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Geological Observations in the Ladakh Area (Himalayas)

A preliminary Report

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Abstract

In Central Ladakh six zones parallel to the Indus Suture may be distinguished. From north to south they are:

1. The upper Cretaceous to Eocene Ladakh Intrusives which are predominantly tonalitic in character in contrast to the potassium rich granites of the Main Himalayas.
2. The Tertiary Indus Molasse, comprising a northern autochtonous (above the Ladakh Intrusives) and a southern parautochtonous belt (Hemis conglomerates). The basal parts of this Molasse are rich in granitoid components where the stratigraphically higher layers are rich in andesitic to dacitic volcanic components.
3. The Indus Flysch, containing a Upper Cretaceous to Paleogene section i.e. the Namica La Flysch and a lower section the Lamayuru Flysch that has yielded lower Mesozoic fossils.
4. The andesitic to basaltic Dras volcanics which in their western parts all contain pillow lavas and pyroclastics. The volcanics grade into a sedimentary facies towards the east.
5. Ophiolitic Mélange belts bordering the Dras volcanics, have been recognized for the first time. They are bounded by major thrust zones along which glaucophane schists and other crystalline rocks have been dragged up.
6. The Zaskar platform, consisting of a crystalline basement and overlaying Paleozoic to Mesozoic sediments.

In the first five of the above zones, regional metamorphism is only of zeolite to prehnite-pumpellyite grade. In zone six, the Zaskar belt, metamorphism increases from greenschist to amphibolite grade and cannot be related to the metamorphism of the first zones.

Successive north and then south vergent tectonic transport has been recognized in the area. The latter is documented by the presence of ophiolitic klippen (Spongtang Klippe) on top of the Zaskar belt. It is believed that subduction took place successively at least along two major sutures (Indus and Shyok).

These observations are incorporated into a tentative evolutionary scheme of the Himalayas in Central Ladakh.

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INTRODUCTION

The 2500 km long Indus Tsangpo Suture Zone divides the Himalaya from the Tibetan "block" and enters Indian territory in the Ladakh area (Fig. 1). From here to the west this is the only territory where this major structural element can at present be studied by "western" geologists. The Ladakh area has been opened recently to tourism and with this began a renewed geological investigation. The present report is based on mapping on a 250,000 scale obtained during a rapid but concentrated field campaign during October and November 1975 and, for a more generalized picture, on a study of enlarged 1 : 500,000 ERTS photography (AG). After the 7th November heavy snow falls closed the Zoji La, which had to be crossed on foot. Most of the rock samples were left behind. Only a part of this collection reached us after one year.

STOLICZKA (1865) and LYDEKKER (1883) were among the first geologists to visit the Ladakh area. STOLICZKA died tragically at the age of 36, when returning from the Karakorum Pass. An excellent account of the wider Ladakh area is given by LYDEKKER (1883), including previous investigations. His map is in certain regions even up to the present day. The Italian ex-

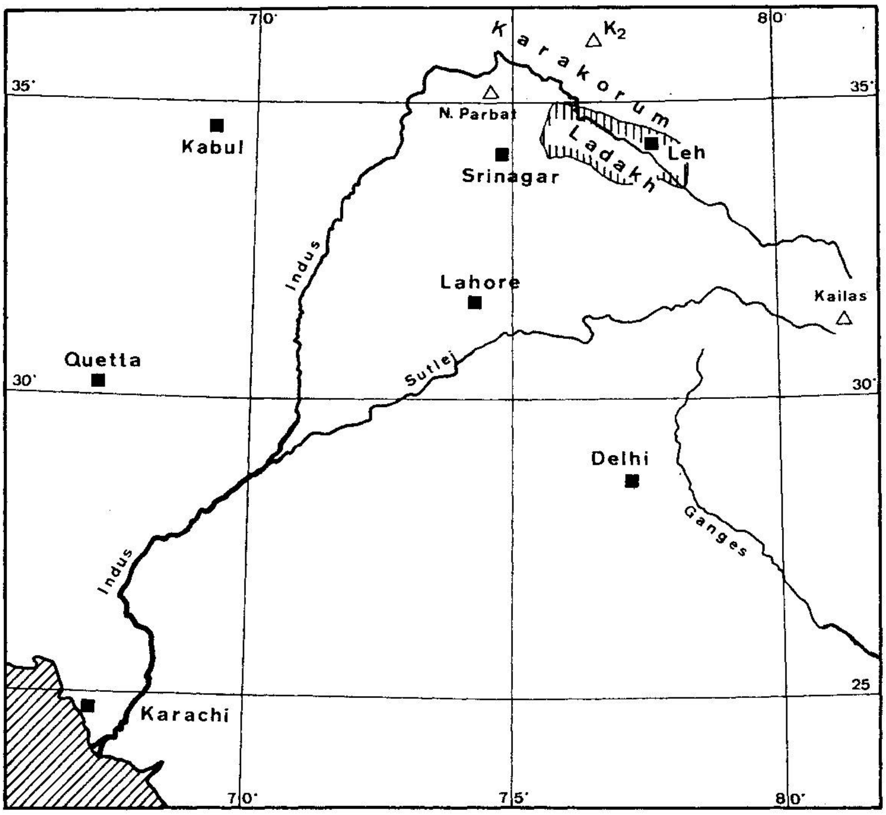

Fig. 1. Outline of the investigated area.

pedition by DE FILIPPI covered the area in 1913–1914, and a wealth of geological results was published by DAINELLI (1934). His map on a scale o- 1,000,000, partly based on LYDEKKER's previous work, is still a useful contrif bution. However, DAINELLI traced a Cretaceous band along the Ladakh granites and assigned a Cretaceous age to the transgressive Molasse since he did not recognize the tectonic contacts. He also discussed in detail the previous work by STOLICZKA, LYDEKKER and other workers. A comprehensive study with a valuable map is given by DE TERRA (1935), as results of the Yale University North India Expedition, and further information was published by WADIA (1928 and 1937). NORIN (1946), while exploring the Karakorum region, reached the northern border down to the Shyok river. AUDEN in his work "Traverses in the Himalayas" (1935) presents some geological information between Kashmir and the Karakorum. He did not separate the Dras volcanics from the Panjal traps. He continued from Kargil down to the Indus river and observed metamorphic basic and ultrabasic rocks intruded by granite at the confluence of the Indus and Shyok rivers. More recently BERTHELSEN (1953), who reached the Indus in the Rupshu district where he found a zone of exotic blocks, and TEWARI (1964) stressed the existence of an Indus Molasse. Finally, GUPTA and KUMAR (1975) reviewed the geology of the wider Ladakh area and SHAH et al. (in press) have given a most recent account on the stratigraphical and structural aspect of the Indus Suture belt of western Ladakh. Of greatest interest are the investigations of FUCHS (in press) carried out in 1976, dealing with the Spongtang Klippe in Zaskar and its relation to the Ladakh ophiolite belt. In spite of the considerable geological activity in the Ladakh area opinions vary widely as far as structural aspects are concerned. One reason may be the fact that no comprehensive maps have yet been published. Considering the geological importance of the Ladakh area, where one of the major suture zones of the world can be studied, this situation is somewhat unfortunate.

The authors studied the Ladakh area from Dras in the west to Upshi in the east. Unfortunately permission was not obtained to continue to the Puga area in the east, nor was it possible to cross the Ladakh range northwards into the Shyok area, where a second ophiolitic belt is suggested from the ERTS photographs, striking into the lower Shyok valley from the southeast. There the presence of a rock suite reminiscent of Ophiolitic Mélanges was confirmed by S. K. SHAH (verbal information). During our field investigations the irregular ultramafic outcrops with its associated blocks and lenses of radiolarites, carbonate and other rocks were recognized as Ophiolitic Mélange, bounded by tectonic contacts (GANSSER, 1974). Obviously the Mélange zones need to be separated from the Dras volcanic belt, which brings a new structural aspect into the Ladakh area.

Our preliminary observations are only limited and have no regional character. The following results must be viewed accordingly. We propose the following major subdivisions from north to south:

1. The Ladakh Intrusives.
2. The Indus Molasse, subdivided into a northern autochtonous belt and a southern parautochtonous zone (Hemis conglomerates) with lateral lithological facies changes.
3. The Indus Flysch subdivided into a upper Cretaceous Paleogene section: the Namika La Flysch and a lower Mesozoic part: the Lamayuru Flysch.
4. The Dras Volcanics with a predominantly volcanic facies and an easternwards increasing sedimentary facies.
5. The Ophiolitic Mélange belts, and finally.
6. The Zaskar zone with a sedimentary and an underlying crystalline unit.

1. THE LADAKH INTRUSIVES

These are generally also known as Ladakh Granites and form part of a conspicuous belt north of the Indus – Tsangpo Suture zone, which can be followed intermittently from east to west for over 2000 km. Their general composition is regionally surprisingly constant, varying from tonalite and granodiorite to granite, although locally the petrological aspect is much more complex. In the Kargil area, for example, a mafic complex is found ranging in composition from gabbro, gabbronorite and gabbroic anorthosite to diorite and tonalite. From structural relationships it is obvious that the more mafic rock types are older than the felsic ones (Fig. 2). Variations in composition and accompanying transitions from one rock type into another have mainly been observed among the mafic members of the suite. In many areas felsic and mafic dykes are found to crosscut the intrusives. Although some authors (S. K. SHAH, 1977) have invoked two separate episodes of igneous activity

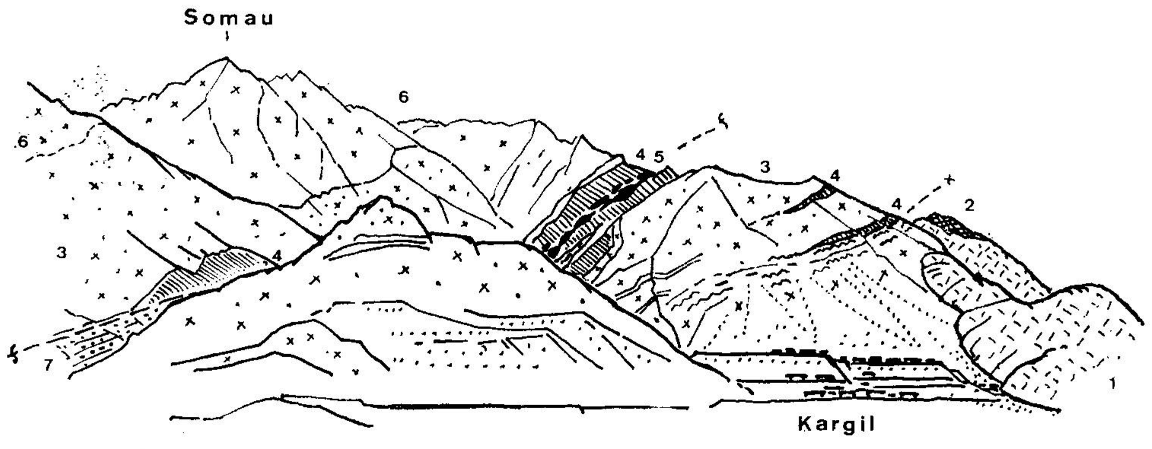

Fig. 2. The northern slope of Mt. Somau. View towards SSW. 1 anorthositic gabbro, 2 olivine gabbro to peridotite, 3 tonalitic granite, 4 metamorphosed Dras volcanics, 5 Ophiolitic Melange zone, 6 Somau granite, 7 Molasse.

we have not yet found any evidence to believe that the whole intrusive suite of Ladakh does not belong to one major plutonic event. In the area of Kargil the Ladakh plutonics intrude the Dras volcanics and all the rock components of the northern Ophiolitic Mélange zone. On the other hand arkosic sandstones and conglomerates belonging to the tertiary Upshi (-Kailas) conglomerate (HEIM and GANSSER, 1939) are found to unconformably overlie the erosion surface of the intrusives at Kargil and Upshi. These conglomerates contain, of course, pebbles of the Ladakh intrusives.

In addition to late thrusting, deformation of the Ladakh plutonics has been observed on a mesoscopic to macroscopic scale in several areas. For example, near Leh a schistosity striking parallel to the Indus zone is observed in the tonalites. Later felsic and mafic dykes were also affected by this deformation. Although by no means pervasive, signs of this deformation of the Ladakh intrusives are also recognized in thin section. Intensive bending of feldspars in the Kargil gabbronorites and diorites is not uncommonly observed, whereas the more granitic types tend to develop mortar textures.

All samples of *gabbroic rocks* were collected from a gabbronorite complex west of Kargil and may thus not be representative of other Ladakh intrusives. The gabbros and gabbronorites locally show mineralogical layering but more commonly seem to grade irregularly into each other. They sometimes contain anorthositic schlieren with more than 80% plagioclase. In contrast to the dioritic rocks of the area the plagioclase is weakly zoned and was found to range in composition from An 70 to An 90. Olivine, orthopyroxene and clinopyroxene in some of the specimens show spectacular reaction textures, the pyroxenes being converted into early brown and later actinolithic amphibole, whereas olivine is occasionally rimmed by orthopyroxene and hornblende. Spinel was found in a number of specimens together with amphibole to replace augite. The late actinolite and epidote that occur along veins and shear planes may be ascribed to a regional metamorphic event. The other features are more likely due to reactions that occurred during slow cooling of the complex. The only metamorphism on a regional scale that can be recognized in the area is at highest subgreenschist grade. The gabbroic rocks show gradual transitions into *diorites and tonalites*. Again most of our samples are from the Kargil area and were sampled from the west, north and east slopes of Mt. Somau. The dominant mafic constituent is hornblende and transitions into holomelanocratic hornblendites were not uncommonly observed. In many of the dioritic rocks primary relic augite was found within the hornblende. Some of the more leucocratic rocks contain also appreciable amounts of biotite. Plagioclase often contains irregular cores of bytownite, grading down to An 30 in the rims. Secondary actinolite and epidote were commonly observed in the diorites. The mafic rocks are cross-cut along sharp contacts by

Granitoid rocks. Unfortunately only a few samples of our collection have arrived in Europe. As far as can be told from these samples they compare well with the granitic rocks of Mt. Kailas (Heim and Gansser, 1939). They are predominantly hornblende bearing granites to granodiorites. Chloritisation of hornblende and in some samples saussuritisation of plagioclase indicate also for these latest intrusives a weak regional metamorphic overprint. This, of course may not apply to all granitoid rocks of the Ladakh/Karakorum range.

Contact metamorphism. Contact metamorphism caused by the Ladakh intrusives has been studied particularly at the north- and northwest slopes of Somau Peak, south of Kargil. The contact metamorphic aureoles observed in this area are only a few hundreds of meters wide. The Dras volcanic suite is converted into biotite-epidote-plagioclase-hornblende hornfelses and in the immediate vicinity of the contacts into pyroxene hornfelses. At 3500 m north of Somau Peak the members of the accompanying Mélange zone are contact-metamorphosed. Serpentinite yields cummingtonite + anthophyllite + olivine and talc-olivine hornfelses both containing ferrit-chromite plus chlorite. In these rocks secondary biopyroboles (Veblen, 1976) have been observed. The carbonate rocks of the Mélange in the same area and SE of Mt. Somau are metamorphosed into hornfelses containing wollastonite, anorthite, idocrase, grossularite and diopside.

2. THE INDUS MOLASSE

The Indus Molasse was first recognized as such by A. P. Tewari (1964), who compared it with the Kailas conglomerate in the east (Heim and Gansser, 1939), Tewari separates the Indus Molasse from the Cretaceous Indus Flysch, observing the tectonic nature of the contact.

We have subdivided the Indus Molasse into a northern belt, directly transgressing the Ladakh intrusives and a southern, more consolidated belt, well exposed at Hemis Gompa and therefore called the Hemis conglomerates. The Hemis conglomerates are steeply thrusted over the northern Molasse belt. They are also in thrust contact with the Ophiolitic Mélange zone, and with the Dras volcanics.

The transgressive northern belt is well exposed just west of Upshi in normal contact with the eroded Indus intrusives (Fig. 3, 4). The intrusives consist here of hornblende granite with a pinkish, more felsitic border. A few meter thick reddish arkose sits directly on the granite, followed by about 20 m of a very coarse poorly sorted but well rounded conglomerate with an arkosic matrix and predominantly granitic boulders. After about 20 m of granitic material other components appear while the pebbles decrease from head to fist size and the arkosic sandstone fraction increases. In the middle part a

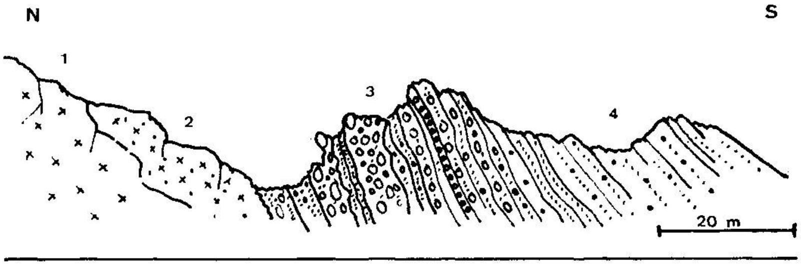

Fig. 3. Transgressive contact of basal conglomerate (Molasse) on Ladakh granite, W of Upshi. 1 tonalitic granite, 2 pinkish felsitic granite, 3 conglomerate with large irregular granitic boulders (at contact locally red arkose), 4 conglomeratic arkose.

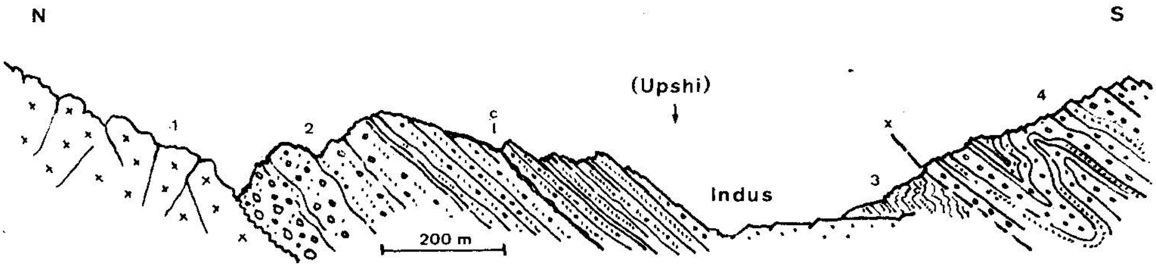

Fig. 4. The Ladakh Molasse in the Indus valley west of Upshi. 1 tonalitic granite, 2 basal conglomerate, C coaly shale band, 3 folded red beds of Basgo type, 4 isoclinally folded Hemis conglomerates thrust on 3.

thin coaly seam occurs, which however has not yielded any determinable flora. A rough pebble count gave the following distribution: granite 30%, vein quartz 30%, radiolarites 10%, carbonates 10%, volcanics 5–10%, gneiss ± 5%.

The crystalline components of the autochtonous conglomerate at Upshi show a rich variety. Although plutonic rocks and volcanics predominate a few low grade metamorphic components have also been recognized. By far most common particularly in the lower strata are pebbles of tonalite, granodiorite, granite and aplite-granite reflecting very well the variety of plutonic rocks displayed by the Ladakh intrusives. Also one pebble of gabbro was sampled. Some of the pebbles compare remarkably well with the components of the Kailas conglomerate and with granitoid rocks found at Mt. Kailas i.e. leuco-biotite-granodiorites (Heim and Gansser, 1939). A number of the granitoid rocks show signs of strain and weak metamorphism. In particular some granites with mortar textures of quartz around feldspar have been recognized. It is obvious from the structural relations in the conglomerate that these deformations must have predated the formation of the conglomerate. Some of the carbonate pebbles contain calcareous algae, ostracodes, echinoderms, various foraminifera, radiolaria, sponge spiculaes etc. None of the forms can give a definite age, but generally they seem to range from Permian to lower Cretaceous (dated by Beckmann). It is interesting to note that no post mesozoic fossils were observed in the carbonate rocks of this particular profile. Within the upper part of the northern Molasse belt a conspicuous red section can be recognized in various places. It is best developed at Basgo, where steeply eroded red silty shales and crossbedded soft pebbly green sandstones form a syncline below the Basgo monastery (Fig. 5). With a sharp fault contact a more consolidated section follows to the south with green micaceous shales and irregular sandstones of a more flyschlike

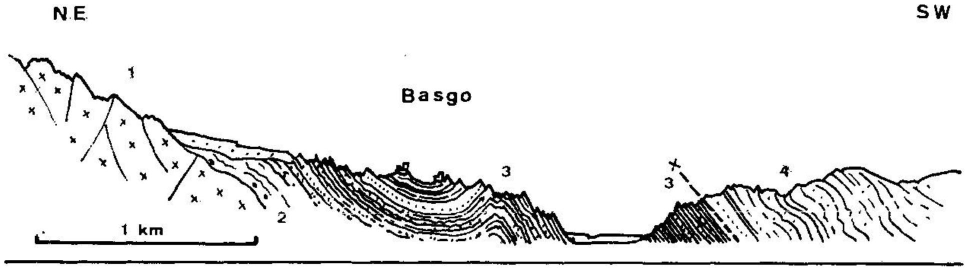

Fig. 5. The synclinal red beds at Basgo, Indus Molasse. 1 Ladakh granodiorite, 2 basal conglomerate, 3 Basgo red beds (red silty gypsiferous shales alternating with green pebbly soft sandstones), 4 green micaceous silty shales and irregular sandstones, flyschlike.

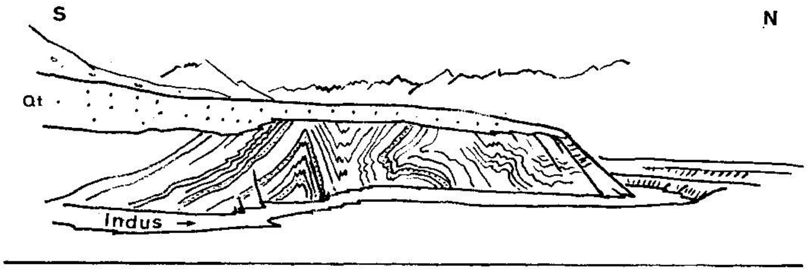

Fig. 6. Steeply folded flyschoid section topped by young terraces, just below the confluence of the Indus/Zaskar rivers.

aspect. They grade into a complicated sequence of hard sandstones, reddish shales and badly sorted greenish conglomerates. This section is well developed between Ronga La and Saspol. The slightly flyschoid aspect of this section is more apparent than real, caused by a very strong tectonisation a weak metamorphism and intricate folding (Fig. 6). These facies variations coupled with strong deformations are responsible for the general confusion of Flysch and Molasse and the reported transitions (Shaw, in press). The northern Molasse belt is again very well exposed in the Pashkyum area east of Kargil (Fig. 7). It outcrops in a somewhat different facies. Just below the thrust zone of Pashkyum follow thick bedded conglomerates alternating with thin layers of violet sandstones. The pebbles consist of fresh felsic volcanics and limestones, some rich in alveolinas and less frequent of siliceous slates and siltstones, quartzites and marbles, fine diorites, and rare aplitic granite. The suggested

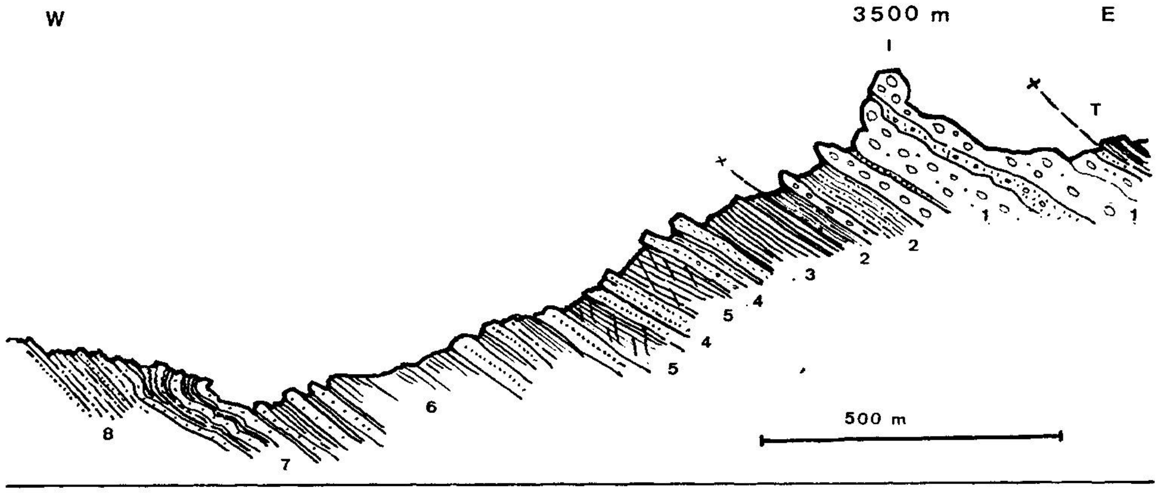

Fig. 7. The Molasse section north of Pashkyum. T Dras-Melange thurst, 1 upper conglomerate (Molasse), 2 red silty shales, 3 gray shales, 4 graywacky sandstones, 5 cleavaged hard gray shales, 6 violet silty shales and thin sandstones, 7 red marly siltes and white argillaceous sandstone, 8 olive shales and green sandstones (flysch type).

age of these carbonate pebbles is lower Eocene to lower middle Eocene (dated by Beckmann). Downwards the section becomes more argillaceous, olive gray and violet, with a marked cleavage forming locally pencil shales. This basal part which is much more consolidated seems to be separated by a thrust zone from the more conglomeratic-arkosic sequence transgressing directly on the Ladakh intrusions.

The Hemis Conglomerate: Separated by a steep thrust from the northern Molasse the Hemis conglomerates are most conspicuous through their outstanding sharp and constant layering, which forms one of the most characteristic morphological features of the central Ladakh area (Fig. 8). The Hemis conglomerates were studied in the Hemis gorge (Fig. 9). The single conglomerate layers vary from 2–10 m, divided by thin intercalations of phyllitic silts and fine sandstones. These intercalations often show synsedimentary complications (Fig. 10). The conglomerates are generally medium sized, the pebbles subrounded to rounded and often well sorted. Of particular interest are the *volcanic* components of the Hemis conglomerate. They range in composition based upon mineralogy from rhyolite through dacite to andesite and comprise lavas, volcanic breccias and agglomerates, tuffs and ignimbritic rocks. A great number of these volcanics in particular andesites are phantastically fresh. Other than in the pebble collection of Mt. Kailas (Burri, in Heim and Gansser, 1939) no predominance of acid volcanics was recognized. As at Mt. Kailas the whole collection of volcanic pebbles seems to fit quite well the compositional range of their plutonic counterparts within the Indus Molasse conglomerates. However, none of the volcanic pebbles collected is holocrystalline and thus their actual composition may differ from that determined by

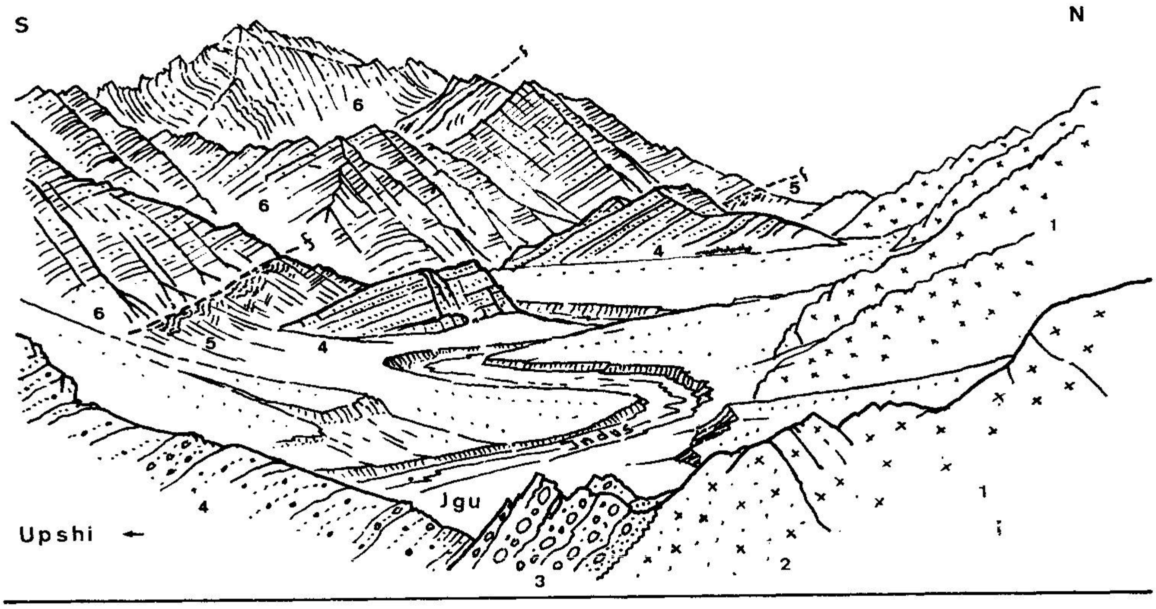

Fig. 8. The Indus valley west of Upshi. View to the West. 1 tonalitic granite, 2 felsitic granite, 3 basal conglomerate, 4 arkosic Ladakh Molasse, 5 folded red beds (Basgo type), 6 Hemis conglomerate wiht basal and internal thrust.

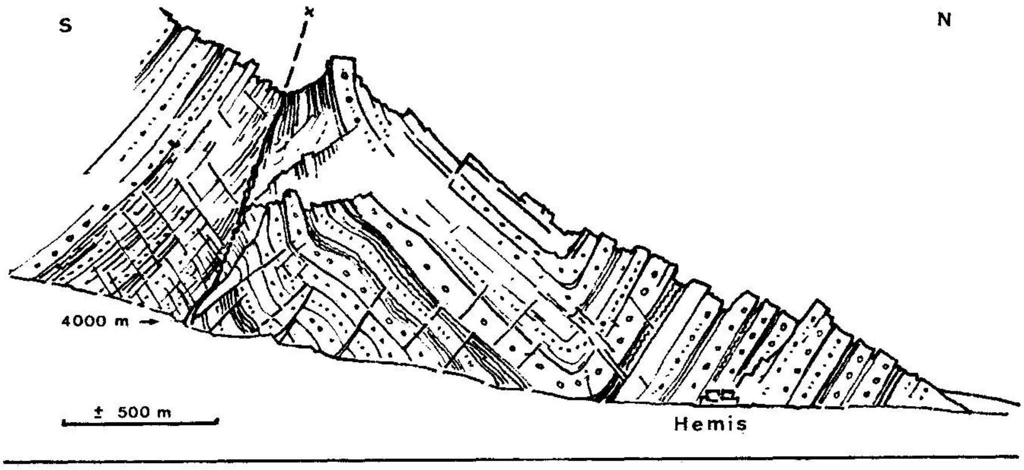

Fig. 9. The Hemis conglomerate section in the gorge of Hemis monastery.

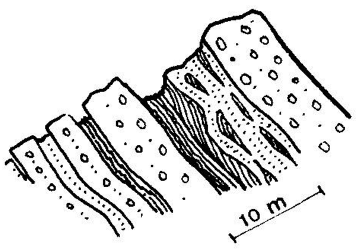

Fig. 10. Sedimentary details within Hemis conglomerate. Fine sandstone intercalations with shale nests.

microscopy. Among the phenocrysts quartz and plagioclase ± biotite dominate in the acid types and augite ± plagioclase in the more mafic ones, whereas hornblende, an otherwise quite typical component of many andesites was not detected. The collected pyroclastic pebbles show components from felsic rocks as well as from andesites together with vitreous types. Secondary zeolites, chlorite, epidote, amorphous silica and carbonates are found in the matrix. One sample of dacitic tuffite shows affinity to ignimbrite: In a fluidal textured matrix occur corroded breccia components of dacite and corroded crystal fragments of quartz, plagioclase and biotite. Metamorphic components are very minor and feebly metamorphosed. In our collection one sericite-chlorite-quartz schist and one albite-pumpellyite-actinolite-epidote rock was sampled. Following the Hemis gorge to the south, after passing a marked syncline, a steep thrust zone is encountered, where an older section seems to have been thrusted over a younger part. Here pebbles are less frequent, the granites decrease and volcanics increase. Also the matrix has a more volcanic admixture and exhibits a slight metamorphism to zeolite grade. More to the west, near Nurta in the Indus valley, the conglomerates are already somewhat thinned. They consist mostly of limestones, volcanics, radiolarites, quartzitic sandstones and vein quarz. The limestones represent quite different ages such as lower Eocene to Paleocene, upper Cretaceous, upper part of lower Cretaceous (mostly Aptian) and again Permian to lower Mesozoic similar to the pebbles near Upshi. No fossils younger than Lower Eocene were noted (dat. BECKMANN). Or collection of the crystalline components of the Hemis conglomerate at Nurta contains only a few plutonic and volcanic rocks. As in the Upshi conglomerates the intrusives consist of quartzdiorites and tonalites and the volcanics of dacites and andesites. Secondary epidote and chlorite are more common here than in the basal conglomerate collection and may reflect a somewhat higher metamorphic grade.

The Hemis conglomerate is regionally folded and thrusted, and this increases the already considerable "normal" thickness of 3000–4000 m (Fig. 11). Further south. nummulitic limestone intercalations (already known to LYDEKKER, see also DAINELLI, 1934) suggest an Eocene age. The conglomerate

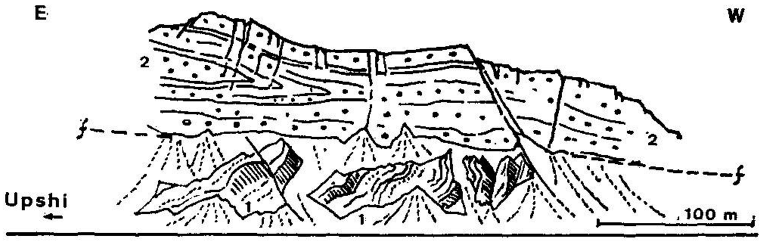

Fig. 11. Hemis conglomerates thrust on steeply folded red beds of Basgo type, W of Upshi. 1 highly disturbed red silts and sandstones with conglomeratic arkoses (Basgo type). 2 Hemis conglomerate, locally with isoclinal folds.

decrease towards the west. In the Kargil area they are no longer visible when their tectonically reduced continuation is probably covered by the Dras/Ophiolitic Mélange thrust zone.

3. THE INDUS FLYSCH

From the contributions by Dainelli (1933–34), De Terra (1935), Wadia (1937), Tewari (1964), Pande and Gupta (1971), Gupta et al. (1975) and others, it is obvious that this section forms the most controversial part of the Ladakh area and our preliminary observations are far from solving the problem. We noted above how certain sections discussed under the term Indus Molasse have some flyschoid aspects. We prefer, however, to limit the Indus Flysch to a zone roughly between the Dras volcanics in the north and the Zaskar thrust in the south, excluding the conspicuous mélange belts.

Within this zone we distinguish two types, differentiated lithologically and by age: the *Namika La Flysch* and the *Lamayuru Flysch*. It was not possible to find a clear separation of these two types in the field. The indicated boundary shown on our sketch map is arbitrarely drawn.

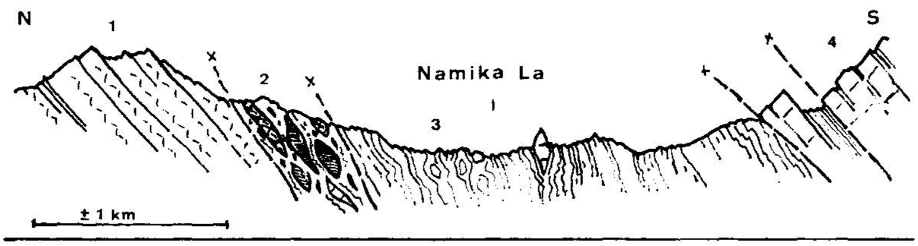

Fig. 12. Composite section through Namika La. 1 Dras volcanics, 2 Ophiolitic Melange belt, 3 Namika La Flysch with exotic limestone blocks (Trias), 4 north front of Zaskar thrustzone.

The Namika La Flysch consists mostly of monotonous, phyllitic, olive coloured shales and silts with fine, often graded sandstones. Conspicuous are intercalations of blocks and lenticular (boudinaged) zones up to a few kilometer long "exotic" limestones (Fig. 12). They are well exposed from Fotu La westwards, where they form the strikingly steep spectacular cliffs crowned by the monasteries of Bod Kharbu and Mulbeck. At both places already De Terra (1935) has observed megalodon and corals suggesting an upper *Triassic* age (Kioto limestones). Our own investigations from Mulbeck, based on algae, foraminifera, small diplopora and hydrozoa suggest predominantly a Norian age (dat. Beckmann). The gray limestone block containing the famous statue of Miatreya is reported to be of Permian age (S. K. Shaw, verbal information). The limestone is locally brecciated and slightly marmorized. It represents a Kioto limestone facies somewhat different from the Trias limestones and dolomites of the Zaskar thrust front and seems exotic to the nearer surroundings.

In the eastern part of the same belt, east of Fotu La, we distinguish the *Lamayuru Flysch.* Its type locality is the famous Lamayuru monastery. This Flysch consists of dark gray, phyllitic, silty, often calcareous shales with fine graded sandstone layers and well preserved flute casts. At a well exposed roadcut just north and above the monastery, a more well bedded platy calcareaous silty slate section contains a rather well preserved fauna of Daonella sp. The deformation makes a specific determination difficult. Prof. H. Rieber believes that most likely *Daonella indica* is represented but *D. longobardica* or *moussoni* are not excluded. A probable Middle Ladinian age is suggested. FUCHS (verbal information) found southeast of Lamayuru a Ceratites and belemnites. The Lamayuru Flysch may thus range from Triassic to Lower Jurassic. Graded bedding north of Lamayuru indicates a younging of the Flysch from north to south. Possibly the Namika La Flysch follows above Lamayuru, but the relations are not yet clear.

4. THE DRAS VOLCANICS

The Dras volcanics constitute one of the major geological features of the Ladakh area. In its lithologic complexity they are not unlike the Panjal Traps except for their younger age, and in general stronger tectonization and metamorphism. AUDEN (1935) has made no distinction between these two groups, while traversing from Kashmere to the Karakorum. The Dras volcanics begin in the eastern Ladakh area with a larger sedimentary part and continue westwards, where the volcanic facies dominates. The pronounced facies change is well exposed in the gorge between Lamayuru and Khalsi (Fig. 14). The Dras volcanics are not known further east along the Indus-Tsangpo-Suture zone but continue westwards around the western syntaxis

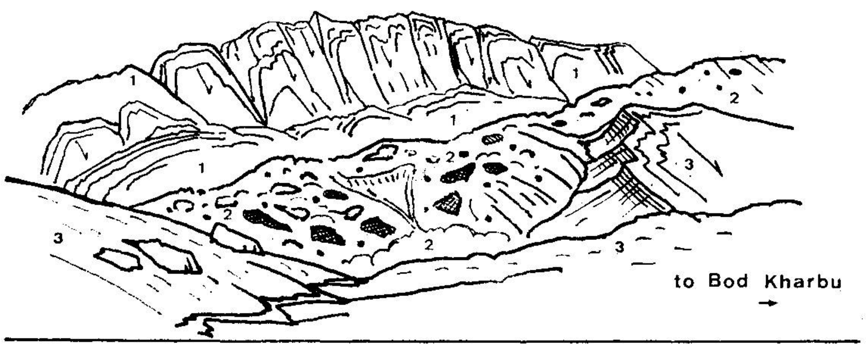

Fig. 13. The Dras and Ophiolitic Melange belt seen from east of Namika La. View to north-east. 1 South dipping Dras volcanics, 2 Ophiolitic Melange, 3 "transgressing" Flysch belt with some exotic blocks.

(Nanga Parbat spur) as a highly metamorphosed belt (Wadia, 1937; Misch, 1936). Between siliceous sediments practically free of volcanoclastics to pyroclastic rocks, agglomerates, diabasic lavas and locally pillow lavas, we observe all types of transitions. Ultrabasics are so far not known as normal intercalations, except as tectonic slices but are mostly restricted to the Ophiolitic Mélanges. Locally limestone bands with Orbitolinas have been reported (Gupta and Kumar, 1975). These and upper Cretaceous faunas place the Dras volcanics between middle and upper Cretaceous. The few samples obtained of the Dras volcanic suite comprise low grade metamorphosed effusiva and corresponding dykes mainly augite andesites and basalts and hornblende-andesites, their volcanoclastic products plus interbedded metasediments. In all of our samples the vitreous groundmass is replaced by epidote, carbonates and chlorite. The plagioclase phenocrysts frequently show incipient saussuritization and hornblende and augites are often partly replaced by actinolite and chlorite. In samples from the road between Lamayuru and Khalsi assemblages with albite + actinolite + chlorite and prehnite + actinolite + chlorite indicate metamorphic conditions close to and below greenschist facies. Similar conditions hold for the section between the Suru and Dras valleys. In structurally well preserved variolithic rims from pillow lavas SE of Mt. Somau in the Suru valley, chlorite and calcite form the matrix and albite, quartz plus epidote the interiors of the varioles. Volcanoclastic sediments from the same area and from Kharbu south of Kargil contain the synkinematic assemblage calcite + chlorite + albite + actinolite and sometimes stilpnomelane. The whole Dras zone, however, deserves a much more detailed study. Contact metamorphosed Dras volcanics have been sampled in the area of the Somau Peak intrusives and were briefly described in a previous chapter.

5. THE OPHIOLITIC MÉLANGE

The Ophiolitic Mélanges (for its definition see Gansser, 1974) were recognized by us for the first time in the Ladakh area. They are of outstanding structural importance, as they reflect the deep seated disturbances within the Suture zone. They are best exposed in a broad band following the Dras volcanics in the south between Mulbeck and Lamayuru (Fig. 13). Here serpentinized peridotites, radiolarites and various limestone lenses and schists represent the typical mixed association with irregular rodingite bodies belonging primarily to the ultramafics. They are again clearly exposed along the Indus in the Khalsi region, where the classical orbitolina and rudistid limestone layers, already reported by Lydekker (1883), may belong to the Mélange band or still to the highly tectonized northern edge of the Dras volcanics (Fig. 14). Both Mélange zones limit the Dras volcanics on the south and north side

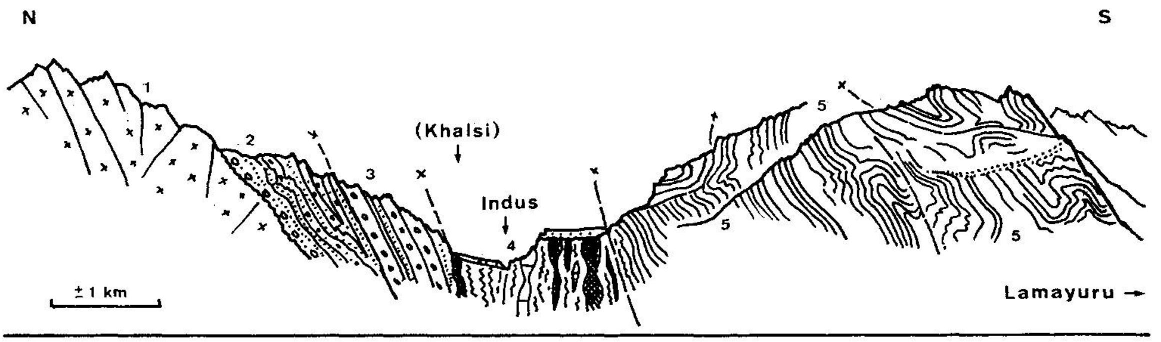

Fig. 14. Composite section between Lamayuru and Khalsi (Indus valley). 1 Ladakh granite, 2 basal Molasse and Basgo red beds, 3 Hemis conglomerate, 4 Ophiolitic Melange Zone, 5 Dras volcanics and pyroclastic sediments.

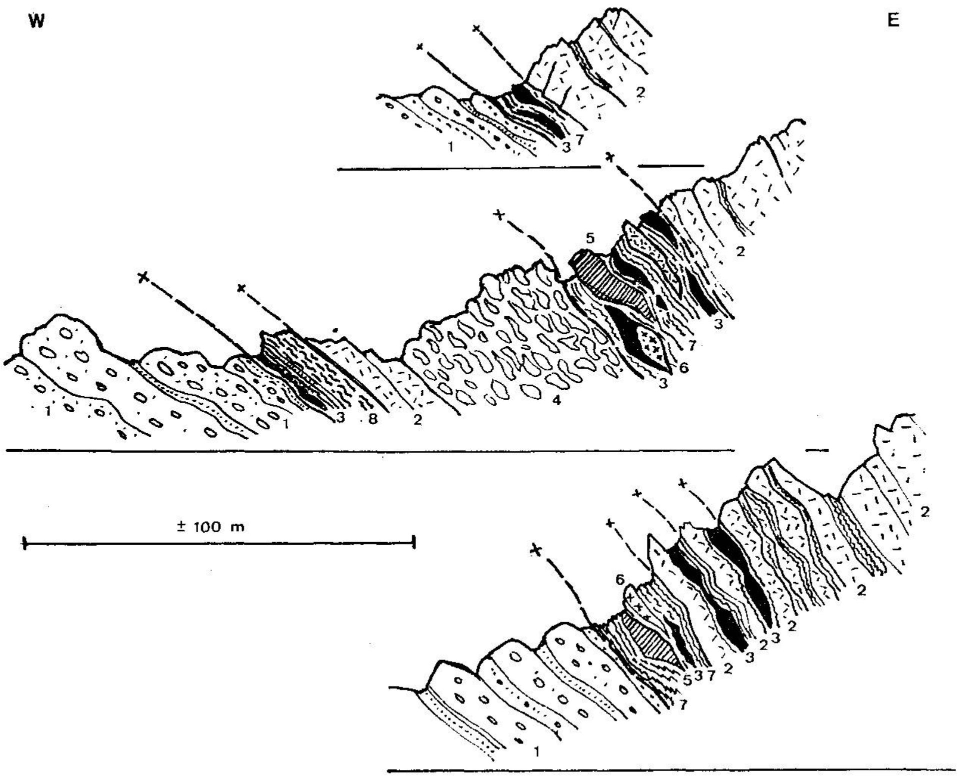

Fig. 15. Thrustcontact of Dras volcanics with Molasse, involving Ophiolitic Melange. 1 Molasse, 2 Dras volcanics, 3 serpentines, 4 pillow lavas, 5 radiolarites and red siliceous volcanics, 6 gabbros × × × and porphyries + + +, 7 phyllites (flysch type), 8 glaucophane schists.

respectively, where they are directly related to the steep thrust zone, in the south against the Flysch, in the north, against the Molasse. North of Shergol outcrops an excellent section of a reworked Mélange. The steeply dipping deposits are highly sheared, subfolded and larger components boudinaged. This section lies exactly between the Mulbeck Mélange and the Namika La Flysch. A further Ophiolitic Mélange zone appears just below the Zaskar thrust south of Lamayuru. Its extend seems however limited, but its location is again most significant.

One of the most obvious thrust contacts of the Dras volcanics on the Molasse zone with involved Ophiolitic Mélange can be studied northeast of Pashkyum, east of Kargil (Fig. 15). The Dras volcanics are partly imbricated with the Ophiolitic Mélange. The thrust on the Molasse is always sharp and the Molasse is very little affected by thrusting. A section of well developed pillow lavas occurs between elements of the Mélange. The latter are strongly tectonized and contain, apart from boudinaged serpentinite lenses of pyroclastic red radiolarites, strongly veined with epidote, some gabbro, diabases, felsic volcanic lenses and slices of crystalline rocks including glaucophane schists. The occurrence of such rocks that are otherwise not found in the area suggests a significant suture along the Schuppenzone. The transgressive tertiary sandstones are of zeolite facies grade, whereas our samples of fragments from the suture are of greenschist-glaucophane schist- and amphibolite facies grade.

One sample of *glaucophane schist* contains a prekinematic assemblage of weakly zoned, often broken crossitic glaucophane, ankerite, stilpnomelane, epidote and albite. This assemblage has been overprinted by syn- to postkinematic chlorite (along cracks in and replacing glaucophane, by calcite and actinolite. Other rock components from the same zone are *antigorite serpentinite* (nowhere else in the Mélange zone antigorite has been found) containing also brucite + magnetite and several samples of *mica schists and gneisses* containing quartz + muscovite + biotite + plagioclase.

A western continuation of the Ophiolitic Mélange thrust of Pashkyum can be recognized within the granodioritic intrusions southwest of Kargil, along the northern slopes of the Somau peak. Here, the outcrops are obviously not continuous. The intrusives are younger than the Dras volcanics and the Ophiolitic Mélange, but on the other hand, late thrusting related to those zones is post-granitic and the granites are strongly mylonitized. The rather inhomogenous intrusives near such contacts and the prolific dyke intrusions are related facts. A tentative north-south section and a general view west and south of Kargil shows complicated relations (Fig. 2 and 16). Various Dras volcanic inclusions expose intrusive contacts at one side and mylonized fault zones on the other. They first appear just to the south of the conspicuous uplift of basic anorthositic intrusives and border a first mylonite zone in the granites. The actual Ophiolitic Mélange thrust zone is recognized by lenticular serpentine bodies associated with highly tectonized siliceous slates with some cherty layers and lenses of sericite and muscovite schists. The latter reflect a higher metamorphism and correspond to the crystalline slices in the Pashkyum section with their glaucophane rocks. The Mélange belt borders metamorphic Dras volcanics, here with an intercalation of pyroxenite, which

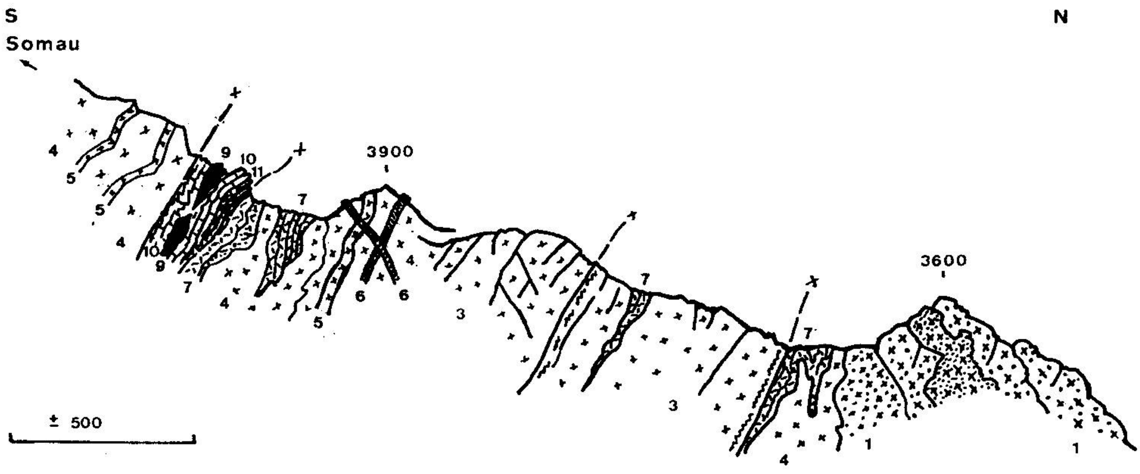

Fig. 16. Composite section across Mt. Somau north slope. 1 anorthositic gabbro, 2 olivine gabbro to peridotite, 3 tonalitic granite, 4 biotite granitoides (Somau type), 5 aplite dykes, 6 diabase (dolerite) dykes, 7 metamorphosed Dras volcanics, 8 pyroxenite, 9 boudinaged serpentinite, 10 calcschists and siliceous shales, 11 muscovite schists.

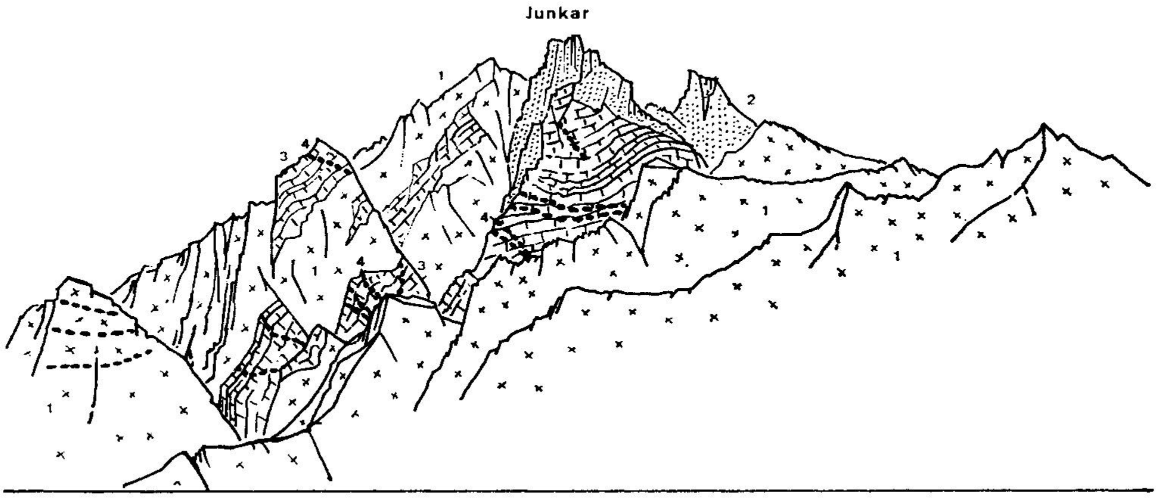

Fig. 17. The complex Junkar uplift within Ladakh granite N of Kargil. Observed from Pt. 3610 above Kargil. 1 Granodiorite to Gabbro, 2 metamorphosed Dras inclusions (?), 3 banded marble zones cut by granitic dykes, 4 acide dykes.

is cut by irregular aplite granites. Southwards follow, with a sharp tectonic contact, the Somau biotite granitoides. Along the contact they are strongly mylonized. Further complications are exposed in the Junkar Mt. N of Kargil (Fig. 17).

The regional metamorphic grade within the mélange zones does not differ notably from that of the Dras and comprises mainly assemblages below greenschist facies grade.

The ultramafic members of the Ophiolitic Mélange are mostly serpentinized. They are derived from spinel-harzburgites and less commonly from lherzolites and contain sometimes relics of orthopyroxene, olivine and clinopyroxene. The serpentine mineral in nearly all samples are chrysotile and lizardite. Various sections of rodingite from Mulbekh have been studied. Some of them show relic ophitic structures and relic pyroxenes from the original mafic dykes. The assemblage in the rodingites is epidote + actinolite + chlorite + diopside + grossularite ± albite ± calcite. The bordering zones of the rodingites contain the assemblage prehnite + chlorite + actinolite. Calcareous schists forming the matrix of the Mélange contain calcite + quartz + albite + muscovite and rarely stilpnomelane.

Of particular interest is a "Klippe" of probable Ophiolitic Mélange composition 25 km south of Fotu La in the middle of the Zaskar sedimentary basin. This occurence was discovered previously by La Touche and described by Mac Mahon (1901). He mentions serpentines and gabbros and stresses the similarity with occurences along the Indus valley. It is shown on Lydekker's map (1883), near Scirseir La, and has since been figured on all regional maps. G. Fuchs (Vienna), who visited the area during 1976, called this locality the Spongtang Klippe (Fuchs, in press). He kindly provided us with a specimen of ultramafics from this locality. He is convinced of its Klippen nature and similarity with the Indus Flysch and the Dras volcanics.

We obviously have here a structural equivalent, though on a much smaller scale, of the ophiolitic nappes well exposed in the Kailas region (Gansser, 1964 and 1974). The small chromite bearing ultrabasic outcrops at the northern Tso Morari (Berthelsen, 1953) may be in a structurally similar position. Considering the regional north vergence of the Zaskar mass, an Indus ophiolitic Mélange Klippe originating in the north and transported to the south is difficult to understand. It certainly suggests various, partly opposed phases of tectonic events. We were also able to sample boulders derived from these rocks at Bod Kharbu, east of Namika La. All specimens show intensive straining and in part mylonitic textures. They are spinel harzburgites that compare very well with samples from the Jungbwa Peridotite thrust on top of a Mélange Nappe (Heim and Gansser, 1939, Gansser, 1974). Enstatite is rich in clinopyroxene lamellae and shows intensive kinking and bending. Olivine is throughout kinked and forms a mortar texture around major olivine grains and around orthopyroxene. The lack of serpentinization and the freshnesss of these peridotites suggest a deeper seated origin and a tectonic history differing from that of the serpentinite lenses within the Mélange.

6. THE ZASKAR ZONE

The Zaskar range borders the Indus area in Ladakh on its south side and the contact is generally a sharp, north-vergent thrust, contrary to the general southern thrust direction in the Himalayas further south. The ERTS photography clearly shows how this is more or less parallel to the structural units of the Indus valley in Ladakh but obliquely to the internal structural trends of the Zaskar range, except for some adjustment towards the actual thrust line. For this reason we find different units bordering the thrust. In the east (Rupshu area) the crystalline north of the Tso Morari borders the thrust. Further westwards we find lower Paleozoic, then upper Paleozoic and finally Triassic rocks along its trend. This regional trend of the Zaskar thrust is broken in the Kargil area. Here a complicated spur of the Ladakh intrusives projects southwards with its structural complications visible along the lower Suru valley, which cuts through this area. The normal picture is resumed in the Dras area, where Triassic carbonate rocks are thrusted northwards over the Dras volcanics. We studied the Zaskar thrust only south of Fotu La and again south of Mulbekh. Following the Suru valley to the south, we also entered the crystalline part of Zaskar range towards the Nun-Kun area.

The sedimentary unit is well defined along the Zaskar thrust and the facies of the Paleozoic and Mesozoic rocks is different from corresponding age equivalents in the exotic blocks. South of Fotu La the probably Paleozoic to Triassic carbonates are steeply thrust over the Flysch. The platy, partly siliceous green, white and pinkish coloured dolomites and limestones display a very pronounced cleavage parallel to the thrust face, while the limestones are steeply folded. In the section south of Mulbekh the main thrust zone is complicated by two imbrications of similar limestones separated by highly sheared flysch type phyllites. The slaty siliceous limestones and dolomites expose intensely subfolded white, green and pink bands. No fossils were seen during the short investigation. The higher terraces trapped between the limestone wedges suggest a subrecent strong uplift, increasing towards the main thrust. *Crystalline rocks* of the Zaskar area were observed along the Suru river as far as to the foot of the Nun-Kun group. As already mentioned, this region is complicated by a northwards extending spur of the Ladakh intrusives and a break in the regional Zaskar thrust (Plate I). At Sanko the crystalline basement begins abruptly with a steep thrust on a flyschoid section with Mélange-type inclusions. This could represent a highly sheared Ophiolitic Mélange belt.

After the break at Sanko a continous increase in grade can be observed along the Suru valley profile. The first crystalline rocks comprise metagranitoid gneisses (Sanko) with garnet + biotite + epidote + microcline + albite + muscovite + quartz. Metasedimentary rocks contain calcite + quartz + albite + epidote + biotite ± garnet. Amphibolites from a few kilometers south (Chandra) have a bluegreen hornblende + epidote + albite + rutile. South of Chandra the feldspar in the calcarous metasediments becomes oligoclase and at Panikhar, further south and close to the Nun-Kun massive it turns into andesine.

The same is true for the mafic rocks, its feldspar at Panikhar is oligoclase. Also for other rock types the highest grades recognized so far are from a boulder collection south of Panikhar. Metapelitic rocks contain muscovite + biotite + garnet + poikiloblastic staurolite + kyanite + quartz + plagioclase. Dolomitic marbles have calcite + quartz + dolomite + tremolite. The metamorphism is syn- to postkinematic. Garnet and staurolite show s-shaped inclusions whereas crystallization of cross-micas is clearly later than the deformation.

SOME THOUGHTS ABOUT THE EVOLUTION OF THE INDUS TSANGPO SUTURE ZONE IN THE LADAKH AREA

The interpretation of the Indus Tsangpo Zone as the remnant of the former oceanic crust between Asia and the Indian subcontinent is now a widely accepted view. However, great differences still exist about the amount of shortening and the mode of producing the "double sialic crust" of Tibet and the Northern Himalayas.

Sea floor spreading data (JOHNSON et al., 1974) and palaeomagnetic data consistently point to a very great drift distance, although the position of the former southern border of stable Asia is disputed (see KLOOTWIJK, 1976). On the other hand the evolution of sedimentary facies in similar climatic zones have been advocated for a considerable closer proximity of the two continents but this argument remains ambigous.

The model discussed in this paper (Fig. 18) fits our field observations, it is the simplest possible, but of course tentative (compare DEWEY and BURKE, 1973, POWELL and CONAGHAN, 1975). The oldest dated rock sequence of the Suture Zone so far is the Lamajuru Flysch forming a part of the Indus Flysch. We assume that the flyschoid-pelitic sedimentation continued in the same zone from the Middle Triassic to the Lower Tertiary. No volcanic influence is known in this sequence, deposited adjacent to the Zaskar platform type sediments and separated from the Dras volcanics by the southern Mélange zone (see also FUCHS, 1977). Whereas the Zaskar sediments definitely rest on an old sialic crust, we have no information on which rock series the Indus Flysch was resting. In our model we assumed that a metamorphic basement if at all present was extremely thin, further to the N an older oceanic crust with thin sedimentary cover may have existed.

The Dras volcanics, basaltic to andesitic in composition, including Upper Cretaceous sediments developed in the northern part of the Indus Flysch zone. Without geochemical information it is difficult to decide whether they are related to an oceanic rift volcanism or to an island arc volcanism. From the association of the submarine Dras volcanics with some ultramafics, more

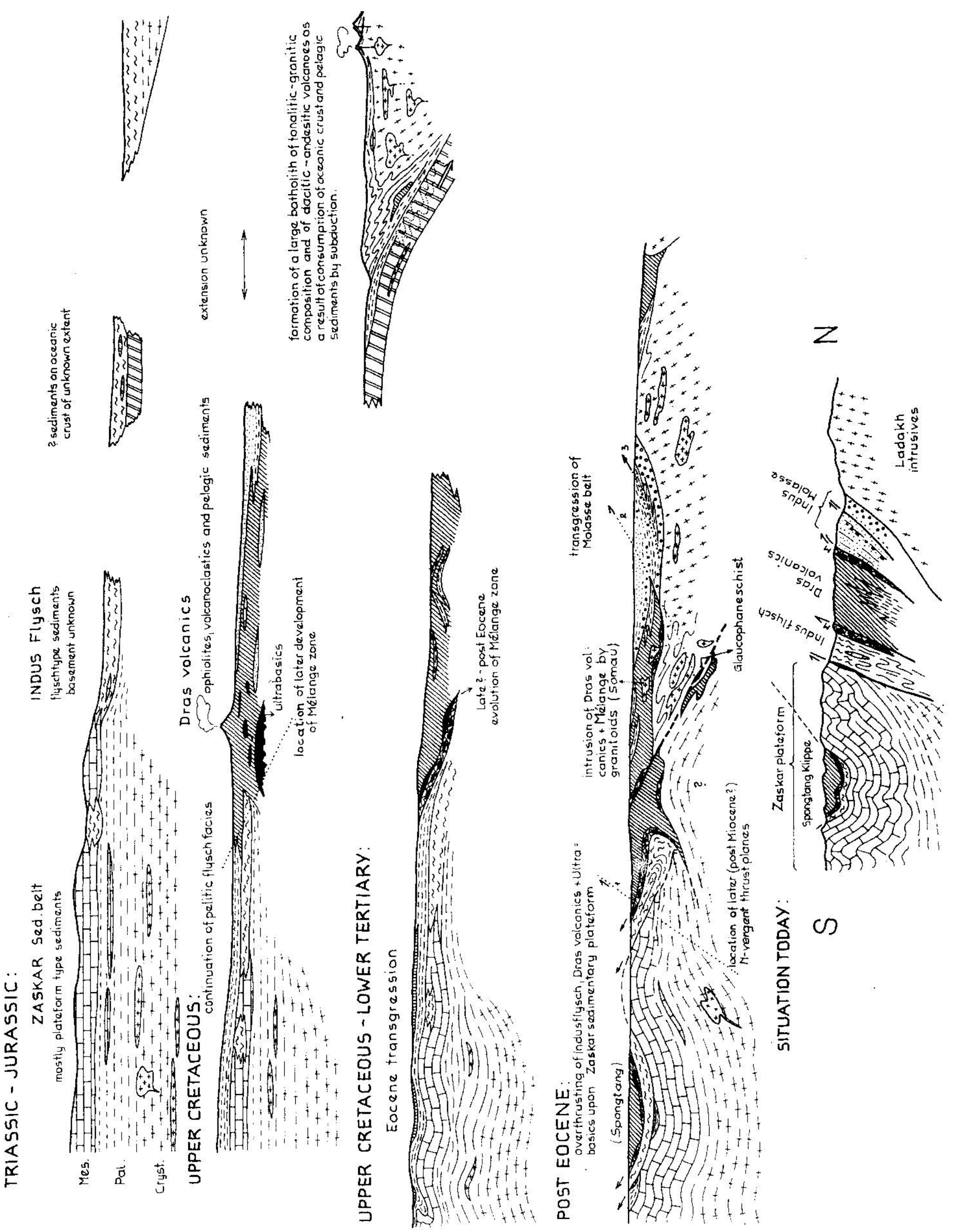

Fig. 18. Tectonofancyful (term introduced by BERTHELSEN [1976]) evolution scheme of the Indus-Tsangpo Suture Zone in the Ladakh area.

widely with deep sea sediments and from the later evolution of Mélange zones with mantle slices, we are inclined to prefer the first interpretation. Although the present occurrence of the Dras volcanics is limited to the westernmost part of the Indus-Tsangpo Suture Zone, the existence of the same volcanic sequence in the Spongtang Klippe (FUCHS, 1977) in the Zaskar mountains which is exactly analogous to the exotic nappes in the Amlang La area (HEIM and GANSSER, 1939) points to a much greater earlier distribution of the Dras series.

Although conclusive age determinations of the Ladakh intrusives are still missing, we are convinced from the field observations that this zone represents a continuous? Late Cretaceous – Early Tertiary magmatic event. They presumably formed by accumulation of intrusives as the result of the consumption of the former crust between India and the Asian continent. Most probably this consumption did not take place in a single subduction zone. Earlier and more northerly situated zones may have existed and became later inactive (e.g. in the Shyok area where basic volcanics are known along a lineament subparallel to the Indus Zone). It is an essential fact, that all the Early Palaeozoic and Late Alpine intrusives in the Himalayas are generally rich in Potassium and their initial Sr^{87}/Sr^{86} values are remarkably high (FRANK et al., 1976, HAMAT and ALLEGRE, 1976, MEHTA, 1977) indicating their origin from a recycled old sialic crust. Contrary to this the composition of the Ladakh intrusives and their volcanic counterparts is very different, essentially "intermediate" with K-feldspar only as a minor component. This fact was already recognized by HAYDEN, 1907. We would expect initial Sr-isotope values considerably lower than from the Himalayan granites. This then could suggest that the consumed crust was essentially oceanic and no major part of continental crust was involved until the last stages of evolution of the Ladakh intrusives. The oceanic crust may exceed 1000 km.

The complex structural history is shown in the lower sketches of the model (Fig. 18). The Mélange zones (GANSSER, 1974) on both sides of the Dras series developed in the late stages of convergence. Even major slices of ultramafics have been dragged into these tectonically highly disturbed zones. The large scale overthrusting of the Spongtang Klippe to the S is a pronounced post (? Middle) -Eocene tectonic feature which has its correspondence in the Amlang La area. The mechanism of this overthrusting is still not understood, but most probably is in close relationship with the final closure of the ocean by collision of the two continental masses which presumably ended before that time ($\sim$40 my), when also the drift rate dropped remarkably (MOLNAR et al., 1976). Somewhat later than this event the thermal peak of the Alpine metamorphism in the Himalayan Crystalline occurred in the Kulu-region (FRANK et al., 1976). According to DAINELLI (1933–1934) the Molasse sedimentation had began already by Eocene time which is very close to the end of the supposed collision. The nature of the pebbles indicate a clastic influence from both sides. The renewed convergence (±20 my) caused the pronounced N-vergent thrust planes in this area whereas in the southern Himalaya the large scale S-vergent nappes developed (MCT). Younger thrust planes, partly along Mélange zones, cut obliquely to older structures and so tiny relics of glaucophane schist were brought to the surface in the Kargil area.

Transformed to a narrow and steepened zone between thickened continental masses, except late strike slip movements the Indus Tsangpo Suture Zone then became inactive.

Acknowledgements

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