THE GEOLOGY & TECTONIC SETUP
OF THE WESTERN MARGIN
OF NANGA PARBAT - HARAMOSH LOOP,
GILGIT, NORTHERN PAKISTAN.

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1986
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ACKNOWLEDGEMENTS

I am extremely grateful to Dr. M. Majid (Chairman, Dept. of Geology) for his painstaking efforts in supervising this work and thoroughly reading the manuscript. I feel that this work could not have been possible without his perseverance.

I also gratefully acknowledge Dr. R.D. Lawrence and Dr. Lawrence Snee of Oregon State University who provided me guidance in the field and financial support through the NSF project between OSU and Peshawar University. I am also thankful to Ian Madin of OSU, for his nice company in the field, help during mapping, and many fruitful discussions.

Thanks are due to Professor A.A.K. Ghauri who involved me in the said project and critically read the structure portion of the thesis. Dr. M. Qasim Jan is thanked for providing useful literature, discussion and checking part of the script.

In the end I want to thank Mian Munir Munayun for his very helpful discussion and assistance regarding geochemistry.

Mr. Sabir Hussain is thanked for typing manuscript patiently.
ABSTRACT

Part of the western margin of the Nanga Parbat-Hunza ophiolite has been studied in detail in the present work. The loop represents the tectonic boundary between the Kohistan island arc to the west and the Indian plate to the east.

Major rock types, west of the fault are pyroxene-granulite and a sequence of interlayered amphibolite-gneiss-marble. Chemical constraints of these rocks are indicative of their derivation from an igneous parent, in an island arc-type environment. The rocks east of the fault are mostly schists and gneisses of the Nanga Parbat granitoid group.

The fault which separates the two contrasting lithologies is a young, right lateral, reverse fault. It trends roughly north-south and dip steeply east, with an east-side-up displacement. It is the northern extension of Raskot fault locally named as Shahbatot fault. Beside this other, major, active faults are present in the area, both showing evidence of recent activity. Indus river has been laterally offset for about 15 km along Shahbatot fault.

Three episodes of folding have also been recognized in the area, all of them related to younger tectonics and are produced by rapid uplift of the Massif.
INTRODUCTION

The Nanga Parbat-Haramosh Massif is one of the most significant geological features of northern Pakistan. The southerly convex east-west Himalayan chain, which continues for about 2700 km from Pakistan to Nepal, takes a sharp turn at its western end around a protruding edge of the Indian plate in northern Pakistan. The protruding Precambrian basement rocks of the Indian Shield, consisting of schists, gneisses and amphibolites intruded by granites and diorites, are encircled by a tight loop of the Himalayan rocks. These together constitute a most striking tectonic feature in the geology of northern Pakistan.

The Shishka component being described as the Nanga Parbat-Haramosh Massif. The Main Mantle Thrust (MMT, Takirkhel, 1979) demarks the Massif from Ladakh batholith in the east, Asian mass in the north and from the Kohistan island arc in the west.

Inaccessibility and lack of exposures due to glaciers hindered geological investigation of the Nanga Parbat-Haramosh Massif in the past, but the construction of the Karakoram Highway (KKH) made it possible even to penetrate the deep interior of the area and carry out detailed geologic mapping. Recent studies include the petrological and structural aspects of the Massif by a number of workers (details given in the section on previous work).

The present work involves 1:50,000 scale mapping of various rock units in the section between latitude 36° 35' - 55' N and
longitudes 74°, 35 - 45 E. Along with petrography and chemistry of the samples obtained in the field, special emphasis has been given to the details of the structures with a view point of identifying the tectonic boundary (see map) between rocks of Indian plate and Kohistan arc either as continuation of the MMT or as trace of the Raktot fault (Lawrence and Ghauri, 1983). Raktot fault is a young and active reverse fault, which has brought Precambrian basement rocks of the Indian Shield up and over the Kohistan rocks. The petrochemical indices of the component rocks from both side of the fault have also been usefully employed while making conclusions about the tectonic set up of the study area at plate scale.

The study area starts from Anser army camp in the Indus gorge, about 55 km southeast of Gilgit, and extends to Burumdoin bridge about 20 km upstream along the right bank of the Indus river. Northward it extends upto Khaltara and Iskara villages (foot hills of the Haramosh peak). Survey of Pakistan toposheet No. 43-I/9,13 were used as the base maps during field work.

PREVIOUS WORK

The first published account of the geology of the area is given by Wadia (1933) in a reconnaissance study of the Nanga Parbat region. He mapped the tract to the south and west of the present study area on 1:250,000 scale and proposed that the Nanga Parbat region is a promontory of the Indian Peninsula, mainly composed of biotite-gneiss, intruded by granites. He considered
Precambrian Sakhalin rocks of Hazara to have undergone granitization, and reported masses of black basic rocks, intrusive into the former units mostly to the north and east of the Nenga Parbat region. Regarding the origin of the syntectal loop, Wadia (1931) postulated that the Himalayan geosyncline has been bent round a triangular promontory of the Indian Peninsular Horst.

Misch (1935,1949) supported Wadia's hypothesis and considered rocks of the series grading from phyllites, slates, mica-schists, biotite-gneiss, kyanite schist to sillimanite schist as products of a synkinematic progressive (Barrovian type) metamorphism of argillaceous and calcareous material. Misch (1949,1964) further believed in synkinematic granitization caused by metasomatism in potash-rich kyanite zone and potash-rich augen gneiss. This process, however, was selective because of the presence of calcareous bands which escaped the process and served as a check to granitization.

Misch (1949) suggested a lit-par-lit replacement along active foliation planes, rather than injection for the formation of augen gneisses found in the Indian peninsular Horst. He reported a complete structural continuity from weakly metamorphosed sedimentary series to intensely granitized zones. Presence of extensive masses of metarorites and hypersthene-gneisses with local dunites, bordering the Massif both on eastern and western limbs was also described. He noticed static
development of crystallobilastic hornblende and epidote, etc. in the mafic rocks and dikes. However, near the boundary of the Massif, kinematic crystallization is evident. This, in fact, seems to be the earliest indication of a major tec- tonic break across the border of the Massif, even though Misch has not suggested it.

Zanettin (1964) recognized the eastern contact of the Massif as a zone of sheared garnet-amphibolite, separating the high-grade pelitic schists and gneisses of the Massif from the basic intrusives and their metamorphosed equivalents. Like other previous workers, he also thought of the Precambrian Marlles to be the precursors of the gneisses in the Massif. East of the Massif, in Ladakh area, he found some scarce Creta- ceous fossils.

Gansser (1964, 1980) has made important contributions to the geology of Himalayas in general and to their tectonics in particular. He does not consider Himalayas to be of geosynclinal origin (1964), instead he advocates the collisional theory. He has described the Massif as a large antiform, particularly in the Askos river section.

According to Gansser (1980) the contact of the Nanga Parbat - Harsmough Antiform is marked by a series of marble bands with amphibolites along its western flank. He identified the actual trace of the suture (MMT), the contact of a highly sheared and mylonitized retrograde chlorite-schist with a thick section
of noritic gabbros, just south of Sassi village on Skardu road. He noticed the absence of Petit type volcanics from the north-south trending spur, present in other sections along suture.

Gansser (1964) discarded the idea of metasomatic origin for gneisses and suggested a process of chemical and textural reorganiization of Salkhalas during metamorphism for their formation.

Desio (1964) considered Nanga Parbat-Haramosh Massif as an individual orographic and tectonic unit constituting a tightly folded anticline: structures of late phase and enveloping intermediate to high grade metamorphic rocks. Desio (1979) also considered the Massif as a kind of protuberance of Indian subcontinent, inserted as a wedge into the "flysch deposits" of Karakoram. According to him, junction between the two continents suggest the presence of a deep crustal suture incorporating probably remnants of an oceanic floor. About the eccentric position of the Massif with respect to the Nazara-Kashmir Syntaxis, Desio (1979) says that this could be the result of clockwise rotation from previous position, parallel to the axis of Central Asian knot. The upper Indus Suture Line and the Kohistan Line represent a scar formed by the collision of the two plates.

Crawford (1974a) believes that Himalayas are not the result of the collision between the two continents but are strictly intracontinental type mountains, i.e., within Gondwanic India. He believes that Tibet and India have always been parts of one plate. During the Late Panarzoic, vigorous sea-floor spreading in the
NW Indian Ocean brought Indo-Tibetan Plate closer to the rest of Asia, and when it could not move further towards each other, overthrusting produced the Himalayas. Crawford (1974b) suggests that the eastward movement of Turan block relative to Tarim block caused an east-west compression, which along with the NNE movement of India, produced the tight Pamir arc. These movements are also responsible for the uplift of the Massif later in the Pleistocene time.

Tahirkheli (1979) considered the Nanga Parbat - Haramosh Massif as an anticline and the western termination of the higher Himalayas in Pakistan. He found stratigraphic relationship between the Hazara-Kashmir lesser Himalayan lithofacies and the Nanga Parbat gneisses which are highly metamorphosed equivalents of the earlier (Salkhalas). He thinks that an east-west compressional phase postdating NMT is responsible for the formation of the anticline.

Tahirkheli (1979) in an east-west cross-section across the loop established the following sequence of rock units:

1) Muscovite-schist, biotite-schist and garnet-schist.
2) Paragneiss and mafic pyroxene-granulite.
3) Biotite-gneiss with granodiorite inclusions.
4) Amphibolites within the loop.
5) Nanga Parbat gneiss (biotitic) forming the base of the anticline.
6) Amphibolites intruded by gneisses.
Tahirkheil (1979), Tahirkheil et al. (1977), Jan (1979) and Bard et al. (1980) have described norites exposed on the fringes of both the limbs of the loop, as part of the Kailash and Ladakh arc material forming a thin rim around the loop.

According to Tahirkheil (1982) the cause of selective granitization in the Massif has been the presence of calcareous bands as well as inhomogeneous and differential deformation in different parts of the Massif. He has suggested a high tectonic activity in the core of the anticline where migmatites are frequent and pressure-temperature gradient has reached sillimanite isograd.

Shams and Ahmed (1979) have agreed upon a migmatitic nature of the rock of the Nanga Parbat - Haramosh Massif and reported a massive granite looking material in the interior. They have suggested that the Salhala metasediments suffered metamorphism dominantly with the introduction of soda and potash.

Lawrence and Ghauri (1983) have reported a young and active fault (namely Raikot Fault) near Chilas. It extends along the western boundary of the Nanga Parbat - Haramosh loop. The existence of fault was indicated because of the presence of sliken-sided-fish-gravel, offset fans, aligned hot-springs and local emplacement of bedrock over alluvium in the area. They have attributed this fault to the rapid uplift of the Massif.
Yeatts and Lawrence (1984) suggest that the Nanga Parbat Haramosh Massif represents the western edge of the Himalayan crystalline belt. The MMT, according to these authors, must pass south of the Nanga Parbat and terminate against MMT towards the west. This has been suggested on the basis of deep seismic sounding profile between Kashmir and Panir which reflects a substantial rise in the Moho under Nanga Parbat (Kaila, 1981; Belloursov et al., 1980).

Zeitler et al. (1982) have calculated an uplift rate of 5mm/yr from 2 million years to 0.5 million years and 9mm/yr from 0.5 million years up to present for Nanga Parbat-Haramosh Massif, on the basis of the cooling dates of apatite, zircon and sphene. This means that the Massif has risen and cooled very rapidly during the past 0.5 million years. Sphene dates also suggest that cooling/uplift was active at least 3.5 million years before present. The observed uplift rates, however, have been estimated at 0.5 – 1.0 mm/yr. They have also suggested that the Nanga Parbat region has experienced nearly 1cm/yr uplift during Pleistocene. Zeitler (1985), however, considered this rate to be too high later on.

Zeitler et al. (1982) suggested that there has been no activity along MMT for the last 15 million years, but later (1985) he suggested that rapid uplifting of Nanga Parbat-Haramosh Massif has locally reactivated and steepened MMT with a reverse sense of motion at its western margin. The cause of
uplifting according to him is not unroofing due to erosion only, but also the tectonic activity related to continental collision.

Chamberlain et al. (1986) have suggested a tectonic model in which the Kohistan arc was subducting northwards, later it was thrust over the Nanga Parbat Massif along MMT during Tertiary. They have suggested that metamorphism of the Massif took place in Tertiary and that the Massif has experienced more rapid and accelerated rate of uplift as compared to the Kohistan arc across MMT.

Coward et al. (1986) have reported that though no ophiolitic relics or blue schists have been found along the tectonic boundary, separating high grade basic rocks of Kohistan from the high grade metasediments and porphyritic granitic gneisses of the Indian Plate, yet it has been recognized as MMT. The Nanga Parbat gneisses in this region are intensely deformed and most of the original textures have been obliterated. They have reported that the MMT is a 10 km thick ductile shear zone with intense strain. Three phases of deformation have been identified as F1, F2, F3, with F3 being the youngest, and not coaxial with the two earlier phases. Along the western margin of the loop, foliations and axial structure dip steeply on the limb of F3 structures.
REGIONAL TECTONIC SETUP

The Nanga Parbat-Haramosh Massif occupies a pivotal position in the geological setup of Northern Pakistan. It is imperative to understand the regional tectonic setup for the proper understanding and study of the Massif.

The Himalayan mountain belt is, in general, a classical example of orogeny resulting from collision between two continents. The collision of India and Asia is responsible for the spectacular elevation and tectonic activity in the Himalayas (Dewey & Bird, 1970; Molnar & Tapponier, 1975).

Opening and closing of the ocean basins has been termed as the Wilson Cycle by Dewey and Burke (1974). The opening of the Neotethys marks the beginning of the Wilson cycle (Jacobs et al., 1974) followed by rifting of the Indian Plate from Gondwana land about 100 million years before present and subsequent northward movement culminating in Neotethyan closure and subsequent Himalayan orogeny (Klootwijk, 1979; Powell, 1979; Tahirkhel et al., 1979; Andrews-Speed and Brookfield, 1982; Honegger et al., 1982).

The beginning of the Himalayan orogenic cycle was marked by large basaltic extrusions (Punjab Traps) of Permian to lower Triassic age at the northern margin of the Gondwana continent, followed by more alkaline volcanism of Triassic to Jurassic age (Honegger et al., 1982).
Northward movement of the Indian Plate started in Late Cretaceous and was accommodated by subduction of Tethyan oceanic crust under the Asian Plate along a moderately north-dipping subduction zone during Upper Jurassic and Cretaceous (Honegger et al., 1982; Malinconico, 1982). Continued northward movement of India and intra-oceanic subduction produced the Ladakh and Kohistan Island Arcs, represented by tholeiitic and calc-alkaline volcanic rock series and related intrusives, accompanied by volcaniclastic flysch deposits toward the Tibetan continental margin (Tahirkheli et al., 1979; Tahirkheli et al., 1979; Jan, 1979; Bard et al., 1980; Honegger et al., 1982; Malinconico, 1982).

Radiometric studies of samples from Kohistan-Ladakh batholiths date this event between Mid-Cretaceous and Eocene (Maluski et al., 1982; Honegger et al., 1982; Scharer et al., 1984; Petterson & Windley, 1985), while paleontological evidences suggest an Upper Jurassic to Early Cretaceous age (Ivansc et al., 1956; Dietrich et al., 1983).

During 80–55 million years, India's northward rate of migration was roughly about 20cm/yr, which slowed down to about 6cm/yr, after India collided with Island Arc-Tibetan block during Eocene (Molnar & Tapponier, 1975; Powell, 1979). By this time India had moved about 2000 km north from its original position which is recorded by many east-west trending geological and structural zones (Powell, 1979; Malinconico, 1982; Molnar, 1986).
The obduction of Kohistan-Ladakh arc onto the Indian platform started along a shallow suture zone, later recognized as MMT (Tahirkheli, 1979). During the collision, oceanic crust and mantle material was squeezed up along the thrust and high density ultramafic bodies were emplaced along the MMT (Malinconico, 1982).

There is a disagreement among the researchers as to whether the northern or southern suture closed first. Malinconico (1981) presented a model showing that with continued northward migration of India the southern suture (Indus Suture Zone; ISZ of Ganasser, 1964 and Main Mantle Thrust, MMT of Tahirkheli, 1979) closed first. With obduction of the Kohistan Island arc onto the Indian Plate along MMT, the back-arc basin formed north of the arc, began to close and established a new subduction zone between arc and the Asian mass. This suture has been recognized as Main Karakoram Thrust (MKT, Tahirkheli, 1979) as Indus Range Suture, (IZS by Ganasser, 1982) and also as Karakoram Fault Zone (KNZ by Coward, 1986). The northern suture also dips to north. It has also been suggested that the northern suture existed between Kohistan Arc and another microcontinent, i.e. between the arc and the Asian Plate (Jan & Asif, 1981; Tapponier et al., 1981).

In an alternate model presented by Patterson & Windley (1985) and Coward et al. (1986), it has been suggested that the northern suture closed earlier between 102 to 75 million years
before present and the southern suture or main Tethys closed later during Eocene. The back-arc basin eventually closed, the Asian plate rocks were thrust over the arc material along MKT, and ultramasics were emplaced from the mantle along the suture (Tahirkhel, 1982; Coward et al., 1982b).

It has been suggested by Uyeda and Kanamori, (1979) that faster the rate of subduction, shallower the dip of subduction zone. The reported dip values for MMZ vary between 30°-50°, while that of MKT are around 20°. These values, according to Uyeda and Kanamori (1979), suggest that while India was moving faster before collision, the first subduction zone established along MMZ and later when it slowed down the southern suture was closed and MKT was formed. However, recent rapid uplifting in the Nanga Parbat-Haramosh Massif has reactivated and steepened the traces of MMZ and MKT along its margins (Malinconico, 1986; Zeitler, 1982).

Presently India's northward migration is accommodated not only by subduction of Indian plate under Asian plate, causing telescoping and squashing of Tibetan Plateau (Molnar, 1986), but also by deformation, metamorphism and crustal shortening along shallow northward dipping thrust (Main Boundary Thrust or MBT (Natauer, 1975; Powell, 1979; Seebier et al., 1981). In future, southward migration of thrusting and deformation is expected (Le Fort, 1975).
The formation of Nanga Parbat syntaxis has been attributed to a diapiric rise of the anatectic magma, in the core of the Massif, aided by an east-west compression causing a syntakial looping of the rocks around it (Sarwar & DeJong, 1979). Coward (1986) has suggested a shear couple in one of the main Himalayan thrusts joining the MMT beneath the Kohistan, responsible for the formation of the syntaxis.

The Nanga Parbat-Haramosh Massif is located at the northwestern corner and leading edge of the Indian Plate in northern Pakistan. The area manifests the junction of Karakoram, Himalayas and Hindu Kush, two suture zones and an intervening island arc between them. All these features make the area tectonically significant and unique in the region.
LITHOSTRATIGRAPHY

Rocks exposed in the study area are distinguishable into two main groups: 1. Rocks of the Kohistan Island Arc 2. Rocks of the Precambrian Indian basement. Shutsa Pyroxene-granulites and Henuchal Amphibolites are members of Kohistan Island Arc and are mostly basic in composition. These two rock units occupy the western half of the mapped area, and are separated from the eastern half by an imbricate active reverse fault zone (Plate-1). The eastern half area is occupied by a thick monotonous unit of coarse-grained biotite-gneiss intruded by acid pegmatite and amphibolite veins. In between these two major lithologic units, there is an intervening, lensoid zone of Haramosh Schists and gneisses with interlayering carbonate material transformed to marble.

THE SHUTSA PYROXENE-GRANULITES

The rocks of this unit were previously described as norites. However, on the basis of petrographic and mineralogical studies by Jan (1979) in Swat and Indus valley, this unit is now identified as pyroxene-granulite. These rocks are dark-grey in colour, coarse to medium-grained and equigranular. In hand specimen, dark-green clinopyroxene, dirty white plagioclase and pale-brown hypersthene are conspicuous. Subparallel alignment of minerals has produced weak megascopic foliation, with minor compositional banding because of concentration's variation of dark and light coloured minerals. Rocks of this unit are invariably cut by
GEOLOGICAL MAP OF THE WESTERN MARGIN OF NANGA PARBAT - HARAMOSH LOOP, GILGIT, NORTHERN PAKISTAN.
numerous small to large, undeformed pegmatite and granodiorite
dikes in the form of a network structure.

The Shuta pyroxene-granulites occur as a thick monotonous
unit throughout the western half of the mapped area. To the
east these granulites are in contact with a lensoidal body of the
Manuchal Amphibolites between Burumsoin bridge in the south
and Manuchal village in the north (Plate-2). North of Manuchal
village however, granulites are having a faulted contact with
the Haramosh schist unit. South of Burumsoin bridge, the pyrox-
ene granulites are directly in contact (faulted) with the
western most unit i.e. Iskera gneiss (see map).

Since the pyroxene granulite unit belong to Kohistan
Island arc, therefore, the age of this unit is considered to
be Early-middle Cretaceous (about 110 million years) according
to Bard (1983), and Jan & Asif (1983).

HANUCHAL AMHIBOLITES

The Manuchal amphibolites form a 2-3 km thick lensoidal
body of coarse to medium grained amphibolites of dark-green
colour with biotite-garnet gneiss/schists of grey colour and
pale-yellow interlayering marble.

The gneiss- and schist component of the Manuchal amphi-
bolites is a strongly foliated assemblage of fine- to medium-
grained biotite, feldspar, deformed garnet and stretched boudins
Plate 2. The contact of Shuta pyroxene-granulites with Manchul amphibolites (background ridge) near Ansar Army Camp. The black patch represents hornblende intrusion.
of quartz. Garnet in some specimens reveals rotation and flow structures. The unit is less frequently intruded by granodiorite veins cutting across the trend of foliation and are themselves tightly folded.

The amphibolites of this unit are medium to coarse-grained, dark-green in colour and interbedded with yellowish marble bands (Plate-1). They consist of elongated grains of dark-green hornblende with interstitial quartz, feldspar and biotite. Besides, garnet and epidote are also noticeable in hand specimen.

Along the contact with schists and gneisses the amphibolites are usually structureless, however, metamorphic foliation and mineral lineation develop rapidly towards west and within a few meters of the contact, it becomes a well foliated metamorphic rock. The contact relationship of the amphibolites with the gneissic component of this unit suggests that these are ortho-amphibolites which were intruded into the country rocks before the two were metamorphosed in the amphibolite facies.

The marbles of this unit are thin to thick bedded, coarse-grained, equigranular, and consist of calcite with medium-grained muscovite flakes and are interbedded with amphibolites.

The attitude of foliation in the Hanuchal amphibolites generally trends between NNE-NNW with a steep westward
Plate 3. An outcrop of the Hanuchal amphibolites with interbedded marble (white). About 1 km upstream from Shahbatot village.
The pattern of foliation becomes increasingly disrupted toward the fault zone. Evidences like oversteepening of the foliation and shearing, resulting in mylonitization, suggest that the contact of Hanuchal amphibolites unit as a whole is faulted to the east against another lensoidal body of Harmosh schist (Plate-4). The mylonites along the contact are derived from amphibolites and are highly sheared and altered. The nature of the contact is probably a strike slip fault.

Besides this major lensoidal body of amphibolites and associated rocks, (about 12 km long and 2 to 3 km wide), there are a few other small lenses of Hanuchal Amphibolites scattered within the Shuta pyroxene-granulite sequence, mostly west of the fault. The Hanuchal Amphibolites have a faulted contact with rocks of the Indian plate sequence (see map and Plate-5).

THE HARAMOSH SCHIST

The Haramosh schist/gneiss unit is an assemblage of strongly foliasted rocks. The unit consists of muscovite schists, biotite-gneiss, biotite-garnet-gneiss, and some highly deformed calc-silicite marbles. Foliation and lithological banding is well developed. The general trend of foliation is NNE, steeply dipping towards West. In the proximity of the fault zone, the Haramosh schist/gneiss are mylonitized in several localities, and contain epidote.

The gneisses of this unit are light to dark-grey in colour, and very hard. Biotite, quartz, feldspar, garnet and hornblende
Plate-4. Contact of the Haramosh gneisses with the Hanuchal amphibolites, exposed on the road near Hanuchal village. The western side represents the Hanuchal amphibolites intruded by granodiorite veins, while the eastern side is Haramosh schist with the trend of foliation N15E/72°NW.
Plate 3. Faulted contact between the Manuchal amphibolites with interlayered marbles, and Iskara gneiss exposed along the Skardu road, 2 km south of Shabstot village.
The schistose bands are rich in muscovite and chlorite. Quartz and feldspar occur in the form of thin lenses within the schistose bands. Individual mica plates are about 1 cm in diameter and show parallel alignment. Discontinuous bands of quartz and mica are distinct in some sections. As in gneisses, the schists also have carbonate interlayering, but much less frequent. Psammitic schists were also found in a locality north of Sassi village.

Marbles associated with gneisses and schists within the Haramosh schist unit are predominantly waxy, greenish-grey in colour, and medium-grained texture. Calcite grains are elongated in shape with a tendency of parallel alignment to define the foliation. Reddish-brown specks of iron oxide are also common. Marbles occur as thick to thin bedded interlayers in gneisses and schists, and have been intensely folded in the form of tight intrafolial folds.

The Haramosh schist unit as a whole is frequently intruded by pegmatite and tourmaline granite dykes and veins (Plate-6). The attitude of these dykes and veins vary from concordant to
Plate-2. A tightly folded tourmaline-bearing granite vein in marble gneisses, exposed on the road at the confluence of Khaltaro creek with Indus river. The fold axis measures N37W/63°.
discordant at different places. Acid pegmatite veins have been
metamorphosed. These are composed of feldspar, quartz and mica,
and are mostly concordant to the main foliation of the unit. In
some cases the black tourmaline (schorl) crystals are crushed
and sheared. The tourmaline granite veins are concordant to the
foliation. It is interesting to note that both the frequency
of tourmaline granite veins and gneissosity of the host rocks
increase towards west.

In general the gneisses contain more biotite than schists
in the series. Biotite, however, has altered to chlorite in the
schists. Structural variation from place to place are typical
of gneisses. Gneisses exposed in the western part of the mapped
area, for example, are much less segregated and are homogeneous
as compared to their occurrence else where.

The Haramosh schist unit occurs in the form of a wedge. It
extends from about 2 km south of Shahbatot village on Skardu
road towards north up to about 4 km beyond Tassi village. The
thickness varies from 1 to 3/4 km with a maximum of 3/4 to 4 km
between Hanumal and Khaltaro villages. It tapers down further
north and eventually pinches out about 1 km north of Darchan
village in Khaltaro canyon. The total length of the Haramosh
schist unit is about 20 km north-south.

The western contact of the Haramosh schist unit is strike-
slip fault, which separates it from the Hannuhal Amphibolites in
the south, and the Shuta pyroxene-granulites in the north. The eastern contact of this wedge-shaped body is also a thrust fault which separates it from the thick and monotonous unit of Iskere gneisses. Near Shahbatot village, there is a 200m wide and 1 km long lens shape body of the Hanuchal Amphibolites exposed along the eastern contact with the Iskere gneisses.

**The Iskere Gneisses**

The Iskere gneiss unit, has been named as Nanga Parbat Biotite-Gneiss by Tahirkheli (1979). It is a thick sequence of gneissic rocks which form the bulk of the Nanga Parbat-Haramosh Massif in the form of a large north plunging antiform. These gneisses are coarse-grained, biotite-rich and contain plagioclase, stretched augens of quartz and feldspar upto 2cm long.

The long axis of the flattened augens and parallel alignment of biotite flakes give rise to the regional foliation S1.

From west to east the Iskere gneiss unit grades into a medium grained biotite-gneiss with minor muscovite. The contact of these two gneisses, which is exposed on the Skardu road about 3 km south of Shahbatot village, is parallel to the foliation and is marked by a shear zone. Since there is a marked difference in the degree of competence of the two neighbouring gneiss units, it could, therefore, he suggested that this shear zone was developed during the collision of the Indian plate with the Kohistan Island Arc. Otherwise no petrographic or geochemical
difference was found between the two. The biotite-rich and biotite-poor gneisses are mapped as a single unit as shown in the map.

The Iskere gneiss unit as a whole, shows amphibolite lenses concordant to the foliation, and pegmatite veins cross-cutting the foliation. It is, therefore, suggested that pegmatite veins are younger to the amphibolites. Since no sign of any relic bedding in the Iskere gneisses is observed,

there formation by metamorphism of an igneous parent is preferred in the present work. Previously many workers (Wadia, 1933; Misch, 1949; Tahirkhel, 1979), suggested that these rocks are of sedimentary derived character. Amphibolites present within the gneisses could be lenses of basic material, in the granite, which were intruded and deformed later, parallel to the foliation.

Part of the Iskere gneiss unit is migmatized. There is an extensive zone of migmatites exposed along the Skardu road in the southeastern corner of the mapped area (Plate-7). The migmatites are marked by very coarse banding of quartz, feldspar and mica in discontinuous segments. Partial melting and synkinematic recrystallization related to the tectonic activity in the centre of the Massif, has resulted in the foliation of discontinuous quartz, and feldspar veins. The migmatized zone of Iskere gneiss is bounded to the east by half a kilometre thick gauge zone,
Plate-7. An extensive zone of migmatites within the Injera gneiss unit, near Burundoin, about 7 km upstream from Shabatot village.
which seems to be the result of a landslide. The gouge zone consists of fine grained matrix and coarse angular fragments of the biotite gneiss. The landsliding has been suggested because no evidence of faulting was observed.

The western contact of the Ikare gneiss unit is an active reverse fault which separates it from the Haramosh schist unit in the north and from the Shuta pyroxene-granulites south of Shabbatot village. Glaciers of the Haramosh area have covered most of the Ikare gneiss unit at high altitudes in the north.

Since the Ikare gneiss unit belongs to the Indian plate sequence and represents the basement material, therefore, the age of the unit is considered to be Precambrian.

QUATERNARY GEOLOGY

A number of quaternary units occupy different parts of the Indus valley. Within this section, a brief description of the Pleistocene to Holocene glacial tills, tectonic landslides, lake beds, river and fan-gravel is given. The proper understanding of these Quaternary units is important because they give direct indications of neotectonic activity in the area.

Glacial Tills: The glacial tills are lying in different parts of the study area, on both sides of the Indus river. These consist of small to large, angular and striated fragments of gneiss and schist in a fine grained matrix, and are mostly
unsorted and unstratified. The glacial tills are divided into Pleistocene and Holocene-type, on the basis of their position and altitude in the valley. Unclassified and unstratified tills lying in association with the glacial ice at high altitudes, have been assigned a Holocene age. While those which occupy the lower reaches of the valley, and are competent and consolidated, have been given a Late Pleistocene age.

A major till plateau, about 1000 feet high from the road, occupies a position between Dassu and Khaltaro creeks, near Dassu village to the right of the Indus river (Plate-8). Similarly majority of the population of the Sassi and Murhan settlements is spread over a till plateau which is faulted, with a total vertical displacement of 200 m. Small exposures of glacial tills are ubiquitous throughout the area. Further east, in Jutiel stream east of Dassu village, there is a till mass which is deformed, and thrust over the bedrock. It indicates past Pleistocene tectonic activity. Holocene glacial till masses are found near Iskere village and Kutwal Sar Lake, in the foothills of Macamosh peak.

Landslides: Young and active faulting, steep exposures of rocks and predominant erosion by ice, together make the study area prone for mass-wasting, especially through landsliding. Four major landslides were recognized in the area which have eventually played an important role in the development of geomorphic features in the study area. In fact some of these
Plate 8. A large Pleistocene glacial till plateau north of Rasi village. The top of this plateau is a flat surface and is about 1000 feet high from the road.
landsides have actually temporarily dammed the Indus river, and have caused local deposition of lake beds in the valley which are still essentially horizontal.

The northernmost of these landslides in the study area is named as SUMARI SLIDE. It is about 2.5 km² large block lying between Sassi and Rumari creeks. It consists of fractured and highly weathered, coarse grained, foliated biotite-gneiss. On the basis of the position of this slide to the Late Pleistocene glacial till where the slide material overlies the glacial till, a Holocene age has been assigned to it.

Next major slide is ISHKAPEL SLIDE, which is about 100 m thick mass of fractured biotite gneiss. Ishkapel slide lies about 1000 feet high from the road on the northern wall of the Ishkapel stream, east of Shahbatot village on the right bank of Indus river. There is a drastic change in the attitude of foliation within the slide to that of nearby coherent bedrock. Since there is no apparent displacement along an active trace of fault which passes underneath it, therefore, it is considered to be a recent slide.

PAZAL AHMAD SLIDE is located south of Shahbatot with about 10 m thickness. It is composed of fragments of amphibolite and marble rubble. The base of the landslide is exposed along the current water line of the Indus river, which implies that it is
landsides have actually temporarily damned the Indus river, and have caused local deposition of lake beds in the valley which are still essentially horizontal.

The northernmost of these landslides in the study area is named as SUMARI SLIDE. It is about 0.5 km$^3$ large block lying between Sassi and Sumari creeks. It consists of fractured and highly weathered, coarse-grained, foliated biotite-gneiss. On the basis of the position of this slide to the Late Pleistocene glacial till where the slide material overlies the glacial till, a Holocene age has been assigned to it.

Next major slide is ISKAPEL SLIDE, which is about 100 m thick mass of fractured biotite gneiss. Ishkapel slide lies about 1000 feet high from the road on the northern wall of the Ishkapel stream, east of Shahbatot village on the right bank of Indus river. There is a drastic change in the attitude of foliation within the slide to that of nearby coherent bedrock. Since there is no apparent displacement along an active trace of fault which passes underneath it, therefore, it is considered to be a recent slide.

FAZAL AHMAD SLIDE is located south of Shahbatot with about 30 m thickness. It is composed of fragments of amphibolite and marble rubble, the base of the landslide is exposed along the current water line of the Indus river, which implies that it is
recent and has dammed the Indus river behind it, causing depo-
sition of horizontal, siltstone lake-beds.

The fourth and the southern most of these slides is loca-
ted within the study area near Burundoin bridge and is known
as BURUNDOIN SLIDE. It is about 2 km³ in volume, and consists
of sharnred end weathered biotite-gneiss, overlying a Pleisto-
cene glacial till. The age of the slide is, therefore, Holocene.

Siltstone Lake-beds: Horizontal siltstone lake-beds are
exposed along the east bank of the Indus river at several loca-
lities; The absence of these lake beds from the west bank could
be attributed to steep valley slopes on the left bank of the
Indus river.

Noticeably thick siltstone beds are exposed between Sassi
and Bassu villages within the glacial tills (Plate-9). These
beds are the result of the temporary damming of the Indus river
by advancing moraines and tectonic landslides. The upper surface
of some of the beds show ripple marks, indicating shallow basin
of deposition. The lower surface exhibits convolute marks
and load casts. The maximum thickness of these beds, exposed
east of Sassi village within a glacial till is about 100 feet.
The height of these beds from the bed of the river is between
300-400 feet. Mostly the base of these beds is not exposed and
is covered by fan-gravel and talus. The age of these beds is
considered to be Late Pleistocene.
Plate 9. Horizontal siltstone lake beds exposed within the lower glacial till, east of Sassi. The thickness of these beds is about 100 feet and they are between 300 - 400 feet high from the road.
CHAPTER - 3
PETROGRAPHY AND GEOCHEMISTRY

Petrography

Schistose rocks from the Haramosh group are medium- to coarse-grained muscovite-biotite-schist. The most common minerals found in thin sections are muscovite, plagioclase, quartz, and biotite. Garnet and sphene occur as traces. Muscovite occurs in the form of large flakes, usually broken and polygonized and sometimes show kinking (Plate-10). Biotite in association with muscovite give rise to S1 foliation. Quartz is normally present as flattened, fine-grained ribbons, showing complete deformation. Plagioclase, in most sections, occurs as equant, anhedral grains or porphyroblasts, which sometimes show twinning and little deformation. Plagioclase porphyroblasts are normally wrapped around by S1 foliation.

The gneisses from the study area are medium to coarse-grained well-foliated and contain megacrysts of quartz and feldspar. The most common mineral assemblage identified within the thin sections of the gneisses is quartz+alkali feldspar+plagioclase+biotite (Table 1 column 4), with traces of muscovite.

The rocks are generally inequigranular with subrounded to anhedral grains of quartz, K-feldspar and plagioclase. Muscovite and biotite exhibit alignment to the direction of foliation. Shearing, kinking, and segregation of the individual grains are
Plate-19. Photomicrograph showing kinking in biotite from gneisses of Iakara area. (Nicols crossed, Mgn.x45).
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Qtz = Quartz  
Alk-F = Alkali Feldspar  
Pl = Plagioclase  
Musc = Muscovite  
Bio = Biotite  
Epi = Epidote  
Chl = Chlorite  
Sph = Sphene  
Opa = Opaque Minerals
also common. Mortar texture signifying cataclasis is conspicuous in some sections (Plates 11 & 12).

Quartz is fine- to medium-grained, and in some sections it is fractured and has been stressed along the fabric direction. Most commonly the quartz grains show pressure shadows and undulose extinction.

K-feldspar is most commonly orthoclase, which occasionally show myrmekitic intergrowth with quartz. This is the dominant feldspar in the rocks obtained from MurDân area.

Plagioclase is the abundant feldspar in the Manuchal gneisses. It occurs in association with K-feldspar and quartz. It is in the range of oligoclase (An 20%). It is quite fresh and rarely show twinning. Inclusions of muscovite and biotite are common.

Biotite and muscovite occur as elongated flakes following the general fabric of the rocks. Biotite is light brown to greenish brown in colour. Alteration to chlorite is distinct in some sections.

Two samples of pegmatite obtained from the Manuchal area were studied in thin sections. Petrographically these are consisting of plagioclase, quartz, biotite and muscovite. Fracturing and minor faulting in plagioclase grains within thin sections of pegmatite were observed (Plate-13).
Plate 12. Photomicrograph showing cataclastic texture and crushing of quartz and feldspar grains in gneisses near the Shebatot fault. (Nicol's crossed, Mg. x 2.5).
Plate-13. Photomicrograph showing fracturing and minor faulting in plagioclase grains from pegmatite of Namuchal area. (Nicols crossed, Mgn. X 45).
Amphibolites

Hornblende, plagioclase, epidote, biotite and sphene are the common minerals found in thin sections of amphibolites from the thesis area. Chlorite, quartz and opaque minerals are the common accessories. Apatite and garnets are found in traces.

In thin sections, the amphibolites are medium- to coarse-grained rocks, having inequigranular, occasionally porphyroblastic to subidioblastic texture. Majority of these rocks show a well developed fabric.

The hornblende generally shows light-green to dark-green colour. It is quite fresh and occurs in the form of subhedral to anhedral grains. Occasionally it is replaced by a complex of scattered minute opaque grains and colourless amphibole. In some sections of fresh amphibolite, a pepermesh type intergrowths of hornblende and quartz is common. The fabric of the rock is defined by the parallel alignment of the hornblende grains.

The next abundant mineral in thin sections of these rocks is plagioclase. It occurs as distinct anhedral grains and also as inclusions within the epidote crystals. It varies from 3 to 10% by volume in these rocks. The plagioclase grains are fresh and unstrained and commonly display twinning in thin sections. The anorthite content of plagioclase is about 50% (andesine).

Epidote occurs as subhedral grains (occasionally as granular aggregates) in close association with hornblende and plagioclase.
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Hbl = Hornblende  Pl = Plagioclase  Epi = Epidote
Sph = Sphene     Bio = Biotite      Chi = Chlorite
Qtz = Quartz     Cpa = Opaque mineral
Fracturing and inclusions of minute plagioclase grains are commonly seen within the epidote crystals. It is present from traces up to approximately 25% by volume in these rocks (Plate-14).

Biotite is present as slightly kinked flakes of light brown to greenish brown colour, occasionally altered to chlorite along the cleavage planes. Opaque minerals, chlorite and quartz are the common accessory minerals present in amphibolites.

The sphene content of these rocks is unusually high. It ranges from 5 to 10% by volume. In thin sections, it is found as coarse, rounded sphenoids or in the form of irregular aggregates. Quartz occurs as distinct grains which are strained and slightly elongated in one direction. Interstitial behaviour is not uncommon. Among the studied sections, it varies up to about 5% by volume. Apatite is the common accessory mineral in these rocks.

Pyroxene-granulites

Samples of these rocks were collected from Shute area and are mainly composed of plagioclase and clinopyroxene (augite) with subordinate K-feldspar, orthopyroxene and biotite. Hornblende and chlorite are found as alteration product. Traces of opaque minerals are also common.

Plagioclase in these rocks exhibits rounded/irregular margins, with bending of their twin planes in some cases due to deformation. The anorthite content has been estimated 50% (andesine). Common replacement with K-feldspar is noticeable along crystallographic planes.
Plate-14. Photomicrograph showing high content of epidote in the form of tabular crystal in amphibolites from Manuchal area. (Nicol's crossed, Magn. x 2.5)
Plate 15. Photomicrograph showing zylonitized schist with well-developed folia of crushed plagioclase feldspar and quartz with development of muscovite and sericite. Foliation is wrapping around micro gneissose texture in Naramosh schist. (Nicols opened, Magn. x 2.5).
Plate 16. Photomicrograph showing chess-board albite and development of biotite within feldspar of Iskere gneisses. (Nials Crossed, Magn. x72)
Plate 17. Photomicrograph showing parallel alignment of hornblende grains and alteration of hornblende to biotite in Hanuchal amphibolite. (Nicols opened, Magn. X 2.5).
Plate 74. Photomicrograph showing muscovite grains in
Marnaceous schist. (Nicole crossed, Magn. X 30).
Plate 19. Photomicrograph showing wrapping of biotite around quartz porphyroblasts and sheared grains of plagioclase in Iskere gneisses. (Nicol's crossed, Magn. x 45).
Plate 20. Photomicrograph showing cataclastic texture in amphibolite near the fault zone. (Nicol Crossed, Mag. x 2.0)
Plate-21. Photomicrograph showing kinked biotite, anhedral crushed grains of quartz in plagioclase and the development of biotite along shear zone in the Ixere gneiss. (Nicols crossed, Magn. x 2.5).
Augite grains in thin sections of these rocks show a moderate preferred orientation, and are commonly associated with biotite and orthopyroxenes. Exsolution lamellae of orthopyroxene are common in the augite crystals.

Biotite occurs as coarse shreidy grains, slightly strained and are associated with augite. Preferred orientation of the biotite flakes imparts in some cases a weak macroscopic foliation appearance to these rocks.

K-feldspar is found as myrmekite and as interstitial material between various grains.

A small quantity (6%) of pink-green, euhedral to sub-hedral orthopyroxene is also present in the thin sections. It is associated with clinopyroxene. Minor hornblende and chlorite produced by alteration of clinopyroxene and biotite are conspicuous.

GEOCHEMISTRY

Samples of amphibolite and gneisose/schistose rocks, showing least altered characters in thin sections, were analysed for major elements by X-ray fluorescence spectrophotometer, using S-2, DNC-1 and BCR-1 as internal standard. Total iron was determined as Fe₂O₃, and the weight percent of FeO was determined through a calculation procedure suggested by Irving and Baragar, (1971). According to their calculations, FeO is determined from Fe₂O₃ as follows:

\[
\text{Fe}_2\text{O}_3 = \text{SiO}_2 + 2.5 \quad (1)
\]

\[
\text{FeO} = (\text{Fe}_2\text{O}_3 - \text{Fe}_2\text{O}_3 \text{ determined in Eq. 1}) \times 0.9
\]
The results of these analyses (on anhydrous basis) are presented in table 3 and 4 for schists/gneisses and amphibolites respectively. C.I.P.W. Norms, Higgli values, and some useful oxide ratios are calculated through a computer program and included in the relevant tables.

Characteristic chemical features of amphibolites listed in table No. 4 are i) the basicity of their nature, ii) constant concentration level of Fe₂O₃, and iii) low contents of Fe₂O₃. Samples SM-23 and SM-28 are characterized by having proportionally high contents of total iron.

Column 1 of table 6 shows the average chemical data of the amphibolite analyses, which is matching well with the average epidote-amphibolite of the Kohistan arc sequence from the Shargash NCR area in Allai Kohistan (Shah, 1986).

Chemical parameters of the amphibolites listed in table 4, when employed graphically in a genetic context, suggest an igneous parent for the derivation of these rocks (Fig. 1).

Plotting the data on Evans and Landis diagram (1966) in Fig. 1, concentration of the data points within the field, defined for Karoo dolerites is noteworthy. This indicate a basic igneous parent material for the derivation of these amphibolites. This is further supported by the distribution of the analyses points of the amphibolites in Mg vs C diagram (Fig. 2) and on the C-Mg-
Fig. 1. Plot of MgO wt% against C for the gneisses and amphibolites from the Harasmoon area. Various boundaries are after Evans and Leake, 1966.

Symbols: ▲ = Gneisses (Iskare)
+ = Amphibolites
■ = Gneisses (Manuchali)
○ = Pegmatites
Fig. 2. Plot of Niggli mg against C for the gneisses and amphibolites from Haranosh area. The igneous trend is shown by arrow after Leske, 1983. Key as in Fig. 1.
Fig. 3. Plot of mg-(al-alk)-C for the gneisses and amphibolites from Heranush area. Trend of Karro dolerites is after Leake, 1964. Key as in Fig. 1.
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cl</th>
<th>Br</th>
<th>I</th>
<th>NO3</th>
<th>SO4</th>
<th>HCO3</th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Zn</th>
<th>Cu</th>
<th>Mn</th>
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</table>

### Table 3: Major Ions Analysis of Waters from the Western Margin of the Red Sea Area

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<tr>
<th>Sample No.</th>
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<th>Br</th>
<th>I</th>
<th>NO3</th>
<th>SO4</th>
<th>HCO3</th>
<th>Na</th>
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<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Zn</th>
<th>Cu</th>
<th>Mn</th>
</tr>
</thead>
</table>

### Notes
- Quart. 11.52 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91
- Calc. 11.40 12.07 11.71 10.84 19.82 29.18 29.20 29.19 29.78 30.97 30.64 13.41 45.91

### Water Values
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49
- Na 39 40.00 45.00 40.00 31 43 41 41 45 49

### Total Ions Expressed as Fe2O3*
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<th>Sample No.</th>
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<th>Sh-5</th>
<th>Sh-16</th>
<th>Sh-23</th>
<th>Sh-24</th>
<th>Sh-25</th>
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</table>

**RIDGE VALUES**

| SiO₂ | 25 | 29 | 15 | 16 | 24 | 17 | 25 | 22 |
| Cl   | 21 | 29 | 17 | 17 | 27 | 20 | 24 | 22 |
| K₂O | 26 | 13 | 34 | 54 | 52 | 39 | 55 | 28 |
| Na₂O | 9 | 10 | 14 | 3 | 6 | 12 | 9 | 17 |
| MgO | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| Fe₂O₃ | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |

**Eig. Index**

| e | 26.21 | 34.61 | 50.83 | 25.72 | 26.39 | 42.58 | 55.49 | 59.90 |
| d | 30.43 | 28.85 | 29.21 | 30.24 | 31.05 | 25.93 | 29.21 | 23.94 |
| a | 26.30 | 29.95 | 45.09 | 17.95 | 21.37 | 26.89 | 34.16 | 47.93 |
| f | 95.57 | 81.60 | 69.29 | 87.36 | 67.89 | 64.60 | 45.18 | 86.46 |

63
<table>
<thead>
<tr>
<th></th>
<th>Haramosh area</th>
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<th>Mansehra area</th>
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</table>

*total iron expressed as Fe₂O₃.*

1. Average gneiss from the study area. (This report)
2. Average gneiss from the Haramosh area (Shah, 1979)
3. Average gneiss from Shergach Sar area (Shah, 1986)
4. Average gneiss from Mansehra area. (Le Fort, 1980)
TABLE 6. Average major oxide percentage of amphibolites from Hanuchal area compared with amphibolites of arc sequence from the Shergarh Sar area, Allal Kohistan.

<table>
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<tr>
<th></th>
<th>Hanuchal area</th>
<th>Arc sequence (Shah, 1986)</th>
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<tr>
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<td>TiO₂</td>
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<tr>
<td>Al₂O₃</td>
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<td>14.45</td>
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<td>Fe₂O₃</td>
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<td>FeO</td>
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<td>MnO</td>
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<tr>
<td>MgO</td>
<td>0.89</td>
<td>7.70</td>
</tr>
<tr>
<td>CaO</td>
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<tr>
<td>Na₂O</td>
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<tr>
<td>K₂O</td>
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<td>0.10</td>
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<tr>
<td>P₂O₅</td>
<td>0.24</td>
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</table>

1. Average amphibolites from the study area. (This report)
2. Average amphibolites from Shergarh Sar area (Shah, 1986)
(al-alk) diagram (Fig.1). All these variation trends have already been established within the amphibolites of the Shergargh Saz area in Allai Kohistan, in the south of studied area (Shah, 1986).

Fourteen complete major element analyses of the gneisses are presented in table 3, along with the C.I.P.W. norms and Huggins values.

\[ \text{SiO}_2 \text{ content in these rocks varies from 62\% to 72\%, with an average value of 67.5\%}. \]
\[ \text{Al}_2\text{O}_3 \text{ varies from 15\% to 21\%, with an average of 16\%. The total iron ratio ranges between a maximum of 6\% and a minimum of 2\% with an average of 4\%. CaO varies from 2\% to 5\%, the average being 2.3\% (Table 5).} \]

The major oxides have been plotted against Differentiation Index in (Fig.4-9). Na\(_2\)O, Fe\(_2\)O\(_3\), MgO, Al\(_2\)O\(_3\), CaO and SiO\(_2\) exhibit a rather scattered continuum of variation, while K\(_2\)O vs D.I. diagram (Fig.10) is patternless.

Three analyses i.e. SH-7, SH-10, and SH-33 are having anomalous values of Al\(_2\)O\(_3\) and Fe\(_2\)O\(_3\) and, therefore, plot off the general variation curve in Fig. 5 and 7.

The Ab/Or ratios are varying in the range of 0.66 to 1.01 with a normal average of 0.84 for majority of the gneisses, while the three specimens collected from Mesuchal area i.e. SH-7, SH-10, SH-33 have an average Ab/Or ratio of 5.61 (Table 7). These are the
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Ab/Or</th>
<th>Ab+An/Or</th>
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</thead>
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<tr>
<td>SH-13</td>
<td>1.83</td>
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<td>SH-14</td>
<td>0.68</td>
<td>0.86</td>
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<tr>
<td>SH-17</td>
<td>0.66</td>
<td>0.97</td>
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<tr>
<td>SH-20</td>
<td>0.82</td>
<td>1.28</td>
</tr>
<tr>
<td>SH-21</td>
<td>0.67</td>
<td>0.92</td>
</tr>
<tr>
<td>SH-22</td>
<td>0.70</td>
<td>0.80</td>
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<td>SH-37</td>
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Average: 0.84 1.11

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
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</tr>
<tr>
<td>SH-33</td>
<td>7.04</td>
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</tbody>
</table>

Average: 5.41 8.16

Gneisses from the Iskere and Hurban area.

Gneisses associated with amphibolite from the Hanuchal area.
samples obtained from the gneisses interbedded with amphibolites and appears different from the gneisses collected from Iskew and Kurban areas.

On the basis of Ab-An/Or ratio, the analyses are again distinguished into two groups. Samples with Ab-An/Or ratios from 0.80 to 1.32 plot in granite and adamellite field, while the gneisses from Hanuchal area have Ab-An/Or ratio of 4.56 (Table 7) and are confined to the lower part of the tonalite field outlined by O'Connor (1965) in the system Ab-Or-An (see Fig. 13).

The average gneiss composition from the studied area is compared with the similar Indo-Pakistan Plate rocks in northern Pakistan in Table 6. Differences in percentages of SiO₂, Al₂O₃ and CaO are distinct.

The possibility of the comagmatic character of amphibolites with Iskew gneisses from the studied area across the fault is greatly hindered by a wide compositional gap and different variation trends of these rocks on various two dimensional plots as shown specially in Figures 5, 7 and 12. However, close association of Hanuchal gneisses with amphibolites in the field, their exceptionally high ratio of Ab/Or, Ab+An/Or, and clustering of their data points at high Differentiation Index end of the amphibolite variation curves suggest a genetic relationship of these gneisses with amphibolites.
Fig. 4. Plot of Na₂O against Differentiation Index for the gneisses and amphibolites from Haramosh area.
D.I. = Qtz+Ab+Or(Normative) Thorntom & Tuttle, 1960.
Key as in Fig. 1.
Fig. 5. Plot of Fe$_{2}$O$_{3}^{5}$ vs Differentiation Index for the gneisses and amphibolites from Waremash area. Key as in Fig. 1.
Fig. 6. Plot of MgO vs Differentiation Index for the gneisses and amphibolites from Haramosh area.
Key as in Fig. 1.
Fig. 7. Plot of $\text{Al}_2\text{O}_3$ vs Differentiation Index for the gneisses and amphibolites from Harashah area. Key as in Fig. 1.
Fig. 8. Plot of CaO vs Differentiation Index for the gneisses and amphibolites from Haramosh area. Key as in Fig. 1.
Fig. 9. Plot of SiO$_2$ vs Differentiation Index for the gneisses and amphibolites from Haramosh area. Key as in Fig. 1.
Fig. 10. Plot of $K_2O$ vs Differentiation Index for the gneisses and amphibolites from Maramesh area. Key as in Fig. 1.
Fig. 11. Plot of SiO₂ vs Solidification Index for the gneisses and amphibolites from the Haramosh area.

\[ S_{\text{SI}} = \frac{100 \text{ MgO}}{\text{MgO} + 2\text{Fe}^3\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O}} \] (Kuno, 1959).
Fig. 12. Plot of MgO vs Solidification Index for the gneisses and amphibolites from the Haramosh area.
Fig. 12. Ternary plot of normative An-Ab-Or for the gneisses from Innere and Manuchal area. Boundaries are after O'Connor (1965).
CHAPTER - 4
STRUCTURAL GEOLOGY

The study area lies in a complex structural province because a major suture (MHT) and a set of active faults pass through the area. The complex deformation pattern of several rock units indicates a multiphase deformation history including a pre-Himalayan episode and at least two younger episodes separated by an interval of at least one million years. This fact is indicated by the presence of tight intrafolial folds in the Precambrian biotite-gneisses and young faults cutting Late Pleistocene glacial tills. Almost all the rock units in the area including Quaternary lake sediments are folded, faulted, boudinaged and mylonitized. Besides, the recognition of different episodes of folding in different rock units also suggest a multiphase deformation history. However, complexity of the deformation pattern generally increases towards the fault zone and reduces away from it.

Most of the field work including mapping and structural measurements was completed during successive falls of 1963 and 1964. Structural measurements were confined to the accessible parts of the area only, because steep valley slopes, high altitudes and the general absence of bridges on Zious river made it next to impossible to explore certain areas. However, along road cuts, valley sections and accessible trails on ridges, about 100 foliation attitudes and around 40 fold axes were measured directly in the field. Slickensides and other fault related phenomena were also closely observed.
Structures of the area generally include a series of active faults with associated fault gouge and mylonites, and at least three episodes of folding and foliation development in bedrock. A detailed description of these structural features is given in the following pages.

**FAULTS**

Faults are by far the most important structures of the area. There are at least three traces of major and a number of minor faults present in the area. These faults have played an important role in bringing together rocks of diverse origin and mineralogical composition, as well as modifying geomorphic features of the area.

Previous workers (Gansser, 1980; Tahirkheli, 1979; Coward, 1986) have all mapped the boundary between the Kohistan Arc and the Indian Plate as the southern suture or MMT in this area. The discovery of Raikot Fault (Lawrence & Ghauri, 1983; K.S. Ali Pers. Comm, 1986) immediately south of the study area opened a different dimension of approach i.e. transform tectonics in contrast to the convergent tectonics in this area. More work was, therefore, necessary to find out the nature of contact between the two contrasting lithologies. The present work was specially aimed at the structural features related to recent tectonic activity in the area. This project has shown that a zone of active faulting present in the area, has displaced Pleistocene glacial tills and lake sediments along steep to almost vertical scarps. This active
Fault runs along the western margin of the Haramosh Massif, in the position previously considered to be the NNW.

The study area includes a series of imbricate thrust sheets bounded by north trending and steeply east dipping reverse faults, and large drag structures associated with the thrusting. These faults bring the Shuts pyroxene-granulites and Hanuchal amphibolites in contact with the Haramosh schist in the northern part of the area and the same pyroxene-granulite with the Irkere gneisses in the southern part. During the present work, the three strands of Raikot fault north of Shabbatot village have been locally named as Shabbatot fault, Murban fault and Sumari fault, from west to east respectively.

The Raikot Fault

In the southern part of the study area Raikot fault is a single discrete fault zone extending between the Aster river mouth in the south and Bunji village in the north. It juxtaposes garnet-biotite-schists/gneisses of the Haramosh group with the pyroxene granulites and amphibolites of the Kohistan group. The fault zone is up to 1/2 km wide, consisting of a single active trace and an extensive mylonite and gouge zone. The fault zone roughly trends between due north and NNE dipping 50°E to almost vertical.

The Raikot fault passes about 5 km east of Bunji and enters the Indus gorge. Here it crosses the ridge, Indus river and Skardu road, about 2 km south of Shabbatot (Plate 5). In this stretch, the Indus river flows in the form of a loop, and the Raikot fault runs
along the eastern leg of the loop. From here northwards Raikot fault bifurcates into the three major traces, which coalesce again into a single fault about 5 km north of Khaltaro.

The fault zone in the northern part of the area trends NW with dip values between 65° and almost vertical. The thickness of the fault zone reaches its maximum i.e. about 3 km with minor faults and fault gouge. Most of the minor faults run parallel to the foliation and it seems that many faults eventually die out in foliation planes. Drag and other offset features indicate an east side up displacement with a certain dextral strike slip component.

The total displacement along these faults could not be determined due to the general absence of significant geological features or marker horizons on either side of the fault. However, the loop shaped course of the Indus river in this area does indicate a right lateral offset in the recent past. The Indus river flows in an east-west stretch till about 8 km west of Shangus. Here it suddenly takes a 90° turn towards north, and then for about 15 km it follows a north-south course until it reaches Khaltaro bridge beyond Sassi. The active trace of Raikot fault and the river run parallel to one another in this stretch. This suggests that total displacement along the Raikot fault was about 15 km. The geomorphic features of Indus valley and age of Jalipur tills (140,000 - 2,000,000 years according to Schoder, and Saqib, 1286 Pers. comm.) suggest that this displacement along
Raikot fault took place within the last 2 M.Y. i.e., long after the NNZ was tectonically active (15 Million years before present according to Zeifler, 1985). So 15 km within 2 Million years, means that a rate of about 0.75 cm/yr might have been the displacement average.

The Shahbatot Fault

The Shahbatot fault marks the boundary of the Kohistan arc and Indian plate rocks in the study area. It juxtaposes a wedge-shaped body of Hanuchal amphibolites and pyroxene-granulites with the Haranosh schist. There is a 200 m wide gouge zone and mylonites associated with this fault derived from the adjacent lithologies. The fault zone trends between due north and N20°E dipping 65° east to almost vertical. The slickensides and mineral lineation, which plunge 60° to 60° N in this fault zone, indicate a reverse and right lateral strike slip movement along the fault. This fault can, therefore, be called a dextral reverse fault. It runs between Shahbatot and Parchen villages as a single discrete trace and is eventually joined by the other eastern trace.

About 1 km south of Shahbatot village, the fault plane is exposed in a road cut, where it is measured to be almost vertical. Here, the fault separates mylonitized rocks of Haranosh group from mylonitized amphibolites with 2.5 m associated gouge (Plate-22). From this exposure to about 3 km beyond Sassi, the fault and the river run parallel to one another, and while the fault heads straight north, the river takes a westward turn (Plate-23).
Plate 62. The westernmost trace of Raikot Fault, exposed about 1 km south of Shahbatot village in a road cut. To the left is a nylonic zone derived from Karamosh schist unit and to the right are interbedded marbles with amphibolites of Manuchal amphibolite unit.
Plate 23. A panoramic view of the Indus gorge downstream of Sassi. Nos. 1 and 2 represent the confluence of Dasu and Khaltoro creeks with the Indus river respectively. The fault heads straight north while the river takes turn towards west. In the background the rocks of island arc sequence and Hanuchel village are noticeable.
The trace of the Shanikot fault can be followed further north, passing through the ridge which separates Passu from Khararo valley. It dips moderately at depth but ramps up near the crest of the ridge, where it marks the contact between pyroxene-granulites and Maramosh schists. It trends due north in Khararo canyon, dipping 70° east. East‐side-up displacement is common throughout the fault zone which is shown by many acid pegmatite veins displaced along such faults (Plates 24 & 25).

Many evidences can be placed in favour of the fact that the boundary fault in the study area is not the southern suture or MNT, and that is rather an active fault. The first evidence in that throughout the western extension of MNT, it has a dip of around 40° towards north, therefore, it should have more or less the same amount of dip towards west in the western leg of the loop. As a matter of fact the present fault dips steeply towards east. Secondly the expected strike slip component of MNT along this part would be left lateral in response to the northward movement of the Indian plate, which is contrary to the observed right-lateral movement. No gneisses or blueschists were found anywhere along the trace of the fault in the study area. And lastly, there has been no documented tectonic activity along MNT for the last 15 Million years (Seithar et al., 1982) while there are irrefutable evidences of recent tectonic activity along this fault. It is therefore, suggested that Roikot fault has cut the MNT east of Chilas near Bunar Sah, and through dextral
Plate-44. A small fault trending north and dipping steeply east located in a creek south of Sassi. East side up displacement is obvious, which is a common character of the area.
Plate 25. About 2 km north of Sassi village along the road the Marasosh schist unit is folded and faulted. The picture shows about 2 parallel east dipping reverse faults with an east-side up displacement. Thick gneiss layers are folded and boudinaged.
movement has displaced it far north (probably under the present glacial cover) and occupies the position which was considered to be NNE.

The Hurban Fault

The central strand of the Hurban fault marks the eastern boundary of the Haramosh schist unit with the Iskere gneiss in the east. It trends NNE and dips between 45° - 65° east through Shahbatot - Hanumal section. Beyond Hanumal, however, it gradually swings towards west and finally merges with the Shahbatot fault north of Khaltaro. South of Sumari creek the Hurban fault is itself displaced along a small east-west tear fault. At this place a small 200 m wide body of Hanuchal amphibolites is bounded on all sides by this fault and has been thrust over a sheeted mass of glacial till. The trace of Hurban fault is marked by a 50 m thick zone of mylonite and cataclastic gouge derived from the Haramosh schist and Iskere gneisses. A number of small to large faults are associated with the active trace, trending between NS and N20W with steep dips towards east. East side up displacement however, has been found to be a common character of faulting in the area.

The Sumari Fault

The Sumari fault is the easternmost strand of Reikot fault within the area. It runs as a discrete single trace between Shahbatot and Hanumal villages. The fault trends due north and dips
70° east. Unlike other faults the Sumari fault is a intraformational fault which runs through the Istere gneiss unit only (Plate-26). Since Pleistocene glacial tills are displaced along the trace of this fault, therefore, it is also considered to be post pleistocene or active. The fault gouge makes the width about 1/2 km and again east side up displacement is indicated by several offset features. The fault can be recognized by steep fault scarps, lateral offsets in the stream courses across the trace and beheaded fan/talus deposits.

Neotectonics

Neotectonic activity is suggested on the basis of young deformational features like displacement of Pleistocene glacial tills along certain scarps, lateral offset in the courses of streams, the presence of slickensides and fault gouge and alignment of hot-springs with the active traces of faults.

Several scarps can be readily noticed in the area, along which there has been recent movement. These scarps include the one immediately east of Sassi, which is about 123 m long and about 200 m high. A glacial till plateau has been vertically displaced along this scarp which lies along the trace of Murban fault. The lower surface is used by the inhabitants of Sassi village, while the upper flat surface is occupied by the people of Murban village (Plate-27). Another steep scarp can be observed east of Dassu along the ridge which has abruptly cut a fan/
70° east. Unlike other faults the Sarsai fault is an intraformational fault which runs through the Iskere gneiss unit only (Plate-26). Since Pleistocene glacial tills are displaced along the trace of this fault, therefore, it is also considered to be post pleistocene or active. The fault gouge makes the width about 1/2 km and again east side up displacement is indicated by several offset features. The fault can be recognized by steep fault scarps, lateral offsets in the stream courses across the trace and beheaded fan/talus deposits.

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Plate 26. About seven small east dipping faults associated with Sumari fault in Iskere gneiss unit. This picture was taken in Ishkapel stream, the displacement along the faults is not very clear.
Plate-27. A general view of the Indus gorge between Sassi and Shebbatot. The ridge to the right belongs to the Kohistan arc and to the left are glacial till vertically displaced along Hurban fault by 200 m. The upper surface is occupied by Hurban village while the dwellers of Sassi village have occupied the lower portion.
talus deposit. An almost vertical scarp in the bed rock is present west of Susmari village. The vertical cliff indicates recent faulting along the active trace of Susmari fault in the Iskere gneiss.

At least at two localities, the glacial tills are deformed by superficial folding and are thrust over the bedrock, indicating post Pleistocene activity. As already mentioned, the first thrusting of tills over the bed rock can be seen in Susmari creek, where amphibolite body overlies a glacial till with a highly sheared contact between the two. The other example is in Jutial stream where the till sequence is folded and a block of Iskere gneiss lies over it (Plate-28).

Other features like a knick point in the Jutial stream with a vertical drop of about 100 m in the base of the valley along the trace of Musari fault, lateral offset of stream courses and the presence of hot-springs in Iskere valley, Dassu village, and along Indus river near Shahbatot village are solid evidences of young faulting in the area.

All these evidences, like old ductile deformation and young rupture of tills, suggest a right lateral reverse slip with east side-up-displacement along these faults in the study area. The rate of uplift has been estimated at about 8 mm/yr from several features including total displacement along some of the scarps, and lateral offset of the Indus river etc.
Plate-28. Sedimentary structures and deformed glacial till in Jutiel stream suggest neotectonic activity in the vicinity. This trace is the active strand of Raikot Fault.
FOLIATIONS

Almost all the rock units of the study area are foliated. Of these, the Shuta pyroxene-granulite unit is weakly foliated. The attitude of foliation resulting from subparallel orientation of dark and light minerals could not be measured directly in the field. However, all other rock units are reasonably well foliated. The attitude of foliation was measured directly at about 300 localities in the field. Exposures in this steep terrain are so excellent that inspite of access problems that prevented actual measurements, the attitude of foliation clearly indicates a tectonic break between adjacent units. They are also considered important because they indicate the degree of deformation and the folding style of rock units.

The Hamuchal Amphibolite unit lying close to the Shahbatot strand of the Makot fault, displays the most complex pattern of foliation. As already mentioned the unit consists of interlayered marble, gneiss and amphibolite (thin to thick-beded) in which marble is the most incompetent unit. This is the only unit of the area in which the initial layering or S1 is so tightly folded that it is partially transposed to S2 foliation (Plate-29).

Measurement of the attitude of foliation was extremely difficult in the tightly folded part of this unit. The general attitude of foliation in the northern part of the unit varies from N8/90° to N208/62° NW. However, in Shahbatot section the attitude of
Plate 29. Interlayered sequence of marble-oneiss-amphibolite of Manuchal amphibolite unit exposed in a road cut just south of Shabbatot. The initial foliation $S_1$ has been so tightly folded that it has almost completely transposed to $S_2$. 
foliation ranges between N30W/40° to N25E/80° NW. Approaching the fault from west, the attitude of foliation becomes disrupted and stretched. The common behaviour of foliation in the gneissose component of the Maruchal Amphibolites is that there are minor undulations in the foliation planes and they pinch and swell around porphyroblasts of quartz and feldspar. The contacts of this unit are readily observable on either side because of the drastic change in the attitude of foliation in the adjacent units.

To the east of the Shishbatot fault lies the Haramosh Schist/gneiss unit with thin to thick-bedded marble and calc-silicate beds. It is also a strongly foliated unit, in which the schistose component is obviously better foliated than its gneissose counterpart. The general attitude of foliation in this unit ranges between N10E/81° NW to N20E/89° NW. Many minor faults run parallel to the foliation, and slickensides on some foliation planes (plunging 50°N) indicate that considerable movement have been absorbed by the foliation planes. This is further confirmed by the presence of mylonites and gouge, parallel to the foliation planes. The shear and mylonite foliation, present in the Haramosh unit is oriented due north and vertical. In Sumari section the attitude of foliation measures a bit different and is oriented between N 20-30° E, dipping 40° - 50° W. In Khaltaro valley section the foliation undulates around a steep NW plunging axis, and
has the pinch and swell structure. The attitude of foliation here measures NW/71°W and many minor faults disappear into the foliation.

The Iskere gneiss unit being the western most rock unit exposed in the area lies away from the main trace of Rekot fault and is therefore, less affected. In general, the Iskere gneiss unit is coarsely foliated with an average attitude of N20°E/60°W. But close to its western contact the Hurban fault runs within the formation and has developed strong foliation in the vicinity. The attitude of foliation in this sheared part of the unit measures N30°W/45°NE and N65°W/71°NE, which is quite different from the rest of the unit. Another set of foliations measured in the Iskere gneisses varies between N2W/55°NE and N35W/36°NE. There are amphibolite veins concordant to the attitude of foliation within this unit. Unlike other rock units close to the main trace of fault, the foliation planes are not undulating around NW plunging axes.

FOLDS

Folds of varying styles, wavelengths and amplitudes belonging to different generations can be recognized in the area. They include two macroscopic antiformal structures, broad and gentle undulations within foliation planes, open mesoscopic folds and minor tight interfolial and secondary folds. Close to the main trace of the Shaalbatot fault, the rocks are intensely
folded with steeply plunging axes, and away from it, folds become less frequent. The Shota pyroxene-granulite are, therefore, the least deformed rock unit, west of the fault. East of the Reikhot fault, away from the trace, the Jakare gneiss has tight to isoclinal folds that predate all structures of the area (pre-Himalayan folding) and are, therefore, termed as F1 folds (Madin, 1986). The lithology of the area is so fault controlled, that even two adjacent units exhibit different style and intensity of folding. On the basis of fold analysis, at least four episodes of folding i.e. F1, F2, F3 and F4 have been recognized in the area.

**F1 Folds**

F1 folds represent the earliest phase of folding in the area. These are tight to isoclinal intrafolial and sheet folds within the Jakare gneiss, generally developed towards the centre of the Massif outside the area. According to Madin (1986) these folds predate all other structures present in the area. This type of folds are not developed in the marginal areas of the Jakare gneiss.

**F2 Folds**

The second oldest folding in the study area is represented by two large F2 antiforms. The length of these are measurable in kilometers. Both these antiforms located to the east of the main fault, are almost parallel to each other and are north plunging.
The western antiform is formed by regional folding of the Haranosh schist. The west dipping limb of this structure forms the ridge which separates Dasu from Khaltoro valley. The eastern limb dips in the ridge which passes east of Dasu as far north as Hanuhal. The axis of this antiform trends NNE with a shallow plunge towards north. The active trace of Nurban fault passes through the axis of this antiform, and has offset the rocks in the core. This has probably followed by glacial erosion and the development of a valley along the core through the axis of the antiform. The fact that the fault has cut the antiform through its axis certainly indicate that the antiform predates the fault.

Another major F2 antiform is within the Iskere gneiss unit, lying to the east of first antiform. The biotite-gneiss of this unit is well foliated with concordant amphibolites within the gneisses. This unit constitutes the core of the Massif, and its exposure in antiformal structure indicates uplift causing considerable deformation and upwards bulging of the core. The axis of this antiform rests NNE, with about 50° plunge. Iskere valley exposes a perfect section through the west dipping limb of this antiform, where one can actually see the curve and arching up of the foliations. The amplitude of this antiform is about 1 km in this section, while the total length of the structure is measureable in kilometres. The foliation date from Iskere gneiss unit in Sassi-Sumari
section indicate a significant rotation of the foliation. In this section close the trace of active fault, the foliation dips east as compared to the overall westerly dip. It is suggested that east side up, reverse motion along the fault, has caused reversal of the dip in this region indicating that the antiform predates the faulting.

**P3 Folds**

The next episode of deformation in the study area is represented by P3 folds, which have NW plunging axes and are common both in Haramosh schist and Namuchal Amphibolite. The rocks of Haramosh schist unit are tightly folded along steep NW plunging axes. The folds are generally small-scale mesoscopic, close to tight with about 1 m amplitude. The attitude of fold axes measured directly in the field varies from N30-65W/66-56° (table 8). The field study shows that these folds have a counterclockwise vergence. Some of the fold axes measured close to the trace of Shahbatot fault trend NWW with steep plunges e.g., N15W/67° and N10W/70°. It can be suggested that these folds have developed on the western limb of the large F2 antiform, which itself plunges north. On the basis of the variation in the attitude of fold axes, (being NNW in the vicinity of the fault and NW away from the fault zone with steep plunges), it is concluded that P3 folds have developed as a result of right-lateral strike-slip movement along Shahbatot fault.
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Fig. 14. Stereographic projection showing F3 folds in Manuchal amphibolite unit. The fold axes trend northwest and have shallow plunge angles. The south 11 E/14° represent the F4 fold.
These folds can be observed in deformed felsic layers, and tourmaline-granite dykes and calc-silicate bands of the Haramosh schist unit (Plate-31).

F3 folds are also present in the Hamuchal amphibolites, as close, mesoscopic folds. The amplitude of these folds can be measured in metres. Axes of F3 folds in Hamuchal amphibolite unit also trend NW with moderate plunge angles, generally less steep than the fold of Haramosh schist (Table 8, Fig. 14). In the easternmost part of this unit, close to the fault trace, the foliation is tightly folded about similar axes (N40°W/57°) and is partially transposed. Here, minor tight rolls are common. However, large mesoscopic recumbent to reclined folds with shallower axes are common in the southern part of this unit. The shallow axes have trend and plunge as N40°W/32°, N45°W/25° and N55°W/30° (Plates-30). The attitude of these fold axes, and their recumbent to reclined position, suggest that these folds were formed just prior to faulting, in response to the stresses that caused the faulting. However, continued motion along the fault has rotated these folds to the present position, because of the drag effect. The close alignment and resemblance in style of the folds in the Haramosh schist and Hamuchal amphibolites suggest that these folds have originated under the same stress system almost simultaneously. Therefore, these folds are grouped into the same class as F3.
Plate 30. Namuchal amphibolite unit across Shhabtek fault about 1 km south of Shhabtek. The photograph shows F3 recumbent to inclined mesoscopic folds. The attitude of folds axes is about N40°/30°.
Plate 31. A felspathic vein folded in a mylonite derived from gneisses north of Sass village. The fold is plunging N104/70, and is verging to left which is the common behaviour of folding in the area. Minor folds have developed on the limbs of major fold.
F4 Folds

The youngest phase of folding has produced F4 folds in the study area. This type of folding is represented by gentle to open folds on the limbs of F3 folds. The attitude of fold axes belonging to this generation, trend due south to SSW with about 30° plunge. The reason that the F3 folds are nearly cylindrical is that, F3 folds have been refolded along shallow south dipping axes in both the units. Corresponding to SSW axes, some folds have NNW trends also with about the same plunge values i.e. 20°-30°. It is, therefore, suggested that these folds postdate all the other deformational structures in the area. The trend of axes fall in a north-south direction, which suggest that compression was from east-west. This is certainly in alignment with the stress direction responsible for thrusting and are, therefore, thought of as the product of the same phase.
CONCLUSIONS

Gneisses and amphibolites are the dominant rock types of the Nanga Parbat - Haramosh area. Gneisses are distinguished into two subgroups. (1) Iskere gneisses (Nanga Parbat biotite gneisses, Tahirkheli, 1979). These are abundant rocks east of the Rakot fault. (2) Hanuchal gneisses, represent an interlayered sequence with amphibolite in the western part of the studied area.

The Iskere gneisses, Hanuchal gneisses as well as the Hanuchal amphibolites, all are derivative from igneous parents. Distribution of data points along smooth variation curves (Fig. 14 through 11) signify the role of crystal-liquid equilibrium in the origin of the parent material of these rocks.

Idea of the genetic relationship between amphibolites and Hanuchal gneisses is supported by their chemistry (see Fig. 5-11) as well as by their interlayered character in the field (Plate-29). Production of the amphibolite parent in an island arc environments is exhibited by similarities in composition of the average amphibolite from the studied area with average epidote-amphibolite from the Kohistan arc sequence in Alissi Kohistan (Shah, 1986) (Table 6).

The Iskere gneisses are different from the Hanuchal gneisses in terms of major oxide abundances specially Al2O3/Fe ratio and A12O3/Fe ratio (See Fig. 12 and Table 7). These are not comagmatic with the Hanuchal amphibolite-gneiss association.
The U/Pb dating on zircon from the Iskare gneisses as 1.6 billion years, (R. Zartman, 1966, personal communication) makes the mechanism of production of the Iskare gneisses from the Myakhole in the Nanga Parbat - Haramosh area, very much doubtful. Differences in the average major oxides analyses of the Iskare gneiss, Mansehra granite (Le Fort et al., 1980) and granitic gneiss of the Ali Kohistan (Shah, 1986) distinguish the former from the latter types (see Table 5 Column 3 & 4). The chemical contrast is in fact a reflection of the diversities in the mode and time of origination and nature of the parent material. The Iskare gneisses are members of the Nanga Parbat granitic prolate possibly as a result of crustal thinning and arching event (Jan pers. comm.) or during a proto-orogenic episode (Valdiya, 1961). About 1.6 billion years ago (Zartman, 1966, personal communication), The Mansehra granites are belonging to the rock group of the lesser Himalayan granitic belt with a well-defined whole rock isochron age of 516±16 m.y. (Le Fort & et al., 1980). Their production is attributed to a process of crustal strike and slip movement giving rise to a thermal or tectonic and/or to a zone crustal thinning with simultaneous arching of the crust.

The contact between the amphibolite and related gneisses of the Kohistan island arc with Iskare gneisses of the Indian plate sequence is faulted. A single right lateral reverse fault immediately south of the thesis area divides into three branches.
before merging into a single trace about 5 km north of Khaltar village within the study area. Fault scarp in glacial fills, presence of fault gouge and slickensides, knickpoints and lateral offsets in stream courses and alignment of hot-springs all provide evidences of recent activity along these faults. Therefore, these are considered as active faults.

The three strands of Raikot fault are named locally as Shahbatot fault, Murban fault and Sumeri fault from west to east respectively. Almost all the faults trend N-S and dip steeply east. The sense of slip is right lateral and reverse with east-side-up displacement.

The western most of these i.e. the Shahbatot fault, juxtaposes schists and gneisses of Indian Shield against gneisses and amphibolites of the Kohistan arc sequence and occupies a boundary position. This fault has previously been mapped as NNE by many workers. Evidences of young activity, reversal in the direction of dip and right-lateral sense of slip along this fault indicate that this is a different and much younger fault. In all likelihood the western margin of the Nanga Parbat-Haramosh loop is the northern extension of Raikot fault.

The rate of uplift, determined from displacement along scours and right-lateral offset in the course of Indus river is suggested to be slightly higher than the previously estimated rates (1 cm/yr, Reitler et al., 1982).
At least three phases of folding were recognized in the study area i.e., P2, P3, and P4. The P2 folds are represented by two north plunging major antiformal structures which predate the faulting and seem to have been produced as a result of a diapiric uplift in the core of the Massif. The P3 folds are younger, microscopic folds, developed on either side of the fault. The axes of these folds plunge steeply towards NNW, and show a counterclockwise vergence. The P4 folds represent the youngest phase of deformation. These folds are also developed on either side of the fault through refolding of the P3 folds. The axes of P4 folds plunge SSE-SSW at shallow angles.

On the basis of mutual relationship of these latter folds, it is concluded that east of the fault, P3 folds were produced in response to the strong right-lateral strike slip component along the fault, while west of the fault they were simultaneously produced as normal upright folds. These were reoriented later, because of the continued thrusting effect along the fault. The P4 folds were produced after the faulting and, therefore, they have similar plunge values on either side of the fault.
Fig. 16. Map showing the F3 fold axes in the Hanuchel amphibolite and Paranosh phyllite, across the Shabbatot fault. The right-lateral strike slip component has resulted in counterclockwise vergence of the folds. Near the fault, the axes trend due north while away from it, the axes trend northwest.
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