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Indus Tsangpo suture zone in Ladakh—its tectonostratigraphy and tectonics

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Abstract. The Indus Tsangpo suture zone in Ladakh lies between the Phanerozoic sequence of the Zanskar Zone of Tethys Himalaya in the south and Karakoram zone in the north. The five palaeotectonic regimes recognized in the suture zone are: The Indus palaeosubduction complex, the Ladakh magmatic arc, the Indus arc-trench gap sedimentation, the Shyok back-arc and the Post-collision molasse sedimentation. The Ladakh magmatic arc, comprising intrusives of the Ladakh plutonic complex and extrusives of the Dras, Luzarmu and Khardung formations, owes its origin to the subduction of the Indian oceanic plate underneath the Tibet-Karakoram block. The Indus Formation, lower Cretaceous to middle Eocene in age, was laid down in a basin between the magmatic arc and the subduction complex. The Shergol and Zildat ophiolitic melange belts exhibit green-schist and blue-schist facies metamorphism and show structural geometry and deformation history dissimilar to that of the underlying and overlying formations. The melange belts and the flysch sediments of the Nindam Formation represent a palaeosubduction complex. The Shyok suture zone consists of tectonic slices of metamorphics of the Pangong Tso Crystallines, Cretaceous to lower Eocene volcanics and sedimentaries, together with ultramafic and gabbro bodies and molasse sediments. This petrotectonic assemblage is interpreted as representing a back-arc basin. Post-collision molasse sedimentaries are continental deposits of Neogene age, and they occur with depositional contact transgressing the lithological and structural boundaries. Two metamorphic belts, the Tso Morari crystalline complex and the Pangong Tso Crystallines, flank to the south and north respectively of the Indus suture zone in Eastern Ladakh. Three generations of fold structures and associated penetrative (and linear) structures, showing a similar deformation history of both the metamorphic belts, are developed. The shortening structures developed as a result of collision during the post-middle Eocene time.

Keywords. Indus-Tsangpo suture zone; tectonostratigraphy; tectonics; Tso Morari crystalline complex.

1. Introduction

The Indus Tsangpo suture zone is interpreted as the boundary between the Indian and the Eurasian plates (Le Fort 1975; Molnar and Tapponnier 1975; Gansser 1977). In plate tectonic interpretation, it is believed that the Indus Tsangpo suture zone coincides with the zone of subduction that was responsible for closing the oceanic gap of the Tethys as a result of the collision of the Indian plate against the Karakoram-Tibet block of the Eurasian plate.

The Ladakh region shows a well-exposed cross-section of the Indus Tsangpo suture zone. Stoliczka (1865) and Lydekker (1883) were among the pioneer geologists to give an account of the geology of Ladakh. Geological investigations of the Italian expedition by De Fillipi in 1913–1914, were published by Dainelli (1934) who gave a comprehensive report with a geological map of the area lying between Kashmir and the Indus valley. Wadia (1937) described the geology of the Astor-Deosai and

adjoining regions of Ladakh, and Auden (1935) in his work "Traverses in the Himalayas", presented some geological information on the area between Kashmir and Karakoram. In his compilation of the geology of western Tibet, Norin (1946) described the geology of Shyok and the western Karakoram region. In recent years the geology of the Indus Tsangpo suture zone in Ladakh has been studied in greater detail by several workers (Shah *et al* 1976; Frank *et al* 1977; Srikantia and Razdan 1980; Thakur 1981; Honnegger *et al* 1982 and Thakur and Misra 1984).

2. Tectonostratigraphy

The Indus Tsangpo suture zone in Ladakh lies between the Tethys Himalaya zone of Spiti and Zanskar (Zanskar Supergroup) in the south and the Karakoram zone in the

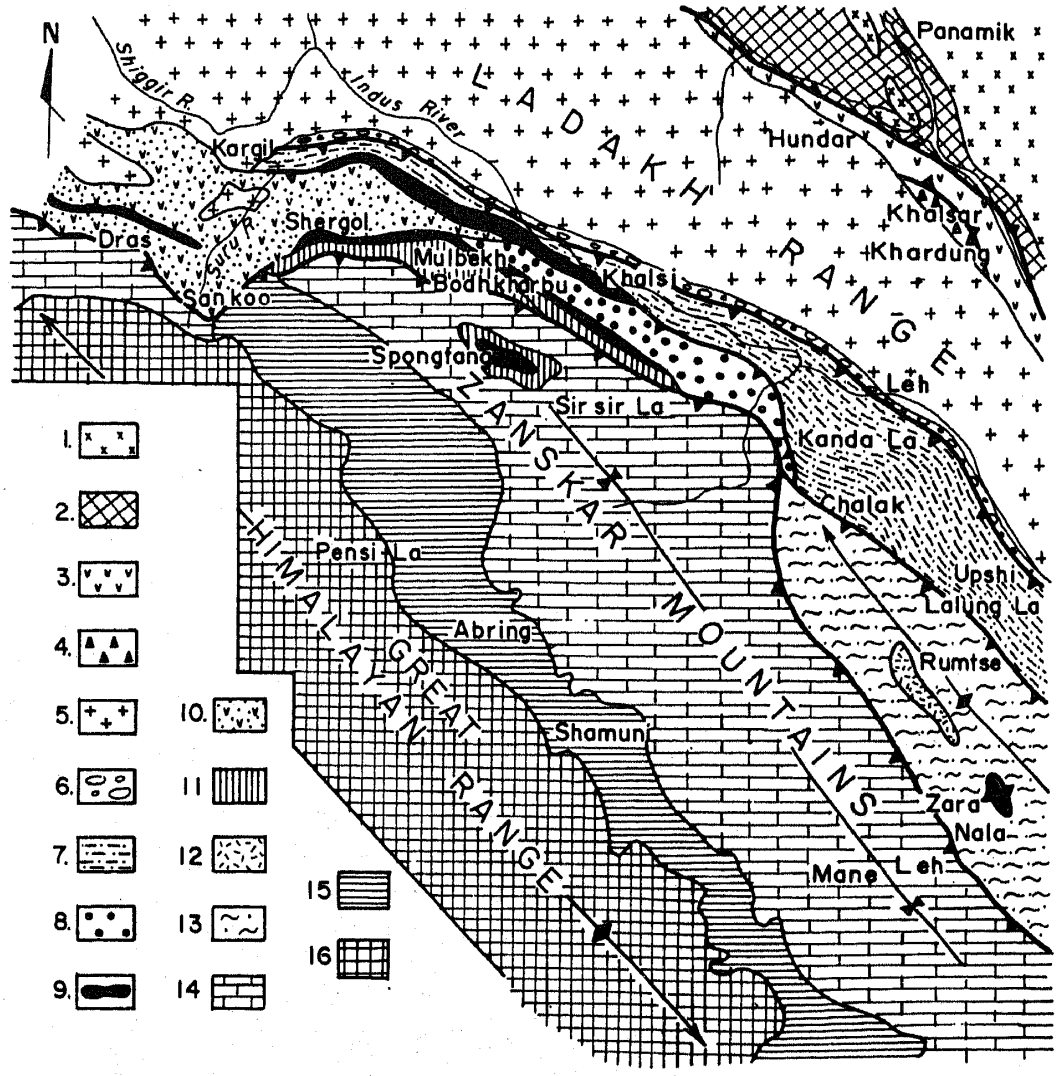

Figure 1. Geological map of Indus Suture zone in western Ladakh. Index: 1—Karakoram plutonic complex; 2—Shyok group; 3—Nubra group; 4—Khardung Formation; 5—Ladakh plutonic complex; 6—Kargil Formation; 7—Indus Formation; 8—Nindam Formation; 9—Shergol ophiolitic melange; 10—Dras Formation: 11—Lamayuru Formation; 12—Polokong granite; 13—Tso Morari crystalline complex; 14—Mesozoics of Tethys Himalaya; 15—Palaeozoics of Tethys Himalaya; 16—Zanskar Crystallines of Higher Himalaya.

north, separated by the south-hading Zanskar thrust in the former and by the north-hading Karakoram thrust in the latter (figure 1). The Indus Tsangpo suture zone is divided into the Indus suture zone and the Shyok suture zone.

3. Indus suture zone

In the western part of the Indus suture consisting of the area lying west of Leh, the principal tectonostratigraphic units are: the Lamayuru Formation, the Dras Formation, the Shergol ophiolitic melange, the Nindam Formation, the Kargil Formation, the Indus Formation, the Ladakh plutonic complex and the Khardung Formation (figure 1). Of these rock units the Lamayuru, the Dras formations, the Shergol ophiolitic melange and the Nindam Formation do not extend further east of Leh in eastern Ladakh. Two different lithostratigraphic units known as the Nidar ophiolite complex and the Tso Morari crystalline complex are exposed in the east of Leh located in the eastern part of the Indus suture (figure 2). The Indus and Kargil formations and the Ladakh plutonic complex extend along the whole length of the Indus suture zone. Acid and intermediate volcanics of the Khardung Formation, which otherwise overlie the northern margin of the Ladakh plutonic complex in western Ladakh, are seen to override the southern margin of the plutonic complex in the eastern part of the suture zone. A scheme of tectonostratigraphic classification is given in table 1.

3.1 *Tso Morari crystalline complex*

In western Ladakh the rocks of the Indus suture zone are in contact with the Zanskar Supergroup of the Zanskar zone, whereas in eastern Ladakh a belt of metamorphics and granites occur between the two tectonostratigraphic zones (figure 1). This sequence of metamorphics and granites is referred to as the Tso Morari crystalline complex. To the south this complex is thrust over by the Mesozoic sediments of the Zanskar Supergroup, and to the north it is overlain along a thrust by the Nidar ophiolite complex and the Indus Formation.

Earlier workers (Berthelsen 1953; Gansser 1964; Sharma and Kumar 1978) described the Tso Morari crystalline complex as Precambrian and a continuation of the Central Crystallines. However, Virdi *et al* (1978) discovered upper Carboniferous to lower Permian fauna (*Neogondolella bisselli* clark and *Behenken. Hyperaminu* sp., *Hemidiscus* sp., *Lituotuba* sp., *Ammobaculites* sp.) in the middle part of the Taglang La Formation of the Tso Morari crystalline complex.

3.2 *Lamayuru Formation*

The Lamayuru Formation has an average thickness of 3000 metres and includes the Lamayuru and Namikala flysch described by Frank *et al* (1977). It consists of shale, siltstone and graded sandstone with flute casts and occurs as a thrust slab sandwiched between the Zanskar Tethys zone (Zanskar Supergroup) in the south and the Shergol ophiolitic melange and the Dras Formation in the north (figure 1). The lower part of the Lamayuru Formation has been dated a middle Ladinian age on the basis of the occurrence of *Daonella indica, D. longobardica*, and the upper part of the formation

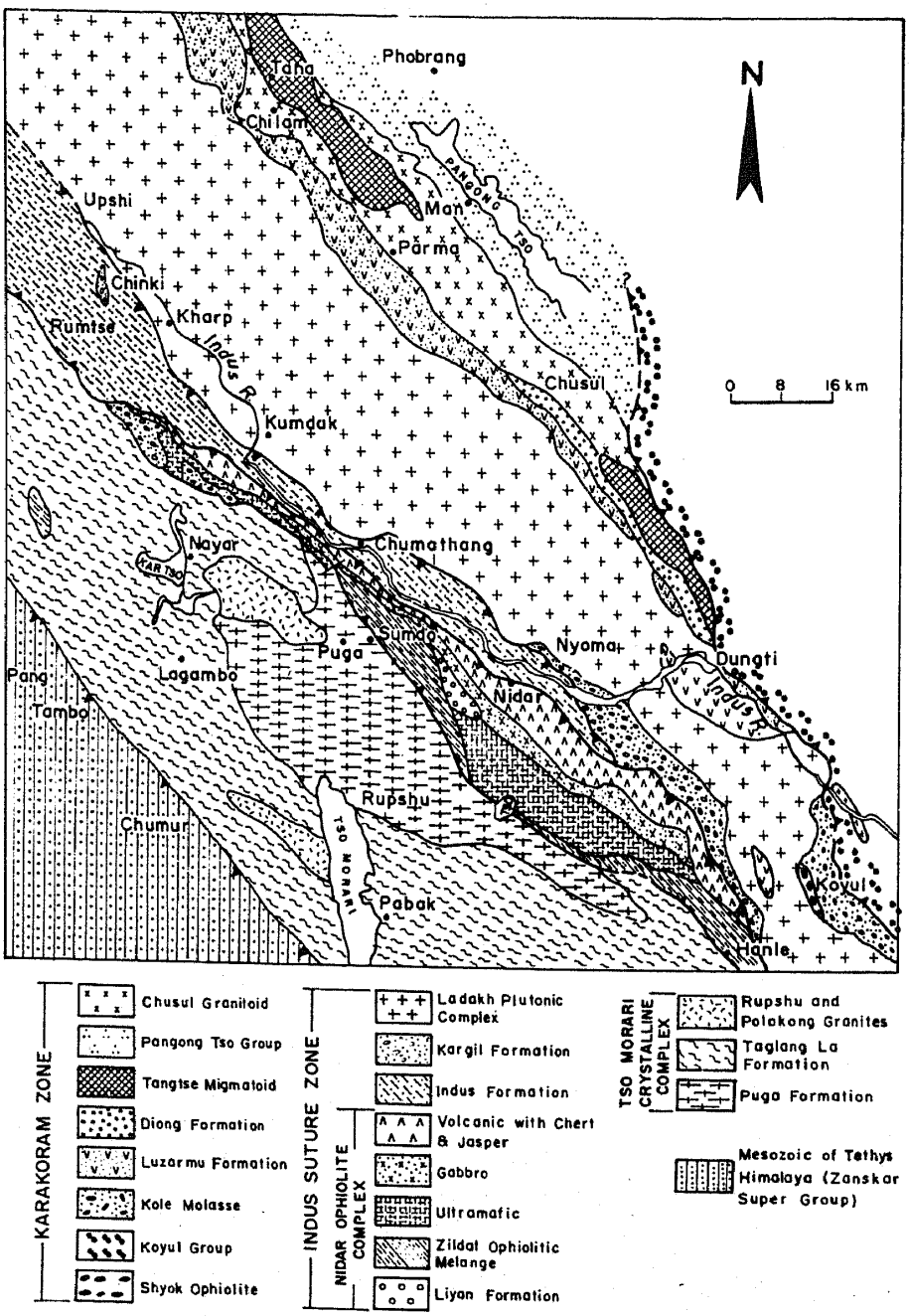

Figure 2. Geological map of eastern Ladakh (after Thakur and Misra 1984).

has yielded *Meekoccras lilangense* Krafft *M. affdircus* Waagen and other ammonite fauna of lower Scythian age (Bassoullet *et al* 1980). Large blocks and lenticular bodies occur upto a few kilometres length of 'Olistostromal limestones of Permian age (Tewari and Pande 1970) within the Lamayuru formation.

3.3 *Dras Formation*

Dras Formation is best found near Dras and in the gorge between Pashkyum and Mulbekh where the outcrop attains the maximum width of 15 km. It does not extend

Table 1. Tectonostratigraphy of Indus-Tsangpo suture zone in Ladakh.

Tectonic Zone	Western Ladakh Stratigraphic units	Eastern Ladakh Stratigraphic units	Age
	Karakoram plutonic complex		90–100, 40, 20 m.y.
Karakoram	Karakoram Supergroup		Upper Palaeozoic to Upper Cretaceous
	Pangong Tso Group		Pre Cambrian-Lower Palaeozoic
		Karakoram Thrust	
		Kole molasse	Pliocene?
	Saltoro molasse	Transgressive	Oligocene?
	Shyok ophiolitic Melange	Shyok ophiolite	Cretaceous?
	Thrust		
Shyok	Hundri formation	Luzarmu formation	Cretaceous
Suture	Thrust		Lower Eocene
	Shyok volcanics		
	Thrust		
	Khalsar formation	Diong formation	Cretaceous, Permian
		Shyok Thrust	
	Khardung formation		Oligocene
	Intrusive contact		
	Ladakh plutonic complex		100, 40, 20 m.y. radiometric dates
	Intrusive contact		
	Dras Formation (Volcanics)		Jurassic-Cretaceous
	Kargil Formation	Transgressive contact	Lower Miocene-Lower Pliocene
	Transgressive		
	Indus Formation		Lower Cretaceous Oligocene
	Thrust		
Indus	Shergol ophiolitic melange	Zildat ophiolite melange	Cretaceous
Suture	Thrust	Thrust	
	Nindam formation	Nidar ophiolite	Jurassic-Cretaceous
	Thrust		
	Lamayuru formation		
	Thrust	Tso Morari crystalline complex	Late Precambrian and Permian
		Zanskar Thrust	
	Zanskar Supergroup	(Tethyan Zone)	Cambrian to Lower Eocene

further east of Leh but continues westward nearly 400 kilometres strikewise around the Nanga Parbat spur as a highly metamorphosed belt.

Dras Formation consists of a succession of volcanics, pyroclastics, volcanoclastic sediments and radiolarian cherts measuring over 5000 m thick together with limestone and serpentinite lenses. It overlies the Kargil Formation along a thrust dipping south between Khalsi and Kargil, but further westward in Kargil and the Astor area it is overlain by the Ladakh plutonic complex with an intrusive contact. Along its southern contact, the Dras Formation is thrust over by the different units which include Mesozoic of the Zanskar Supergroup, Lamayuru Formation, Shergol ophiolitic melange and Nindam Formation. Based on orbitolina limestone, the Dras

Formation was dated as being early to late Cretaceous age by the early workers (Wadia 1937; Shah *et al* 1976). More recently Honegger *et al* (1982) assigned Callovian to Cenomanian age to this formation.

The volcanics of the Dras Formation mainly comprise of irregular basaltic and dacitic flows, pyroclastic flows and tuffs (Prasad *et al* 1980). They range in composition from basaltic andesites to dacite. Bulk chemistry of the volcanics of the Dras Formation suggests that they belong to the island arc tholeiites and calc-alkaline rock series, typical of present island arcs in the Caribbean and the Pacific (Dietrich *et al* 1983). Petrochemistry of the Dras volcanics suggests that tholeiitic magma of the Dras island arc was derived from dehydration or incipient melting of the subducted Tethyan oceanic crust in the mantle (Honnegger *et al* 1982).

Thakur and Misra (1984) have recognized a marked variation in structural styles and deformation features between Shergol ophiolitic melange belts and their underlying Indus Formation and overlying Lamayuru Formation. They suggest that the melanges were generated in a different tectonic environment than that of the underlying and overlying units. These were brought to the present structural juxtaposition with the adjoining units at a later stage.

Petrographically and chemically the basaltic rocks from the melange belt closely resemble the mid-oceanic ridge basalt (MORB) but differs from the island-arc volcanics of the Dras Formation (Honnegger *et al* 1982).

3.4 *Nindam Formation*

The sedimentary unit lying between the two belts of the Shergol ophiolitic melange was interpreted as an eastward extension of the Dras Formation showing a lateral facies variation by Frank *et al* (1977). Thakur and Misra (1984) in their mapping have shown that the two melange belts merge with each other north of Namikala, separating the Nindam Formation into a different tectono-stratigraphic unit from that of the volcanics of the Dras Formation. The Nindam Formation consists of thinly-bedded sandstone, siltstone and shale and has an average thickness of 3000 metres. It shows sedimentary structures which are typical of a flysch sequence. Faunal evidence indicates a Cretaceous age to the Nindam Formation.

3.5 *Nidar Ophiolite Complex*

The Zildat ophiolitic melange and the Nidar ophiolite are the two main units of the Nidar ophiolite complex (figure 2). The Zildat ophiolitic melange in its basal part consists of green hornblende schist of metavolcanic origin together with lenses of serpentinite limestone and glaucophane schist. This unassorted assemblage, 100 m thick, is succeeded upward by green and purple schists of metavolcanic origin and intercalation of 1–2 m thick layers of limestone. These schists are overlain by a conglomerate schist which contains garnet porphyroblasts and aplite veins. The conglomerate schist is succeeded upward by green schist, agglomerate, amygdaloidal basalt and dark grey slate, together with large lenses of limestone within the volcanics. The pebble in the conglomerate and amygdales in the volcanics are strongly deformed showing a fabric lineation of their long axes.

The three mappable units of the Nidar ophiolite are ultramafics, gabbros and volcanics with pillow lavas, cherts and clastics. The ultramafics constituting the

lowermost layer of the ophiolite sequence is thrust over the Zildat ophiolitic melange. It comprises peridotite with lenses of dunite. The ultramafics passes upward into the gabbros without any apparent tectonic break. The main body of the gabbros also encloses pyroxenite lenses and dolerite and pegmatite dykes. The volcanics, overlying the gabbros, consists of pillow lavas in their upper part. It is overlain by an interbedded succession of chert, jasper and clastic sediments. The clastic sediments are thickly bedded and comprise sandstone, grit and conglomerate.

The bulk chemistry of the volcanics member of the Nidar ophiolite gives a wide range of compositional variation within the investigated rock suite (Thakur and Bhat 1983). Except a very minor proportion of basalts, the analytical data indicates predominance of basaltic andesite rhyolite series. The discrimination diagrams (Zr/Y–Zr, TiO_2–Y, Cr–Y, Zr/Y–Ti/Y) indicate an island arc, mid-oceanic ridge and plate margin basalts tectonic settings, suggesting an anomalous chemistry of the rocks.

3.6 *Indus Formation*

A sedimentary belt of a thickness of over 5000 metres, extending NW–SE for more than 500 km strike-wise, is located between the Ladakh plutonic complex in the north and the Shergol ophiolitic melange, Taglang la Formation and the Nidar ophiolite complex in the south. A variety of nomenclature and modes of environment have been proposed for this sedimentary belt. Dainelli (1934) reported Cretaceous and Eocene fauna from the Indus Formation and described it as the Indus flysch. The sedimentaries of the Kargil Formation was first recognized as the Indus Molasse by Tewari (1964). Frank *et al* (1977) described the whole of the Indus sedimentary belt as the Indus Molasse. They divided the Indus Molasse into northern and southern belts, the northern belt directly transgressing the Ladakh plutonic complex and the southern belt, called Hemis Conglomerate, steeply over-thrusting the northern belt. Sharma and Kumar (1978) and Pal *et al* (1978) designated the northern belt as the Karu Molasse and the southern belt as the Indus Formation describing the former as the molasse and the latter as the flysch.

According to Thakur (1981) two distinct tectonostratigraphic units are recognized in the Indus sedimentary belt. They are the autochthonous Kargil Formation and the allochthonous Indus Formation, the former overlies the granitoids of the Ladakh plutonic complex with a transgressive contact, whereas the latter is thrust over either the Kargil Formation or directly over the Ladakh plutonic complex.

This scheme of stratigraphic nomenclature for the Indus sedimentary belt is followed here. The Indus Formation consists of a thickly interbedded succession of predominantly conglomerate, sandstone, siltstone and shale together with subordinate calcareous shale and limestone. It is separated from the Shergol ophiolitic melange, Dras and Nindam formations, Tso Morari crystalline complex and the Nidar ophiolite complex by a steep south dipping thrust (figure 1). A steep south dipping thrust also separates the Indus Formation from the Kargil Formation and the Ladakh plutonic complex.

Based on fossil assemblages from four blocks, namely Khalsi, Kunda la, Miru and Chumathang-Nidar, Mathur (1983a) has classified the Indus Formation into ten biozones. In ascending order these bio-zones are: I—*Orbitolina* zone; II—Plant fossils zone; III—*Pitar* (Calipitaria) carteri-*costacallista semilunaris* zone; IV—*Pelecyora* (*Cordiopsis*) *subatho-ensis-clio* zone; VI—*Ostrea* zone; VII—*Nummulites*

sp. *N. obtusus* zone; X—*Clio* zone. Based on the fossil assemblages described in these zones, Mathur (1983a) has assigned an early Cretaceous to middle Miocene age to the Indus Formation.

According to Thakur and Bagati (1983) the Indus Formation does not show a continuous stratigraphic sequence as the boundaries between different stratigraphic units have incorrect contacts. According to them, three principal stratigraphic units are recognized in the Indus Formation. These are: (a) Conglomerate, sandstone and shale with *Hippurites* bearing limestone of Cretaceous; (b) *Nummulitic* limestone and calcareous shale of lower to middle Eocene, and (c) *Livistona wadiai*, a fossil palm and other plants bearing conglomerate, sandstone and shale of late Eocene-Oligocene (Lakhanpal *et al* 1983). The entire sequence of the Indus Formation ranges from lower Cretaceous to Oligocene. The shallow marine condition of deposition prevailed in lower Cretaceous to middle Eocene, but the plant-bearing beds of upper Eocene-Oligocene indicate a near-shore to continental environment.

The petrographic and modal analysis of sandstones indicates that the clastics are predominantly derived from volcanic and plutonic rocks with a subordinate amount from metamorphic and sedimentary provenance. The major part of the detritus was supplied from the nearby source with a fast rate of deposition and the provenance lay to the north. The presence of hypersthene as heavies and gabbro and mafic rock fragments in some thin sections indicates their source from the ophiolite and the ophiolitic melange, suggesting that the subduction complex to the south was partly also the provenance. The Indus Formation lies in a belt between the Ladakh plutonic complex (magmatic arc) and the ophiolitic melanges, flysch and ophiolite (subduction complex). This tectonic setting and the data on petrographic and modal analyses of the sandstones lead Thakur and Bagati (1983) to interpret the Indus Formation as representing an arc-trench gap sedimentation (fore-arc basin).

3.7 *Kargil Formation*

The Kargil Formation, exposed at its type locality Kargil, shows its maximum thickness up to 1500 metres. It extends in an eroded belt along the Indus valley, overlying the southern margin of the Ladakh plutonic complex with a gentle southerly dip (figure 1). At localities Kargil, Karu, Chumathang and Loma, the conglomerates of the Kargil Formation are seen to overlie the eroded surface of the intrusives. The carbonate and radiolarite clasts, yielding Permian, Cretaceous and middle Eocene fauna, have been reported.

Based on a rich assemblage of fauna collected from the Kargil Formation along a stratigraphic section of the Wakha river in the Kargil area, Mathur (1983b) assigned late Miocene to late Pliocene age to the formation.

Three large outliers of the molasse sedimentaries, located south of the main belt of the Indus and Kargil sedimentaries in a different tectonic setting, were described as Liyan Formation from the area north of Tsokar and near Liyan Gompa in eastern Ladakh (Shankar *et al* 1976). They were later correlated with the Kargil Formation by Thakur and Virdi (1979). This belt of molasse rests unconformably over the Indus Formation, Nidar ophiolite complex and Tso Morari crystalline complex, transgressing the lithological and structural boundaries of these formations.

3.8 *Ladakh Plutonic Complex*

The Ladakh plutonic complex is also designated as 'Ladakh intrusives', 'Ladakh Granites' and 'Ladakh Batholith' by other workers. The Ladakh plutonic complex is composed of quartz diorite, granodiorite and monzodiorite to granite, with occasionally plutons of gabbro, norite, anorthosite and pyroxenite as exposed at Kargil. Four types of granites recognized in the batholith by Sharma and Choubey (1983) are Quartz-monzodiorite and granodiorite, hornblende and biotite-bearing porphyritic granites and biotite and muscovite bearing leucogranite. The marginal parts of the batholith enclose xenoliths of basic (metavolcanics, diorite and amphibolite) and metamorphic (quartzite, mica schist and marble) rocks.

Geochemical data on the granitic rocks of the Ladakh plutonic complex have been described interpreting their crustal evolution from western Ladakh by Honnegger *et al* (1982) and from eastern Ladakh by Sharma and Choubey (1983). In the AFM diagrams the differentiation trend corresponds to the typical calc-alkaline suite of many Cordilleran batholith. The REE pattern of the Ladakh plutonic complex is very similar to that of the Mesozoic Cordilleran batholiths from South and North America. A negative slope in the REE pattern, the enrichment in LREE as well as in K, Ba and Sr may invoke dehydration or incipient melting of subducted oceanic crust in the mantle as the source material for generations of the plutonic complex.

3.9 *Khardung Formation*

The Khardung Formation constitutes a sequence, about 2000 m thick, of acid to intermediate volcanics together with volcanoclastic sedimentaries towards the upper part. They overlie the northern margin of the Ladakh plutonic complex dipping NE at 30–50°, and is overlain along a steep NE dipping thrust by the rocks of the Shyok suture zone. The Khardung Formation consists of predominantly rhyolitic, with subordinate dacitic and andesitic flows and thin bands of pyroclastic and tuffaceous material. The flows are mostly massive but some are amygdaloidal and studded with epidote, quartz and calcite. The pyroclastics in the Khardung Formation include ash flows, tuff flows, crystal tuff, vitric tuff, welded tuff (ignimbrite), lapillistone and volcanic breccia.

The major elements chemistry indicates that the volcanics of the Khardung Formation are predominantly rhyolitic with subordinate dacitic and andesitic in composition. Plots in AFM diagram show that the volcanics are calc-alkaline in nature (Sharma and Gupta 1983). In the Khardung-Khalsar section the volcanic has been dated as 38 ± 2 m.y. (Sharma *et al* 1978).

4. Shyok suture zone

Preliminary geological accounts of the Nubra and Shyok regions were given by the early pioneer workers (Stoliczka 1865; Lydekker 1883; Norin 1946). Based on the early geological accounts and interpretation of satellite imageries, Gansser (1980) proposed a second suture along the Shyok zone. In recent years the geology of Shyok

suture zone has been described by several workers (Gupta and Sharma 1978; Bhandari *et al* 1974; Thakur *et al* 1981; Rai 1982, 1983; Thakur and Misra 1984), but some confusion prevails about the classification and nomenclature of different rock units strike-wise and inaccessibility of some areas have led to different interpretations of the contact relationships and the classification of rock units under different names. A revised lithostratigraphic scheme (table 1) and the geology is described on the basis of Thakur *et al* (1981). Thakur (1981), Srimal *et al* (1983), Rai (1982, 1983) and Thakur and Misra (1984). The geology of the Shyok suture zone is described here separately for Nubra-Shyok region and Chusul-Koyul region (figure 3).

4.1 *Nubra-Shyok Region*

The main tectonostratigraphic units of the Shyok suture zone in Nubra-Shyok region

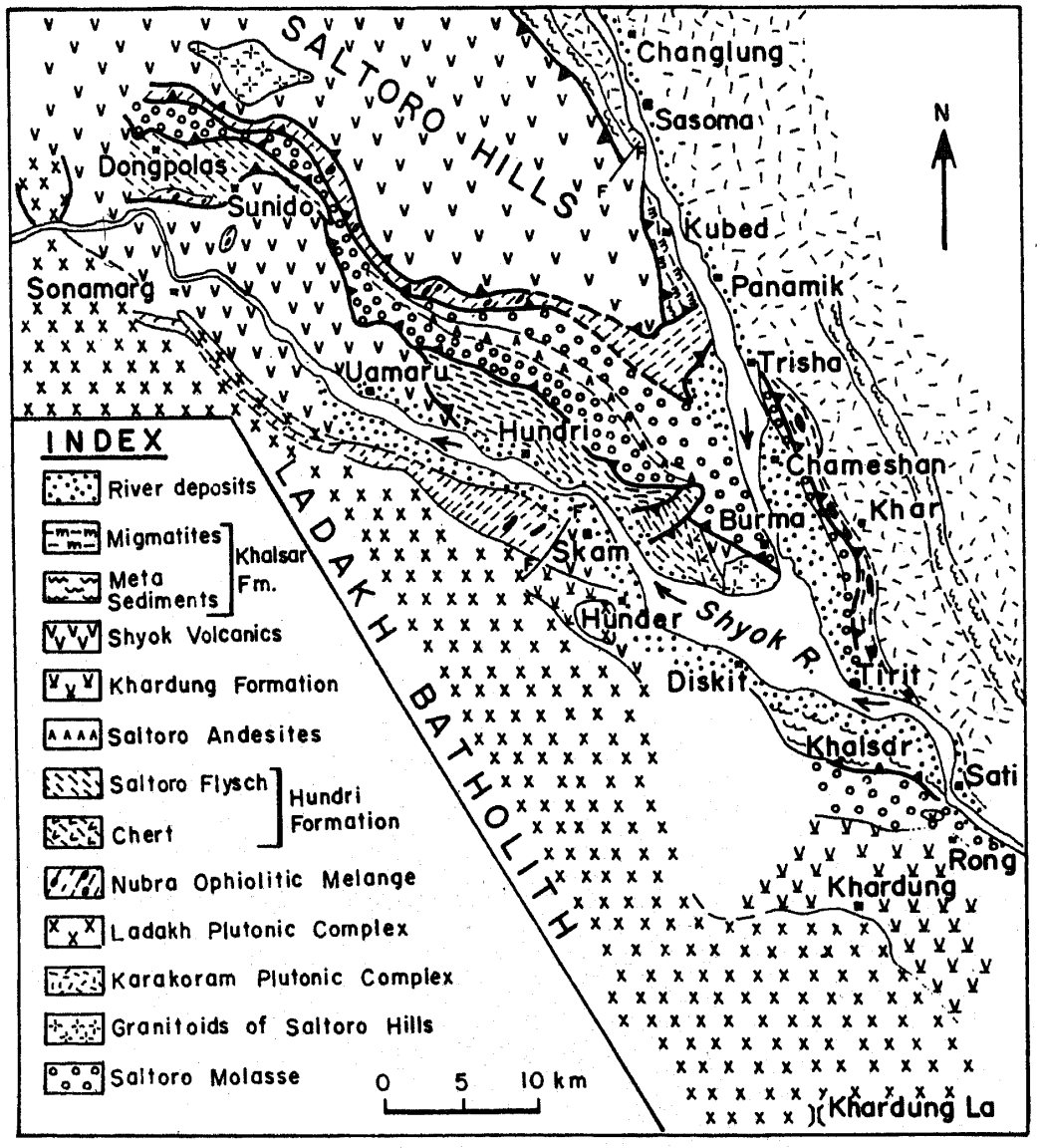

Figure 3. Geological map of Shyok suture Zone (after Rai 1983).

are: Khalsar Formation, Shyok volcanics, Hundri Formation, Shyok ophiolitic melange and Saltoro Molasse.

The Khalsar Formation consists of calcareous phyllite, chlorite and mica schist, limestone, gneiss intruded by granitoid plutons. The Shyok volcanics constitutes basaltic and andesitic volcanics, and the Hundri Formation consists of flyschoid slate and limestone which have yielded upper Cretaceous-Eocene fauna. The Nubra ophiolitic melange is composed of stratigraphically disordered assemblages of volcanics, shale, limestone and slate together with lenses of serpentinite and peridotite. The conglomerate, sandstone and shale constitute the Saltoro molasse which is interbedded with penecontemporaneous volcanic layers.

4.2 *Chusul-Koyul Region*

The Shyok suture zone rocks, lying between the Ladakh plutonic complex and the Karakoram zone, extend from Shyok valley eastward into the Chusul and Koyul area. In this area Thakur and Misra (1984) described four tectonostratigraphic units, viz. the Luzarmu Formation, the Shyok ophiolite, the Diong Formation and the Kole Molasse.

Luzarmu Formation consists of andesite and dacite with interbedded chert and limestone. *Orbitolina*-bearing limestone of lower to middle Cretaceous has been recently reported from the volcano-sedimentary succession near Chusul (Srikantia *et al* 1982). The Diong Formation overlies the Luzarmu Formation, and is comprised of thickly-bedded limestone, quartzite, sandstone, conglomerate and interbedded volcanics. The Shyok ophiolite consists of dismembered units of pyroxenite, peridotite, gabbro and volcanics together with chert. In its southward extension the Shyok ophiolite, exposed along the northern margin of the Ladakh plutonic complex west of Koyul, is composed of peridotite, gabbro and volcanic with chert. The Kole Molasse unit, 500 m thick, consists of arkosic sandstone, grit and conglomerate and is exposed west of Koyul. They overlie at a low angle transgressing the Shyok ophiolite, other units of the Shyok suture and the Koyul Formation of the Karakoram zone.

5. Karakoram zone

Stoliczka (in Blanford 1878) was among the earliest workers to give an account of the geology of Karakoram. In later years several teams on expedition to the Karakoram described the geology along the expedition routes (DeTerra 1932; Dainelli 1932). Norin (1946) compiled a monograph along with a geological map of western Tibet which included the eastern Karakoram region. Investigations of the Italian expedition teams to the western Karakoram were published in a series of monographs, and recently Desio (1979) published a review on the geology of Karakoram. The Wadia Institute team has mapped the eastern Karakoram and has described the geology of the area. The geology of Karakoram zone described here deals with the eastern Karakoram region and is mainly based on Gergan and Pant (1983).

The rocks of the Karakoram zone are separated from the Shyok suture zone by a north hading thrust called Karakoram thrust. Three principal tectonostratigraphic units of the Karakoram zone are the Pangong Tso group, Karakoram Supergroup and Karakoram plutonic complex (figure 4).

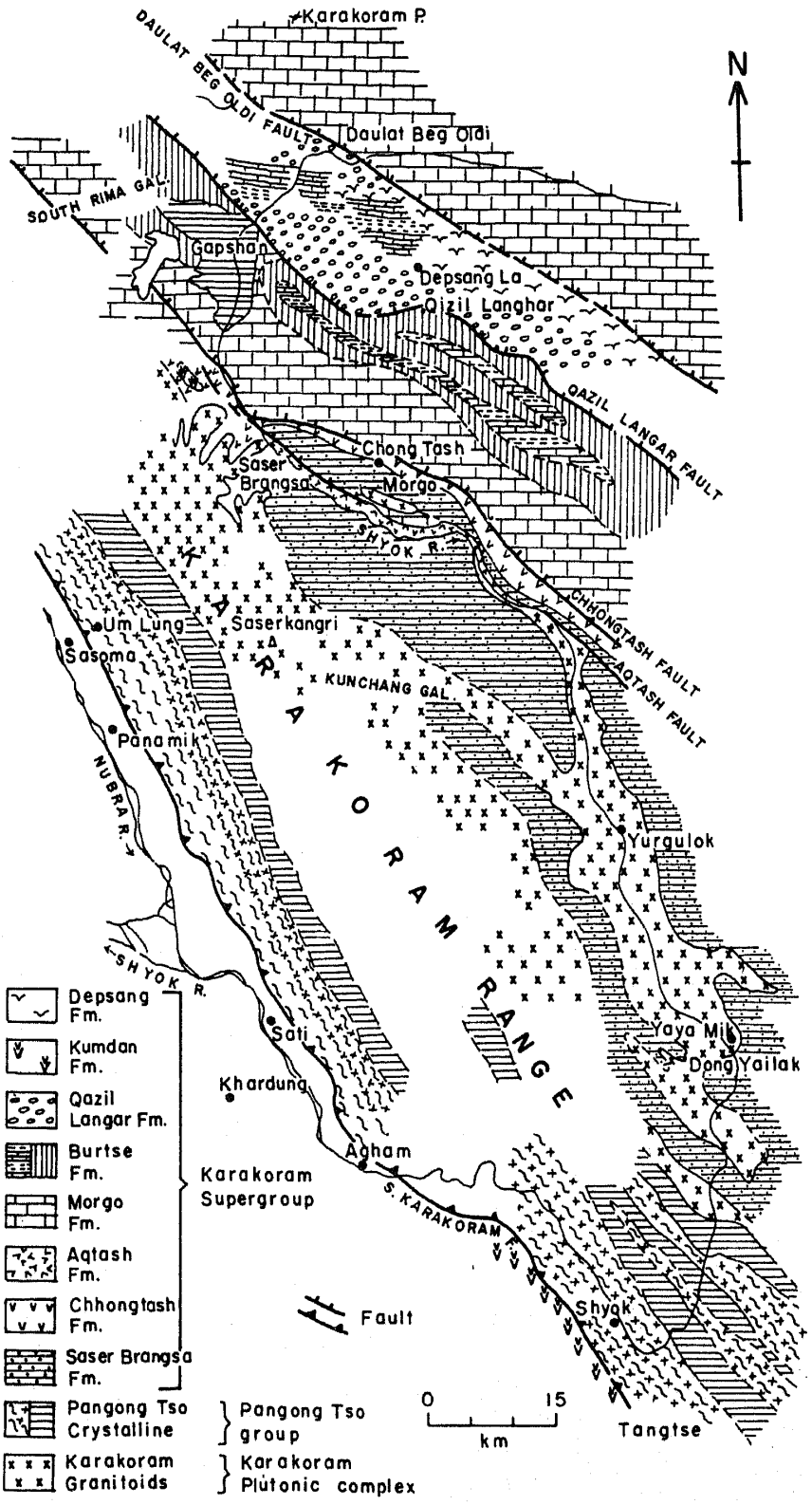

Figure 4. Geological map of Karakoram region (after Gergan and Pant 1983).

5.1 *Pangong Tso group*

The Pangong Tso group rocks underlie the upper Palaeozoic-Mesozoic sequence of the Karakoram Supergroup. It consists of metamorphic sequence which shows a

progressive regional metamorphism ranging from chlorite to sillimanite grade. It shows a gradational contact between the Pangong Tso group and the overlying upper Carboniferous beds. In Pangong Tso area the metasedimentary sequence of the Pangong Tso group is underlain by Tangse Migmatoid band which in turn overlies the granite of the Karakoram plutonic complex.

5.2 *Karakoram Supergroup*

The Karakoram Supergroup consists of a predominantly sedimentary sequence and range in age from Carboniferous to Cretaceous. Norin (1946) was one of the earliest workers to give an account of the regional stratigraphy of the eastern Karakoram region. Recently Gergan and Pant (1983) described the geology with a geological map and lithostratigraphic column. The Karakoram Supergroup is classified into Saser Brangsa, ChhongTash, AqTash, Morgo, Burtsa, Qazil Langer, Kumdan and Deapsang formations.

5.3 *Karakoram plutonic complex*

The Karakoram plutonic complex consists of predominantly granite and granodiorite but tonalite plutons are also common. Aplite and pegmatite dykes are the late phase intrusives into the plutons. Xenoliths and large septas measuring up to 100 metres long of mica schist, quartzite and marble occur in the granitoids of the plutonic complex. The granites and granodiorites contain quartz, K-felspar and plagioclase as the main constituents.

The granitoids of the Karakoram plutonic complex have intruded into the Pangong Tso group metamorphics and the sedimentaries of the Karakoram Supergroup as well as the rocks of the Shyok suture zone. Intrusions of the granite plutons into the fossiliferous dates Permian and Triassic rocks are observed at several localities, indicating the post-Triassic age of the Karakoram plutonic complex.

5.4 *Shyok Suture Zone in Koyul Area*

The Tangse Migmatoid, Pangong Tso group, Koyul Formation and Chusul Granitoid are the principal units of the Karakoram zone described from a belt extending from Pangong Tso to Koyul.

The Koyul group consists of sandstone, greywacke, quartzite, cherty sandstone, diamictite, shale and limestone. Its sandstone and shale beds have yielded plant fossils—*Raphaelia diamensis* Seward, Piazopteris cf. *branneri* (White) Lorch, *Acrotichopteris* sp., *Taeniopteris* cf. *uwatokoi* Oishi, *Nilssonia* sp., *Cycadites* wadianus n. sp. *Pterophyllum* sp. and others. This floral assemblage indicates a middle to upper Jurassic age and resembles the floral assemblages known from Eurasia (Bose *et al* 1983). The Jurassic plant-bearing bed of fluviatile facies has been also described earlier from the Karakoram Supergroup sedimentaries.

6. Tectonics

The Indus Tsangpo suture zone is bounded to the south by the Tethys Himalaya zone and to the north by the Karakoram-Tibet zone.

The Zanskar Supergroup in Ladakh represents the Phanerozoic sequence, late PreCambrian to lower Eocene, of the Tethys Himalaya zone of Zanskar and Spiti. It overlies the Central Crystallines rocks of the Higher Himalaya zone. The Zanskar Supergroup sequence represents sedimentation over the continental margin of the northern edge of the Indian plate. In this sequence, shallow marine sedimentation on the shelf margin is recorded in Triassic and Jurassic and a sudden deepening is recorded in Campanian. Shallow marine condition again prevailed in lower Eocene marking the final marine deposit in the Tethys Himalaya zone. The Lamayuru Formation, which lies between the Zanskar Tethys zone and the ophiolitic melanges of the Indus suture, represents a flysch sedimentation in Triassic-Jurassic time along the continental slope of the continental margin.

Carboniferous to Cretaceous sequence of the Karakoram Supergroup and the underlying lower to middle Palaeozoic metamorphics of the Pangong Tso group belong to the Karakoram-Tibet zone. The Karakoram-Tibet zone was part of Gondwanaland till Permian. It was fragmented from the Indian plate and was accreted to the Eurasian plate in Mesozoic (Bassoulet *et al* 1980; Thakur 1981; Nicolas *et al* 1981).

In the Indus Tsangpo suture zone, which represents the collision zone between the Indian continent and the Karakoram-Tibet block, the different palaeotectonic regimes have been recognized (figure 4). These are Indus palaeosubduction complex, Ladakh magmatic arc, Indus arch-trench gap sedimentation, Shyok back-arc basin and post-collision molasse (Thakur 1981, 1983).

The Shergol and Zildat ophiolitic melanges, Nidar ophiolite and the Nindam Formation belong to Indus palaeosubduction complex. Nidar ophiolite represents tectonically dismembered fragments of an obducted slab of the Tethys ocean. The ophiolitic melanges and the flysch prism were generated along a zone of subduction of the Indian oceanic plate under the Karakoram-Tibet block.

A plutonic-volcanic arc, called the 'Ladakh magmatic arc' is recognized. Three principal phases of this magmatic arc are represented by the tholeiite and calc-alkaline volcanic rocks of the Dras Formation, the calc alkaline intrusives of the Ladakh plutonic complex and the acid volcanics of the Khardung Formation. The Ladakh magmatic arc was developed in an Andean-type margin by subduction of the Indian oceanic plate under the Karakoram-Tibet block. The magma for the arc was generated as a result of dehydration of incipient melting of the subducted Tethyan oceanic crust in the mantle.

Sedimentation took place in a basin that lay between an evolving magmatic arc to the north and the subduction complex to the south. A sedimentary sequence, over 5000 metres thick, of the Indus Formation is interpreted as representing sedimentation in an arc-trench gap region.

The petrotectonic assemblages and tectonic setting of the Shyok suture zone point to a tectonically compressed marginal basin that lay between the Ladakh magmatic arc and the Karakoram block. Tectonic reconstruction suggests that the Shyok basin had an oceanic crust overlain by flyschoid and volcanic sequence which in turn was succeeded upward by the molasse sedimentaries.

Based on the analysis of structural framework, petrotectonic assemblages and geochemical and geochronological data, it is inferred that the collision between the Indian plate and the Tibet block involved the following sequence of tectonic events.
(i) Subduction of Indian oceanic plate under the Karakoram-Tibet block in Jurassic-

Cretaceous in an Andean-type margin, generating Ladakh magmatic arc and leading to arc-trench gap sedimentation of the Indus Formation. (ii) Incipient collision of the Indian plate against the magmatic arc in middle to upper Eocene giving rise to the palaeosubduction complex zone. (iii) Closure of the Shyok back arc basin. Emplacement of the ophiolitic melanges nappe, such as Spongtang klippe, to the continental margin of the Indian continent. (iv) Penetrative deformation and regional metamorphism of the Tso Morari crystalline complex and the Pangong Tso group and formation of the anatectic granites of the Karakoram plutonic complex owe their origin to crustal shortening in Oligocene-Miocene as a result of suturing (welding) of the Indian continent against the Karakoram-Tibet block. (v) Post-collision molasse sedimentation of Kargil and Kole formations in Mio-Pliocene under continental environment, suggesting an uplift of the suture zone area.

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