

## Geology of the Trans Himalaya in the Ladakh sector

### 2.1 Geotectonic subdivisions of Himalaya

The Himalaya can broadly be classified into four major geotectonic units (Fig. 2.1) (Ganser, 1964; Valdiya, 1984), which from south to north are,

- 1) Siwaliks or Sub Himalaya separated from the Indo-Gangetic plains by the Himalayan Frontal Fault (HFF) in south.
- 2) Lesser Himalaya is separated from the Siwalik by the Main Boundary Thrust (MBT)
- 3) Higher Himalaya or Himadri which is separated from the Lesser Himalaya by the Main Central Thrust (MCT) and the
- 4) Trans Himalaya or the Tethyan zone which is north of the Higher Himalaya.

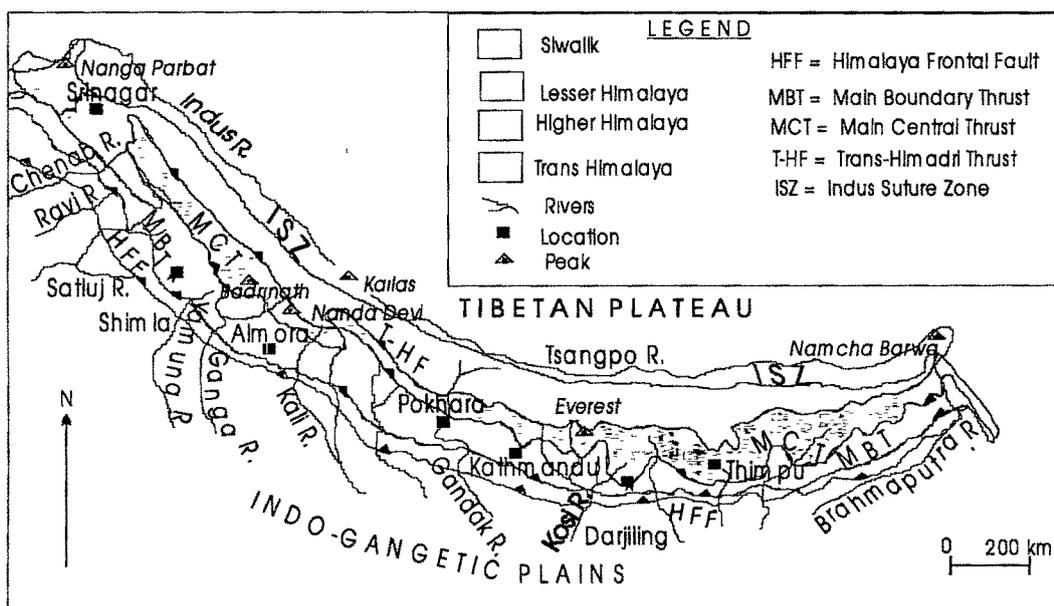


Fig. 2.1 Geotectonic subdivisions of Himalaya (adapted from Valdiya, 1998).

## **2.2 Subdivisions of Trans Himalaya**

The Trans Himalaya, as the name suggests is the terrain lying beyond the main Himalayan ranges towards the north. The Trans Himalaya again can be subdivided into following units (Searle et al., 1987), which from south to north are

- 1) Continental passive margin sediments, (Lahoul supergroup and Zaskar-Spiti basin sediments in Ladakh) of the northern Indian margin
- 2) Indus Suture Zone including the arc-trench sediments, ophiolites and continental molasse deposits,
- 3) Trans Himalayan Batholith (Ladakh-Gangdese batholith) representing the subduction related calc-alkaline magmatism and
- 4) Shyok Suture Zone representing the suturing between the magmatic arc and the Asian margin.

All the above units of the trans Himalaya can be found in the Ladakh region (Fig. 2.2) of the northwestern Himalaya

## **2.3 Geology of Ladakh**

### **2.3.1. General Introduction**

Ladakh, the land of many passes, of freezing high barren landscapes in Trans Himalaya is among the world's highest inhabited terrains. Situated on the northwestern Trans Himalaya, Ladakh has three major mountain ranges, Zaskar, Ladakh and Karakoram range with Higher Himalaya forming its southern border. Being in the rain-shadow region the annual rainfall is a mere 5 cm here and it is melting snow in summer, which sustains life. The temperatures go as low as  $-30^{\circ}\text{C}$  in Leh and  $-50^{\circ}\text{C}$  in Dras. With three months of subzero temperatures (Dec-Feb) and the rest of the months facing zero degree temperatures, it is a long and hard winter here. High aridity and low temperatures lead to sparse vegetation as a result the landscape is desert-like with sand dunes. In summer the temperature goes above  $20^{\circ}\text{C}$ . In the short intense summer, cultivation is sustained by melting snow and carefully harnessing the water. Apples, apricots and barley are grown here in summer. The major waterway of Ladakh is Indus which enters India from Tibet at Demchok, starting near Mt. Kailash. Its tributaries, the Zaskar, Shingo, Shyok, and Nubra and their river valleys form the main area of human habitation. Ladakh also has

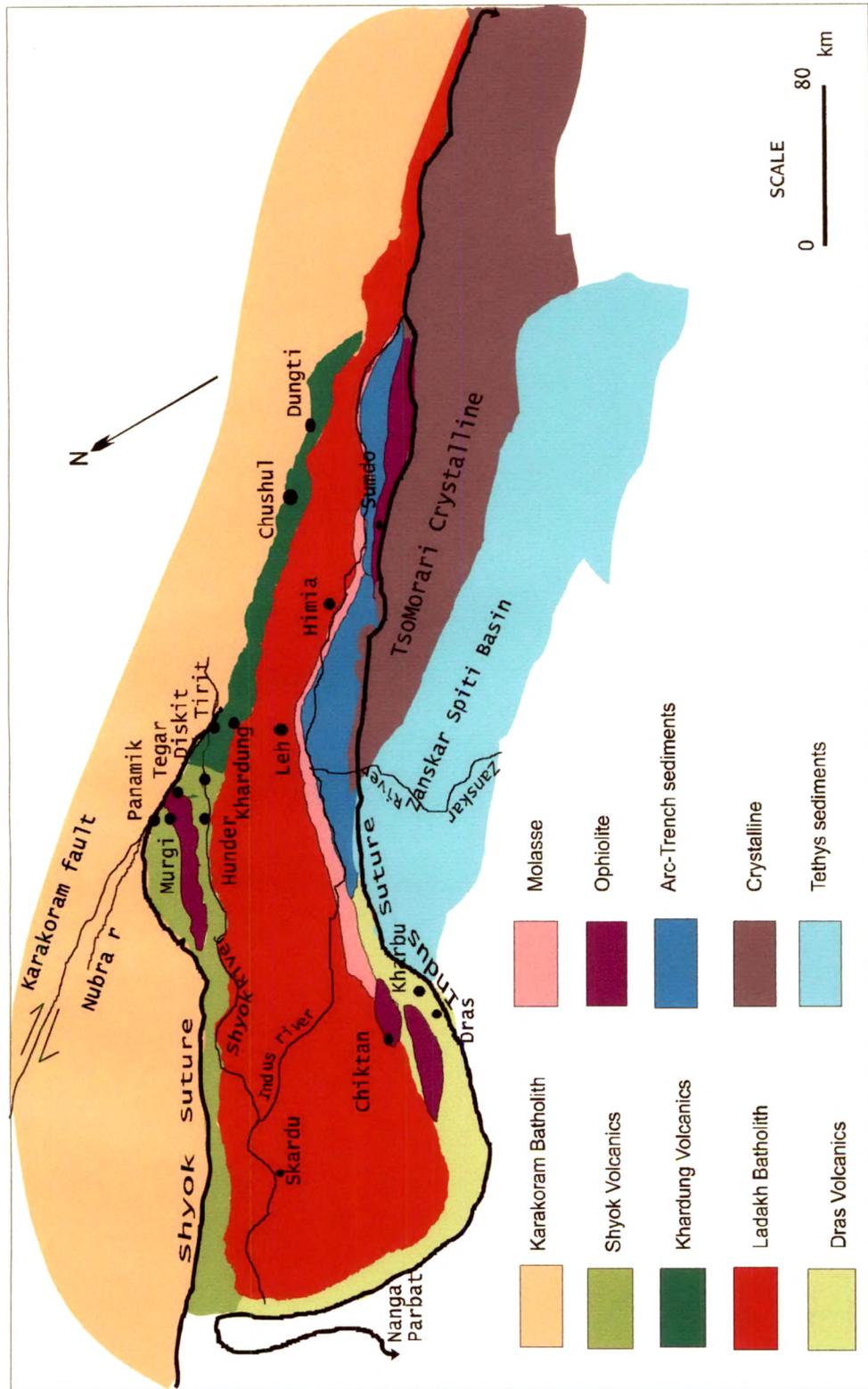
one of the largest and most beautiful natural lakes in the country Pangong Tso, 150 km long and 4 km wide, is at the height of 4300 m. Tso Morari, a pearl shaped lake and Tso kar are the other brackish water lakes of Ladakh. Yaye Tso, Kiun Tso and Amtitla are among the fresh water lakes. Ladakh, covering an area of approximately 98,000 sq km of the northwest Trans Himalaya provides a complete section through all the major geological units of the Trans Himalaya (Fig. 2.2).

### ***2.3.2. The passive continental margin deposits***

The passive continental margin deposits are represented by the Paleozoic Lahoul supergroup and Mesozoic Zaskar supergroup. These are separated by the rift related Panjal Traps which erupted in Permian and are well exposed now in Kashmir valley. These are continental tholentes and mildly alkaline flood basalts (Searle et al., 1987). With this rift in Permian, the Neo-Tethys passive margin evolved in Mesozoic. This period is represented by the thick Triassic platform carbonate and Jurassic transgression of the shelf marked by the fossiliferous Spiti shales. The shallow marine carbonate deposition continued up to late Cretaceous as represented in the Zaskar ranges and the Kangi-la flysch is overlying these shallow marine deposits representing the deep water conditions. The fossiliferous Eocene limestone of the Zaskar is believed to be the youngest shelf deposit of the Neo-Tethys margin (Mathur and Pant, 1983).

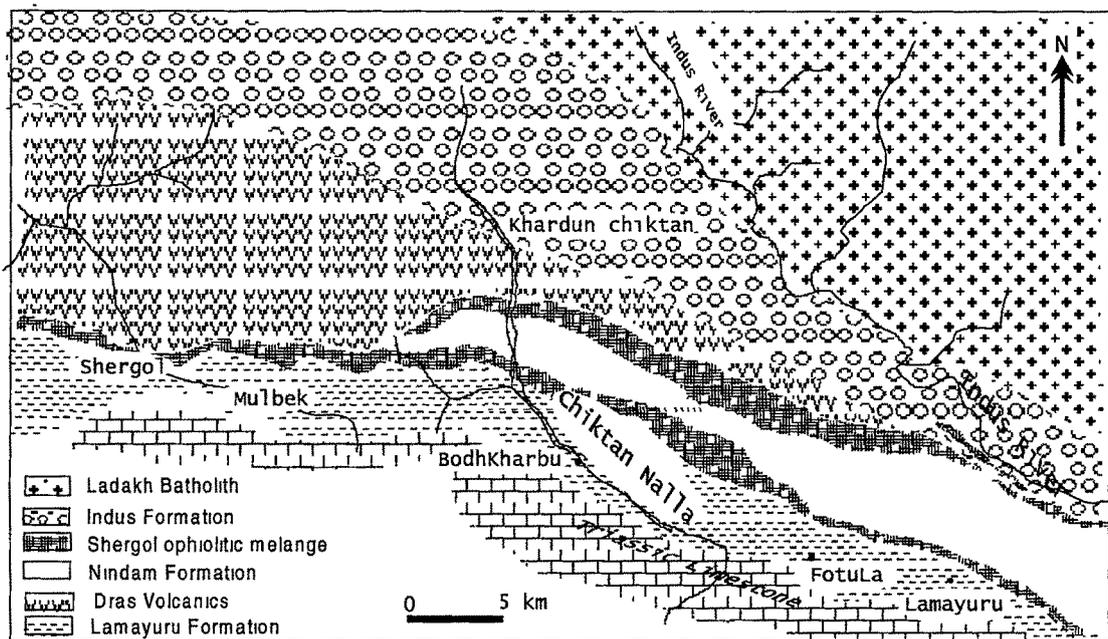
### ***2.3.3. Indus Suture Zone***

Indus suture zone contains the deep-sea sediments of the northern Indian plate and southern Tibetan plate separated by fore arc-trench sediments and overlain by ophiolitic mélanges and molasses (Fig. 2.2). In Ladakh area, the deep sea sediments are represented by Lamayuru complex which consists of Triassic to Cretaceous shales, sandstones, turbidites and deep sea radiolarian cherts (Searle et al., 1987 and the references therein). The Lamayuru complex is believed to represent the deep-sea facies of the Indian passive margin and are time equivalent of the Zaskar shelf deposits (Mathur and Pant, 1983). The Lamayuru complex grades into the fore arc Nindam formation. Nindam formation is intra oceanic deposits on the southern flank of Dras island arc (Fig. 2.3). It comprises volcanoclastic sediments and pelagic carbonates. The trace and rare earth element signatures of sediments are similar to that of Chalt and Dras volcanic rocks but are distinct



**Fig. 2.2** Geological map of Ladakh showing the sample locations (Modified from Sharma, 1991)

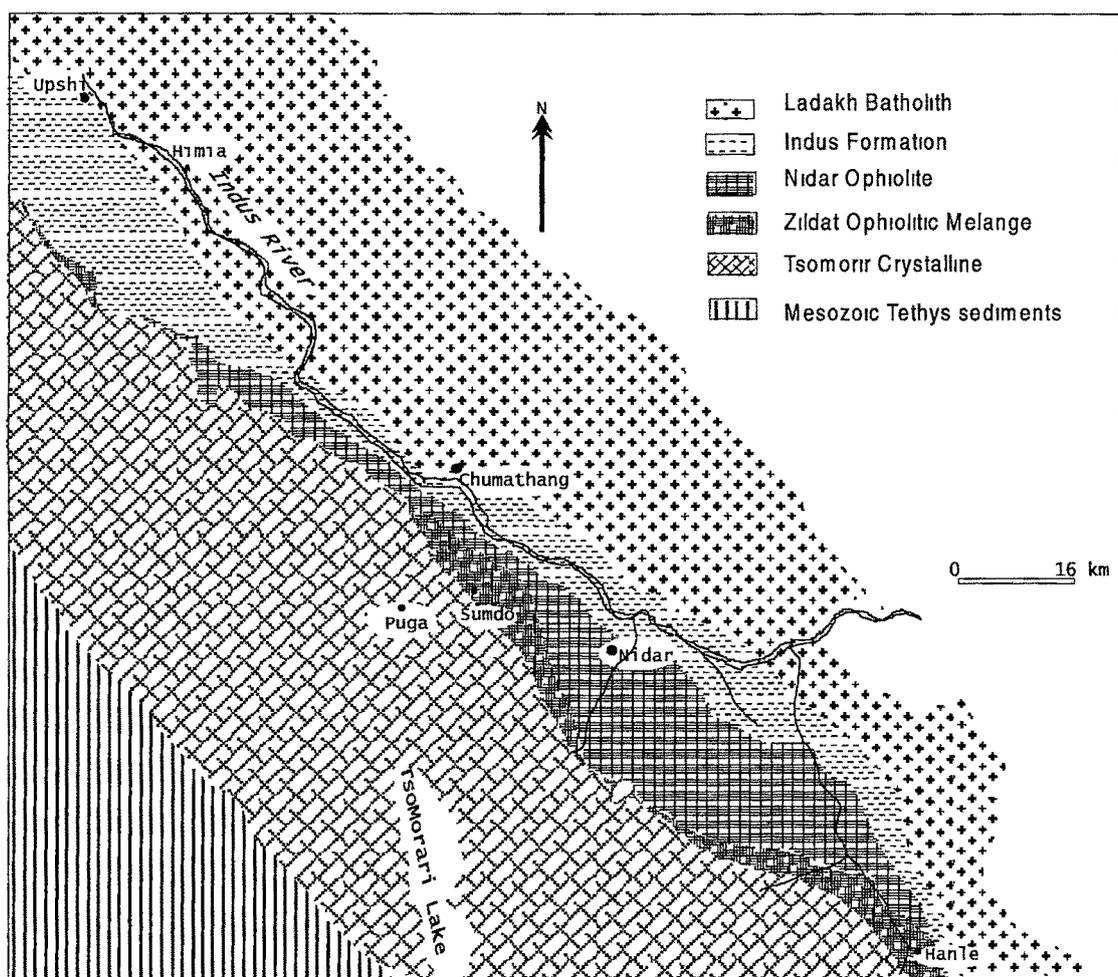
from Khardung volcanics (Clift et al., 2000). Ophiolitic mélanges with exotic sedimentary blocks are characteristic features of the Indus Suture. Ophiolitic mélanges occur in two distinct tectonic settings (Searle et al., 1987). In the first it occurs as autochthonous unit within Indus Suture and in the other it occurs as allochthonous units forming nappes and klippen on the younger Tethyan sediments. In the western Ladakh (Fig. 2.3) two belts of Shergol ophiolites have been recognized to the north and south of the Nindam formations (Thakur and Bhat, 1983).



**Fig. 2.3** Geological map of western Ladakh (Thakur and Misra, 1983).

The Shergol ophiolitic mélange exposed near the BodhKharbu and Chiktan Nala comprises mainly serpentinites, peridotites, basic volcanics along with jasperoid shale, green sandstones and phyllites. In the eastern Ladakh, Zildat ophiolitic mélange is found to be thrust over Tso Morari crystalline complex and is overlain by Nidar ophiolites (Fig. 2.4). Zildat ophiolitic mélange in Mahe-Sumdo nala section is composed of serpentinites, purple shale, exotic limestone and volcanics with pillow lavas (Thakur and Misra, 1983). Nidar ophiolite has thick units of ultramafics, gabbros, volcanics with pillow lavas, cherts and clastics. The allochthonous part of the Indus Suture ophiolites are well exposed in the Spong tang area of the Ladakh and is known as Spong tang klippe. This ophiolitic mélange is thrust 30 km south of its main root zone in Indus Suture. It comprises of ultramafics, gabbro, serpentinites and some volcanics. The timing of the

obduction of the Spongtang ophiolite onto the northern passive margin of the Indian plate has been debated hotly. Fuchs (1979), Keleman and Sonnenfeld (1983) and Reuber (1986) suggested a post early Eocene age of the obduction because the Spongtang ophiolite and its underlying thrust sheets comprising deep water sediments, alkalic volcanic rocks and mélanges have been thrust over Paleocene-Early Eocene limestones. Searle (1986, 1988) first proposed that the post collisional restacking of the units obliterated the actual Late-Cretaceous Early Paleocene obduction event. Searle et al. (1997) presented field data and structural mapping in favor of a Cretaceous obduction.



**Fig. 2.4** Geological map of eastern Ladakh (modified from Thakur & Bhat, 1983).

The ophiolitic mélanges in Ladakh are overlain by another fore arc basin known as Indus Group or Indus Formation, south of the Ladakh batholith (Fig. 2.4). This fore arc seems to have evolved from middle Cretaceous to Eocene. (Thakur and Bagati, 1983; Garzanti and Van Haver, 1988). This basin in Ladakh represents a complex transition from marine

to continental deposition conditions and thus becomes important to constrain the timing of initiation of the collision (Rowley, 1996). The transition from marine to continental deposition starts from the Eocene Indus clastics and Indus molasses overlying the Numulitic limestone. Hemis conglomerate from near the Hemis gompa south of Leh representing the continental Molasses has clasts from volcanic, plutonic, sedimentary and metasedimentary rocks. The major part of the detritus in the Indus group is supplied from the nearby source and the provenance lies to the north (Thakur and Bagati, 1983).

#### ***2.3.4. Ladakh Batholith***

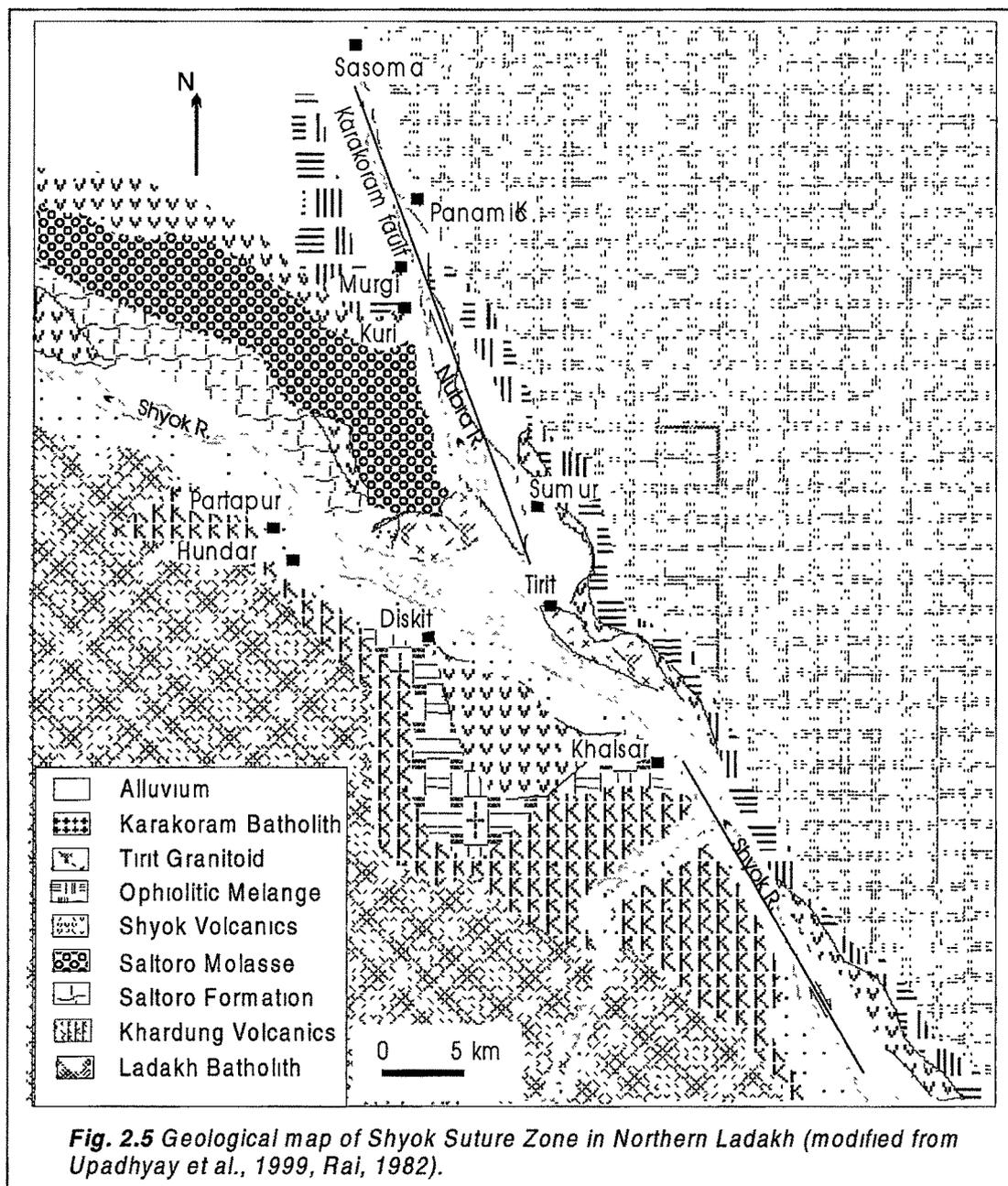
Ladakh Batholith is a part of 2500 km long Trans Himalayan Batholith (THB), that is mainly subduction related calc-alkaline magmatism evolved along the southern margin of the Eurasian plate in mostly Andean type tectonic setting except in the western sector of Kohistan batholith where it seems to have intruded into a Chalt-Dras island arc (Sharma, 1990; Honneger et al., 1982; Weinberg and Dunlop, 2000). Ladakh batholith is around 500 km long and 30-40 km wide (Fig. 2.2). The rocks range from gabbro norite to granites and leucogranites. Granodiorites and biotite bearing granites are the dominating rock types of the Ladakh batholith. At places the different rocks are quite intermingling and their intrusive relationship is difficult to ascertain (Ahmad et al., 1998). The Ladakh batholith is cut by andesitic and basaltic dykes.

The existing geochronological data range from 100 Ma to 40 Ma, frequently interpreted as the duration of subduction. The ending of the magmatism is widely used to constrain the age of initiation of the collision (Honneger et al 1982, Weinberg and Dunlop, 2000). However, younger ages have been obtained recently which probably are post-collision. The significant crustal anatexis also may be involved in the batholith formation as indicated by the previous isotopic studies (Honneger et al., 1982; Weinberg and Dunlop, 2000).

#### ***2.3.5. North of the Ladakh Batholith***

Shyok suture zone marks the northern boundary of the Ladakh batholith and separates it from the Karakoram batholith (Fig. 2.5). Shyok suture in Ladakh is the eastern continuation of the Northern Suture of the Kohistan sector of Pakistan. Kohistan-Ladakh sectors usually are believed to be Island arc type with Chalt volcanics of Kohistan sector and Shyok volcanics of the Ladakh representing the back arc basin sequences (Pettersen

and Windley, 1985; Upadhyay et al., 1999). A recent study, however, indicated that the Northern Kohistan is chemically quite different than the Northern Ladakh. This requires



a different evolutionary scenario of Northern Ladakh than the Northern Kohistan (Rolland et al., 2000). The relative timing of suturing along the two sutures bounding the Kohistan-Ladakh sector has remained controversial. While many workers believed Shyok suture to be older being closed in Cretaceous (Pudsey, 1986; Petterson and Windley, 1991; Treloar et al., 1996); Brookfield and Reynolds (1981) and Reynolds et al. (1983) suggested that it did not close until Miocene. Rai (1983), however, argued

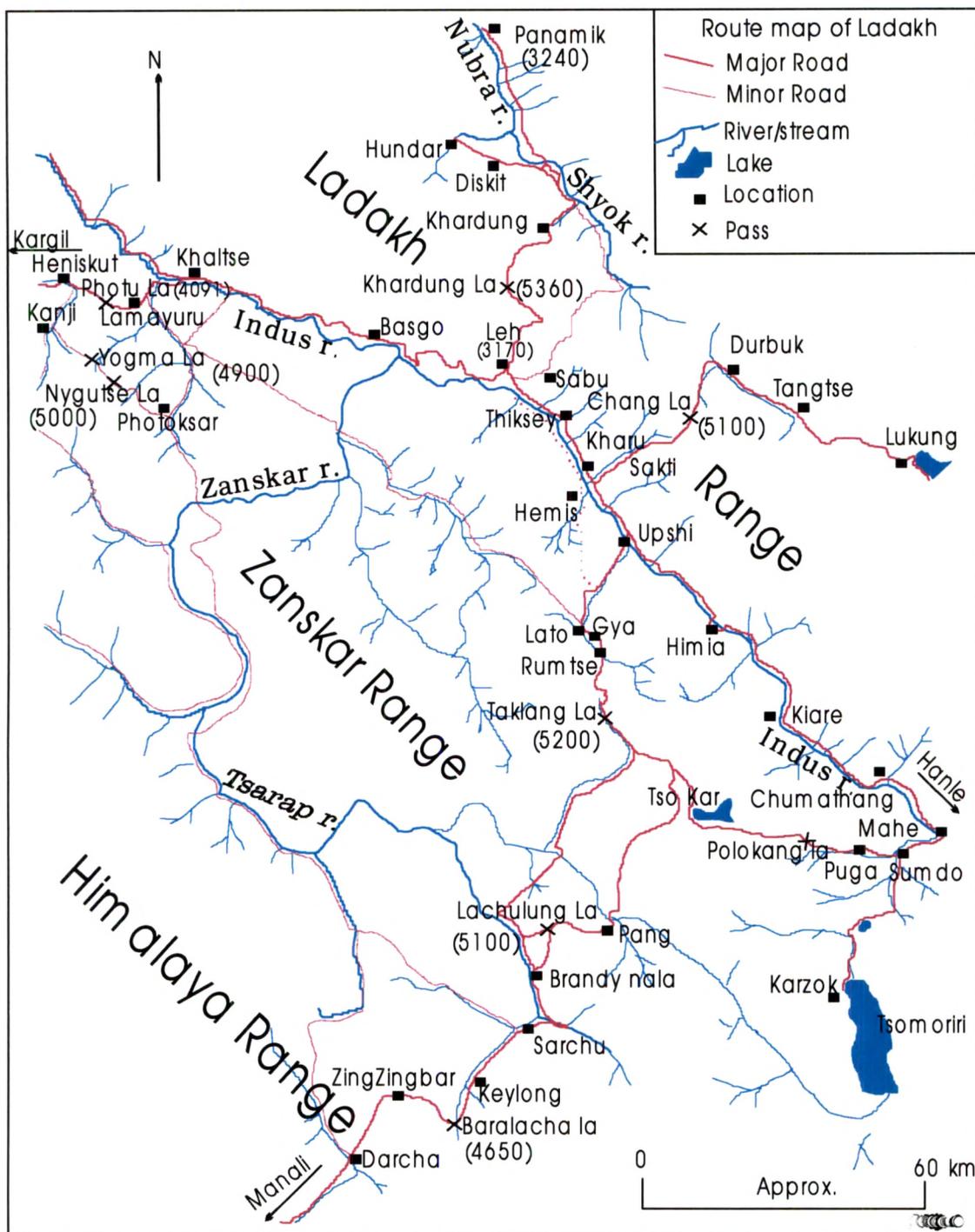
against any separate suturing along the Shyok suture. According to his interpretation Indus and Shyok zones are segments of one single suture, which has been cut by the Ladakh batholith. Shyok suture zone has volcano-sedimentary sequences and mélangé zone exposed in Shyok-Nubra valley north of Ladakh batholith. The volcanics range from basalt to rhyolites and ignimbrites. Thakur (1981) grouped acidic and explosive rhyolites and ignimbrites in Khardung volcanics. These directly overlie the Ladakh batholith. Ophiolitic mélanges in Shyok suture zone is exposed in the Nubra valley and comprises serpentinites, shales, limestones and basic volcanics. Other volcanic units grouped under Shyok volcanics range from tholeiitic basalt to basaltic andesites to andesites. Continental sedimentation in Shyok suture is represented by Saltoro molasses (Fig. 2.5) and comprises shales, sandstones and conglomerates. Upadhyay et al. (1999) found it to be in thrust contact with the Shyok volcanics. All major units of Shyok suture zone are usually described from the Shyok Nubra valley, their characteristics and relationships are less clear to the east of the Nubra valley (Fig. 2.5). The Shyok suture is not found to the east of Ladakh. The eastern part appears to have evolved as a pure Andean type margin.

## 2.4 Fieldwork and samples

Fieldwork in Ladakh, to collect the samples, was carried out in months of August-September 1997. We traversed through the Lahoul-Spiti and Zaskar basins of Paleozoic-Mesozoic continental passive margin sediments. We reached Sabu 4 kms south east of Leh in three days from Manali after crossing four major passes, viz., Rohtang pass, Baralacha la (La meaning pass), Lachunglung la, and Tanglang la. Observations and samples were taken in five major traverses from the main Sabu camp (Fig. 2.6). Field observations and sample locations are described according to these traverses. Sample locations and descriptions are tabulated in Table 2.1. The longitudes and latitudes were obtained by a hand-held GPS (Global Positioning System).

### 2.4.1. Sabu-Leh-Khardung la –Khardung-Hunder

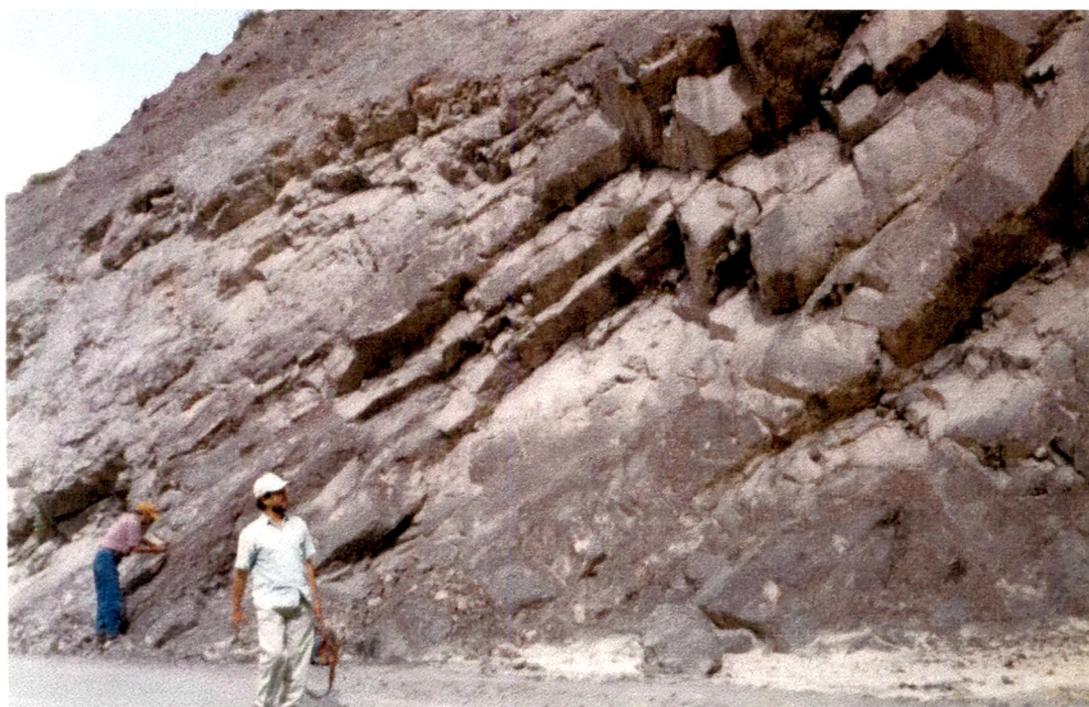
This route cuts across the almost NW-SE trending Ladakh ranges of Ladakh batholith and reaches Nubra-Shyok valley in northern Ladakh. On the southern margin of the batholith, near Sabu and Leh, the rocks are generally biotite granites with hornblende. The sample LK 24 was collected from *Shanti Stupa* in Leh (a Bodh stupa built by the Japanese). This is a coarse grained biotite hornblende granite. Some more mafic enclaves



**Fig. 2.6** Route map of Ladakh showing important locations, rivers and passes (numbers in parentheses are altitude in meters) (Source:Lombard, 1981)

were seen in the biotite granite of the *Shanti Stupa*. The granodiorites and biotite granites are found through out the width of the batholith. However, there are numerous basic as well as aplitic dykes found cutting it. Near South Pullu an ultramafic body was also seen within the batholith. Near the Khardung glacier, the granodiorites have pinkish shades

giving them an appearance of monzonite. Acidic volcanics and rhyolites are dominant rocks towards the base of the batholith and are in tectonic contact with the main batholith near the Khardung village. Between the Khardung village and the Khalsar traffic check post (TCP) we found the signatures of the explosive volcanics in the form of ignimbrites, lapilli textures, tuffs, and volcanic breccias. They form the type locality for the Khardung volcanics (Fig. 2.7). Rhyolite samples, LK 88 and LK 90, of Khardung volcanics were collected near the Khardung village towards the Khalsar TCP.



**Fig. 2.7** Rhyolite and ignimbrite of Khardung Volcanics near Khardung village in northern Ladakh

Sample LK86 is taken from further north, between Khalsar and Khardung and is a green colored volcanics at the contact between acidic Khardung volcanics and Shyok volcanics. Basic volcanics, at places green colored, grouped under Shyok volcanics are seen in contact with the acidic volcanics in Hunder Nala and also further north near the villages Scampuk and Partapur. A traverse along Nubra river was taken to observe and collect the samples from the various units of the Shyok suture zone.

#### 2.4.1.1. Tirit-Diskit-Tegar-Panamik-Murgi

Tirit village is south east of the Shyok-Nubra confluence. Pink granite usually described as Tirit granite is exposed between Tirit and Khalsar TCP. Towards the north Tirit granite is in tectonic contact with the serpentinites near the Diskit village at the Shyok-Nubra confluence. Between Diskit and Tegar, ultramafics and serpentinites are seen. North of the Tegar towards Panamik ultramafics and serpentinites appeared to be intruded by doleritic dykes, basic volcanics, and acidic volcanics. At Panamik, porphyritic granitoids of Karakoram batholith appears to be in tectonic contact with the Shyok volcanics and ophiolitic mélangé towards south. Porphyritic granodiorites of the Karakoram batholith are seen mylonitized along the Nubra river section due to probably Karakoram fault. The ophiolitic mélangé of Shyok suture zone is exposed near the village Murgi (Fig. 2.8) which can be reached from Panamik by crossing the suspension bridge over the river Nubra (Fig. 2.6).



**Fig.2.8** Ophiolitic mélangé near the village Murgi on the bank of Nubra river. Green colour is of serpentinitization intermingling with the purple shale, chert and basalts.

Sample LK 47 is taken from the mylonitized Karakoram batholith granitoids along the Nubra river section. This is mafic segregation and mainly consists of the micaceous minerals. Sample LK 48 is of a very fine-grained volcanics at the contact between

Karakoram fault related mylonitized granitoids and the Murgi mélange. LK 57 is medium grained basic volcanics 15 km north of Sumur towards Panamik. Samples LK67 and LK 68 are taken from a sharp contact between basic and acidic volcanics between Tegar and Panamik about 7 km south of Panamik. Sample LK 70 is a medium grained basic volcanics collected from between Panamik and Tegar.

#### ***2.4.2. Kharu-Sakti-Chnag la- Darbuk-Tangtse-Lukung (Pangong Tso)***

This route cuts across the Ladakh batholith, and crosses the Ladakh ranges at Chang la. Near Sakti village, gabbroic and granitic bodies are intercalated with each other. 11 km from Sakti towards Chang la (Fig. 2.6), a large body of fine-grained black colored mafic rock is found as an enclave within the granite. Further north near Chang la, acidic dykes cutting the gabbros are found. The area north-east of the Chang la, from near Darbuk to Lukung, seems to have undergone large scale and wide spread deformation with migmatization very clearly exposed between Tangtse and Lukung. Serpentinized and brecciated rocks are found near Tangtse while the mylonitization of granitoids with elongated phenocrysts of feldspars are seen near the Tangtse Indo-Tibet border police post, indicative of the widespread deformation, which could be related to the suturing along the Shyok Suture.

#### ***2.4.3. Shey-Thiksey-Upshi-Himia-Gaik-Kiari-Chumathang***

This route runs parallel to the Indus river (Fig. 2.9) along the southern margin of the Ladakh batholith. Near Thiksey Gumpa Gabbro is the main phase of the batholith, while near Upshi the pink granite with big crystals of K-feldspar dominates. Between Likche and Himia Muscovite-Biotite leucogranite, with some hornblende as well, appears to have intruded in the pre-existing granodiorites. Sample LK 198, of these two-mica bearing leucogranites is taken from near the Himia village. Near Gaik porphyritic granite with big phenocrysts of the K-feldspar grains is exposed. Near Kiari, the granodiorites are richer in hornblende and forms the quartz-monzodiorites. The exposed southern margin of Ladakh batholith is most spectacular near Chumathang where leucocratic granites criss-cross the gabbro and diorite (Fig. 2.10).



**Fig.2.9** Indus river valley east of Leh. The red colour (between the two black lines) along the river is because of chert and marks the Indus Suture.



**Fig. 2.10** Intermingling of the light colored granites and basic rocks in the southern margin of the Ladakh batholith, near Chumathang village in Eastern Ladakh.

#### **2.4.4. Mahe-Sumdo-Pugga-Polokangla-Tso Kar**

This section cuts across the Indus formation at Mahe and then traverses through the Zildat ophiolitic mélangé (Thakur and Misra, 1983) in Sumdo nala between Mahe and Sumdo village (Fig. 2.11).



**Fig. 2.11** Ophiolitic mélangé at the Sumdo nala section. Light coloured exotic limestone is caught up in the ultramafics.

At Sumdo, it is in tectonic contact with the Pugga formation of Tso-Morari crystalline. The Zildat ophiolitic mélangé has ultramafics, volcanics and pillow lavas exposed in the Nala section. Sample LK 176 collected from the nala section is porphyritic with a few hornblende needles as phenocrysts. While the sample LK 182 is fine-grained volcanic collected from the same Nala section.

#### **2.4.5 Leh-Bhodhkarbu-Shergol-Kargil-Dras**

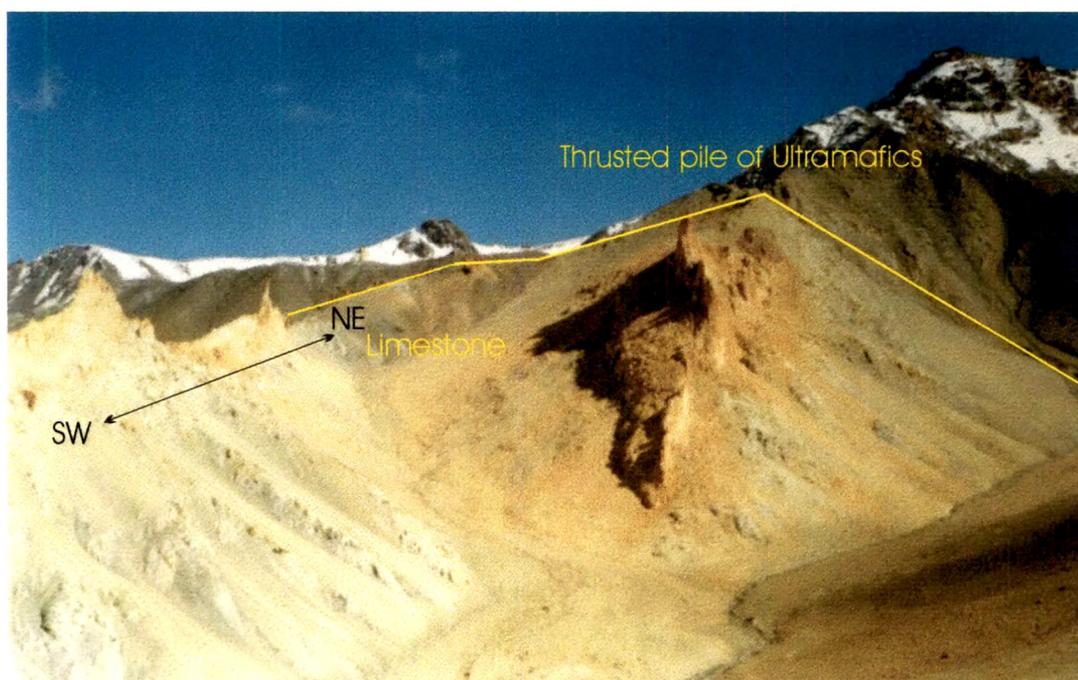
The southern margin of the Ladakh batholith in the western Ladakh has more mafic component in comparison to the southern margin of batholith in the eastern Ladakh. This route runs parallel to Ladakh batholith and traverses the Kargil igneous complex, Shergol ophiolite near Shergol and Chiktan and traverses the green colored Dras volcanics after Kharbu to Dras (Fig. 2.3). Sample LG 290 of Dras volcanics is from near Kharbu village.



**Fig. 2.12** Pillow lavas near the village Chiktan in the western Ladakh

#### 2.4.5.1 Hiniskut-Kanji-Yogma La-Nyigitse La-Spongtang river

This is a trek route to the Spongtang Klippe ~ 25 km south of the main road (Fig.2.6). This route cuts across a thick band of limestone, with shale and sandstones in between upto the Spongtang river. Klippe which is made up of peridotites and serpentinites with gabbro and basalt rests over the Eocene limestones which form the SW-NE trending sharp peaks as seen in the Fig. 2.13.



**Fig. 2.13** Spongtang klippe. Light yellow coloured sharp peaks are of Limestones, the dark coloured ultramafics are seen to be thrust over these younger limestones.

**Table 2.1** Location and description of samples

Sample	Location				Tectonic setting	Description
	Longitude (°E)	Latitude (°N)	Altitude (m) ±100 m	Village name		
LK198	78°5.1'	33°29.2'	3870	Himia	Ladakh batholith	coarse grained, muscovite, biotite and hornblende bearing granite leucogranite
LK198- Muscovite	78°5.1'	33°29.2'	3870	Himia	Ladakh batholith	Hand picked >95% white muscovite of ~1 mm.
LK24	77°34.5'	34°10.4'	3630	Leh	Ladakh batholith	Coarse grained biotite granite
LK24- Biotite	77°34.5'	34°10.4'	3630	Leh	Ladakh batholith	Hand picked >99% biotite grains of ~1 mm
LK182	77°36.9'	33°15.3'	4200	Between Sumdo and Mahe	Indus suture zone	Basalt from ophiolitic mélange
LK176	77°45.2'	33°50.1'	4210	Between Sumdo and Mahe	Indus suture zone	Basalt from ophiolitic mélange with small phenocrysts of pyroxenes
LK209	76°31.7'	34°25.6'	3150	Chiktan	Indus suture zone	Pillow lava belonging to Shergol ophiolite
LG290	-	-	-	Dras	Dras volcanics	Green colored basic volcanic rock.

LK47	77°31.4'	34°45.7'	3250	Murgi	Karakoram fault	Mafic segregation along the fault within the Karakoram porphyritic granite.
LG166	77°27.7'	34°35.2'	3180	Hunder	Shyok suture zone	Andesitic basalt
LG197	77°36.9'	34°38.4'	3090	Tegar	Shyok suture zone	Basalt
LG188	77°37.1'	34°38.1'	3090	Tegar	Shyok suture zone	Basalt
LK48	77°31.4'	34°46.1'	3250	Murgi	Shyok suture zone	Mylonite in the suture zone
LK57	77°34.2'	34°43.1'	3240	Between Panamik and Tegar	Shyok suture zone	Dolerite, with plagioclase and pyroxenes
LK67	77°34.5'	34°42.4'	3180	Between Panamik and Tegar	Shyok suture zone	Dolerite in tectonic contact with serpentinites
LK68	77°34.7'	34°42.1'	3170	Between Panamik and Tegar	Shyok suture zone	Fine grained basic volcanic rock
LK70	77°35.1'	34°41.5'	3110	Between Panamik and Tegar	Shyok suture zone	Dolerite
LK86	77°37.1'	34°35.2'	3550	Between Khalsar and Khardung	Khardung volcanics	Green colored basic volcanics in contact with the acidic volcanics.
LK88	77°38.2'	34°29.1'	3600	Khardung	Khardung volcanics	Rhyolite
LK90	77°38.9'	34°24.2'	3810	Khardung	Khardung volcanics	Rhyolite

LG87	-	-	-	Chushul	Khardung volcanics	Acidic rock	volcanic
LG601	-	-	-	Dungti	Khardung volcanics	Acidic rock	volcanic