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INDUS-TSANGPO SUTURE IN THE HIMALAYA: CRUSTAL EXPRESSION OF A PALAEO-SUBDUCTION ZONE

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Abstract: The Indus-Tsangpo suture zone extending from Kohistan through Ladakh to southern Tibet represents the line along which the Indian plate embraced the Tibetan plate subsequent to its northward drift during the Mesozoic and collision during the Eocene. The Indus-Tsangpo suture zone is constituted by more or less parallel belts composed of rock types attributable from south to north to: 1) platform at the northern margin of Indian shield, 2) trench zone, 3) fore--arc basin, 4) magmatic arc, 5) back-arc basin and 6) platform at the southern margin of Tibet. These belts now occur with more or less vertical or steep tectonic junctions. The trench sequence of ophiolites and ophiolitic mélange exhibits metamorphism of high pressure blueschist facies whereas the magmatic arc and back-arc sequences together exhibit a low pressure-high temperature metamorphism. The two jointly constitute paired metamorphic belts. The glaucophane-lawsonite bearing rocks are widespread in Kohistan, Ladakh and Southern Tibet. These features indicate that the Indus-Tsangpo suture zone represents the site of an old subduction zone which lay at the southern margin of Tibet.

Key words: Indus-Tsangpo suture, tectonic evolution, palaeo-subduction, magmatic arc, paired metamorphic belts, Himalaya, southern Tibet, review.

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INTRODUCTION

The Indus-Tsangpo suture zone is one of the most fascinating regions in the Himalaya due to its unique position and broad spectrum of constituent petro--tectonic assemblages widely regarded as formed at and indicative of zones of crustal convergence or subduction. The Himalaya are regarded the type example of collision type orogenic belts (Dewey & Bird, 1970), the suture thus represents the line along which the Indian plate embraced the Tibetan plate subsequent to its northward drift during the Mesozoic and collision during the Eocene.

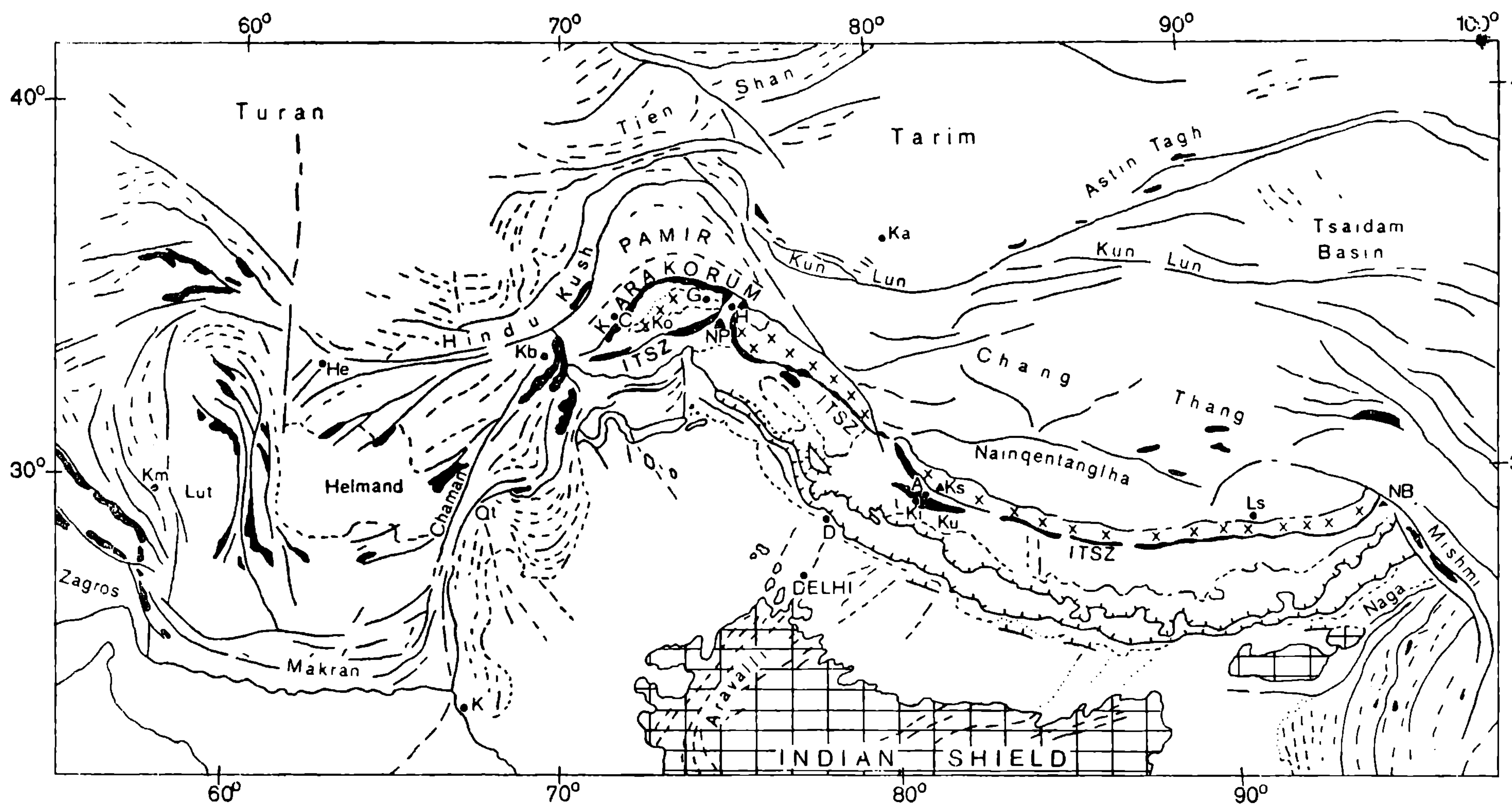

Fig. 1. Tectonic map of Himalaya and Tibet. Black – ophiolites; crosses – Trans-Himalayan plutonic belt; *Km* – Kerman, *He* – Herat, *K* – Karachi, *Qt* – Quetta, *Kb* – Kabul, *C* – Chitral, *Ko* – Kohistan, *G* – Gilgit, *H* – Harmosh, *NP* – Nanga Parbat, *Ka* – Khotan, *D* – Dehra Dun, *A* – Amlang La, *Ki* – Kiogad, *Ks* – Kailash, *Ku* – Kumaon, *Ls* – Lhasa, *NB* – Namche Barwa, *ITSZ* – Indus-Tsangpo suture zone (after Gansser, 1980)

The Indus-Tsangpo suture zone and its constituent lithotectonic belts can be traced more or less continuously from Kohistan region of Pakistan in the west through Ladakh in India and Kailash and Lhasa regions of southern Tibet in the east (Fig. 1). Stoliczka (1866a, b), Lydekker (1883), McMahon (1901), Kraft (1902) and Hayden (1904, 1907, 1916) were the earliest workers who presented preliminary accounts of the geology of the Indus-Tsangpo suture zone and the surrounding regions. Subsequent and notable contributions came from Dainelli (1933—1934), De Terra (1935), Wadia (1932, 1937), Heim & Gansser (1939), Norin (1946), Berthelsen (1953), Tewari (1964), Gansser (1964, 1966) and Gupta *et al.* (1970). Amongst the recent contributors to our knowledge of this important zone we have Gupta and Kumar (1975), Shanker *et al.* (1976), Shah *et al.* (1976), Frank *et al.* (1977), Gansser (1977, 1980), Virdi *et al.* (1977, 1978), Thakur & Virdi (1979), Thakur (1981), Farah & De Jong (1979), Thakur & Sharma (1983), Shackleton (1981), Jixiang (1981), *Science Press* (1981), Fuchs (1977, 1979, 1982), Coward *et al.* (1981a, 1982b), Wan (1982), Rai (1982, 1983), Virdi (1981a, b, 1983, 1984a, b), Thakur & Gupta (1984), Xuchang *et al.* (1983), Tapponnier *et al.* (1981), Tahirkheli (1982), Honegger *et al.* (1982), Searle (1983), Allégre *et al.* (1984), Schärer *et al.* (1984a, b) and Klootwijk (1984). As a result of these studies a more or less unified picture has emerged and it has been clearly established that the Indus-Tsangpo suture zone marked the northern boundary of the Indian plate and during its evolution, like other zones of subduction, it was characterized by not only a well developed system of volcano-magmatic arc, fore-arc and rear-arc basins and a trench, but also paired metamorphic belts.

The present paper discusses the geotectonic evolution of the Indus-Tsangpo suture zone and the role it played in the development of the Himalayan mountains, particularly within the Indian territory of Ladakh. An attempt is also made to compare the sequence of events in Ladakh with those in the western and eastern extension of the suture zone in Kohistan and southern Tibet, respectively.

LITHO-TECTONIC SETTING OF THE LADAKH REGION

The Indus-Tsangpo suture zone in Ladakh region extends as a longitudinal zone bounded by the Karakorum mountains in the north and Zanskar mountains in the south. The two mountain ranges are constituted by Phanerozoic shelf sediments deposited at the northern shelf of the Indian shield and southern shelf of the Tibetan landmass, respectively.

The suture zone is characterized by a number of lithotectonic belts composed of rock assemblages developed in different parts of a subduction zone and related volcano-magmatic arc. Table 1 presents comparative litho-tectonic setting of the suture zone in Kohistan, Ladakh and southern Tibet, while Figure 2 shows the areal distribution of these units in Ladakh region. A brief description of characters of various units is given in the sequel.

Table 1

Litho-tectonic setting in the Indus-Tsangpo suture zone (excluding Upper Tertiary transgressive molasse)

	Litho-tectonic unit			Age	Probable environment of formation
	Kohistan	Ladakh	South Tibet		
KARAKORUM	Karakorum Group	Karakorum Group	Nyainquentanglha Group	Precambrian to Cretaceous	Platform sediments and metamorphic basement at southern margin of Tibet
		— thrust —			
INDUS-TSANGPO SUTURE ZONE	Ynsin Group (Lower Cretaceous) (Burjila and Katazara Formations)	Shyok Group	Linzizong Formation Takena Formation	Late Early Cretaceous to Late Cretaceous	sequence of sediments and volcanics formed in back-arc basin behind magmatic arc and in front of Tibet
		Shyok Thrust —			
	Rakaposhi volcanics (Upper Volcanics) Kohistan plutonics Kamlla amphibolites (Late Jur.-Cretac.)	Khardung Formation Ladakh plutonic complex Dras Formation	Cretaceous-Tertiary Kangdese Volcanics Gangdese plutonic complex Sangri Group volcanics	Early Cretaceous to Eocene Jurassic to Early Cretaceous	complex of basic to acid volcanics and volcano- and pyroclastic sediments intruded by plutonic rocks developed as a volcano-magmatic arc at southern margin of Tibet
			unconformity/thrust —		
	?	Indus Group	Shiagaste (Xigaze) Group	Cenomanian or Aptian to Lutetian	flysch of the fore-arc basin
		— thrust —			
	Jijal ultramafic complex	Nidar ophiolites	Yarlang-Zambo ophiolites	Jurassic to Early Cretaceous	oceanic crust of the Tethys deformed and metamorphosed under high pressure-low temperature
		— thrust —	— thrust —		
	Bahrain pyroxene granulites	Shergol-Zildat mélange	ophiolitic mélange zone		
		— thrust —	— thrust —		
		Lamayuru Formation	Gongbala flysch mélange belt	Late Triassic to Early Cretaceous	wild-flysch and flysch at north margin of Indian plate
	Main Mantle Thrust —	— Zanskar Thrust —	— thrust contact —		
HIMALAYA	Salkhala Group (?)	Tethyan Phanerozoic sediments	Tethyan sediments	Palaeozoic to Cretaceous	platform deposits at northern margin of Indian plate

ZANSKAR MOUNTAINS

Zanskar Group

The Zanskar mountains to the south of the Indus suture zone are constituted by Phanerozoic Tethyan sediments which were deposited on the northern shelf of the Indian plate. These sediments rest on a basement of metamorphic rocks referred to as the Central Crystalline Complex of Proterozoic age. Though in general unmetamorphosed, the Tethyan sediments in some places exhibit metamorphism

Table 2

Stratigraphic succession of Zanskar mountains in Ladakh
(based on Thakur & Gupta, 1984)

Age	Name of Litho-unit	Lithological characters
Cretaceous	Chikkim	Calcareous shales and thin layers of limestone
Jurassic	Spiti Shale Formation	Black shales with ferruginous horizons Black nodular shales Carbonaceous and dark calcareous shale Dark grey to greyish black nodular shale
Triassic	Triassic	Kioto limestone Quartzite, shale and limestone (dolomitic splintry, concretionary or coralline) richly fossiliferous
Permian	Ralakung Volcanic Formation	Dark, green to grey green, fine- to medium-grained massive and amygdaloidal lavas and inter-trappean limestone Dark brown agglomeratic slates and conglomerates
Carboniferous	Luneak Formation	Grey limestone and quartzite locally intercalated with brownish calcareous and arenaceous shales. Fossils of brachiopods, crinoids, bryozoa, fishes and conodonts common
Devonian	Muth Formation	White quartzite locally gritty, hard, compact, with current bedding, ripple marks and dark ferruginous spots Upper part with thin dolomite layers, richly fossiliferous
Silurian	Tanze Formation	Thick sequence of gritty, quartzite shale and phyllite slate agglomerates Fossils of crinoids, brachiopods, trilobites and fish
Ordovician	Karsha Formation	Medium to coarse grained, dark to pale grey crystalline limestone, locally interbedded with quartzite, phyllite and greywackes. Fossils of trilobites and brachiopods
Cambrian	Phe Formation	Phyllites overlain by grey and greenish slates, locally pyritiferous Carbonaceous band and sandstone alternations also observed. Fossils of trilobites and brachiopods indicating Cambrian to Lr. Ordovician?
Precambrian (Proterozoic)	Zanskar (Suru) Crystalline Complex	Streaky gniesses, banded gneisses, mica schists, quartzites and amphibolites

transgressive up to Permian and Triassic rocks (Fuchs, 1982; Virdi *et al.*, 1978; Virdi, 1983). However, due to their prolific fauna and low degree of deformation and metamorphism, stratigraphy is well defined. Table 2 gives the stratigraphy of the Tethyan sequence in the Zanskar mountains of Ladakh region. This sequence continues in Lahaul and Spiti regions of Himachal Pradesh. In the eastern extension it continues into Kumaon, Nepal, Bhutan and southern Tibet.

Tso Morari metamorphic complex

In the southeastern extension of the Indus-Tsangpo suture zone in Ladakh (Fig. 2) a thick sequence of low to medium grade metamorphic rocks is exposed, forming a wedge shaped outcrop bound in the north and in the south by major

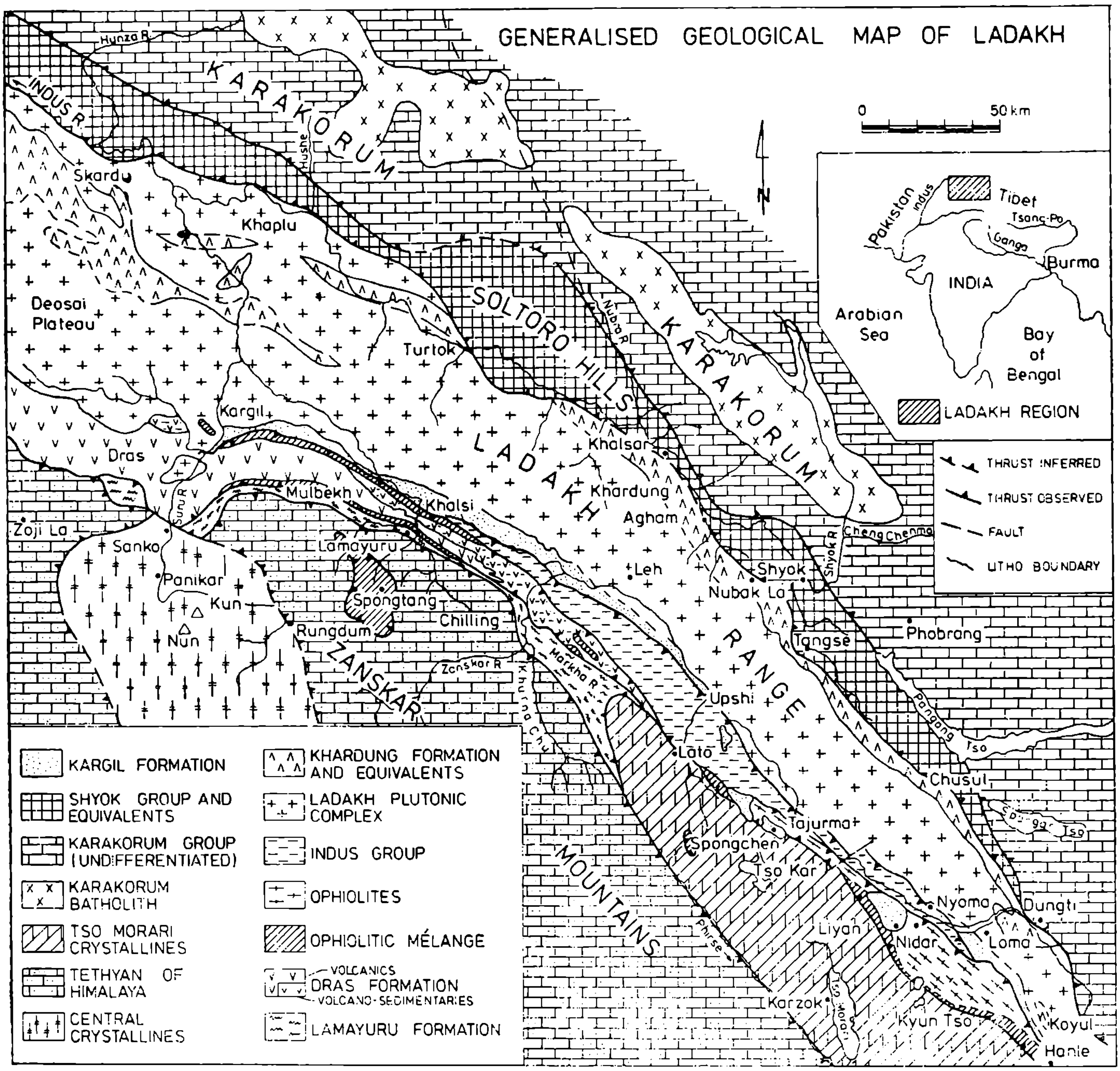

Fig. 2. Generalized geological map of Ladakh region, Kashmir Himalaya, India

thrusts. The rocks occur as a major NW-SE trending anticline plunging towards NW. The limbs are occupied by low to medium grade Thaglang-la Formation composed of phyllites, micashist, calcschist, marble and amphibolite bands. The calcschists and marble have yielded micro- and mega-fossil assemblages indicating Carboniferous to Triassic age (Virdi *et al.*, 1978; Virdi, 1983; Gupta, 1984). The core of the anticline is occupied by high grade gneisses and intrusive granites. However, there appears to be no break in stratigraphic succession and these rocks, grouped as Puga Formation, possibly represent Lower Palaeozoic sediments now metamorphosed.

The Tso Morari complex has been intruded by Rupshu, Zarra and Polokong granitic plutons which have been assigned a Jurassic age (Virdi, 1983). As the fauna in the rocks has a Tethyan affinity, it has been suggested that the complex was metamorphosed and intruded by granites during northward drift of the Indian shield.

The Tso Morari metamorphics have similar tectono-stratigraphic setting as the Guntshu and Gurla Mandhata structural highs in central Himalaya, described by Heim and Gansser (1939) and Gansser (1964). Here also Palaeozoic metasediments occupy huge anticlinal structures, between the Indus-Tsangpo suture zone in the north and Tethyan sediments in the south.

INDUS-TSANGPO SUTURE ZONE

The Indus-Tsangpo suture in Ladakh and its constituent litho-tectonic belts extend as a zone trending NW-SE and 50–60 km wide. The zone is delimited to the south by the Zanskar thrust and to the north by the Karakorum thrust (Table 1, Fig. 2). From north to south we have the following succession:

North ————————————Karakorum Thrust——————————

i. Shyok Group
ii. Khardung Formation
iii. Ladakh Plutonic complex
iv. Dras Formation
v. Kargil Formation
vi. Indus Group
vii. Indus Ophiolites
viii. Lamayuru Formation

South ————————————Zanskar Thrust———————————

Lamayuru Formation

The Lamayuru Formation forms a belt running NW-SE, parallel to the Tethyan platform sediments in the south and the ophiolites and ophiolitic mélange in the north. These represent flysch and olistostroms scrapped off the northern margin of the Indian Plate during its northward movement.

That the Lamayuru basin was adjacent to northern Zanskar shelf is suggested by the occurrence of units typical of northern Zanskar. These either interfinger or occur as slump masses, i.e. continental slope deposits. The sediments were deposited over oceanic crust. Large exotic masses of limestone occur at many locations and have yielded Upper Palaeozoic to Mesozoic fauna. These limestone blocks may represent Permian and Mesozoic sea guyots. These are now tectonized and mixed up in a mélange.

The limestone occurs as:

a) olistolites or olistolite breccia,

b) grain-stones redeposited at outer border of shelf and

c) grain flows deposited in flysch (Bassoullet *et al.*, 1981).

The overall lithology of the Lamayuru unit consists of soft olive green shales alternating with sand and siltstones and dark limestones or dark grey, frequently laminated, shales, slates and phyllite, silty and calcareous shales which alternate with dark to light grey impure sandstone or siltstone beds (up to 30 cm thick) and blue platy limestone. Load casts, flute casts and current bedding are frequent in sandstones. Argillites often show graded bedding. The rocks have distinct flysch characteristics. Locally the rocks exhibit low grade greenschist facies metamorphism. Fossils in the argillites include *Daonella indica, Monotis salinaris rotunda* Che, indicating Upper Norian age. However, the overall faunal assemblage indicates late Triassic to Lower Cretaceous age (Wan, 1982).

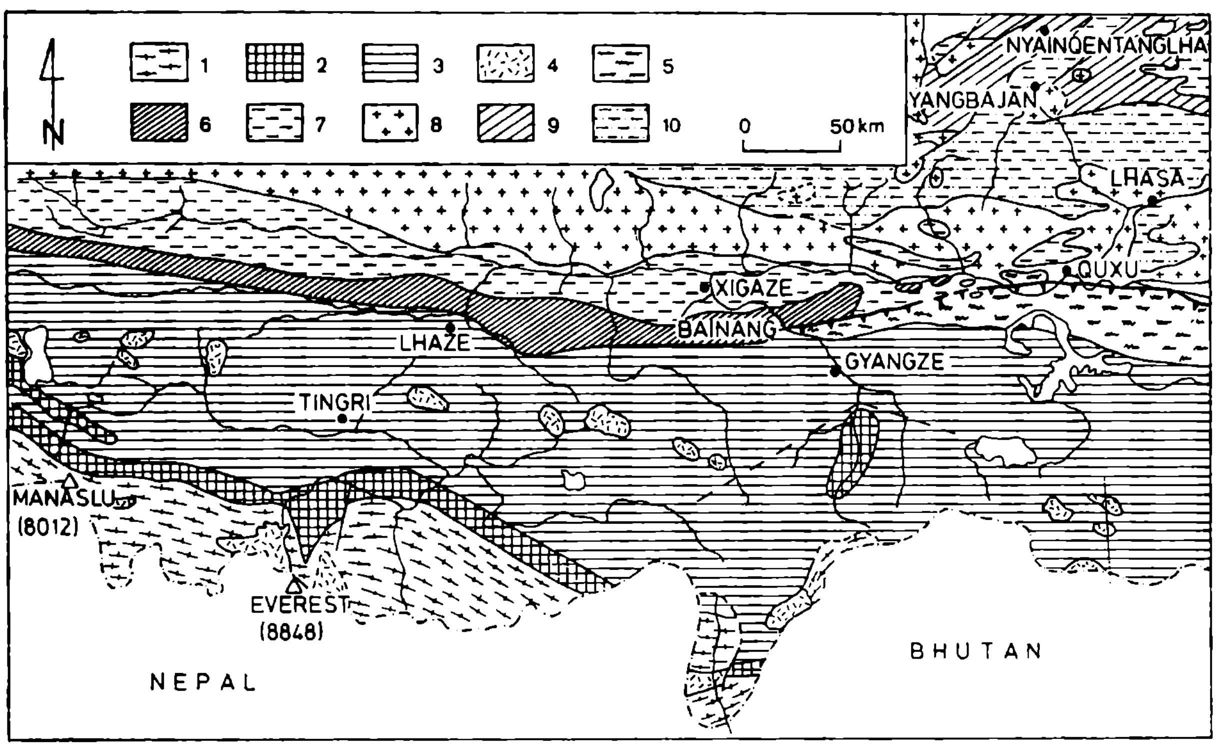

Fig. 3. Generalized geological map of the southern Tibet. *1* — Central Crystallines in the Higher Himalaya, *2* — Palaeozoic of Tethyan region, *3* — Mesozoic of Tethyan region, *4* — Tertiary granites of Higher Himalaya, *5* — Triassic (wild-) flysch in the Indus-Tsangpo suture, *6* — ophiolitic mélange and Indus-Tsangpo ophiolites, *7* — Xigaze (Shigaste) Group, *8* — Gangdese plutonic complex, *9* — metamorphics and Palaeozoic of the Nainquetanglha region, *10* — Mesozoic of the Nainquentanglha region (after Tixiang, 1980)

In southern Tibet (Fig. 3) this sequence has been described as Triassic Flysch by Shackleton (1981) and Flysch mélange by Wan (1982) and exhibits similar characters as in Ladakh. Shackleton (1982) describes it as a sedimentary mélange and compares it with Argille Scagliose in the Appennines and Monian mélange in Anglesey. No equivalent litho-units are known in the Kohistan region. Even northwest of Dras in the Deosai plateau, the Dras Volcanic Formation comes in tectonic contact with the Tethyan sequence or the Salkhala Formation (Desio, 1978; Tahirkheli, 1982).

Indus Ophiolites

Throughout the extent of the Indus-Tsangpo suture zone there are very few areas where ophiolite suites are present in their totality. Normally they are dismembered and one or the other unit is missing. In the southeastern portion of Ladakh we have one of the best developments of ophiolitic sequence. Here the unit is divided into a southern belt of ophiolitic mélange and northern belt of ophiolites. In western Ladakh around Kargil only mélange zones occur.

Zildat-Shergol ophiolitic mélange

To the north side of the Lamayuru Formation in Ladakh and Triassic flysch in southern Tibet, occurs a very complex jumble of volcanic and sedimentary rocks described as Zildat-Shergol ophiolitic mélange (Thakur & Virdi, 1979; Thakur & Gupta, 1984). In southern Tibet it is referred to as tectonic mélange (Tapponnier *et al.*, 1981; Wan, 1982), which lies at the base of the Yarlung-Zambo ophiolites.

The mélange belt is of a highly variable extent and locally only isolated klippen are observed resting over the Tethyan sediments or the Tso Morari metamorphic complex (Heim & Gansser, 1939; Fuchs, 1977; Thakur & Virdi, 1979).

The ophiolitic mélange sequence in Ladakh consists of a jumble of agglomerates, pyroclastics and lavas. Isolated lenticular blocks of serpentinite and fossiliferous limestone occur in the volcanic groundmass. The rocks of the belt have undergone glaucophane type metamorphism (Virdi *et al.*, 1977; Frank *et al.*, 1977). The rocks show high degree of deformation and metamorphism which is pervasive throughout irrespective of the lithological composition (Virdi, 1981b, 1984b).

There is some doubt regarding the correlation of units in Kohistan with the ophiolitic mélange. Though Tahirkheli (1982) correlates the Chalt ophiolitic mélange with the Zildat-Shergol ophiolitic mélange this is not so since the Chalt mélange lies to the north of the island arc sequence. It would compare with a part of the Shyok Group where limited amount of ultrabasites occur in the back-arc region and the rocks look like a mélange.

In southern Tibet there are narrow zones of ophiolitic mélange on the southern side of the Yarlung-Zambo ophiolites. This however, is not so well developed. The klippen belt of central Himalaya in Kiogar and Amlang la also represents parts of ophiolitic mélange (Gansser, 1974, 1977). These consist of fragmental serpentinites with blocks of epigabbro, garnet hornblendite, diabase and rodingite. These rocks often have a schistose fabric and locally contain garnet-hornblende schist and schistose quartzite. The overall aspect is that of autoclastic mélange with metamorphism of glaucophane schist facies (Wan, 1982).

Nidar ophiolites

The Nidar ophiolites constitute a belt varying widely in extent and width (Fig. 2). It is divided into three principal units in ascending order viz. the ultramafics, gabbros and pillow lavas.

The ultramafics consist of serpentinites and serpentinized pyroxenites and harzburgites. The zone is about 2 km wide northwest of Tsokar but 8—10 km in the southeast in Kyun Tso-Nidar section (Fig. 2). The serpentinites contain podiform chromite bodies at many localities while magnesite is also associated with peridotites.

The gabbro zone occurs north of the ultramafics. The gabbros intrude the ultramafics and xenoliths of the latter are frequent in the former. Though in general the gabbros are massive, layered gabbros are also encountered in many sections. Leucocratic, coarse grained basic pegmatitic intrusions also occur indicating late differentiates of basic magma.

The pillow lavas constitute the uppermost unit of the sequence and consist of basic to intermediate volcanics with pillow structures, 0.5—1 m across. The pillows are often flattened due to subsequent deformation. The uppermost part of the pillow unit is layered in nature containing volcanic lavas interbanded with chert, grit and sandstone. The grit and sandstone are intraformational, containing fragments of chert, jasper and lavas. The cherts are greenish in colour and contain radiolarian and other fossils indicating Jurassic to Cretaceous (Wan, 1982). Near Nidar, red jaspers form a sequence about 100—200 m thick which is folded and thrust northward over the flysch sediments of the Indus Formation.

In southern Tibet ophiolitic suite is well developed and referred to as the Yarlung-Zambo ophiolites. Here, following sequence is observed in descending order:

e) abyssal-bathyal marine deposits,

d) mafic volcanic lavas, pillow lavas with volcanic tuffs and lenticular cherts,

c) sheet-like sills and cluster of dykes,

b) cumulates (homogeneous gabbro or gabbro-diabase, layered olivine gabbro and dialage gabbro, feldspar-dunite, dunite, feldspar-peridotite, peridotite),

a) ultramafic rocks (serpentinized harzburgite, diopside harzburgite, lherzolite and minor dunite).

The ophiolites are overlain locally by the Condu Formation (Albian to Cenomanian) composed of clastic material derived from basic and ultrabasic rocks. This is richly fossiliferous and grades upwards into the flysch sediments of the Shigaste Group (Haoruo, 1984). The ophiolites have been generally assigned Upper Jurassic to Cretaceous age. Recently the magmatic portions (gabbro-dolerite and lavas) of the ophiolites have been dated at 120 ± 10 m.y. (Gopel *et al.*, 1984).

Indus Formation

The Indus Group constitutes a NW-SE trending belt about 10–15 km wide (Figs 2, 4b, c). The belt is separated from the Ladakh plutonic complex in the north or the intervening zone of autochthonous mollasse (the Kargil Formation) by the south dipping Upshi thrust. Towards the south the belt comes in tectonic contact with the Dras volcanic formation, the Zanskar sediments, the Tso Morari metamorphics and the Indus ophiolites. This thrust zone, corresponding to the suture between India and Tibet, is referred to as the Zildat thrust here. The Indus Formation is well exposed along a number of north flowing tributaries of the Indus. Pal & Mathur (1977) and Pal *et al.* (1978) have divided the Indus Formation in the region between Zanskar and Ryul rivers into five units as follows (in descending order):

e) conglomerate flysch, with subordinate sandstone and shale,
d) red shaly flysch with subordinate sandstone and siltstone,
c) grey shaly flysch with subordinate sandstone and siltstone,
b) arenaceous flysch with subordinate shales,
a) red and green shaly flysch with subordinate conglomerate and limestone.

There is frequent repetition and obliteration of these members in different sections due to folding and faulting. The Indus Formation exhibits sedimentary features like current bedding, graded bedding, load casts, flute casts etc., indicative of their flysch nature. The formation is richly fossiliferous and on the basis of assemblages of foraminifers, bivalves, gastropods etc. an Aptian to Lutetian age has been assigned to it by Mathur (1983).

In southern Tibet, the Shigaste or Xigaze Group of sediments constitutes the eastern extension of the Indus Formation. The sequence here is over 6000 m thick and is slightly metamorphosed. The sequence here ranges in age from Cenomanian to Ypresian or Lutetian (Wan, 1982).

The Indus and Xigaze Groups exhibit following general characters:

i. From north to south the sediments gradually change from littoral-neritic facies to bathyal-abyssal facies.
ii. The sediments are of flysch-greywacke-shale formation with well developed cyclothems, turbidite and slump features.
iii. Though now the northern and southern contacts are tectonic, however, at few places the southern side grades into ocean floor type sediments on top of the ophiolite belt. On its northern side the belt is thrust over the volcano-magmatic arc.

These features indicate that the rocks were deposited in front of rising magmatic arc in a fore-arc basin.

Kargil Formation

The Ladakh Plutonic complex on its southern margin is overlain unconformably by molassic sediments represented by the Kargil Formation. Here a sequence of conglomerates, sandstones, and shales showing current bedding and graded bedding is exposed overlying the hornblende granite or tonalites. The basal part of the sequence consists of a few metres of reddish arkosic material followed by a conglomeratic zone about 20 metres thick, with granitic boulders set in a feldspathic groundmass. The boulders, though poorly sorted, are well rounded. In the overlying beds a decrease in the size of granitic pebbles from 20—25 cm to 3—5 cm is accompanied by an increase in the arkosic fraction. A thin carbonaceous band also occurs. The conglomerate contains pebbles of granite, vein quartz, limestone, gneiss, volcanics, low grade metamorphics and gabbro. The molasse sequence dips towards SE at moderate angles and does not exceed 1 km in thickness. Towards the south it is thrust over by the Indus Formation along the south dipping Upshi Thrust.

The rocks of the Kargil Formation do not cover very extensive regions but form isolated outcrops, the main one occurring directly over the Ladakh plutonic complex as a linear belt. One major outcrop of molasse rests unconformably on the Indus Formation, the Nidar ophiolites and Tso Morari metamorphics north of Tsokar while another, northwest of Liyan, rests both on the ophiolites and ophiolite mélange (Fig. 2). The molassic sediments observed north of Tsokar, towards their southern extent transgress over the Thaglang la Formation of the Tso Morari metamorphics. Here the conglomerates have more pebbles of metamorphics, marbles, granite and gneisses.

In southern Tibet this unit has been described as molasse of Epicontinental Mountain Chain and from west to east as Menshi, Qiuwer Formations and Robusha Group. Here also it is composed of conglomerate, sandstone-shale and sandstone--conglomerate intercalated with thin coal-beds or conglomerate, volcano-clastics, volcanics and minor limestone lenses. The exposures are discontinuous and the facies is very variable laterally. The rocks are characterized by poorly sorted and rounded fragments in the conglomerates. The source area of the molasse lay chiefly in the Gandise magmatic arc and the deposition was due to the uplift of the mountain ranges consequent to the final collision of the plates.

In the Kohistan part of the Indus suture, Miocene-Pliocene molassic sediments are described as Gizar molasse and Jalipur molasse (Tahirkheli, 1982). Here also they occur with transgressive contacts over different litho-units.

As no datable fossils have been discovered in this unit it is not possible to assign a definite age to the Kargil Formation. Fossils of vertebrates have been recorded from Kargil, and fresh water molluscs and gastropods from other localities in eastern Ladakh. Well preserved palm leaves and *Prunus* remains have been found at Tajurma and in the Chang Lung nala which indicate a Miocene age. The occurrence of *Prunus* remains in rocks exposed at 6000—6500 m above sea level indicates uplift of the region by at least 4000—4500, since *Prunus* does not grow above heights of 1000—1500 m (Guleria *et al.*, 1983).

Dras Formation

Dras Formation consists of volcanic, pyroclastic and volcano-clastic rocks showing a wide variation in composition and age. Earlier the unit was referred to as Dras volcanics but in view of the close association of sedimentary and volcanic rocks it is referred to as a formation. The Dras Formation can be traced as a belt from Nanga Parbat through Deosai Plateau in Ladakh through Dras, Kargil and Lamayuru. The volcanic facies is dominant in the west, though east of Lamayuru and Khalsi volcanoclastics dominate (Frank *et al.*, 1977; Fuchs, 1982, 1984; Desio, 1978). Westward around the western syntaxis, Dras Formation continues as a highly metamorphosed belt into Gilgit, Chitral and Kohistan (Gansser, 1977, 1980; Tahirkhlei, 1982) where they are represented by the Kamilla amphibolites (Jurassic to Cretaceous) and Bahrain pyroxene granulites.

The unit is up to 15 km thick though due to tectonic junctions it is difficult to estimate the true thickness. The rocks are intensely deformed and metamorphosed. At places they resemble a tectonic mélange and comprise tectonic slices of serpentinite, gabbro, metabasalt and marble set in a tuffaceous matrix. In general we have pillow lavas, dolerite sills, very irregular basaltic and dacitic flows intercalated with pyroclastics, volcanoclastics and radiolarian cherts.

The radiolarian cherts near Dras yield upper Callovian to Tithonian fossils. However, *Orbitolina*-bearing limestone occurring as inclusions indicates that the volcanicity continued up to Upper Cretaceous (Wadia, 1937).

Though equivalent units are not well known from Eastern Ladakh and Central Tibet, however in Lhasa region the Sangri Group (Upper Jurassic to Lower Cretaceous) consists of intermediate to acid volcanics composed of andesite, dacite, keratophyre and large amount of andesitic and dacite crystal tuffs. These are also associated with a sequence of neritic carbonate clastics. Just as in Ladakh these are intruded by plutons from Gangdese plutonic complex. The volcanics are petrochemically referred to the calc-alkaline series. The association of the volcanic and intrusive complexes and their similarity in petrochemistry and geochemistry suggest that they are produced by co-magmatic evolution. Their close association suggests that they originated and erupted along an island arc on the active continental margin of Tibet.

Ladakh-Gangdese Plutonic Complex

The plutonic complex constitutes a prominent longitudinal belt traceable throughout the extent of the Indus-Tsangpo suture zone from Kohistan through Nanga Parbat, the Deosai-Ladakh-Kailash region to southern Tibet along the Tsangpo up to Namche Barwa in the east. Westward of Nanga Parbat, the plutonic belt continues through Kohistan. In Kohistan the plutonics constitute a large complex varying from acidic to intermediate and described as Swat granites and granodiorites and possibly the Deshai diorites (Tahirkheli, 1979, 1982).

The Ladakh-Gangdese magmatic belt consists chiefly of diorite-granodiorite-granite association with wide variation in composition and texture and well defined transitional types. From west to east and from south to north it gradually becomes younger and grades petrographically from intermediate to acid. Just as in Kohistan in southern Tibet, diorites occur near southern margin of the complex. The complex throughout its extent is full of basic xenoliths. There are many remnant volcanic caps indicating that the complex intruded into a cover of volcanic sequence. These volcanics represent Jurassic to Cretaceous volcanics of Dras Formation in Ladakh and Sangri Group in Southern Tibet.

Recent geochronological evidence clearly shows that in Ladakh, the magmatism extended from 103 to 60 m.y. while in southern Tibet it ranged from 99 to 41 m.y. (Schärer *et al.*, 1984a, b). This is further substantiated by palaeomagnetic data which show that the first "collision" between India and Tibet occurred in Ladakh 53 m.y. BP (anomaly 24) but in Tibet 44 m.y. BP (anomaly 20). This would imply more prolonged magmatic activity in southern Tibet than in Ladakh since subduction continued for longer period in Tibet.

Much geochemical evidence is available regarding the genesis of the Ladakh plutonic complex and its eastern extension in the Tibet (Honegger *et al.*, 1982; Schärer *et al.*, 1984a, b). Detailed Rb/Sr and U/Pb systematics and other trace element data show that anatexis of the continental crust was involved in the magma genesis. This confirmed the idea that the first stage of subduction at the continental margin, caused the emplacement of the plutonic belt.

Khardung Formation

The Khardung Formation consists of a complex of acid and basic volcanics and volcano-sedimentaries which lies between the Shyok Group in the north and the Ladakh plutonic complex in the south. The northern junction is NE dipping Shyok Thrust while the southern is an intrusive contact locally tectonized.

The Khardung volcanics consist of grey to dark grey to greyish green coloured lava flows interbedded with welded tuffs, ignimbrites, agglomerates, volcanic breccia and flow breccia. The rocks range in composition from rhyolite to dacite to andesite. Also are observed reddish to brick-red coloured flows of rhyolite and rhyodacite interbedded with reddish and purple to chocolate coloured agglomerates and breccia. The overall sequence is nearly 8—10 km thick and well exposed between Khardung and Khalsar on the northern slopes of Ladakh range. The volcanics in the Shyok valley between Khalsar and Agham are characterized by a thick sequence of volcanoclastic sediments represented by agglomerates, grits and shales.

The Khardung volcanics are in general composed of massive flows, though amygdaloidal varieties are also seen with tiny amygdales containing epidote, calcite and quartz. The volcano-sedimentaries contain fossiliferous horizons also. Calcareous shale from southern slopes of Nubak la contain *Orbitolina* sp., *Orbitolina parma*, and *Orbitolina discoidea* indicating a Lower Cretaceous (Aptian) age.

In south Tibet, the equivalent of the Khardung Formation has been described as Cretaceous-Tertiary Kangdese volcanics. Here it consists of dominantly intermediate and acid volcanics and volcanoclastics breccia, agglomerate, quartz andesite and rhyolites. They are frequently associated with variegated continental clastics. They range in age from late Cretaceous to Palaeogene (Wan, 1982). They are often intruded by granitic plutons, though themselves lie unconformably over sediments older than Early Cretaceous.

In the Kohistan region the Rakaposhi volcanic complex is correlatable with the

Khardung Formation. It consists of 3000—4000 m thick sequence of volcanic flows, tuffs, metasedimentary incorporations and syn- to post-tectonic magmatic intrusions. Flows consist of basalt, andesite, dacite, and rhyolite. Pillow lavas are conspicuous in basalt. The southern margin of the complex is in contact with the Ladakh intrusives and shows a 60—80 m wide chilled zone of volcanogenic rocks. Fossils in sediments include *Globotruncana* and *Thaninasteria matshushitai* indicating Lower Cretaceous age. The rocks are metamorphosed, the central part near Nanga Parbat-Harmosh shows high grade garnet-amphibolite facies while elsewhere greenschist facies is recorded. The complex is intruded by gabbro, diorite, dolerite, hornblendite and pyroxenite in the mafic suite whereas acid to intermediate igneous rocks are represented by granodiorite, granite, pegmatite, aplite and vein quartz.

Shyok Group

The Shyok Group has earlier been described as a part of the low-pressure high--temperature Pongong metamorphic belt (Virdi, 1981b, 1984b) which developed from sediments and volcanics deposited in the rear-arc region north of the Ladakh magmatic arc. The Shyok Group occurs as a NW-SE trending belt of variable width (Fig. 2) bound on the north by the Karakorum thrust and in the south by the Shyok thrust, both dipping north.

The Shyok Group, can be broadly divided into two units. The northern unit referred to as Summur Formation consists of basic volcanics closely associated with alternations of green and purple sandstone and shale which appear to be of flysch nature. Occasional platy and banded limestone units occur as blocks in the volcano-sedimentary association. The limestone contains corals, bryozoans and crinoids of Permo-Triassic age. The volcanics are associated with serpentinite and pyroxenite bodies. The contacts are highly tectonized and rocks are mixed up to simulate a mélange. Towards the south a narrow belt of low to medium grade metamorphics containing amphibolites, marble and mica schist is observed around Khalsar and is referred to as the Khalsar Formation.

Further northwest in the Saltoro Hills between Nubra and Shyok valleys a wide variety of rocks occur. These include nearly unmetamorphosed to medium to high grade metamorphic derivatives of sedimentary, volcanic and volcano-clastic material.

Srimal *et al.* (1982) have grouped the rocks of Shyok belt into two formations, the Biagdong Formation of Early to Middle Cretaceous and the Hundiri Formation of mid-late Cretaceous age. The Hundiri Formation consists of rhythmic sandstone, siltstone, slate unit in upper part and chert, limestone and slate in the lower part. The rocks show flysch characters. These are folded into a major NW-SE trending antiform and the core is occupied by the basic and ultrabasic rocks of the Biagdong Formation.

The Shyok group is metamorphosed to varying degree and the grade of metamorphism changes rapidly from very low to medium grade. Wherever the rocks are

Table 3

Comparison of lithological sequences in the Karakorum and the Lhasa block, north of the Indus-Tsangpo suture zone

Age	Karakorum (Gergen & Pant, 1983)			Lhasa block – Nainquentenglha Tibet (Wan *et al.*, 1983)	
	Group	Formation	Lithological characters	Formation/Group	Lithological characters
1	2	3	4	5	6
Eocene		Khumdan	acid volcanics (rhyolites) and volcaniclastics, 200 m	Daduo Formation	volcanic rocks, tuff, volcanic breccia, sandstone, conglomerate
Cretaceous	KARAKORUM GROUP	Qazil Langer	purple shale, sandstone and red conglomerate, 500 m	Linzizong Formation	andesite, rhyolite and red beds, 1,500–2,000 m
				unconformity	
		Bursta	limestone, black shale, pink carbonaceous shale, 100 m	Shexing	purple red mudstone, 300 m
				Takena/Takela	calcareous shale, siltstone, marls and limestone, 150 m
				Chumulong	thick bedded quartzose sandstone intercalated with slates, 350–900 m
				Linbuzong	coal-bearing clastics, 1,600 m
Jurassic		Morgo	grey to pink limestone with thin bands of calcareous shale, 300 m	Duodigdou Formation	limestone intercalated with shale, 500 m
				fault	
Triassic		Aq Tash	purple and green shale, volcanics and volcanosedimentary sequence, 200 m	Meilonggang Group	sandstone, limestone and shale, 100 m
				fault	
				Chaqupu Group	limestone, sandstone, shale and andesites, 1130 m
Permian		Chongtash	pillow lava interbedded with argillaceous sandstone and grey limestone, 800 m	Lielonggon Formation Luobadui Formation Wulolong Formation	limestone, shale and sandstone, 900 m limestone, intermediate basic volcanics, 400 m thin bedded with black slate, 50 m

1	2	3	4	5	6
Carboniferous		Sasser Brangsa	black slates interbedded with sandstone, quartzite and limestone, 800 m	Pangduo Group	gravel, sand-bearing slate, sandstone and limestone
		unconformity		unconformity	
Precambrian to Lower Palaeozoic		Pongong	shist, gneiss, marble and metabasics	Nainquentanglha Group	granite, gneiss and garnet mica-shists
		Karakorum Thrust		thrust	

intruded by granitic bodies e.g. around Tirit, andalusite bearing hornfelses are developed.

There are no well defined equivalents of the Shyok Group in southern Tibet. However, the rocks of the Nainquentanglha Group (Late Precambrian to Lower Palaeozoic) and other younger sediments of the Lhasa Block are overlain by volcanic and volcaniclastic sequence of Takena, Linzizong and Dabio Formations. These consist of andesite, rhyolites and red beds of Upper Cretaceous age and volcanic lavas, tuffs, volcanic breccia and sandstone conglomerate of Eocene age (Wan, 1982). These may be correlated with the Shyok Group of Ladakh.

In the Kohistan region the volcano-sedimentary and metamorphosed sequence grouped under the Yasin Group, Burjila Formation and Katazara Formation can be correlated with the Shyok Group on the basis of their lithology, age and tectonic disposition (Tahirkheli, 1982; Desio, 1978).

The lithological assemblage of the Shyok Group is representative of the region behind the magmatic arc. In Ladakh these rocks were deposited over the Pongong metamorphic complex which further north constituted the floor of the Karakorum platform deposits formed at the southern margin of Tibet (Gergan & Pant, 1983).

These rocks together with the Khardung volcano-sedimentary succession were metamorphosed under high-temperature low-pressure conditions. Heat was introduced magmatically and thus geothermal gradients were high. Due to intense deformation rocks of different facies have been telescoped and occur together (Virdi, 1981b, 1984b).

KARAKORUM MOUNTAINS

The high ranges north of the Shyok river are the Karakorum mountains which are constituted by a wide spectrum of rocks (Desio, 1979; Gergan & Pant, 1983; Tahirkheli, 1982) ranging in age from late Precambrain to Cretaceous. Towards south we have a group of low to medium grade metamorphics referred to as the Pongong Formation (Virdi, 1981b, 1984b) which is overlain unconformably by fossiliferous sediments. These are intruded by the Karakorum axial granitic batholith which ranges in age from Middle to Upper Cretaceous (Desio, 1979; Le Fort *et al.*, 1983). The fossiliferous sediments grouped under the Karakorum Group range in age from Carboniferous to Eocene and are characterized by Permo-Triassic volcanics. Table 3 shows that a similar litho-tectonic setting is observed in the Nainquentanglha region or the Lhasa Block in southern Tibet (Wan, 1982) where also Upper Precambrian metamorphics of Nainquentanglha Group are unconformably overlain by Carboniferous to Eocene fossiliferous sediments. Here also Permo-Triassic sequence is characterized by volcanic and volcano-clastic suite along with normal shelf sediments. These features indicate that lithological units of the Karakorum mountains continue towards east into the Nainquentanglha belt and represent the former southern passive margin of the Tibetan plate. For further details of fauna and lithological features the reader is referred to Gergan & Pant (1983), Desio (1979), Wan (1982) and Tahirkheli (1982).

GEOTECTONIC EVOLUTION OF THE INDUS-TSANGPO SUTURE ZONE

Much before the application of the concepts of plate tectonics to Himalayan orogenesis, Argand (1924), Wegener (1929) and Holmes (1944) had described the Himalayan orogen as a product of collision and subsequent underthrusting of the Indian shield below the Asian landmass after the former's northward drift consequent to the split of Gondwanaland. Dewey & Bird (1970) were the first to propose a plate tectonical model for the evolution of the Himalaya. A number of variants of this model have since been proposed (Powell & Connaghan, 1973; Le Fort, 1975; Frank *et al.*, 1977; Powell, 1979; Tahirkheli *et al.*, 1979; Virdi, 1981c; Valdiya, 1984). For salient features of these models the reader is reffered to Virdi (1984a). The models have now been further supported by palaeomagnetic and other geophysical data from the Indian Ocean and different parts of the Himalaya both north and south of the Indus-Tsangpo suture (Laughten *et al.*, 1973; Dietz & Holden, 1970; Fisher *et al.*, 1971; McKenzie & Sclater, 1971; Molnar & Tapponier, 1975; Molnar *et al.*, 1977; Molnar, 1984; Lyon-Caen & Molnar, 1983; Klootwijk, 1984; Besse *et al.*, 1984; Patriat & Achache, 1974).

Majority of the models proposed so far favour the development of a Cordilleran-type orogen along the Andean-type southern margin of Tibet. This was followed by collision and subsequent underthrusting of India below Tibet and the uplift of the Himalaya mountains.

Based on lithological characters and regional disposition of various litho-tectonic units in the suture zone in different sectors, the author has proposed (Virdi, 1981b, 1984a, b) that the southern margin of Tibet was similar to the circum-Pacific Japan-type margin characterized by an island arc off Tibet and separated by a back-arc basin similar to the Japan (Fig. 4A). A two staged evolution is envisaged for Indus-Tsangpo suture zone.

The first stage in the evolution of the suture zone was preceded by rifting and extrusion of Permo-Triassic volcanics e.g. Panjal volcanics in Kashmir, Rinam and Relakung in Zanskar and those associated with Thaglang-la Formation of Tso Morari metamorphic complex (Virdi, 1983). This phase was responsible for the formation of the Tethys ocean as the two sides drifted away due to vast outpouring of lavas. The volcanic activity continued intermittently and was also accompanied by deposition of clastic sediments. Gergan & Pant (1983) have reported widespread volcanic activity associated with Permo-Triassic sediments in the Karakorum while similar activity is known from the eastern continuity in the Lhasa block of southern Tibet (Jixiang, 1980; Wan, 1982). This indicates that prior to rifting phase the Karakorum and Lhasa blocks were near to the northern margin of the Indian plate and then drifted away due to rifting and production of oceanic crust of the Tethys along a mid-oceanic ridge (?). This phase continued till the Triassic or Middle Jurassic times when the Lhasa block in Tibet had been welded to the Asian block along the Bangong suture zone. Cheng-fa & Yunshan (1981) have proposed that the northern Xizang structural region belonged to the Tethyan border of Gondwana land but became detached during Early Mesozoic.

After the welding of Lhasa block and Karakorum region to the Tibetan plate, the activity shifted southwards. In order to accomodate the northward movement of India after the split of Gondwanaland along the Mid-Indian Ocean ridge, a new

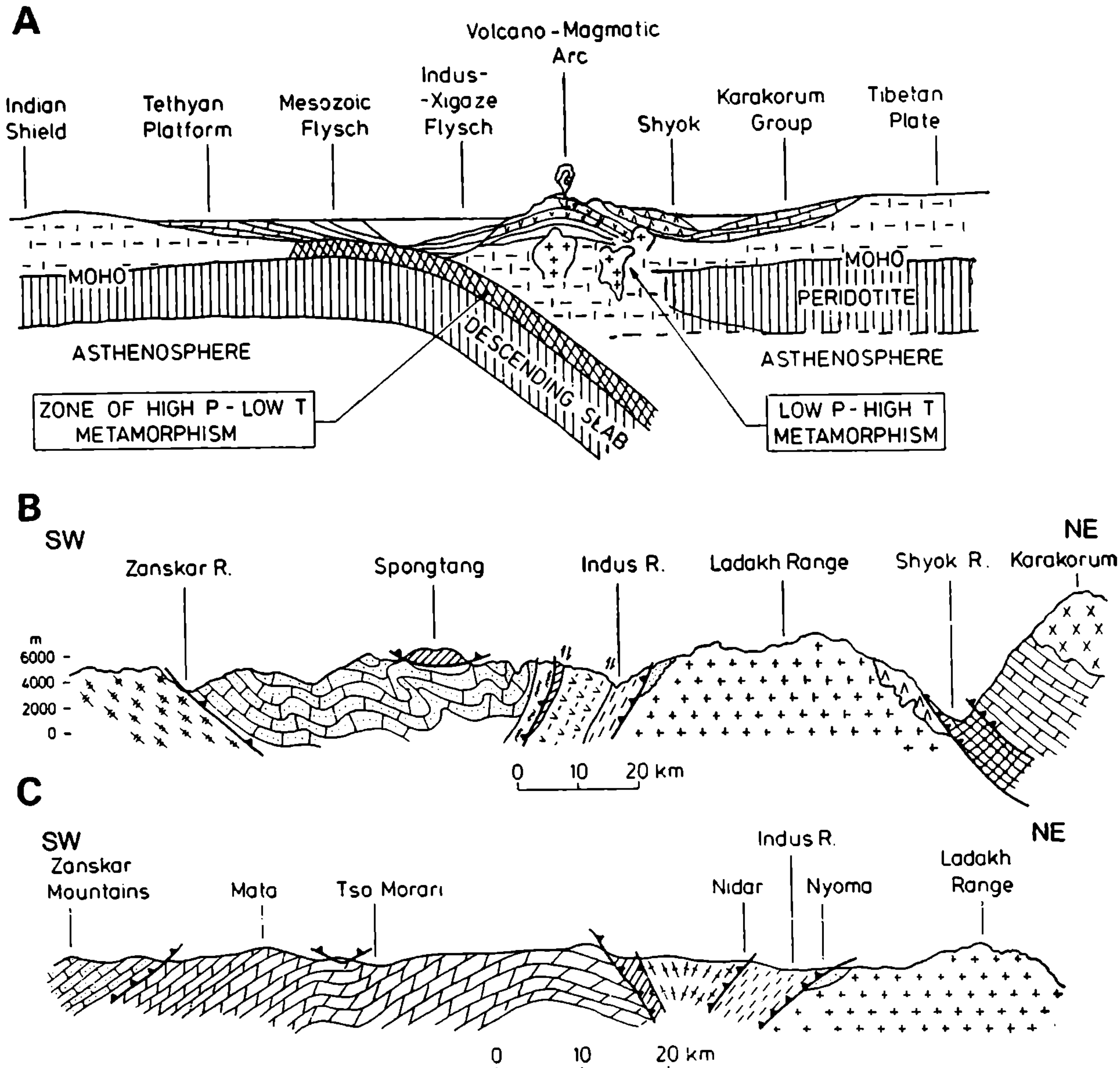

Fig. 4. Cross-sections of the Indus-Tsangpo suture zone. *A*. Schematic model for the evolution of Indus-Tsangpo suture zone prior to the collision of the Indian and Tibetan plates. *B*. Generalized geological cross-section through the Central Ladakh. *C*. Generalized geological cross-section through the South-eastern Ladakh

zone of compensation developed off the southern margin of Tibet during late Jurassic. Consequent to this, the platform sedimentation in the Karakorum Tethyan region was interrupted by the formation of an island-arc system constituted by the Dras Formation of late Jurassic to Upper Cretaceous age and intrusive acid to intermediate granitic plutons of Lower Cretaceous to Eocene age (Virdi, 1981c; Honegger *et al.*, 1982; Dietrich *et al.*, 1983). That the island arc developed over older (possibly Palaeozoic) base is shown by U/Pb and Rb/Sr isotopic dating of these rocks in Tibet and Ladakh (Schärer *et al.*, 1984a, b).

Palaeomagnetic and geochronological data on volcanic and plutonic rocks constituting the magmatic arc further indicate that subduction continued in Ladakh to the end of Palaeocene and the first contact of India and Tibet took place before anomaly 24 (53 m.y.). This was followed by dramatic change and decrease in the velocity of Indian plate at anomaly 22 (50 m.y.). Thus the Tethys closed in Ladakh region while in the eastern extension subduction continued until anomaly 20 (44 m.y.) when the counter-clockwise rotation of India with respect to Eurasia stopped, and India and Australia coalesced to form one plate. During this period 300–500 km of the Indian continental crust was subducted beneath Tibet (Patriat & Achache, 1984; Allégre *et al.*, 1984).

The overall subduction lasted for about 40 m.y. (103–60 m.y.) from Albian to Palaeocene in Ladakh region and for 50 m.y. (99–41 m.y.) from Cenomanian to Lutetian in Southern Tibet. These features lend further support to the idea that the magmatic activity in the island-arc becomes younger from west to east and lasted longer in southern Tibet than in Ladakh (Schärer *et al.*, 1984a, b). This was also associated with a change in composition from diorite through granodiorite to granite from north to south indicating that more and more continental material was consumed during later subduction. The consumption of continental crust for production of more acidic portion of Ladakh-Gangdese plutonics is also evidenced by high initial Sr ratio and inherited radiogenic argon in zircons. The U/Pb study further reveals that the approximate minimum ages of the continental sources ranged from 350–590 m.y.

As the magmatic arc became mature and locally a positive topographic feature, a back-arc basin developed between it and Tibet. In this basin rocks of the Shyok Group and equivalents were deposited. These consisted of volcano-clastic debris, and normal shallow water clastics with occasional outpourings of continental volcanics; frequent granite intrusions also took place. These rocks exhibit low-pressure high-temperature metamorphism since they were formed and metamorphosed in region of high geothermal gradient (Virdi, 1981b, c; Zhang *et al.*, 1981; Zhou *et al.*, 1981). On the southern side of the magmatic arc, flysch sedimentation of the Indus and Xizage groups took place in the fore-arc basin. These sediments were deposited over and also received material from the ophiolitic sequence in the south, though the main contribution was from the magmatic arc (Frank *et al.*, 1977; Thakur & Virdi, 1979; Wan, 1982).

During the progressive northward movement of the Tethyan ocean floor and its encroachment by the Tibetan plate over the subduction zone, cold oceanic material and chaotically deformed sediments were dragged down to greater depths along the trench to zones of low geothermal gradient and high pressures (40–45 kb). Thus the rocks underwent high pressure metamorphism with the production of glaucophane and locally lawsonite bearing assemblages in ophiolitic mélange and parts of the ophiolite sequence all along the subduction zone (Shams, 1980; Desio, 1977; Virdi *et al.*, 1977; Virdi, 1981b; Frank *et al.*, 1977; Tahirkheli, 1982; Xuchang & Yanlin, 1982). Palaeontological and geochronological evidence suggests that metamorphism took place during Early to Late Cretaceous. This is further confirmed by 84 ± 1.7 m.y. K/Ar age on muscovite associated with the blueschists in Sangla metamorphic belt of Kohistan (Desio & Shams, 1980) and 100 m.y. age of glaucophane around Kargil in Ladakh (Honegger *et al.*, 1985).

The high-pressure low-temperature metamorphic belt in the south and low-pressure high-temperature metamorphic belt on the north side of the island arc together constitute paired metamorphic belts similar to those observed in the circum-Pacific region of Japan (Miyashiro, 1961, 1973). The paired metamorphic belts are well developed in Ladakh and Tibet (Virdi, 1981a, b, 1984b; Zhang *et al.*, 1981; Zhou *et al.*, 1981; Xuchang & Yanlin, 1982).

The second stage of evolution involved the post-collision activity when the Indian plate continued its northward journey and widespread penetrative deformation was followed by overthrusting. Most of the original sedimentary contacts were tectonized and became vertical or subvertical. Large blocks of ophiolites and associated rocks were pushed southward over the Tethyan sediments. These occur as klippen at Spongtang, Markha valley, Spongchan and Karzok in Ladakh (Fuchs, 1977; Thakur & Virdi, 1979) and Amlang la and Kiogad region in Central Tibet (Kraft, 1902; Heim & Gansser, 1939). Locally the thrusting was so pronounced that the Tethyan sediments come in direct contact with the Indus Group with no intervening zone of ophiolites and ophiolitic mélange e.g. for over 80 km northwest of Lato up to beyond the Zanskar river (Thakur & Virdi, 1979).

The second stage was also responsible for the development of the main Himalayan topography and structural setting. The area was covered by continental molassic debris shed by rising mountains. These are referred to as Kargil Formation in Ladakh, Jalipur and Gizar in Kohistan and as epicontinental molasse in southern Tibet. The molassic sediments have yielded plant and other fossils indicating that the area had been uplifted by at least 4000—4500 m since Miocene (Guleria *et al.*, 1983) in Ladakh. Similar evidences are available from Tibet and Kohistan.

Post-Miocene activity has shifted to the intracontinental thrust zones further south, first along the Main Central Thrust and then along the Main Boundary Thrust. That the horizontal and vertical movements are still going on in the Himalaya is indicated by uplift of the Himalaya and recent and continued movement along many thrusts in the Lesser and outer Himalaya.

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Streszczenie*

SZEW INDUS-TSANGPO W HIMALAJACH: KOPALNA STREFA SUBDUKCJI

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Abstrakt: Strefa szwu Indus-Tsangpo, ciągnąca się od Kohistanu przez Ladak do południowego Tybetu, jest śladem strefy, wzdłuż której płyta Indii zderzyła się z płytą Tybetu po dryfowaniu ku północy w ciągu mezozoiku i kolizji w ciągu eocenu. Strefa szwu Indus-Tsangpo zbudowana jest z mniej więcej równoległych pasów. Powstanie typów skał tworzących pasy można powiązać z (od południa na północ): 1) platformą na północnej krawędzi tarczy Indii, 2) strefą rowu, 3) spłaszczeniem frontalnym, 4) łukiem magmowym, 5) basenem załukowym i 6) platformą

* Przygotowane przez Redakcję.

na południowej krawędzi Tybetu. Pasy te oddzielone są obecnie pionowymi lub stromymi dyslokacjami. Sekwencja ofiolitów i melanżu ofiolitowego rowu oceanicznego wykazuje metamorfizm wysokociśnieniowy facji niebieskich łupków, podczas gdy sekwencje łuku magmowego i basenu załukowego wykazują metamorfizm niskich ciśnień i wysokich temperatur. Obie te sekwencje zmetamorfizowane tworzą parę łuków metamorficznych. Skały z glaukonitem i lawsonitem są szeroko rozprzestrzenione w Kohistanie, Ladaku i południowym Tybecie. Cechy te wskazują, że strefa szwu Indusu-Tsangpo jest kopalną strefą subdukcji wzdłuż południowej krawędzi Tybetu.

Szew Indus-Tsangpo jest jednym z najbardziej intrygujących elementów w budowie Himalajów. Występuje tu bardzo zróżnicowany zespół kompleksów skalnych, charakterystycznych dla kopalnych stref subdukcji i kolizji. Strefa szwu ciągnie się od Kohistanu w Pakistanie przez Ladak w Indii do rejonów Kailash i Lhasy w południowym Tybecie.

Strefa szwu Indus-Tsangpo zbudowana jest z wąskich jednostek litologiczno-strukturalnych, względnie ciągłych i równoległych na całej długości szwu. Strefy te ograniczone są stromymi lub pionowymi powierzchniami dyslokacji. Budowa tych stref omówiona jest w kolejności od południowego zachodu na północny wschód.

1. Strefa Zanskaru — zbudowana z fanerozoicznych osadów Tetydy powstałych na północnym szelfie płyty Indii. Fundament stanowią proterozoiczne skały metamorficzne ukazujące się w jądrze wielkiej antykliny ze zmetamorfizowanymi skałami paleozoicznymi w skrzydłach. Strefa ta obrzeża strefę szwu Indus-Tsangpo od południowego zachodu i jest od niej oddzielona nasunięciem Zanskaru.

2. Formacja Lamayuru — flisz i olistostromy (trias—kreda) zdarte z północnej krawędzi płyty Indii w czasie jej dryfu ku północy. Flisz zawiera liczne bloki wapieni z fauną permsko-mezozoiczną.

3. Ofiolity Indusu — najpełniej rozwinięte w południowo-wschodniej części Ladaku. Od południa występuje tu melanż ofiolitowy, a od północy sekwencja ofiolitowa (grn. jura—kreda) złożona ze skał ultrazasadowych, gabr i law poduszkowych przykrytych skałami osadowymi.

4. Formacja Indusu — flisz (apt—lutet) osadzony na skorupie oceanicznej, pomiędzy łukiem magmowym a rowem oceanicznym. Od południa obcięta nasunięciem Zildat, które reprezentuje właściwy szew pomiędzy Indiami a Tybetem.

5. Formacja Kargilu — utwory molasowe (miocen +?) występujące w postaci oddzielnych nagromadzeń na różnych jednostkach strefy szwu, głównie na południowym obrzeżeniu kompleksu plutonicznego Ladaku.

6. Formacja Drasu — utwory wulkaniczne, piroklastyczne i wulkanoklastyczne (śr. jura—kreda) silnie stektonizowane, zawierające bloki różnych skał. Obecna miąższość sięga 15 km. Są to utwory wulkaniczne łuku wyspowego.

7. Kompleks plutoniczny Ladak-Gangdese złożony głównie z asocjacji diorytowo-granodiorytowo-granitowej (jura—kreda). Zachowane szczątki pokryw wulkanicznych wskazują, że magmy intrudowały w skały formacji Dras.

8. Formacja Khardungu — skały wulkaniczne i wulkaniczno-osadowe (dln. kreda) o składzie riolitowo-dacytowo-andezytowym i miąższości do 10 km. For-

macja ta stanowi część kompleksu łuku wulkanicznego intrudowanego przez skały kompleksu plutonicznego Ladak-Gangdese.

9. Grupa Shyok — zasadowe skały wulkaniczne współwystępujące z fliszem, z blokami wapieni i ciałami serpentynitów i piroksenitów. Towarzyszy im pas skał zmetamorfizowanych — amfibolitów, marmurów i łupków mikowych. Skały te powstały na zapleczu łuku wyspowego.

10. Strefa Karakorum — oddzielona nasunięciem Karakorum, obrzeża od północnego wschodu strefę szwu Indus-Tsangpo. Budują ją prekambryjskie skały metamorficzne, na których leżą serie osadowe od karbonu do kredy przebite w ciągu kredy batolitem Karakorum. Strefa ta reprezentuje południowe obrzeżenie płyty Tybetu.

Odpowiedniki tych stref występują w południowym Tybecie oraz w Kohistanie.

Ocean Tetydy powstał w ciągu permu i triasu. Związane z tym było oddalenie od północnego skraju płyty Indii bloków Karakorum i Lhasa, które w triasie lub środkowej jurze przyłączone zostały do bloku azjatyckiego. Po tym rozpoczęła się pierwsza faza ewolucji strefy dzisiejszego szwu Indus-Tsangpo. Na południowym obrzeżeniu bloków Karakorum i Lhasa powstał łuk wulkaniczny (formacja Dras) założony na starszych (paleozoicznych?) skałach. Subdukcja strefy Tetydy, stanowiącej północną część płyty Indii, trwała w Ladaku od albu do paleocenu, a w południowym Tybecie od cenomanu do lutetu. W ciągu tego okresu subdukcji uległo też 300—500 km skorupy kontynentalnej płyty Indii. Przesłanki geochemiczne wskazują na wzrost konsumpcji materiału kontynentalnego pod koniec subdukcji. Wiek tego materiału wynosi 350 do 590 mln lat.

W miarę rozwoju łuku magmowego na jego zapleczu powstał basen oddzielający łuk od płyty Tybetu. W basenie załukowym powstały skały grupy Shyok, zmetamorfizowane później w warunkach niskich ciśnień i wysokich temperatur. Po zewnętrznej stronie łuku osadzał się flisz formacji Indusu. W miarę postępu subdukcji skały skorupy oceanicznej i chaotycznie zdeformowane osady podlegały metamorfizmowi w warunkach wysokich ciśnień i niskich temperatur (facja glaukofanowa). Te zmetamorfizowane utwory wraz z utworami metamorficznymi grupy Shyok tworzą parę pasów metamorficznych podobną do występujących w łukach wokółpacyficznych (Japonia).

Drugie stadium rozwoju szwu Indus-Tsangpo, pokolizyjne, wiąże się z dalszym ruchem płyty Indii ku północy. Wcześniejsze, łagodniej nachylone kontakty tektoniczne (nasunięcia) zostały stromo ustawione. Duże masy ofiolitów i skał towarzyszących zostały wepchnięte na południe na osady Tetydy. Wypiętrzaniu masywów górskich towarzyszyła sedymentacja molasy (formacja Kargil). Późniejsza aktywność tektoniczna przeniosła się do położonych dalej na południu stref nasunięć wewnątrzkontynentalnych; pionowe i poziome ruchy tektoniczne w Niskich i zewnętrznych Himalajach trwają nadal.