (kindly identified by Doz. Dr. L. KRYSTYN, Palaeont. Institute, Univ. Vienna). These fossils fit well with the Noric age of the shales.

The Quartzite Beds (30–40 m) exhibit the characteristic white, grey, green and brown quartzites, carbonate quartzites and blue and grey carbonates passing upwards into the Kioto Limestone. This 500–600 m thick formation contains the typical coarse shell beds with *Megalodon* respectively *Lithiotis*. The Ferruginous Oolite (about 100 m) is composed of the ochre to orange weathering sandstones, oolites, limestones, and shales yielding fragments of belemnites.

The succeeding Spiti Shales are tectonically reduced and difficult to separate from the overthrust Noric



Text-Fig. 13.
View from the Marang La towards the NNE, towards the knee of the Zara River.
1 = Dark pelites, sandstones, and carbonates (Lamayuru facies, Noric); 2 = Red coral reef (Rhaetic); 3 = Kioto Limestone (Rhaetic to Dogger). The dark series in the middle ground form the core of isoclinal, SW directed anticlines.

euxinic series, where in direct contact. In some places large blocks of Kioto Limestone mark the thrust plane. They are remnants of an inverted fold limb of the overriding unit.

The Marang La Thrust brings two blocks in juxtaposition exhibiting different facies. The higher unit is characterized by the Noric anaerobic dark pelites and carbonates (Lamayuru facies), missing Quartzite Beds and thus a direct transition into the Kioto Limestone. The lower unit shows the southern Tethyan facies like in Spiti and southern Zanskar. The abrupt facies change indicates that along the thrust rock units have come in contact, which originally were separated for several kilometers. The thrust is comparable to the important lineament separating the Northern Zanskar Unit from the Tibetan Zone s. str. in western Zanskar (FUCHS, 1982a).

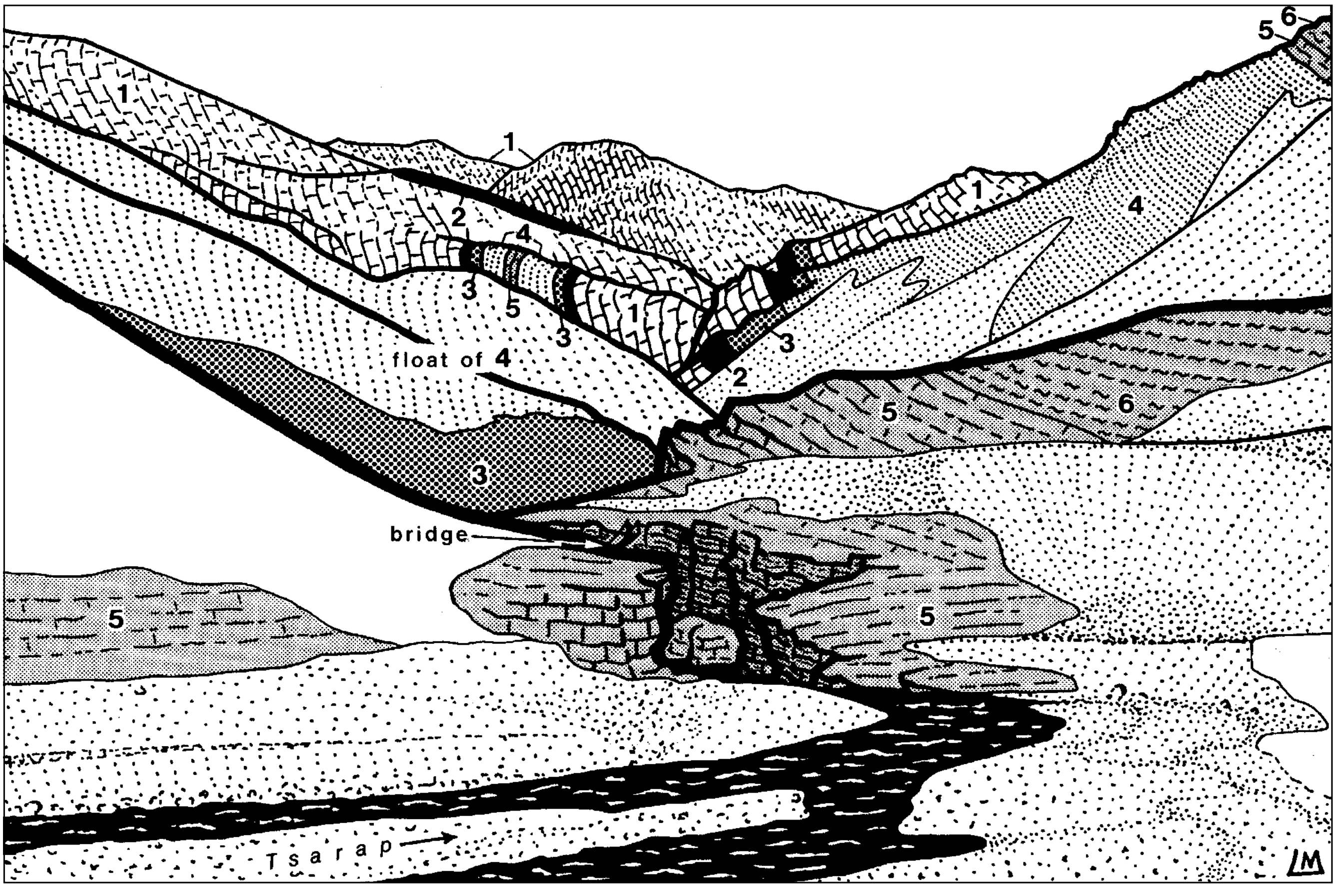
The Marang La Thrust probably continues to the bands of Shillakong (Fotu La) Formation, which were identified from afar high up in the valley NNE of the mountain lake Tsho Tok Phu (FUCHS, 1987, Pl. 1). Further towards the NW the lineament may connect with one of the zones of Shillakong Formation reported by KELEMEN & SONNENFELD (1983) from the Zanskar gorge. Thus the Marang La Thrust seems to die out in the fan like deformed Honupattan Anticlinorium. Towards the SE we think that our Marang La Thrust continues in the second thrust of the upper Tsarap Chu E of Sarchu shown on SPRING's map (1993).

The thrust described above is not identical with the thrust at the base of the "Marang La Unit". SPRING & CRESPO-BLANC (1992) and SPRING (1993) place this dislocation between the Juvavites Shales and the base of the Kioto Limestone, which we accept as undisturbed stratigraphic sequence. As SPRING and STECK et al. (1993) take the carbonates underlying the Juvavites Shales as Kioto Limestone, they assume additional thrust planes. This may be one of the reasons why SPRING (1993) and STECK et al. (1993) show a much larger number of imbricate thrusts in their "Nimaling-Tsarap Nappe" than we do in the same area.

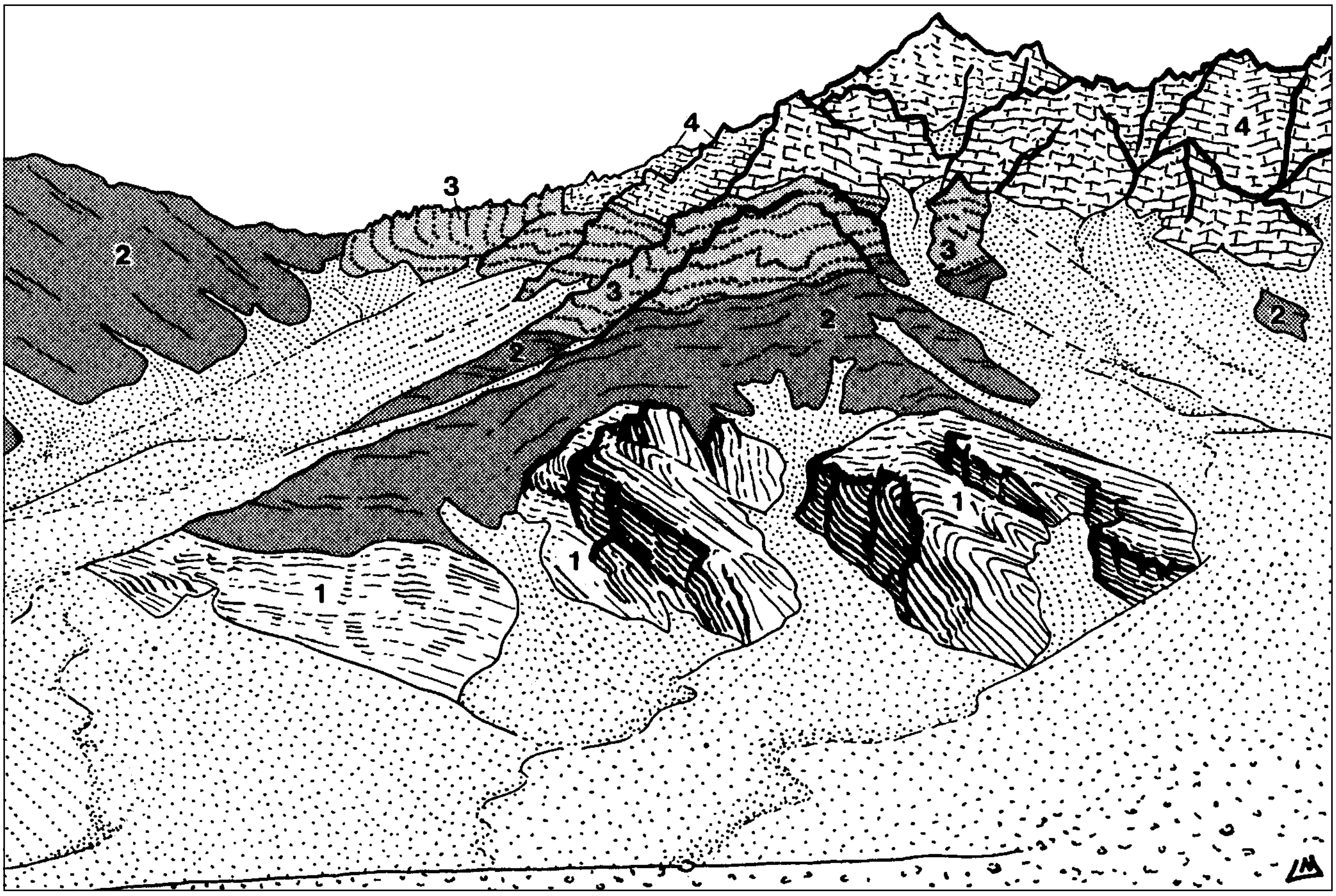
As shown in our Plate 1 the Tropites Limestones and overlying pelites are isoclinally folded and disturbed by local imbrication. We found reverse faults of local importance, which replace each other after a short distance along the strike. The NE limb of the Tsarap Syncline is complicated by these imbrications and isoclinal folding.

The Tsarap Syncline can be traced towards the NW to the Tsho Tok Phu (lake) and the Shade-Tantak area described by FUCHS (1987) and further to the syncline of Chirche La (BAUD et al., 1982). Also there the NE limb of the syncline is overturned and frequently sheared. The type of disturbance is imbrication and not nappe tectonics as assumed by BAUD et al. (1982), GAETANI et al. (1985) and others.

The Tsarap Syncline involves the succession from the Tropites Limestone (Carnic) up to the Kangi La Formation (Campanian–Maestrichtian). Where the trail from the Marang La reaches the Tsarap River the youngest formation seems to be the Chikkim Limestone, but further NW, downstream the Tsarap, Kangi La marls (about 50 m) form the core of the syncline (Text-Fig. 14). Towards the SE upstream the Tsarap the Upper Jurassic–Upper Cretaceous formations soon end and we find much folded, rather



Text-Fig. 14.
View downstream the Tsarap towards the bridge of Charras. The core of the Tsarap Syncline crosses the valley there.
1 = Kioto Limestone (Rhaetic – Dogger); 2 = Ferruginous Oolite (Upper Dogger); 3 = Spiti Shales (Malmian – Lower Cretaceous), 4 = Giumal Sandstone (Lower Cretaceous); 5 = Chikkim Limestone (lower Upper Cretaceous); 6 = Kangi La Formation (Campanian).



Text-Fig. 15.
Mountain E of Sarchu seen from the W.
1 = Tropites Limestone (Carnic?); 2 = Juvavites – Monotis Shales (Noric); 3 = Quartzite Beds (Rhaetic); 4 = Kioto Limestone (Rhaetic – Dogger).
The folds in the Tropites Limestone are distinctly directed NE, whereas the Quartzite Beds and Kioto Limestone are SW vergent.

monotonous carbonates. They seem to represent Tropites Limestone and Kioto Limestone. As we walked up the Tsarap mainly along the strike of the beds and did no regional mapping there, we can not give further information. SPRING & CRESPO-BLANC (1992) and SPRING (1993) report a thrust marked by a band of Spiti Shales between Kioto Limestones. According to these authors the lineament separates the "Zangla-" and "Zumlung Units" (BAUD et al., 1982). This tectonic zone should reach the Tsarap Valley N of Takh. Our trail was on the orographic right side of the river, and thus we are not able to give a comment regarding this thrust. But in its alleged continuation towards the NW (GAETANI et al., 1985; BAUD et al., 1982) we found the thrust not existing (FUCHS, 1987).

The Sarchu region, where the Yunam, Lingti, and Tsarap Rivers have their junctions, is of great geological importance. There the Mesozoic series of the Zanskar Synclinorium are in juxtaposition against the Palaeozoics along a detachment fault. It appears that this Sarchu Shear Zone (STECK et al., 1993) was of great influence on the deformational style in the adjoining blocks:

In the Marang La – Tsarap Valley region the dip of the rocks is prevailingly NE and the folds and imbrications are directed SW. Between the Tsarap-Yunam and the Lingti-Yunam junctions NE vergent folds can be observed on both sides of the valley. There are anticlinal cores formed by the Tropites Limestone mantled by Juvavites-Monotis Shales.

The NE-directed folds are found in the lower parts of the mountain flanks, whereas the higher portions and tops show the SW vergency. This divergency can be seen particularly in the mountain E of Sarchu (Text-Fig. 15). SPRING gave a first hint to this phenomenon (pers. comm.) and in his maps (1993) he shows a thrust, along which the Kioto Limestone rests discordantly on various formations, the Tropites Limestone (Zozar Fm.), Juvavites Shales, Quartzite Beds (Takh Fm.), and Kioto Limestone (see also STECK et al., 1993, Text-Fig. 22). Our map (Pl. 1) does not confirm this tectonic unconformity.

We found the stratigraphic sequence Tropites Limestone to Kioto Limestone just folded. The vergency of folding is NE below the Juvavites Shales, above these argillites it is SW. The change in the direction of movement occurs in the ductile pelites.

What is the cause of this divergence? We explain it with the proximity to the Sarchu Shear Zone. When the hanging wall rock mass slumped down towards the NE, folds directed towards the NE developed due to dragging in the proximity of the shear zone. More distant, in the top portion of the mountain, the regional SW directed folds were not obliterated.

In the Padum area, where the contrast in metamorphic grade in the foot and hanging wall is particularly obvious, BAUD et al. (1982) recognized the tectonic contact and envisaged a nappe boundary. HERREN (1987) demonstrated the gravitational detachment nature of the lineament and termed it the Zanskar Shear Zone. FUCHS (1987, p. 486) found a similar shear zone S of the Sarchu Plain. SPRING & CRESPO-BLANC (1992), SPRING (1993), and STECK et al. (1993) refer to this disturbance as the Dextral Sarchu

Shear Zone and Sarchu Fault. These authors envisaged a complicated history of this lineament: First there developed a ductile dextral transpression zone. This phase of synmetamorphic underthrusting was followed by NE vergent backfolding. Late extension tectonics reactivated gently dipping thrust planes, which were later cut by the steep Sarchu Normal Fault.

The contact of the almost non-metamorphosed Mesozoic formations to the amphibolite facies metamorphosed Palaeozoics is a tectonic plane dipping at medium angles towards the NE. On both sides of the lineament the adjoining rocks are crushed. This zone of cataclasis may be several hundred meters wide. The crushed Triassic limestones of the hanging wall weather in needles and towers like the Quaternary conglomerates of the river terraces. The extreme cataclasis was produced by late fault movements. The extensional tectonics, however, started earlier. DRANSFIELD (1993) accepts that still under conditions of regional metamorphism the shear zone became active simultaneously with the MCT. “The extension is thought to be a result of gravitational collapse of the Himalayan topographic front, leading to the formation of the Zanskar Normal Fault Zone and contributing to the exhumation of the metamorphic rocks below the fault” (p. 16). The belt influenced by drag folding is much broader than the cataclastic zone. It seems to go back to the early stage of the extension tectonics.

Traced towards the W the Sarchu Shear Zone appears to split into several faults. According to SPRING (1993) the fault crosses the Kamirup River in its lowest course and strikes to Chumik Marpo. From there the disturbance was traced by GAETANI et al. (1985) and FUCHS (1987) over the Phirtse La. The faults in the region between this pass and Tanze (FUCHS, 1987) seem to belong to the same fault system. The northeastern blocks are thrown down.

We further suspect that the complex disturbance plane demarking SPRING’s “Chumik Unit” in the N is another continuation of the Sarchu Shear Zone.

The Sarchu Shear Zone is definitely comparable with the Zanskar Shear Zone of the Padam area, but it is not one continuous lineament as suggested by some authors (e.g. “Trans-Himadri Thrust” [VALDIYA, 1987]). The Zanskar Shear Zone dies away around Ichar (FUCHS, 1987). But between Ichar and the Sarchu area several other planes with smaller displacement may take up the detachment.

As noted above the Mesozoics of the hanging wall abut against metamorphosed Palaeozoic formations at Sarchu. These are gently dipping N beneath the Sarchu Shear Zone and are rather horizontal in both flanks of the Yunam Valley. The succession Karsha-, Thaple-, Muth-, Lipak-, and Po Formation forms a huge kilometric recumbent syncline there. BAUD et al. (1984, Text-Fig. 7) described the fold as SW vergent, conformous with the direction of the “nappe” transport. FUCHS (1987) observed the closure of the syncline near Kenlung and thus inferred a NE vergency. This is proved also by SPRING (1993) and accepted by STECK et al. (1993). Such recumbent, NE directed folds are exceptional for Zanskar, but are characteristic for the Tibetan Zone in Dolpo and Manang, Nepal (FUCHS, 1967, 1977a; BORDET et al., 1971, 1975, a.o.). We think that the recumbent folds are related to the Sarchu Shear Zone. The NE directed gravitational movements in the shear zone caused severe dragging in the Palaeozoics of the footwall. This process occurred in the early stage of extensional tectonics, when ductile deformation was still possible.

S of Sarchu, approximately 3 km SW of the cataclastic zone, the Haimantas are metamorphosed to coarse-grained garnet – staurolite – two-micaschists. Under the microscope they show porphyroclasts of garnet, staurolite, and biotite in a fine-grained, mylonitic matrix of muscovite, biotite, plagioclase, and quartz; post-mylonitic biotite and garnet may be slightly chloritized.

The porphyroclasts of biotite exhibit inclusion trails of quartz, indicating an older schistosity (S_1) rotated in respect to the younger S_2. The biotite clasts are coated by fine biotite-muscovite aggregates, which recrystallized in course of the mylonitic deformation. The garnet porphyroclasts show zonation. The poikilitic core exhibits linear to slightly sigmoidal inclusion trails (S_1). The outer rim is free of inclusions and shows idiomorphic form. The internal s was rotated by the mylonitic foliation and the marginal zone was irregularly resorbed. Post-mylonitic an extensional crenulation cleavage (S_3) developed. In this deformation phase the fine-grained micas did not recrystallize.

The garnets are rich in almandine (75 mol % alm, 12 mol % pyr, 8 mol % grs, 5 mol % sps). In regard of chemistry there is a well-pronounced bell-shaped Mn-profile hand in hand with a slightly bell-shaped Ca-profile and bowl-shaped Fe- and Mg-zoning. This indicates that the garnets are prograde zoned. The x_{Mg}-value increases slightly towards the margin.

Staurolite ($x_{Fe} = 0.81$) is not zoned and contains 2 wt.-% ZnO and 0.4 wt.-% TiO_2. The biotite porphyroclasts and fine-grained biotites of the mylonitic matrix are chemically identical. They contain about 1.3 wt.-% TiO_2 by a x_{Mg} of 0.44 and a deficiency in the octahedral site of 0.1. Thus the biotite porphyroclasts recrystallized during the mylonitization under conditions of greenschist facies. Garnet and staurolite, however, are relics of the lower amphibolite facies. The mylonitization was ductile under greenschist facies and produced the mineral assemblage Bt – Ms – Pl – Qtz. Obviously the prograde growth of garnet was put to an end by the mylonitization. During the upheaval, which was related with the mylonitization, garnet was resorbed, but there occurred no retrogressive Fe-Mg-exchange with adjoining biotites. The extensional crenulation cleavage developed when the conditions of deformation became rigid (about 300°C) because fine-grained micas did not recrystallize.

From the coarse-grained two-micaschists in direction to the tectonic plane S of Sarchu, staurolite and garnet disappear; biotite can be traced into the zone of cataclasis. The metapelites, in which these biotites occur, belong to the Thaple Formation. The mylonitization (S_2) and the extensional crenulation cleavage (S_3) increase, which is certainly one cause for the reduction in size of the biotites. The angle between S_2 and S_3 schistosities decreases. Also the granite dike, which intruded the Thaple Formation together with a mafic dike, is strongly mylonitized.

Towards the S in direction to Kenlung Serai the mylonitization decreases rapidly. In the area N of Kenlung Serai the garnetiferous phyllitic micaschists of the Haimanta Formation show strong crenulation cleavage besides of sedimentary schistosity (S_0). The crenulation may represent the fading away of the mylonitic deformation. S of Kenlung Serai also the crenulation dies away. Independently of the S_2 and S_3 schistosities kink bands occur generally vertical to the S_2. They indicate late, lateral compression, that means in a direction parallel to the shear zone.

The metamorphism too decreases rapidly towards the S. Until N of Kenlung Serai garnet is stable and approximately 2 km to the S of Kenlung Serai biotite blasts growing across the S0 schistosity are observed. On the ascent to Bara Lacha La from the N slightly metamorphosed laminated metasiltstones occur, which exhibit beautifully preserved sedimentary structures. Obviously the mineral isograds dip towards the SW, therefore the metamorphism decreases rapidly in direction to the Bara Lacha La.

The deformation profile in the footwall block of the Sarchu Shear Zone divides into a narrow zone of cataclasites at the tectonic contact, a mylonite zone of several hundred meters thickness gently dipping towards the NE, and a zone with heterogeneous deformation. The latter reaches until Kenlung Serai, which implies that its thickness vertical to the shear horizon amounts to several km.

The Zanskar Shear Zone (HERREN, 1987) in western Zanskar is similar to the Sarchu Shear Zone inasmuch as it shows an asymmetric deformation profile with a steep gradient of the metamorphic isolines within the mylonites. A marked difference, however is the rapid decrease of metamorphism S of the Sarchu Shear Zone. We explain this fact as a tilting of the footwall block away from the shear zone. This is inferred from the mineral isogrades inclined towards the SW. Additionally it is important that S of Padum the high-grade crystallines of the Zanskar Range are adjoining the shear zone, whereas at Sarchu metasediments of the Lahul axial depression are adjacent; the high-grade metamorphic complex of the H.H.C. is hidden there below the metasediments.

At Kenlung Serai a large landslide from the orographic right flank filled the whole valley and blocked the Yunam River.

S of Kenlung Serai the country is built up mainly of the Karsha Formation. The rocks are deformed in open folds. Thaple Formation and Muth Quartzite occur in synclines in the top region of the mountains. From the Bara Lacha La to the W following the valley a normal fault caused a down through of the southern block. The sequence Karsha to Po Formations (Cambrian to Upper Carboniferous) is exposed in a large syncline S of the fault. According to STECK et al. (1993) the syncline comprises also Permian and Triassic formations. S of this Pateo Syncline all the country is composed of the Phe and Karsha Formations, which give the geology of Lahul its monotony.

Discussion

After presenting our observations from the Nimaling – Bara Lacha La traverse a review is given and the results are discussed. It is essential that the Palaeozoic formations exposed in the Nimaling Dome are stratigraphically connected with the Mesozoics of the Zanskar Synclinorium. Across the Nimaling Dome the Lamayuru basin facies is reduced in its stratigraphic range from Triassic to Cretaceous in the N, to the Scythian to Noric and the Malmian in the S. Further towards the S the euxinic facies is confined to the Noric and the Malmian. It is also a characteristic of the northern facies belt that the Rhaetic Quartzite Beds at the base of the Kioto Limestone are missing. In the Marang La area red coral reefs occur in the Rhaetian – a facies unknown from other regions of the Himalaya. Thus gradational shallowing – the transition from the continental slope to the shelf – is indicated in the Mesozoic stratigraphy. This gradation is disturbed by the tectonics at Marang La: S of the Marang La Thrust we find the normal Noric development of the Tibetan Zone (Juvavites-Monotis Shales, Kuti Shales, Tarap Shales), and the Rhaetic Quartzite Beds.

Structurally the sequence is deformed mainly by folding. It is predominantly directed SW, only at the Toze Lungpa/ Zara junction NE vergency is prominent. Several SW directed imbrications are observed. Of these the Marang La Thrust is most important because of the abrupt facies change observed there. Other imbrication thrusts can be followed over a limited distance only. We accepted a smaller number of imbrications than STECK et al. (1993) and SPRING (1993). These authors show an intricate schuppen belt, which they term the “Nimaling-Tsarap Nappe“. The individual scales are named as units (e.g. Zangla-, Zumlung-, Marang La-, Zara Unit etc.). Originally such units were assumed as individual nappes by BAUD et al. (1982, 1984) and it is certainly a progress that the Lausanne team takes them as schuppen now. In the term “Nimaling-Tsarap Nappe” they accept the continuity of the Nimaling Dome with the Zanskar Synclinorium proposed by FUCHS (1986).

There is always some ambivalence in the papers of the Lausanne team: In STECK et al. (1993) the “Langtang Nappes” are dropped and the “Nimaling-Tsarap Nappe” is shown as a schuppen zone. On the other hand the authors still talk of “nappes“, within the latter unit responsible for the deformation D_2, inverse metamorphism, gaps in the sequence etc. Further it is not clear whether the front of the “Nimaling-Tsarap Nappe” is at Bara Lacha La or N of the “Kenlung Serai Unit” (STECK et al., 1993). From their illustrations we understand that the “Nimaling-Tsarap Nappe” is envisaged as an accretionary wedge, with intensity of deformation fading away in the frontal portions of the unit (Bara Lacha La). But these are characteristics of a schuppen belt and not of a nappe. The latter is defined as an allochthonous rock mass, which by horizontal transport has come to rest on other rock complexes. In none of the figures the Lausanne authors show such an autochthonous underground. The allochthony of the “Nimaling-Tsarap Nappe” is deduced from the internal deformation only. But in our view it is the width of relative horizontal displacement of two rock units which documents allochthony and rectifies the use of the term nappe. It is insignificant whether the internal deformation of the overthrust unit is large or small.

Nappe tectonics in Zanskar are still assumed by the Lausanne team (in their deformation phases D_1 and D_2). One case of inverse metamorphic zonation and stratigraphic gaps (SPRING & CRESPO-BLANC, 1992; SPRING et al., 1993; STECK et al., 1993) are used as arguments: The anchimetamorphic “Chumik Unit” is overridden by the epimetamorphic “Zangla Unit”, which is referred as an instance of transported metamorphism. This is an exception because elsewhere the metamorphic sequence is normal (SPRING & CRESPO-BLANC, 1992, p. 987). It is stated that the metamorphic leap observed was caused by movements after the metamorphism. That means that it was later than the assumed nappe stacking (D_2) which is taken as synmetamorphic (p. 987 bottom). The importance of extensional tectonics after the synmetamorphic “nappe” movements is emphasized. They reworked the original thrusts to composite tectonic planes and reset the original stratigraphic sequence and metamorphic zonation (except one case, which, however, was also later than nappe stacking). This is the reason for “the scarcity of direct stratigraphic evidence for nappe tectonics in the Tibetan Zone of the Himalayas. Detailed mapping has revealed complex structures where the classical clues allowing the identification of nappes are completely occulted. The effects of a late extensional phase were important enough to cancel the inverse stratigraphic relationship caused by the thrust, but not the inverse metamorphic zonation" (cit. SPRING et al., 1993, p. 94). As this inversion is later than the alleged synmetamorphic nappe stacking (see above) there is actually no indication of the early SW-directed nappe movements assumed by the Lausanne authors.

In connection with this nappe problem we have to discuss also the different metamorphic grades along the Sarchu Shear Zone. All workers agree, since BURG (1983) found the gravitational detachment system in southern Tibet, that also in Zanskar similar extensional tectonics were active. The fact that the amphibolite facies metamorphism S of the Sarchu Shear Zone fades towards the Bara Lacha La is interpreted in different ways. FUCHS (1987) envisaged a connection of the locally increased metamorphism with the granite sills there. SPRING (1993) determined the age of this granite with 284 ± 1 ma, whereas the amphibolite grade metamorphism of the surrounding series is Alpine in age, which proves that they are not related. SPRING thinks that the metamorphism is caused by the overburden of higher allochthonous masses. The decrease towards the S indicates the position of the front of these "nappes".

We should like to point to the ambivalence of the Lausanne authors, who at one hand accept their units as schuppen of their "Nimaling-Tsarap Nappe" with the front at Bara Lacha La, at the other hand assuming a pile of nappes overlying the northern portion of the "Kenlung Serai Unit", which represents the frontal part or their "Nimaling-Tsarap Nappe" (SPRING & CRESPO-BLANC, 1992; SPRING, 1993; SPRING et al., 1993; STECK et al., 1993). With surprise we noted that in their reconstruction of the "nappe" before backfolding and extensional tectonics (STECK et al., 1993, Text-Fig. 16) these authors do not show this alleged overburden of higher units: Above the "Kenlung Serai Unit", which exhibits the amphibolite facies grade, no duplication of the stratigraphic succession is indicated by the above authors.

We follow those workers (e.g. BURG, 1983; BURCHFIEL & ROYDEN, 1985; COPELAND et al., 1987; HERREN, 1987; a.o.) who accept the extensional tectonics N of the Great Himalayan Range as roughly contemporaneous with the compression tectonics on the MCT. Obviously the Alpine metamorphism of the Central Crystalline was put to an end by the overriding of the Crystalline Nappes onto the cool units of the Lesser Himalaya as well as due to the uplift of the central axis of the Himalaya. Uplift led to erosion and the exhumation of the high-grade metamorphic portions and to collapse causing the gravitational slump of the sedimentaries from the crystalline complex. The Zanskar and Sarchu Shear Zones became active during regional metamorphism under ductile shear conditions. This process brought the metamorphism rapidly to an end as shown by the Miocene cooling ages (POGNANTE et al., 1990). In the uplifted block there occurred tilting of metamorphic isogrades. This is indicated by the occurrence of the high-grade rocks near the Sarchu Shear Zone and the decrease towards the S. The high-grade metamorphism affected rocks up to Carboniferous age, whereas the low-grade rocks of Bara Lacha La and Lahul regions are Precambrian to Cambrian in age. This implies that the isogrades of the regional metamorphism cut across the stratigraphic boundaries. In course of the upheaval following, the isogrades were tilted. The recumbent folds related to dragging near the Sarchu Shear Zone seem to have formed in the early stages under ductile shear conditions. In the late stages the normal fault movements have caused severe cataclasis of the adjoining rocks.

7. Lahul and its Relation to Adjoining Regions

Crossing the Bara Lacha Pass we leave Zanskar, the southern part of Ladakh (J & K), and enter Lahul belonging to Himachal Pradesh. Geologically there exists no boundary between Zanskar and Lahul. In the Pateo Syncline S of Bara Lacha La we still find the classical Palaeozoic succession of southern Zanskar and Spiti. Further S in the Darcha-Jaspa region there are only outcrops of the Phe (Haimanta) Formation. The rocks are steeply folded with SW vergency. The monotonous flyschoid series, several thousand meters thick, are intruded by granitic masses. NW of Darcha there is the very large intrusion of the Kado Tokpo Valley. At Jaspa we cross a smaller boss, which was dated by FRANK et al. (1976) 495 ± 16 ma. The contacts of the granitoids to the country rock are not tectonic as proposed by GAETANI et al. (1985) but clearly magmatic as shown by FUCHS (1987).

S of the Jaspa Granite down the Bhaga Valley to Kyelong the rocks of the Phe Formation are rather horizontal or gently dipping either NE or SW. SW of Kyelong SW dip at medium angles becomes prevalent. At the junction of the Bhaga and Chandra Rivers the flyschoid series of the Phe (Haimanta) Formation are succeeded by thick carbonates comprising the famous Tandi Syncline. This conspicuous series was already known to STOLICZKA (1865) and was accepted as late Palaeozoic by LYDEKKER (1883). POWELL & CONAGHAN (1973) found the first fossils dated as Jurassic by PICKETT et al. (1975). SRIKANTIA & BHARGAVA (1979) subdivided the Permian to Jurassic Tandi Group into three formations. Recently VANNAY made a detailed study of the area for his thesis (pers. comm. to B. GRASEMANN): Conglomerates and dolomites are passing upwards into dark siltites (Rape Mb. of Kukti Fm.). They are correlated with the Permian Kuling Formation on the base of lithology and *spiriferida*. A discordant transgressive contact to the underlying Haimantas is suggested, though the boundary is frequently disturbed. In the dark carbonates and marls of the Rashil Mb. VANNAY discovered an Anisian to Ladinian ammonite fauna. The Gushal Formation, divided into the dolomitic Nadgar Mb. and the sandy-silty Shipting Mb., represents the Upper Triassic. The Jurassic Dilburi Formation correlates with the Kioto Limestone.

The succession of the Tandi Syncline is epimetamorphic and strongly folded towards the NE. POWELL & CONAGHAN (1973, 1975) envisaged a SW directed overturned synform. But we agree with STECK et al. (1993) who stress a NE vergency. In view of these authors the Tandi Syncline was overridden by the "Shikar Beh Nappe" in an early stage of the orogeny immediately after continent-continent collision (Eocene). This was before the SW-movements of the "Nimaling-Tsarap Nappe". We have not crossed the Tandi Syncline into the overlying Haimantas. But our observations down the Chandra Valley and from the Chobia Pass section do not support the existence of this nappe. In that area there are only steep vertical or SW directed folds (Pl. 1). A huge NE vergent fold nappe as proposed by STECK et al. (1993) can not end over such a short strike distance. So we regard the Tandi Syncline rather as a major back fold than as base of a NE vergent "Shikar Beh Nappe". The main reason to assume the existence of the "Shikar Beh Nappe" is the high regional metamorphism in the Chandra Valley (Khoksar)-Rohtang Pass region (STECK et al., 1993, p. 251). In our view it is not necessary to envisage the overburden of a higher nappe to explain increased metamorphic grade in Tethyan sedimentary series. There are many examples that the front of regional metamorphism reaches up into different levels of the sedimentaries in many areas of the Himalaya (e.g. Nepal, FUCHS, 1967; Ladakh – Kashmir, FUCHS, 1977b, 1979; HONEGGER, 1983). Thus lateral variation in metamorphic grade does not mean that a hypothetical overlying nappe must be assumed.

Discussion

Lahul is the rare case where the Central Crystalline (High Himalayan Crystalline, HHC) plunges beneath the sediments in an axial depression. There the Tibetan Zone of Zanskar-Spiti is continuous with the sediments of the Chamba Synclinorium. The thick oldest formations, the Haimantas, Chamba, and Phe Formations are connected. Permo–Mesozoic series are exceptionally preserved from erosion in the Tandi Syncline. It is significant that most of the Palaeozoic formations of adjoining Spiti and Zanskar are missing in the Tandi Syncline. This may indicate that the Himalayan axial zone was a region of erosion or non-deposition long before the Alpine orogeny. We think that it was not only the original distance which is responsible for the different stratigraphic development of Lesser and Northern Himalayas, probably there was also a ridge in-between (FUCHS, 1967).

8. Chamba and its Stratigraphic and Structural Problems

The Synclinorium of Kashmir is famous for its Palaeozoic–Mesozoic succession. In continuation towards the SE there is the Synclinorium of Chamba, which, however, is composed mainly of Precambrian–Early Palaeozoic formations. In the N, in the region of the Chandra Valley, it is evident that the high-grade crystallines of the HHC underlie the sedimentary series and pass upwards into the metasediments. We stress this primary connection of crystalline and sedimentary series, because in literature repeatedly a thrust was assumed (e.g. Tethyan Thrust [THAKUR et al., 1990]; Chamba Thrust [SINGH, 1993]; Haimanta Thrust Zone [PAUL & PAUL, 1993]; a.o.). The idea that the Tethyan sediments rest tectonically on the HHC should be dropped – a thrust contact is not existent. In the southern flank of the synclinorium there are no high-grade metamorphic series but Precambrian metasediments of Haimanta or Chail type intruded by the 500 ma granites of the Dhauladhar Range (JÄGER et al., 1971; BHANOT et al., 1975; LE FORT et al., 1986).

From the work of MC MAHON (1881, 1882, 1883, 1885) and LYDEKKER (1883) a traverse across the Sach Pass appeared rather instructive and therefore in 1969 was undertaken by FUCHS (1975). The sequence exposed in the Sach Pass and Kalhel Synclines suggested the correlation with the classical Kashmir succession. Recently the tilloid conglomerates (Manjir Conglomerates) compared by FUCHS (1975) to the Upper Palaeozoic Agglomeratic Slates were found inmidst of Haimantas in the Chandra Valley and therefore were considered as Precambrian by FRANK and GRASEMANN (pers. comm.) and GRASEMANN (1993). As the conglomerates – now of doubtful age – have wide extension in Chamba, all the stratigraphy and in consequence the tectonics became a major problem.

To clarify the problem the team GRASEMANN – MILLER and our group undertook joint fieldwork in the Chandra Valley and individual traverses of Chamba.

S of the village Rape the Tandi Syncline closes. NW of Rape on the crest of the mountains N of the Chandra River a band of carbonates represents an utmost remnant of the Tandi Syncline. Down the Chandra River the Haimantas still dip towards the SW with medium angles. In the area Arat-Udaipur the dip steepens and varies around the vertical.

The Haimantas of the Chandra Valley are rich in fine-grained sandstones and siltstones, pelites being subordinate. The monotonous series is well-bedded and the colours of the rocks are green-grey, sometimes also dark-grey. At the knee of the Chandra downstream of Udaipur the Haimantas form a large anticline.

In this anticline there is a conspicuous black horizon composed of graphitic slates, phyllites, quartzites, but also light sericite schists. The dark band is about 50 m thick and frequently sheared.

SW of the anticline follows an intensely folded syncline axially plunging towards the NW. It is composed of mostly dark grey sandstones, quartzites, and slates. In the SW-limb of the syncline the black band comes up again W of Salgraon. There the rocks dip 30–40°NE. The black band is underlain by Haimantas.

Towards the bend of the valley near Tindi the Manjir Conglomerates underlie the Haimantas. They are several hundred meters thick and consist of dark grey to green slates, silt- and sandstones containing sporadic pebbles and boulders of quartzite, vein quartz, slate, sandstone and porphyric granite with blue quartz. The components are round to subangular. The lithology of the boulder slates suggests that the boulders dropped from melting icebergs into sandy to silty muds of a flyschoid environment. RATTAN (1974) put arguments for an origin from mudflows and submarine slumping. The wide spectrum of clasts and the lithology of the formation, however, are distinct from an olistolith. A glacial source of the boulders was favoured also by LYDEKKER (1878), POWELL & SAXENA (1971), THAKUR & PANDE (1973), and FUCHS (1975).

NW of Tindi thin-bedded sandstones and quartzites are underlain by grey carbonates approximately 30 m thick. It appears that the carbonates are stratigraphically linked with the overlying Manjir Conglomerates. Below the carbonates we find grey, green, fine-grained sandstones and slates. Then a second band of rather massive, grey to blue carbonates and black slates underlies. The carbonates exhibit a characteristic alternation of dark and light carbonate in mm to cm dimensions reminding of feather joints. This seems to be a replacement structure. These characteristic structures were observed in the carbonate-black argillite association all over Chamba.

From beneath the carbonates again sandstones come up and then boulder slates. Thus there are two ENE dipping boulder slate complexes separated by sandstones and carbonate bands. Further downstream the above rock complexes are crossed again from bottom to top (Pl. 1). In the valley the dip is very steep to vertical, but it can be observed that towards the top of the mountains in the SW the dip becomes gentle towards NE.

N of the upper Manjir Conglomerate a third carbonate horizon follows. Then comes a thick steeply dipping sandstone-slate complex of Haimanta type. In this series a black slate-quartzite horizon occurs again. It is vertical and crosses the valley under a small angle. At Dumare our section ends with the road. The described road section along the Chandra River gives the following experience: The Manjir Conglomerates are associated with grey to blue carbonates with local magnesitization and black slates. These formations are under- and overlain by thick sandstone-slate complexes of Haimanta type.

From GRASEMANN's observations made on traverses over the Drati- and Marwa Passes it appears that the Manjir Conglomerates of the Tindi area are confined to the lower slopes of the Chandra Valley. To the S, in the range, over which the above pass routes cross, the conglomerates are overlain by rather horizontal Haimantas. In the tributaries flowing via Tikri to the Siul River the Manjir Conglomerates come out again from beneath the Haimantas and obviously join up with those of the Kalhel Syncline. This will be dealt in the discussion on Chamba.

Whereas the work along the Chandra Valley more or less followed the strike, the section from Arat to Barmaur via the Chobia Pass is a transect across many zones.

The Haimantas dip around the vertical in the Chandra Valley. Further S, up the tributary towards the Chobia Pass, the dip becomes medium towards the NE. Two black bands like those of the region NW of Udaipur are found in the Haimantas. The northern one consists of black phyllites. The southern one is composed of black metapelites and light sericite schists. It is rather sheared and the bedding planes of the Haimantas are locally slightly discordant to the black band (mountains W of the valley). Black slates and subordinate grey carbonates occur before we get into the thick Manjir Conglomerates, which build up the crest of the Chobia Range. The steeply folded conglomerates form the core of an anticline. On the descent S of the Pass almost vertical Haimantas follow. Again a black band is crossed. It is strongly deformed and overlain by folded Haimantas, which build up a conspicuous syncline in the mountains to the S of the Chobia Pass. Due to the large scale folds the black band is traversed several times on the way downstream. The vergency of the folds is SW.

Just before reaching the hamlet Balmul a thin band of grey blue carbonates is crossed. Underlying thick Manjir Conglomerates follow. Along the road from Harser to Barmaur monotonous Haimanta type series with bands of carbonates and black sulphidic slates crop out. Like in the Chandra Valley the carbonates show characteristic replacement structures from magnesitization. About 2–3 km before Barmaur Manjir Conglomerates are found along the road side. The dip of the rocks is generally towards the NE. The Haimanta type rocks and the association of black pelites and blue-grey carbonates resemble those observed in the Chandra Valley. These series are repeated either by folding or imbricate thrusts. We think that the repetition represents a schuppen belt.

The same style of tectonics is found along the further traverse from Barmaur via Grima down to the Ravi and upstream that river. Just W of a small hamlet (Chanaota Khas, Quarter Inch Map) the black argillite-carbonate band is affected by intensive magnesitization. Big blocks of grey-white pignoli magnesite are found along the road. From the Ravi Valley up the tributary to the village Kuarsi very thick Manjir Conglomerates are crossed.

Two medium-grained, green, mafic sills were observed on the ascent to the village (thickness about 3 m). In thinsection the rocks show doleritic texture. Relics of magmatic hornblende and plagioclase are found. Sphene is magmatic accessory mineral and is well-preserved. Weak metamorphic overprinting under conditions of the lower greenschist facies – without deformation but with a pervasive fluid phase – led to alteration respectively hydration of the magmatic minerals. From hornblende fine aggregates of amphibole, biotite and chlorite formed, in plagioclase the secondary minerals clinozoisite, albite, calcite and quartz were growing. Geochemically the doleritic composition was preserved inspite of the above alterations (Tab. 1, Text-Fig. 6). Thus there is much similarity to the mafic dikes in the metasediments of eastern Zanskar. Possibly the sills are feeders of the Panjal Trap, which occurs also in the Chamba Synclinorium (e.g. in the Kalhel Syncline).

SW of Kuarsi the NE-dipping Manjir Conglomerates are underlain by thick Haimantas consisting of sericite-chlorite schists and -sandstones. Compared to the Haimantas of the Chandra Valley-Barmaur area the series is less arenaceous. Though the metamorphism increases towards the S the metasediments are identified as Haimantas by the typical lamination. The rocks dip NNE at medium angles.

In the Kuarsi Valley before the direct ascent to the Indrahar Pass we get into the thick granite complex of the Dhauladhar Range. The boundary is sharp and there is not much penetration by granitic veins in the overlying metasediments, but we do not doubt that the concordant contact is magmatic. Obviously migmatization is missing or at least insignificant.

The granites are predominantly coarse-porphyric with potassium feldspar phenocrysts of 5–8 cm, maximally even 15 cm length. They are euhedral, in strongly foliated types they are deformed to augen. In the coarse-grained granite-gneiss some enclosures of non-porphyric granite were observed. There are also inclusions of dark intermediate rocks, which contain sporadic phenocrysts of potassium feldspar.

In the southern flank of the Dhauladhar Range medium- to coarse-grained, non-porphyric granites become frequent. The various granite types penetrate each other and we found no clear age sequence in this composite intrusion. The granite of the Dhauladhar Range is several thousands of meters thick. The foliation dips towards the NNE at medium to gentle angles.

In the basal portions of the granite we find irregular inclusions of metasediments of several hundred meters dimensions. They consist of white, grey to brown quartzites, phyllitic schists, and grey, silty schists to metasiltstones. The Chail to Haimanta type metasediments show greenschist facies metamorphism. There is no doubt that the granite intruded in the over- and underlying metasediments and that they belong to one structural unit, the Crystalline Nappe.

Discussion

After the description of the traverse from the Chandra Valley across Chamba and the Dhauladhar Range we try to see the section in a wider context.

The fact that the high-grade crystallines of the Great Himalayan Range dip beneath the sedimentary succession in the Kilar-Sach Pass section (FUCHS, 1975) and the connection of these sedimentaries with Lahul, Spiti, and Zanskar document that the Chamba Synclinorium is the southeastern continuation of the Kashmir Synclinorium. This is also proved by RATTAN (1973, 1974) and by the recent work of GUNTLI in the western Chamba region (pers. comm.). Thus there is no possibility to correlate the Chamba sedimentary series with the Simla area as done by SEGHAL (1966). The first represent the higher part of the Crystalline Nappe, whereas the latter belong to the Lesser Himalayan units. The same argument was put already by RATTAN (1973, p. 236).

From the correspondence of the Kashmir- and Chamba Synclinoria it is suggestive to correlate the rock sequence too. This was done by FUCHS (1975) when he described the Sach Pass – Chamba traverse. Particularly the correlation of the Manjir Conglomerates with the Agglomeratic Slate Formation (Upper Carboniferous) of Kashmir became a problem when the team FRANK – GRASEMANN found the Manjir Conglomerates intimately associated with the Haimantas of the Chandra Valley. In his thesis GRASEMANN (1993) designated the Manjir Conglomerates as Middle Haimantas. Our field work in Chamba had the target to clarify this stratigraphic problem.

It is a fact that thick Haimantas are found below as well as on top of the Manjir Conglomerates. We considered larger thrust tectonics to explain the Haimantas resting on the Manjir Conglomerates, however, no distinct shear plane was observed. It is generally not easy to discern the boundary between the conglomerates and the Haimantas, because the matrix of the conglomerates resembles the Haimanta rocks. It is the occurrence of pebbles and boulders which allows the designation of the formations. This is an argument in favor of a stratigraphic boundary.

Another possibility, the existence of two conglomerate complexes, a Precambrian and an Upper Palaeozoic one, was abandoned, because the diverse conglomerates are lithologically identical. Further in different localities they were found associated with the same type of carbonates and black pelites. Thus there is no doubt that there exists only one glacigeneous conglomerate formation in Chamba.

This is also supported by the recent mappings of the Austrian groups: The conglomerates, found by GRASEMANN W of the Drati and Marwa Passes, join up with the Manjir Conglomerates of the Kalhel and Sach Pass Synclines described by FUCHS (1975). They belong to one large domal structure in the Siul Valley (see FUCHS, 1975, Pl. 4). The conglomerates are also connected with those which we observed in the Chandra Valley. The conglomerates of the Sach Pass strike in direction to those of the Karu Nala. According to GRASEMANN (pers. comm.) the Tindi occurrence is connected with the conglomerates W of the Drati Pass beneath the range. Further we envisage a continuation of the conglomerates of Tindi to those of the Chobia Anticline. We do not doubt that the conglomerates of this structure come out beneath the Haimantas near Balmul. In the Barmaur Schuppen Zone we found a tectonic repetition of the conglomerates and associated carbonates and black pelites with Haimantas. We have not mapped the region between Barmaur and Kalhel, but from the strike we expect a connection of the Kalhel Syncline with the Barmaur Schuppen Zone.

Thus it is not only the lithological resemblance but also direct or indirect connection documenting the existence of only one conglomerate formation in Chamba. An exception may be the Bhaderwah area, where SHARMA et al. (1975) report two conglomerates, the Langera Conglomerate (= Manjir) and the Agglomeratic Slates.

From the above considerations we agree with GRASEMANN (1993) that the Manjir Conglomerates are interstratified in the Haimanta complex and therefore are Late Proterozoic in age.

Now the question arises how we have to interprete the Sach Pass-Kalhel section. In his traverse FUCHS (1975) took the Manjir Conglomerates as Agglomeratic Slate Formation because of the great lithological resemblance. This correlation appeared suggestive particularly because of the close association with the Panjal Trap and the fossiliferous Upper Palaeozoic–Triassic series of Kalhel (DATTA & BHATTACHARYYA, 1971; FUCHS & GUPTA, 1971; RATTAN, 1973). Accepting a Late Proterozoic age of the conglomerates implies a huge gap at the base of the Upper Palaeozoic–Mesozoic formations. RATTAN (1973) described an unconformity between the Manjir Conglomerate and the succeeding Salooni Formation (Upper Palaeozoic). From his photo (Text-Fig. 4B), however, we suspect that a local shear plane developed along the limestone-pelite boundary was mistaken as stratigraphic discordance.

A gap between the Haimantas and the Permian–Mesozoic formations of the Tandi Syncline is recently documented by VANNAY (1993). With GRASEMANN (1993) we assume a gap of similar stratigraphic range in the Kalhel Syncline. To the NW of Kalhel near Bhaderwah SHARMA et al. (1975) discerned the “Langera Conglomerate” below Syringothyris Limestone (Lower Carboniferous) – Fenestella Shales (Middle Carboniferous) and Agglomeratic Slates (Upper Carboniferous). The Langera Conglomerate seems to be the direct northwestern continuation of the Manjir Conglomerates. SHARMA et al. (1975), however, regard their Langera Conglomerate as Carboniferous.

In SE Kashmir RAINA et al. (1990) describe diamictites (Zor Member of Ramsu Formation) which seem to correlate to the Manjir Conglomerates of Chamba. The diamictites are overlain by the Zilant Formation, from which these authors report microfossils of Precambrian–Cambrian age. This appears as an evidence for a Proterozoic age of the so widely extended boulder slates, but the fossils, in our view, are rather doubtful.

Regarding the tectonics the sedimentary series of the Chamba Synclinorium are intimately connected with the Central Crystalline (High Himalayan Crystalline) of the Zanskar Range and Chandra Valley. There is a gradational increase in metamorphism and thus a passage from the sedimentary series into the crystallines (FUCHS, 1975; GRASEMANN, pers. comm.). Therefore it is not possible to construct a thrust between the sedimentaries and the underlying crystallines. THAKUR et al. (1990), PAUL & PAUL (1993), and SINGH (1993) assumed the existence of a tectonic plane (termed Tethyan Thrust, Haimanta Thrust, and Chamba Thrust respectively), along which the sedimentaries of the Chamba Synclinorium should have been thrust from Ladakh onto the crystallines. This idea has to be dropped: The Central Crystalline and overlying sedimentary sequence of the Kashmir- and Chamba Synclinoria form one structural unit, the Crystalline Nappe. The root of this unit is the Zanskar Range. As shown by the Kishtwar Window (FUCHS, 1975) the named synclinoria and their crystalline base are allochthonous, resting on the Lesser Himalayan units.

The high-metamorphic series, which form the lower parts of the Crystalline Nappe, are framing the epimetamorphic Chails of the Kishwar Window. In the frontal portions of the Crystalline Nappe the high-grade metamorphics are missing. There epimetamorphosed sedimentary formations intruded by granites rest on epi- or non-metamorphosed units of the Lesser Himalaya. The thrust at the base of the Crystalline Nappe is known as Panjal Thrust in the frontal ranges of the western Himalaya – it is identical with the MCT.

The granites of the frontal portions of the Crystalline Nappe, which form the backbone of the Dhauladhar Range, belong to the 500 ma group of granites (JÄGER et al., 1971; BHANOT et al., 1975; LE FORT et al., 1986).

9. The Lesser Himalayan Front at Dharamsala

In Chamba the Crystalline Nappe has vast extension and its front is very close to the Tertiary Zone. Like in Kashmir, Chamba represents an axial depression and therefore the sedimentary series, which make up the upper portions of the Crystalline Nappe, are preserved from erosion. The Lesser Himalayan units crop out in a narrow band at the foot of the Dhauladhar Range between the granite and associated metasediments of the Crystalline Nappe and the Tertiary Zone.

The granites of the Dhauladhar Range are connected by magmatic contacts with the underlying phyllitic schists and metasiltstones. These show gentle NE dip. Along a vertical disturbance they abut against crushed green and purple, schistose volcanics. These rocks are approximately 100 m thick. Among them a 4 m block of cataclastic, white quartzite was observed. The association of volcanics and quartzite reminds of the Nagthats of the Bhowali area, NE of Nainital in Kumaun. However a correlation with the Panjal Trap can not be excluded. The occurrence of basic volcanics seems to be identical with the Samot Volcanics (CHAKU, 1972) or Dharamsala Traps (SURENDAR KUMAR & MAHAJAN, 1991).

The volcanics are vertical. They are succeeded by steeply SW-dipping alternating blue to black, well-bedded limestones, black slates, and layers of earthy sandstone. The series, about 200 m thick, seems to represent the Eocene Subathus. Then follow 60–80 m of black slates and 100–200 m of resistant, white to grey dolomite and pink to red, banded limestones and marls. These rocks correlate to the Shali Slates respectively the Shali Carbonates (Mundi Dolomite [CHAKU, 1972]; Dharmkot Limestone [SRIKANTIA & BHARGAVA, 1976]).

These typical Lesser Himalayan formations are followed by steeply SW dipping, thick-bedded, grey, green, fine- to medium-grained, rarely coarse-grained sandstones with varicoloured shale layers. Clay gall breccias are not rare in the sandstones; these show earthy weathering surface.

According to the map by DHAR & JHA (1978) these series are Middle Siwaliks. In this case the thrust separating them from the Shali Carbonates correlates to the Main Boundary Thrust, which is accepted also by SURENDAR KUMAR & MAHAJAN (1991). To one of us (G.F.) the lithology is similar to the Murrees of the Kashmir-Jammu foothills. If this is right the thrust would correspond with the Murree Thrust and the MBT is to be expected further SW. This view is in agreement with GUPTA & THAKUR (1974) who refer the rocks in question as Dharamsala Group correlative to Dagshai and Kasauli Formations.

The Tertiaries dip towards the SW in the upper parts of the township of Dharamsala (Macleodganj). After a fault the dip is towards the NE in the lower parts of the town.

Discussion

It may be said that generally the Tertiary series dip towards the N beneath the older formations of the Lesser Himalaya. The latter override the Tertiary Belt along the Murree-, Main Boundary Thrust or other tectonic planes. In Dharamsala the tectonic boundary between the Tertiaries and the Shalis correlates with the MBT or the Murree Thrust as termed by WADIA (1928) in Punch. It is surprising that the Tertiary rocks overlie the Lesser Himalayan units at Dharamsala with southwestern dip. This inversion seems to go back to late orogenic compressional movements.

The Lesser Himalayan units crop out in a very narrow band at the southern foot of the Dhauladhar Range. Their limited exposures are caused by the fact that Chamba represents an axial depression, where the Crystalline Nappe is preserved from erosion and therefore cover the lower units. This resembles to Kashmir or the Dandeldhura and Kathmandu regions in Nepal, where the Crystalline Nappes are rather extended in the Lesser Himalaya and almost reach the Tertiary Belt. Therefore the lower units of the Lesser Himalaya are largely covered and their outcrops are confined to a narrow zone between the front of the Crystalline Nappes and the Tertiaries.

The Lesser Himalayan units of Dharamsala are strongly disturbed. The Shalis, Subathus, and volcanics apparently do not represent a stratigraphic sequence, rather mixed tectonic slices. They dip steeply SW like the Tertiaries and thus are in an inverse position. This and their crushed character suggest that the disturbance was not caused by nappe transport but by late compression and vertical movements. In our view the MCT, or Panjal Thrust as it is called in this part of the Himalaya (THAKUR, 1992, p. 288), is not exposed at Dharamsala. This thrust at the base of the Crystalline Nappe is cut out by a vertical fault. Possibly also the Chail Nappes are cut out and therefore are not represented in our section. The vertical movements may be very young and probably are related to the strong uplift of the Dhauladhar Range. The young age of this upheaval is indicated by the geomorphology of the region: The altitudes of the Dhauladhar Range (about 5000 m) and its steep southern precipices several thousand meters down to about 2000 m. S of the vertical disturbance the hills around Dharamsala show a comparatively gentle geomorphology. We think that the difference in scenery is caused by very young movements, which have partly reactivated older lineaments. JAROS & KALVODA (1978) described several thrusts disturbing the already developed Quaternary relief of the Lesser Himalaya in eastern Nepal. In our view this is a general principle not confined to Nepal. It explains the steep southern faces of the Great Himalayan Range but also of the Mahabharat-, Mussoorie-, Dhauladhar- and Panjal Ranges. It is of great interest that Dharamsala is a very active seismotectonic zone with neotectonics, which was studied by SURENDAR KUMAR & MAHAJAN (1990, 1991) after the 1986 earthquake.

10. Conclusions

Our traverse from the Indus Valley in Ladakh to Dharamsala in the foothills gives a cross-section of the Himalaya. It is rather complete, inasmuch as it touches almost all zones from the Transhimalaya (Ladakh Range) in the N to the Tertiary Belt in the S. A few zones, however, are very much reduced such as the Dras-Nindam Zone or the Lesser Himalayan units, the latter are largely covered by the Crystalline Nappe; the Central Crystalline is not exposed in the section because the sedimentary series of Zanskar are continuous with the Chamba Synclinorium and thus the underlying high-grade metamorphics are hidden.

The Ladakh- or Transhimalayan Pluton in the N represents a magmatic arc in the active continental margin of Asia (Pl. 1, Geodynamic Setting). It was active during subduction of the Indian Plate from Mid-Cretaceous to the collision in the Eocene (SEARL, 1991; a.o.). The composition of the plutonic rocks is basic to acid with prevalence of intermediate rocks (FRANK et al., 1977; a.o.).

The sedimentaries of the Indus Basin transgress with molasse type rocks of Maestrichtian age on the Ladakh Pluton. The Upper Cretaceous sediments of the southern portions of the basin exhibit flysch facies overlying a Mid Cretaceous carbonate platform (Khalsi Limestone, GARZANTI & VAN HAVER, 1988). The flysch stage ends with the collision in the Early Eocene. The conspicuous red beds of the Gonmaru La Formation mark the change from marine flysch to thick continental molasse. In our section across the Indus Molasse the flysch is exposed in the anticline of Miru flanked by the red Gonmaru La Formation. The major part of the Indus Molasse Zone consists of young continental molasse deposits.

The sedimentation of the Indus Basin was put to an end in the Miocene. The molasse belt was folded and overridden by adjoining units along the counterthrusts.

The Dras Volcanics and Nindam Flysch represent an island arc and forearc series of mainly Cretaceous age. E of the Zanskar River this belt becomes highly reduced. In the Lato-Rumtse area just a few lenticular bodies of flysch occur associated with basic volcanics, carbonate klippes and ultramafitites. The latter belong to the ophiolitic melange of the Indus Suture Zone. The lenticular carbonates are of shallow-water type. They contain lapilli in large quantities, which indicates contemporaneous basic to intermediate volcanism. According to THAKUR & VIRDI (1979) the units of the I.S.Z. (Dras Unit and ophiolitic melanges) are better developed to the E of our section.

The Lamayuru Zone borders with tectonic contacts the units of the I.S.Z. respectively the Indus Molasse Zone. In the Omlung area decrease in carbonate content towards the N and the association with ophiolites suggest a primary contact of the Lamayuru Zone and the I.S.Z. (FUCHS, 1986). The dark argillaceous-calcareous sediments indicate an euxinic environment. They were deposited partly under turbiditic conditions in a marine basin and on the continental rise. Sporadic fossils and the interfingering with shelf sediments document a Triassic to Cretaceous, possibly even a Palaeocene age (SINHA & UPADHYAY, 1993) of the Lamayuru calcareous flysch. In western Ladakh a counterthrust separates the Lamayuru belt from the Zanskar shelf sediments, in eastern Ladakh, however, the original passage zone is preserved. In our section the Mesozoic Lamayuru flysch rests stratigraphically on the typical Palaeozoic succession of the Zanskar Shelf. It is significant that the large stratigraphic range of the Lamayuru Formation becomes reduced towards the S and is more and more replaced by shelf sediments.

The Nimaling-Tso Morari Dome is a big anticline exposing the northern edge of the Indian Continent. The Palaeozoic sequence shows the facies of the Tibetan-Tethyan Zone: Phe Formation (Precambrian flyschoid series intruded by 460 ± 8 ma granites [STUTZ & THÖNI, 1987]), Karsha Formation (schists and lenses of Cambrian algal dolomites), carbonates and dark pelites intertonguing with thick quartzite bodies (Devonian?), Lipak Fm. (Lower Carboniferous carbonates), Kuling Fm. (Permian quartzites, carbonates, and pelites), and basic volcanics correlating to the Permian Panjal Trap.

In the NE-flank of the Nimaling Dome the whole of the Mesozoics is represented in Lamayuru facies, whereas in the SW-flank only the Triassic shows this facies; the Kioto Limestone (Rhaetic–Dogger) to Eocene sequence corresponds with the development of the Zanskar Shelf.

The Nimaling Dome is the northernmost fold element of the Tibetan Zone of Zanskar. It appears that the Nimaling Dome has got its shape in a late stage of deformation long after collision, in the Miocene, when the Indus Molasse was folded and the counterthrusts became active. Such a counterthrust made the granite core of the dome override its NE-limb. Large anticlines at the very edge of the Indian continent are not rare (e.g. Gurla Mandata, Honupattan Anticlinoria). They seem to be the product of the final compression of the Indus Suture Zone.

Concerning the metamorphism we discerned three mineral zones in the metapelites: chlorite, biotite, and garnet zone. During this first regional metamorphism the foliation S_1 came into being, succeeded by the blastesis of plagioclase, biotite, and garnet. The schistosity S_2 is related to the formation of the Nimaling Dome and the counterthrusts.

Our work has shown that the ophiolite outlier in the upper Zara Valley S of Debring, which was reported by THAKUR & VIRDI (1979) and is shown in the maps of FUCHS (1986, Pl. 1, 2), actually is not existent.

The Tibetan Zone of Zanskar is composed mainly of Mesozoic shelf sediments deposited during the passive continental margin stage (GAETANI et al., 1986). As emphasized above the shelf series are still connected with the continental slope and basin series (Lamayuru Facies) in eastern Zanskar. In western Ladakh the original facies interfingering is disturbed by counterthrusts (Zanskar Thrust, FRANK et al., 1977). The Palaeozoic formations are exposed only in the marginal portions of the synclinorium – in the Nimaling Dome and adjoining to the Central Crystalline of the Great Himalayan Range.

The tectonics predominating in Zanskar are folding and imbrications. The vergency is prevailingly SW, locally NE (Toze Lungpa, Sarchu). Among the imbrications the Marang La Thrust is most important. It marks a change in facies which indicates a larger distance of transport. A comparable thrust in western Zanskar separates the Northern Zanskar Unit from the Tibetan Zone (sensu stricto) (FUCHS, 1982a).

As in earlier papers we are opposed to the concept of those geologists who regard the Zone of Zanskar as an allochthonous pile of nappes: The facies intertonguing in eastern Zanskar documents that the Lamayuru Zone, Nimaling Dome, and Tibetan Zone of Zanskar had their present relative position to each other from the beginning. This seems to be accepted by STUTZ (1988, Text-Fig. 15). It can be noted that the Lausanne geologists – though they still speak of "nappes" – show schuppen structures in their papers (STECK et al., 1993). Several of their original nappes and thrusts are dropped (e.g. "Langtang Nappes"). We emphasize that no outliers and windows exist in the alleged "Tethyan Nappe" zone. The fact, that the rock series on both sides of most "nappe boundaries" represent parts of one stratigraphic succession and that the metamorphism is not inverted (except in one case), is explained by the Lausanne geologists as re-established by later extensional tectonics (SPRING, 1993). Thus they assumed that the early phase nappe structures are completely obliterated by later deformation. That means that there are actually no observations documenting the early "nappe tectonics" (D_1, D_2).

The Sarchu Shear Zone is a lineament with extensional tectonics correlative to the Zanskar Shear Zone (HERREN, 1987). The block to the NE of the shear zone slumped down gravitationally and influenced the vergency of the folds in the rock complexes adjoining the shear zone: Whereas the tectonics are generally directed SW, near the shear zone NE-vergent folds, even recumbent folds of km dimensions, are an outstanding structural feature. We explain this as an effect of dragging. The shear movements started still under active regional metamorphism, probably contemporaneously with the MCT, and ended under cool, cataclastic conditions during the exhumation of the Himalayan Crystalline (BURG, 1983; BURCHFIEL & ROYDEN, 1985; COPELAND et al., 1987; HERREN, 1987; STECK et al., 1993).

In Lahul the Tibetan Zone of Zanskar and Spiti is continuous with the Synclinorium of Chamba. The sedimentary series are connected because the Central Crystalline, which separates them in most areas of the Himalayas, is hidden in the Lahul axial depression. There are only a series of granitic intrusions (about 500 ma) and low-grade metamorphism in the Proterozoic–Cambrian formations. The high-grade metamorphics of Spiti plunge towards the NW in the Rohtang area and are exposed again in the Zanskar Range.

The Chamba Synclinorium: The sedimentary series form one structural unit with the underlying crystallines. Whereas the sedimentaries of the Tibetan Zone are connected with the Central Crystalline – both being autochthonous – the crystalline and sedimentary series of Chamba repesent one allochthonous unit. In Kashmir WADIA (1934) has termed the correlative unit Kashmir Nappe.

Whereas the succession of the Kashmir Synclinorium reaches up into the Jurassic, the Chamba sequence is predominantly Precambrian to Early Palaeozoic. Only in the Synclines of Tandi and Kalhel Permo–Mesozoic formations are found. A gap at their base seems to comprise the major part of the Palaeozoic (Upper Cambrian–Carboniferous).

Generally folds directed SW are prevailing in Chamba. In the Barmaur area, however, imbrications are important. In the front of the Crystalline Nappe the intrusion of the Dhauladhar Granite is a prominent element. Like in the Kashmir Nappe the high-grade metamorphic series are missing in the frontal portions. It is an experience that in the frontal parts of the nappe the upper members of the sequence are predominant, whereas the lower ones are frequently missing. The basal thrust known as Panjal Thrust is identical with the MCT.

The Lesser Himalayan units crop out in a narrow belt at the foot of the Dhauladhar Range. The highly disturbed zone borders the Crystalline Nappe along a vertical fault. By this disturbance the Chail Nappes seem to be cut out. The squeezed zone is composed of crushed basic volcanics (possibly Panjal Trap), Subathus (?), Shali Slates and pink Shali Dolomites. These rocks dip steeply SW, which indicates inversion. The Tertiary series (Murree or Lower Siwaliks) also show SW inclination. Obviously this is an effect of late compression, which seems also to be responsible for the rapid uplift of the Dhauladhar Range, related neotectonics, and seismicity (SURENDAR KUMAR & MAHAJAN, 1990, 1991).

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