STRUCTURE AND STRATIGRAPHY OF THE AREA, SOUTH OF KOHAT N.W.F.P., PAKISTAN

BY

IFTIKHAR ALAM

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NATIONAL CENTRE OF EXCELLENCE IN GEOLOGY

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2000

IN THE NAME OF

“ ALLAH”

THE MOST BENEFICENT

THE MOST MERCIFUL

DEDICATED

TO

MY

BELOVED

&

DEAR

PARENTS

APPROVED BY

SUPERVISOR
Prof. Arif Ali Khan Ghauri
Ex-Chairman Department of Geology
University of Peshawar

CO-SUPERVISOR
Mr. Sajjad Ahmad
Assistant Prof.Department of Geology
University of Peshawar

EXTERNAL EXAMINER
Mr. Ahmad Hussain
Director Geological,
Survey of Pakistan, (GSP) Muzaffarabad.

Prof. Dr. Mohammad Qasim Jan
Director National Centre
of Excellence in Geology
University of Peshawar

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IFTIKHAR ALAM

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ABSTRACT

This project describes the stratigraphy and structural setting of a 250 Km^2 area located south-west of Kohat city constituting a part of Kohat foreland basin. No rocks older than Eocene are exposed. The outcropping rocks consist of Panoba Shale, Sheikhan Formation, Kuldana Formation and Kohat Formation of the Eocene age unconformably overlain by the Murree and Kamlial Formations of the Rawalpindi group. The imprints of the ongoing Himalayan tectonics is well recorded in the outcropping rocks and is represented by a series of south verging anticlines and synclines with a common east-west axial trend. In addition to these folds several east-west trending and north and south verging thrust faults are present as well. The proposed structural model based on the synthesis of the field data suggests that this part of the Kohat Plateau has undergone three distinct phases of the deformation. The earliest phase which is designated as D1 was responsible for the development of a large overthrust sheet. This thrust sheet was later on folded in a second phase of deformation i.e. D2, during which the entire package of rocks were folded including the autochthonous rocks and the overlying allochthonous thrust sheet. The third phase of the deformation is D3 during which the structurally elevated rocks collapsed due to gravity faulting.

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CHAPTER

NO. 1

INTRODUCTION.

1.1 GENERAL DESCRIPTION.

The Kohat Hill Range is a branch of the Himalayan Mountains belt, located in the NWFP of North Pakistan.

The Kohat foreland fold-thrust belt lies on the southern fringes of the Himalayan orogenic belt and is a product of ongoing collision of the Indian and Eurasion Plate.

The Kohat Plateau forms the western margin of the Himalayan foreland fold and thrust belt. It is bounded to the north by the Main Boundary Thrust (MBT) and to the south by the Surghar Range Thrust (SRT) and Kohat Plateau Boundary Zone (Fig.1.1). The eastern continuation of Surghar Range Thrust is called the Salt Range Thrust which is offset by right lateral movement along Kalabagh Fault. On the eastern side, Indus River separates Kohat Plateau from the Potwar Plateau. On the western side, the Kohat Plateau is bounded by the Kurram Fault.

The Himalayan foreland fold and Thrust belt of northern Pakistan is being under thrust by crystalline basement along a single detachment surface (Seeber et al. 1981; Lilli et al. 1987). The Main Boundary Thrust (MBT) is a regional fault that brought the Mesozoic-Cenozoic shelf sediments to the Hill Ranges (Margalla, Kalachitta, Kohat, Samana and Safed Koh) against a pile of mollase sediments, deposited in the foreland basins of Potwar and

Fig. 1.1 **Regional sketch map showing major tectonic terrian of Pakistan (After Kazmi and Rana 1982) Inset Shows area of Fig 3.4**

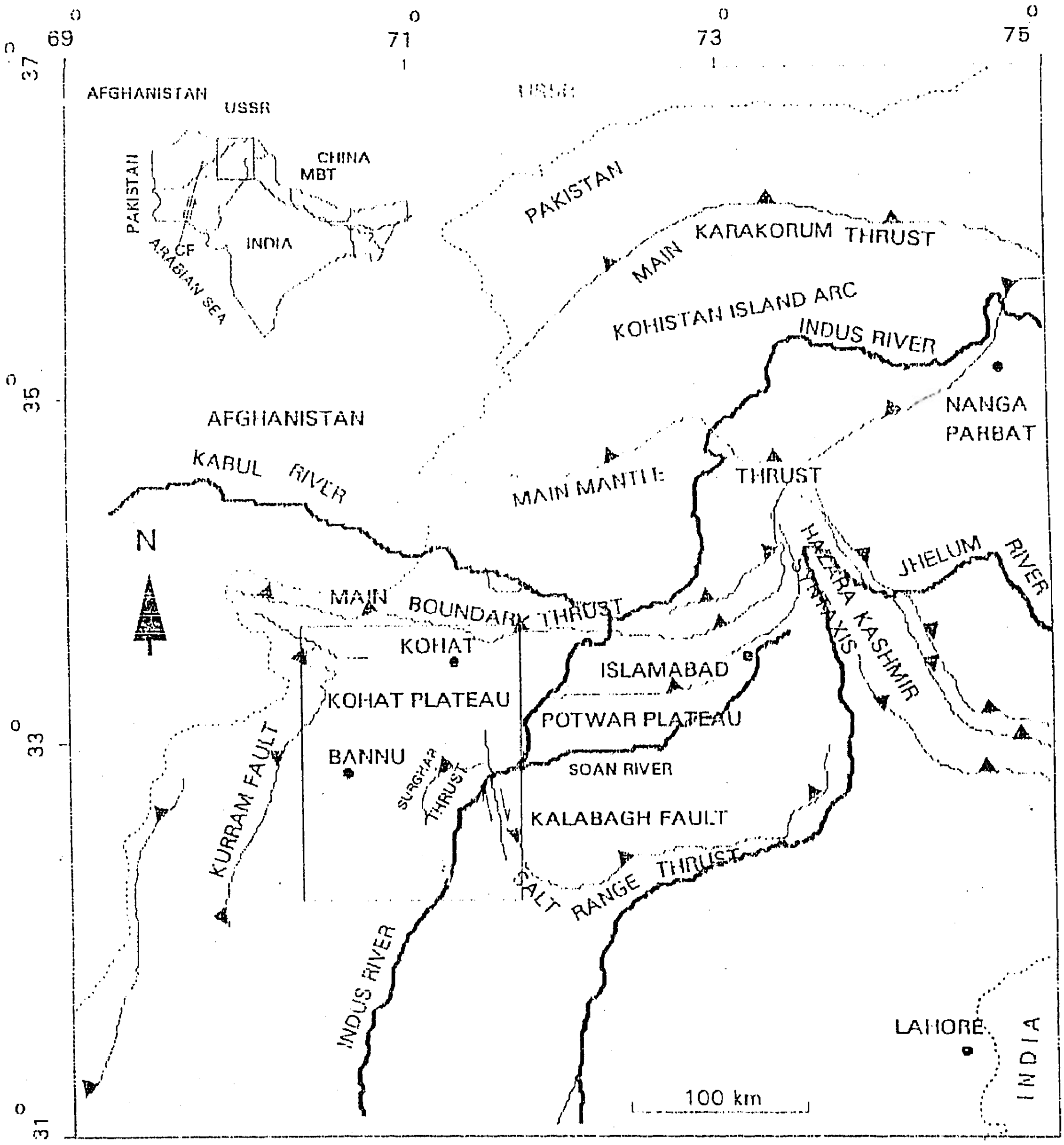


Fig. 1.1 **Regional sketch map showing major tectonic terrian of Pakistan (After Kazmi and Rana 1982) Inset Shows area of Fig 3.4**

Kohat (Yeats and Hussain, 1984). Disruption along the MBT zone started probably around early Miocene times as suggested by the involvement of Miocene Murree Formation in deformation (Burbank, 1983; Yeats and Hussain, 1987). Structures associated with this major fault, include duplex systems, back thrusts (Ghauri et al. In press) fore thrusts and fan folds (Khan et al. 1990).

The project involves the reinvestigation of the structures in the footwall of the MBT along the south-west margin of Kohat city in the Kohat Hill Range.

This Range is highly deformed and consists of elevated thrust sheet. Pop-ups, broad synclines and narrow faults and evaporite-cored anticlines record high level translation of a large thrust mass along Eocene evaporites.

In the study area the youngest phase of the tectonic activity associated with the MBT has resulted in the development of normal fault which has presently been recognized during study.

1.2 GEOGRAPHIC DESCRIPTION.

The Kohat Hill Range mostly lies in the tribal territory of the NWFP, but the project area is out of the tribal vicinity. It is fully covered by the laws of the Government of Pakistan.

The study area is a part of Kohat Quadrangle and encompasses 250 Km^2 of the Kohat Range. It is included in the Survey of Pakistan Topographic sheets No: 38 0/6 and 38 0/7 and is located south-west of Kohat city. It lies between Longitudes 71° 26' 00" and 71° 34' 20 " E and Latitudes 33° 15' 00" and 33° 24' 00: N, (Fig 1.2). Mapping has been carried out on a scale of 1 : 50,000.

1.3 <u>ACCESSIBILITY.</u>

The study area is accessible by the metalled Kohat Bannu Road which passes through the entire area. Mostly the project area lies on the west of this road. Several metalled and unmetalled side roads run east-west in the area which provide excellent sectional views. Many stream courses and paths connecting local villages provide a good chance to study the rocks and sections from different views which are quite helpful in structural interpretation of the region. Accessibility map of the area is shown in Fig. 1.3.

1.4 <u>RELIEF.</u>

The area is characterized by moderate to high relief ranging from 500m to nearly 1400m at the valley floors to the highest peak.

Fig. 1.2 **Index map of Pakistan. The square "A" shows location of the study area.**

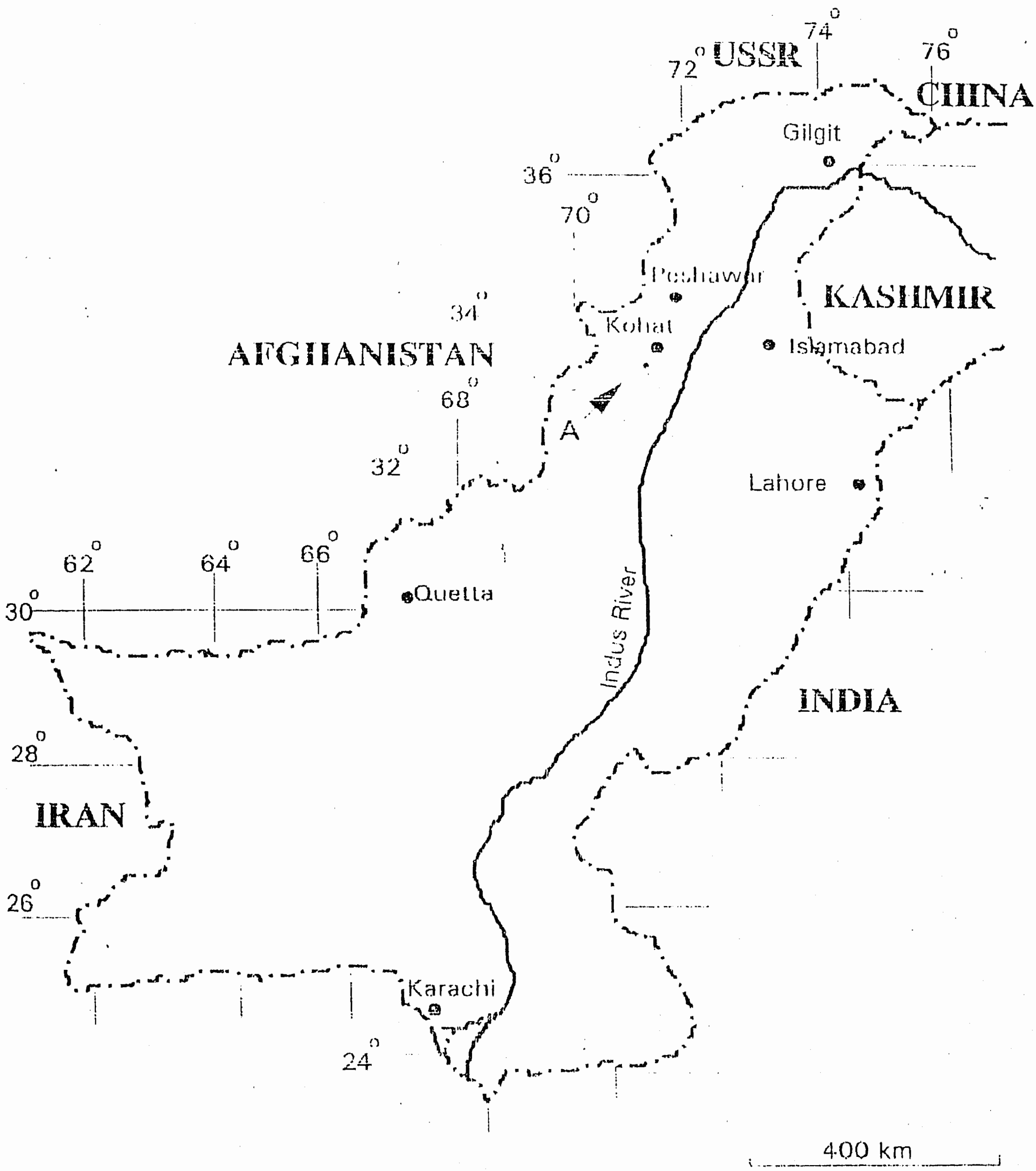
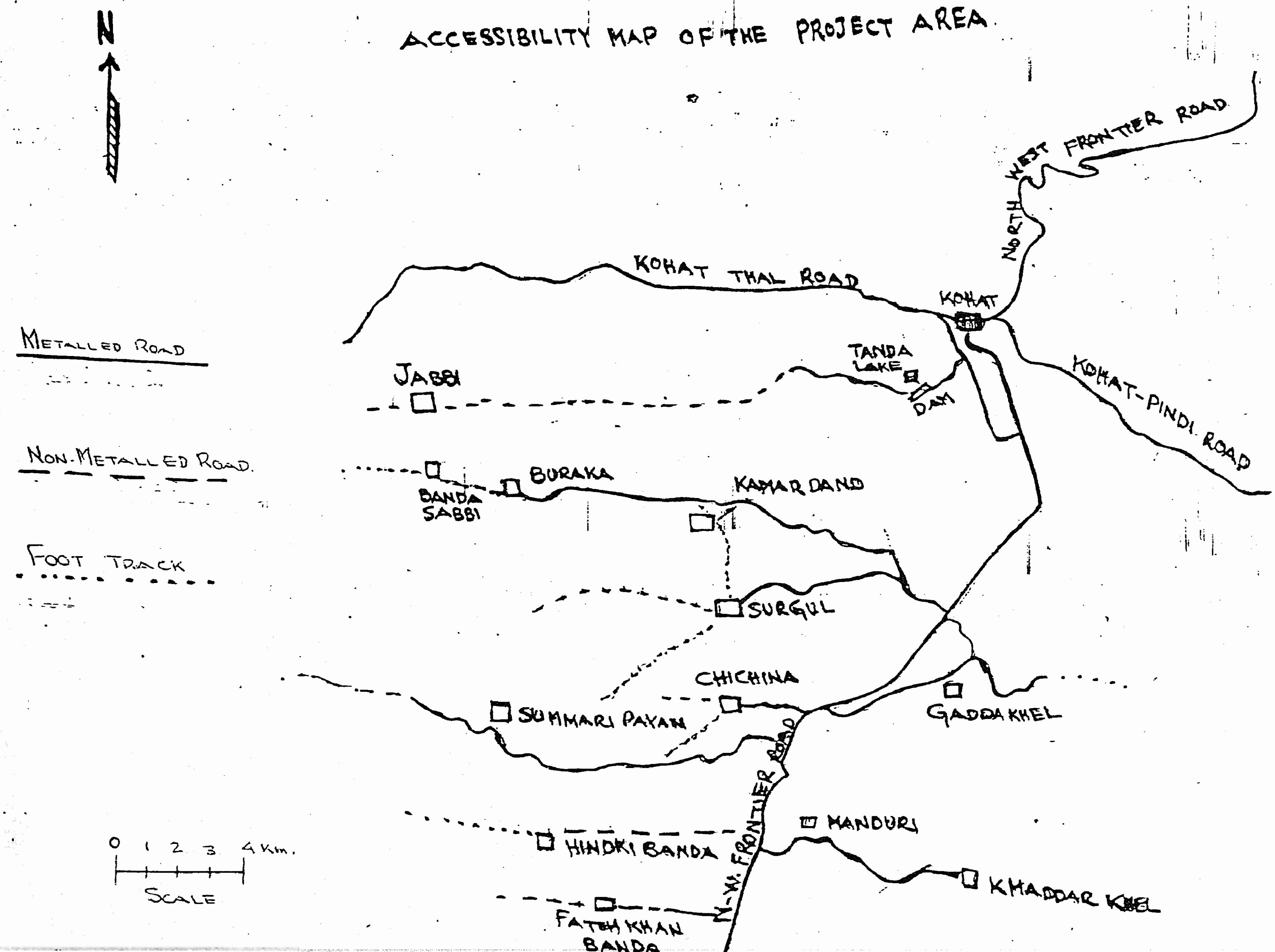


Fig. 1.2 **Index map of Pakistan. The square "A" shows location of the study area.**

Fig. 1.3 Accessibility map of the project area.

ACCESSIBILITY MAP OF THE PROJECT AREA



1.5 PREVIOUS WORK:

The earliest reference to the geological investigations in the area dates back to 1832 when Burnes published a report on the salt occurrences of the Kohat region. These deposits with brief geological account have also been referred to in various papers and articles by a large number of earlier geo-scientists of the Geological survey of India notably C.J.B Karstau (1846), Andrew Fleming (1853), T. Oldham (1864), A.B. Wynne (1857), P.S. Pinfold (1918) and L.M. Davies (1930). E.R. Gee (1945) first presented a regional overview discussing in detail the age and stratigraphic relationship of the Salt Range and the Kohat Salt deposits.

Raza and Khattak (1972) of the geological survey of Pakistan have published a useful report on the gypsum deposits of the Kohat area. M/s Engineers Combine limited (1972) have prepared a report on the bentonitic clay deposits of the Karak area.

Fatmi (1973) described the lithostratigraphy of the Kohat area, but the systematic geological mapping on the scale of 1:2,50,000 of the study area was carried out by Meissner et al;. 1974 with the help of aerial photographs. This work included the stratigraphy, description of rock types and structures of the Kohat area. Gardezi et al. (1976) carried out geological work in parts of the Kohat area and produced a map on 1: 50,000 scale for Dara Adam Khel and adjoining areas outlining the stratigraphy and faces changes. Ghauri et al. (1983) have mapped the southern part of the Kohat pass and divided the area mapped the southern part of the Kohat pass and divided the area into different structural domains. Wells (1984) carried out detailed sedimentalogical studies on the Early Cenozoic sediments of Kohat basin. McDougall (1985 & 1989) described the structural features related to the Kalabagh lateral ramp structure.

1.6 OIL EXPLORATION ACTIVITIES IN THE REGION.

First most of the Petroleum exploration interest was shown to the eastern Potwar basin therefore several attempts have been made by different oil exploration companies before independence but not reported any notable success. After independence exploration was extended west of the main Potwar basin when POL drilled Nandrakhi-1 in 1957 on a surface structure close to oil seeps in the Kohat area. Further activity on this play was limited to the Karak-1 well of Texas Gulf in 1977 and the Shakardarra well of OGDC in 1989, until Amoco showed interest in Kohat in the late 1980's. They licensed a large area located over the Kohat Plateau and undertook an extensive Survey, including surface sampling, airborne geophysics, and seismic acquisition, culminating in the drilling of three wells, all of which were abandoned:Tolanj (1991), Kahi (1992), and Sumari (1993).

The other exploration in the Bannu area has been by Petro Canada who, after an extensive study, drilled the Chonai-1 well in 1991 on a seismic anomaly and by OGDC who drilled

Isakhel well in 1993 in the Mianwali Re-entrant on a wrench structure.

The well that has been drilled in the geological conditions most analogous to Kundi is Ramak-1 which was drilled by Lasmo in 1993 on a fold structure within a deep Miocene trough in the Sulaiman Foredeep.

The activity has occurred over a period of 100 years, the Bunnu / Tank area has been only lightly explored. Most of the participants have drilled one or two wells and then retired from the area, which has then remained unlicensed for long periods.

Further attention is required to the area for exploration and development of Hydrocarbon.

1.7 OBJECTIVES OF THE INVESTIGATION.

The study area constitutes a part of the central portion of the Kohat Plateau which forms the western margin of the Himalayan foreland fold and thrust belt.

The main objectives of this study is to describe the style of deformation and examine the relationship between the structures. The present work was carried out with the following objectives in mind.

1. To carry out detailed mapping of the area on 1: 50,000 scale with special emphasis on all important structural features.
2. To update the stratigraphy of the study area .
3. To work out the structural style of the area.

4. To establish a consolidated structural model of the area.

The author is of the opinion that the study area needs further investigation for better understanding of stratigraphy and tectonic regimes and their associated structural styles which would be helpful in formulating future exploration strategies in the region.

CHAPTER
NO. 2

STRATIGRAPHY

2.1 STRATIGRAPHY BASED ON THE OIL EXPLORATION ACTIVITIES IN KOHAT AREA.

The exposed Eocene Succession consists from bottom to top of Panoba Shale, Sheikhan Formation , Kuldana Formation and Kohat Formation followed by the Miocene Murree and Kamlial Formations. So the exposed rocks in the area under study ranging in age from Eocene to Miocene, but the lithological units encountered during drilling activities in the region is given below.

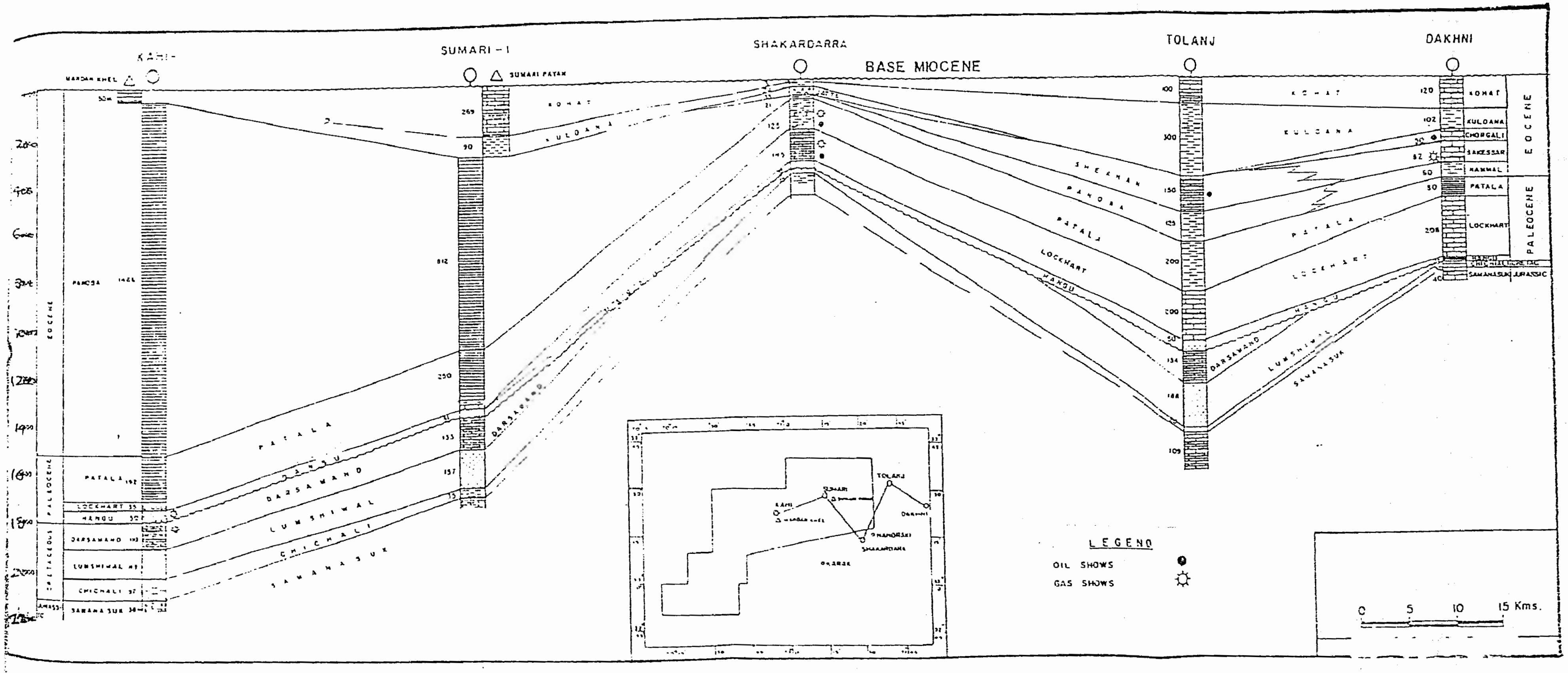
Sumari-1 well drilled in the first quarter of 1993 by AMOCO in the south ~~northern~~ western portion of the area represents the deepest penetration of the stratigrahic sequence of the region (Table-A) . A composite stratigraphic correlation (Table -B) based on the wells drilled in the Kohat Plateau and adjacent areas shows thickness and faces variation in an east west direction. The nomenclature for different formations used in this study is derived from the work of Meissner et al (1974), Gardezi et al (1976), Shah (1977) and Wells (1984). The rock description is based on observation of exposures in the study area and the drill cuttings of Sumari well No. 1. (Data provided with the courtesy of DGPC). The stratigraphic succession drilled in this well is given below:

Table; A. **Stratigraphic column of the study area based on strata encountered in the Sumari well No.1.**

SYSTEM	AGE	FORMATION (Group)	FORMATION	LITHOLOGY	THICKNESS IN STUDY AREA (M).
MIOCENE	MIDDLE	RAWALPINDI	KAMLIAL FORMATION		52
	EARLY		MURREE FORMATION		120
EOCENE	MIDDLE		KOHAT FORMATION		100
	EARLY		KULDANA FORMATION		60
			SHEIKHAN LIMESTONE		65
			PANOBA SHALE		622
PALEOCENE	LATE		PATALA FORMATION		400
	EARLY		HANGU FORMATION		41
CRETACEOUS	LATE		DARSAMAND LIMESTONE		132
			LUMSHIWAL FORMATION		157
CRETACEOUS / JURASSIC	LATE / MIDDLE		CHICHALI FORMATION		81
JURASSIC	MIDDLE		SAMANASUK FORMATION		33+

TABLE. A. STRATIGRAPHIC COLUMN OF THE STUDY AREA BASED ON STRATA ENCOUNTERED IN THE SUMARI WELL NO.1.

Table; B. Composite Stratigraphic correlation chart of the Kohat Platea


KAHI
SUMARI-1
SHAKARDARRA
BASE MIOCENE
TOLANJ
DAKHNI
SUMARI PAYAN
KOHAT
KULDANA
SHEKHAN
PANOBA
PATALA
LOCKHART
HANGU
DARSAMAND
LUMSHIWAL
CHICHALI
SAMANA SUK
CHORGALI
SAKESSAR
NAMMAL
EOCENE
PALEOCENE
CRETACEOUS
JURASSIC
LEGEND
OIL SHOWS
GAS SHOWS
0 5 10 15 Kms.

2.2 JURASSIC SUCCESSION

The oldest rock of Jurassic age penetrated in Sumari-1 well is the Samana Suk Formation, The formation consists of off-white to grayish white limestone containing disseminated dark grey peloids and traces of pyrite. There are trace of micro stylolites with argillaceous/ bituminous infilling. The base of the Samana Suk Formation was not reached and the well was abandoned at a total depth of 1466 M.

2.3 CRETACEOUS SUCCESSION

The rocks of Cretaceous age drilled are represented by the following formations:

1) **Chichali Formation.**
2) **Lumshiwal Formation.**
3) **Darsamand Limestone.**

1) Chichali Formation:

Chichali Formation consists of interbedded Claystone, siltstone and lesser amounts of glauconitic sandstone. Claystone is dark gray to brownish gray in colour, glauconitic with common

pyrite crystals. Traces of carbonaceous material were noted in the well cuttings. Claystone is poorly indurated, soft and crumbly, Siltstone and sandstone are gray-green to black with local white mottling and are highly glauconitic. Glauconitic grains range from very fine to coarse grained peloids. Locally, intergranular calcite and silica cements are present. Thickness of the formation is 81 meters. The Chichali Formation is gradational with the Lumshiwal Formation and is of Early Cretaceous age.

2) **Lumshiwal Formation.**

The Lumshiwal Formation consists of an overall coarsening upward sequence and can be divided into two units on the basis of lithology. The Upper Lumshiwal having a thickness of about 117 meters consists of light to medium gray , very fine to coarse-grained sandstone with stringers of claystone. Grains are subangular to rounded and sands are poorly to moderately sorted with traces of glauconite and mica. Amorphous milky white, crumbly clay with a-sub- chalky texture is commonly present as lumps in cuttings, The upper Lumshiwal is typically well cemented. Cements are primarily siliceous with lesser amount of calcareous cement.

The Lower Lumshiwal Formation having a thickness of about 40 meters consists primarily of siltstone and claystone with

lesser amounts of interbedded sandstone. Sandstone is described as light to medium gray fine-grained quartz- sandstone. Sandstone is contains carbonaceous material and traces of mica and pyrite and are typically heavily burrowed. There is no visible porosity and cements are primarily siliceous with lesser amounts of calcareous cement. Siltstone is medium gray and very argillaceous with disseminated carbonaceous material. Claystone and mudstone are medium to dark medium gray, slightly to highly silty and slightly calcareous. Claystone is soft and crumbly. Traces of indurated dark gray subfissile shale are present.

3) Darsamand Limestone.

Darsamand Formation consists predominantly of Limestone with stringers of siltstone and shale. The limestone is light to medium gray and buff colored microcrystalline. It shows no visible matrix porosity. Towards the base there is an increase in detrital material. Traces of pyrite and microforms are also noted.

The shale is greenish grey to bluish grey in colour. It is moderately calcareous and grading of claystone. The total thickness is about 132 meters.

2.4 PALEOCENE SUCCESSION.

The Paleocene succession penetrated in the well is represented by the following formations:

1) Hangu Formation.

2) Patala Formation.

Stratigraphically, the only surprising result was the absence of the Paleocene Lockhart Limestone. The Lockhart Formation is present in all nearby out crop sections and in the recently drilled Tolanj-1 and Kahi-1 wells. (Information provided with the courtesy of DGPC). The reason for its absence is probably due to erosion or nondeposition above the Sumari Arch (Sumari Well Completion Report 1993 by AMOCO).

1) Hangu Formation:

The Hangu Formation consists predominantly of very light grey, medium to coarse grained quartzose sandstone. This sandstone is moderately to well-sorted and locally fine-grained with subangular to rounded quarts grains. Cementation is dominantly siliceous. Pores contain interstitial white clay matrix. The Hangu Formation displays in overall fining-upward sequence and was deposited during a major regional transgression (Sumari Well Completion Report 1993 by AMOCO).

Towards the base the well cuttings samples suggest higher porosities with abundant loose sand grains. A total thickness of about 41 meters was encountered.

2) <u>Patala Formation:</u>

At Sumari well No. 1, drilling started in the Eocene Panoba Shale and the same formation continued down to 622 meters. At this depth the Patala Formation was encountered (Sumari well completion report 1993 by AMOCO). The entire Patala section predominantly consists of medium to dark gray or olive green clay stone grading to shale. The units are locally silty, randomly carbonaceous and contain random pyrite crystals. This section also contains light to medium gray, calcareous siltstone and calcareous mudstone.

Traces of vein calcite occur in microfractures and random benthic forams are present. Shales contain abundant black carbonaceous wisps, laminae and patches. Towards the base, the section contains increasing amounts of blue-green claystone and red, mottled claystone. It recorded a total thickness of about 400 meters.

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2.5 : EOCENE SUCCESSION

The Eocene rocks exposed in the study area are represented by the following formations:

4. **Kohat Formation**
3. **Kuldana Formation**
2. **Sheikhan Limestone**
1. **Panoba Shale**

1. Panoba Shale:

The name Panoba Shale was introduced by Eames (1952) for a rock unit represented by the " Green clay" of Wynne (1879), " Green Shales" of Parson (1926) and the " Green clay and sandstone" of Gee (1934).

The type section is located on the eastern side of Kohat city near Panoba village. It is also well exposed in the Sheikhan Nala (Well, 1984). In the study area, the formation mainly consists of pelagic-hemipelagic shales with occasional bands of sandstone. These shales are considered to have been formed by partial dewatering of smectites deposited originally as oozes.

Glauconite associated with smectites forms an accessory mineral. Iron associated with glauconite has been oxidized to form

2 —

SYSTEM	GROUP	FORMATION	LITHOLOGY
MIOCENE	RAWALPINDI	KAMLIAL FORMATION	
		MURREE FORMATION	
EOCENE	KOHAT FORMATION		
	KULDANA FORMATION		
	SHEIKHAN FORMATION		
	PANOBA SHALE		

TABLE 'C' : EXPOSED STRATIGRAPHIC CHART OF THE STUDY AREA.

FIG 2.1 (A)

OLIVE- GREEN OUTCROP OF
THE PANOBA SHALE LOCATED
SOUTH-WEST OF SUMARI PAYAN VILLAGE.

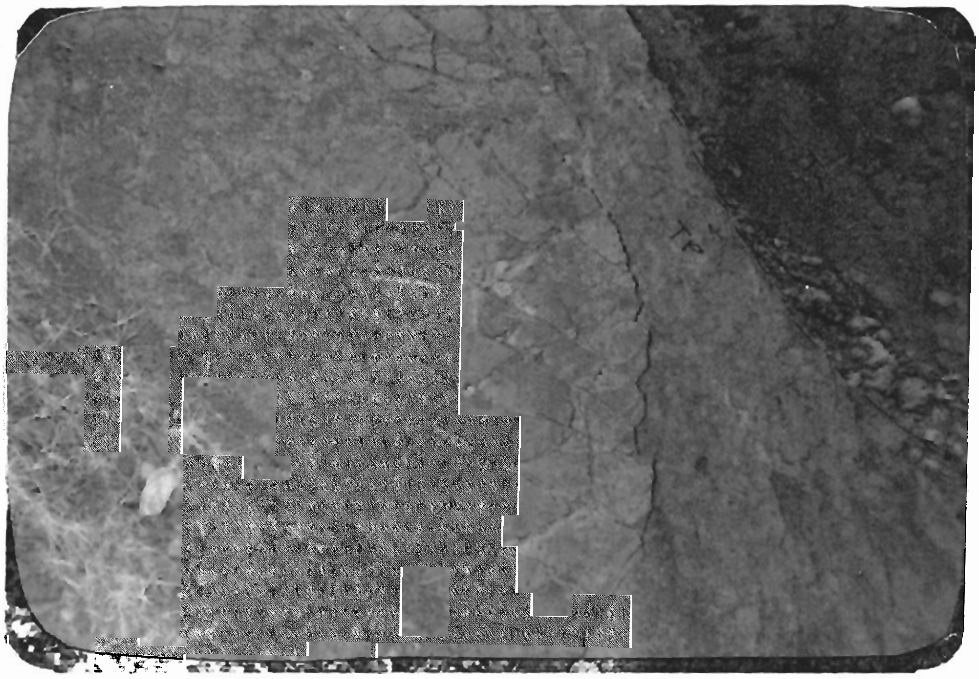


Fig. 2.1 (a) Olive-green out crop of the Panoba Shale located south-west of Sumari Payan village.

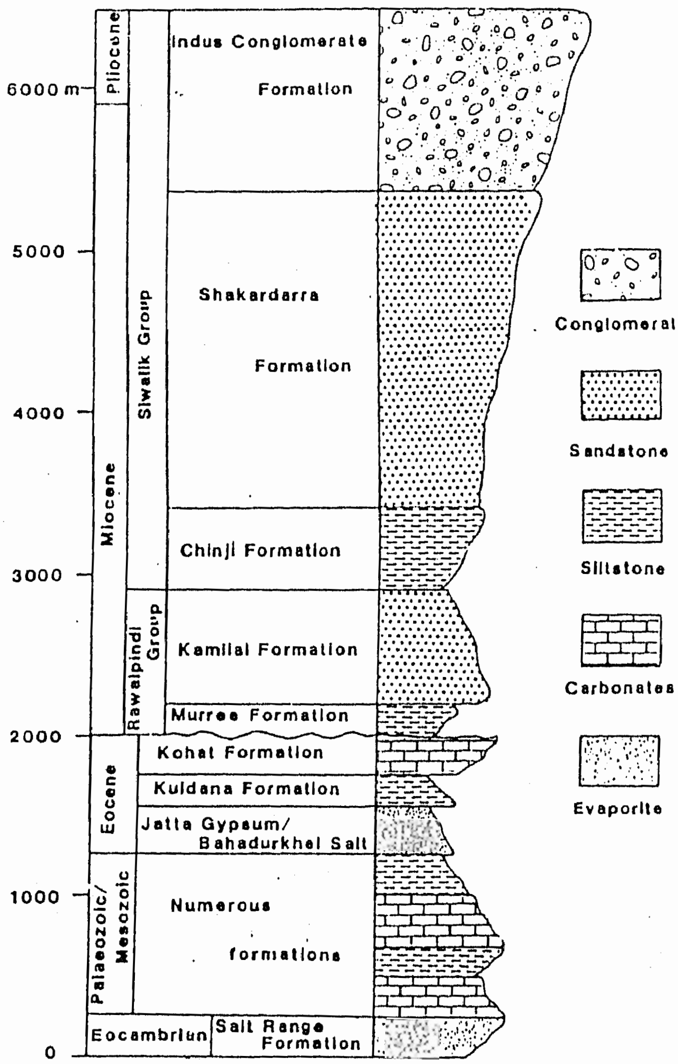
(3)

colloidal limonite, which is dispersed throughout the soft shale giving it a rusty coloration which marks its original green colour (PPL report, 1986), (Fig - 2.1 (a)) . In the mapped area, the lower contact of the Panoba shale is not exposed whereas its top is conformable with the overlying Sheikhan Limestone only in north eastern part of the study area. Whereas in most parts of the area under discussion, Panoba Shale is unconformably underlying the Kuldana Formation. The Formation is mainly restricted to the Kohat area and its thickness ranges from 40 meters at Tarkhobi to 160 meters at Uch Bazar. It is 100 meters at Sumari Well No. 1. Due to its lithology, this formation is highly susceptible to tectonic thinning and thickening causing difficulties in assessing its actual thickness. Meissner et al. (1974) have reported Early Eocene forminifers including Globorotalia acqua, Assilina pustulosa, Orbitolites complanatus, Nummulites species and Eponides species and have assigned an Early Eocene age to the formation. Panoba Shale is correlated with the Bahader Khel Salt of central and southern Kohat Plateau (Meissner et al., 1974) and also with parts of the Ghazij, Laki, Kharan, Rakhshani, Saindak & Nisai Formations in different parts of the Lower Indus basin, Axial belt and Baluchistan basin (Shah; 1977).

2. <u>Sheikhan Limestone:</u>

The term " Sheikhan Limestone" of Davies (1926) has been formalized by the Stratigraphic Committee of Pakistan as Sheikhan Formation to represent the " Gypsiferous

Table; D. Is a simplified summary of the Kohat plateau Stratigraphy (After Fatmi, 1973; Meissner et al; 1974, Shah, 1977; I.A. Abbasi and R. Mc Elroy 1990).



T-D. Stratigraphy of the Kohat Plateau (after Fatmi 1973, Meissner *et al.* 1974, Shah 1977).

beds", " Upper Sheikhan Limestone", " Middle Sheikhan Limestone" and " Lower Sheikhan Limestone" of Eames (1952) in the Kohat area. The type section is located in Sheikhan Nala, which is located east of the Kohat city. In the study area, the formation mainly consists of limestone and gypsiferous shale. The limestone is yellowish grey, thin bedded to massive and nodular. The shale is gypsiferous. In lower portion shale is dominant while in the upper portion limestone and shale are most prominently interbedded.

The formation is mainly confined to the northeastern part of the study area and pinches out south westward abruptly (Shah, 1977; Wells, 1984) . At Sheikhan Nala, its thickness is 54 meters (Shah, 1977), whereas in the proposed area, the thickness of the Sheikhan Formation ranges upto 65 meters. Here the formation has conformable contacts with the overlying Kuldana Formation and underlying Panoba Shale, Nagappa (1959), Pascoe (1963) have reported different species of Forminifers which include Alveolina oblonga, Assilina daviesi, A.laminosa, Nummulites atacicus and Orbitolites complanatus. Besides these Foraminefers, Corals, Molluscus and Echinoides are also reported (Shah, 1977). On the basis of these fossils, an Early Eocene age is assigned to the formation.

The formation is correlated with the Sakesar Limestone and the upper part of the Margalla Hill Limestone in parts of the Potwar province.

3. **Kuldana Formation (Mami Khel clay):**

The formation was named as " Kuldana beds" by Wynne (1874)., the " Kuldana Series" by Middlemiss (1986), " Lower Chharat Series" by Eames and " Mami Khel clay" by Meissner et al. (1974). Latif (1970) renamed it as Kuldana Formation. The Kuldana Formation is well developed in the study area and can be easily identified in the field as red to brownish red clay with interbedded sandstone layers (Fig 2.1 (b). It forms conspicuous red colourd gullies because of being soft as compared to the Kohat Formation and other formation exposed in the area.

The formation is approximately 50-60 meters thick and usually composed of clay, sandstone, limestone and bleached dolomite. The clay is red to brownish red, soft, calcareous and gypsiferous. The sandstone is reddish brown, thin bedded, hard medium to coarse grained and cross-bedded. The Kuldana Formation has a fluvial origin and was deposited by rapidly flowing streams in a semi-arid basin at the end of a marine regression (Wells, 1984).

In the northern and central parts of the study area, the formation has conformable lower and upper contacts with Panoba Shale and Kohat Formation Whereas in the southern part, the formation has conformable lower and upper contacts with the Jatta Gypsum and Kohat Formation respectively. Pinfold (1918), Latif (1970) and Meissner et al. (1974) have reported formainifers, gastropods. Bivalves and some vertebrate fossils also occur in

Fig. 2.1 (b) An out crop of Kuldana Formation showing interbedded sandstone and clay.

FIG 2.1 (B)

AN OUTCROP OF KULDANA FORMATION SHOWING INTERBEDDED SANDSTONE AND CLAY.

different parts of the formation. These fossils indicate early to Middle Eocene age.

4. **Kohat Formation:**

The Kohat Shale of Eames (1952) and Kohat limestone of Meissner et al. (1974) was formally renamed as Kohat Formation by the Stratigraphic Committee of Pakistan (1977). The formation is composed of dominantly limestone with subordinate interbedded shale. The lower Kaladhand Member is composed predominantly of limestone which is light grey, hard, compact and thin bedded with shale intercalations, particularly in its lower part. The Sadkal Member, in the northern Kohat, Kalachitta and northern Potwar area is composed of greenish grey calcareous shale with subordinate light grey limestone. The limestone interbeds become dominant in other parts of the Kohat area where they are characterized by an abundance of Nummulites.The formation is confined to Kohat, northern Potwar and Kalachitta areas, Its maximum thickness is about 100 meters in the study area. The formation lies conformably over Kuldana Formation with sharp and distinct contact whereas its upper contact with the Murree Formation is unconformable (Shah, 1977). The formation has yielded abundant foraminefers and various species of Nummulites.

2.6 MIOCENE SUCCESSION (Molasse Sedimentation).

in
Molasse sedimentation is the Kohat-Potwar foreland basin started in the late Oligocene or Early Miocene. The rock sequence can be divided into the following two major groups:

I. Rawalpindi Group.

II. Siwalik Group (This group is not exposed in the study area).

I. Rawalpindi Group:

The name ' Rawalpindi Group ' was proposed by Pinfold (1918) which was later approved by the stratigraphic Committee of Pakistan (1964). This group belongs to Miocene age and consists of the following formations:

(2) **Kamlial Formation.**

(1) **Murree Formation.**

(1) Murree Formation:

The "Mari Group" of Wynne *1874) , " Murree Beds" of Lydekker (1876) and " Murree Series" of Pilgrim (1910) have been formally named Murree Formation by the Stratigraphic Committee of Pakistan (Shah 1977).

In the study area , the formation consists of dark red and purple clay and purple grey and greenish grey sandstone with subordinate intra-formational conglomerate.

Fig. 2.2 (a) Photograph shows the scattered sandstone boulders of Murree Formation.

Fig. 2.2 (a) Shows the Scattered sandstone boulders of the Murree Formation.

It is well exposed in the northern Potwar, Kohat areas. In Hazara-Kashmir syntaxise an estimated thickness of 8- 10 Km has been reported by Bossart and Ottigar (1989) . It is 120 meters thick in the Shakardarra area (Abbasi, 1990) but only 9 meters thick at Banda Daud Shah (Shah, 1977). It is diachronous, estimated to be about 40 Ma old and of shallow marine (tidal flat) origin in the Hazara- Kashmir syntaxes (Bossart and Ottigar, 1989) whereas 28- 18 Ma old and of fluvial origin in the Kohat- Potwar Plateau (Shah, 1977).

The formation is mainly unfossiliferous and only a few plant remains and vertebrate fossils have been reported from the Kohat-Potwar Plateau.

Murree Formation unconformably overlies the Kohat Formation whereas its upper contact with the Kamlial Formation is transitional. (Fig 2.2 (a))

(2) <u>Kamlial Formation:</u>

Lewis (1937) renamed Kamlial Stage of Pinfold (1918) as the Kamlial Formation, which was later accepted by the Stratigraphic Committee of Pakistan (1977).

The formation is predominantly composed of sandstone with lenses of conglomerate and subordinate shale and siltstone. It is distinguished from the under lying Murree

Fig. 2.2 (b) Dark reddish thick bedded sandstone showing an out crop of the Kamlial Formation.

Fig 2.2 (b) DARK REDDISH THICK BEDDED SAND STONE SHOWING AN OUT CROP OF THE KAMLIAL FORMATION.

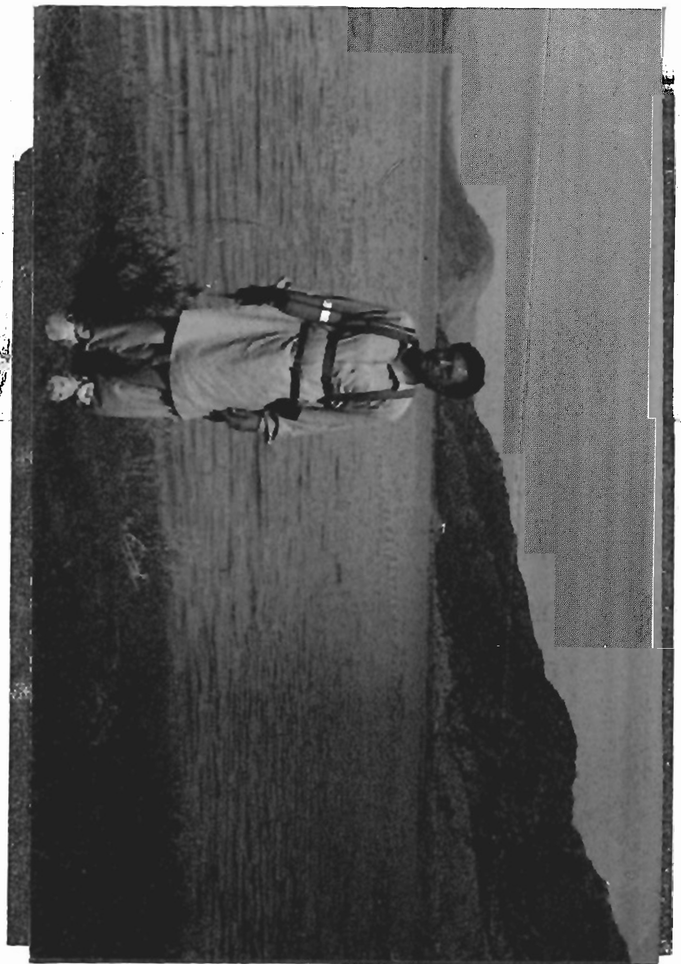


FIG. NO. 2.2 (B)

No. 57

(E)

Formation by its typical spheroidal weathering and heavy mineral contents in which tourmaline dominates over epidote.

At Banda Daud Shah, the Kamlial is 526 meters thick (Meissner et al., 1974). The Formation is predominantly composed of sandstone which is grey to greenish grey in colour, thick-bedded, medium to coarse grained, cross-bedded and contain conglomerate lenses. The clay is soft and is found as thin interbeds in the sandstone. The siltstone is reddish brown, hard fine grained, thin- bedded and intercalated with clay.

A number of fossil mammals have been found in the formation which indicate a Middle Miocene age (Pascoe,1963). The formation overlies the Murree Formation transitionally whereas its upper contact with the Chinji Formation of the Siwalik Group is conformable.

CHAPTER
NO. 3

TECTONIC SETTING OF NORTH PAKISTAN

3.1 REGIONAL TECTONIC SETTING:

The Himalaya-Karakuram-Hindu Kush Ranges in northern Pakistan are considered to be a broad collision zone between the Eurasian plate in the north and the Indian plate in the south (Fig. 3.1). Several micro-continents mostly of Gondwana affinity (Searle, 1991) and more than one Island arcs (Dietrich et al., 1983) are involved in this collision zone. The micro-continents such as the Karakuram plate, Afghanistan block and the Kohistan Island arc developed to the north of Indian continent during the Mesozoic Era. The first block to collide with southern margin of the Eurasian plate was Karakuram plate followed by Afghan block and lastly the Kohistan island arc came in contact with the system (Ganser, 1964; Lefort, 1975; Windley, 1983). In the NW-Himalaya, continent-continent collision followed the accretion of the island arc (Kohistan island arc) which had been formed by northward subduction in Late Cretaceous to Late Jurassic time (Petterson and Windley, 1985).

The Kohistan Island arc (Fig. 3.2 & 1.1) is bounded to the north by Main Karakuram Thrust (MKT) and to the south by Main Mantle Thrust (MMT).

The Main Karakuram Thrust (MKT) which is major tectonic feature in northern Pakistan has been formed as a result of collision between the Karakuram plate in the north and Kohistan island arc in the south (Tahirkheli, 1979; 1982; 1983). It was named Northern Suture by Pudsey

Fig. 3.1 Regional Setting.

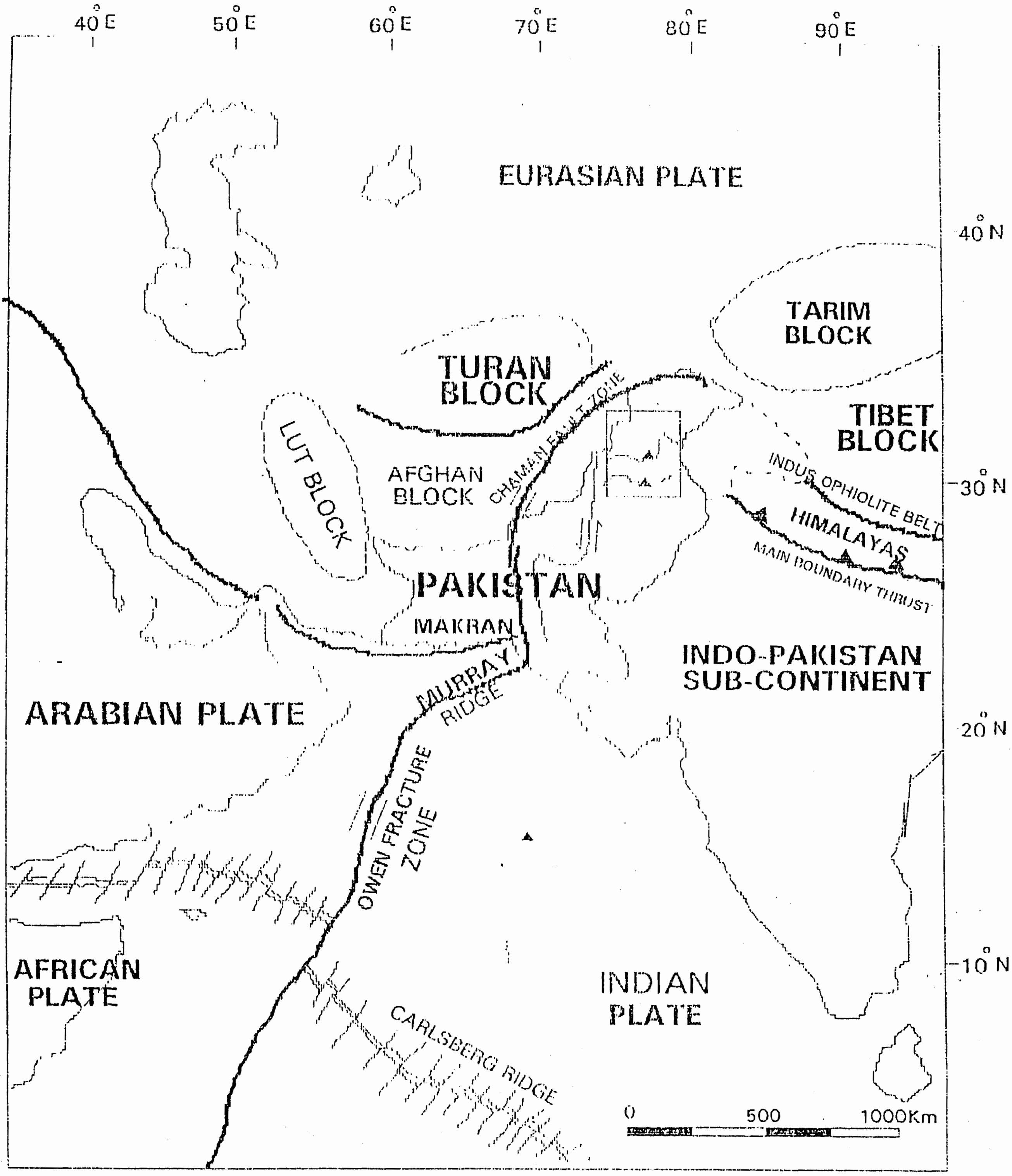


Fig. 3.1 Regional Setting.

Fig. 3.2 Geotectonic setting of central Asia around Karakoram (After Gaetani et al; 1990).

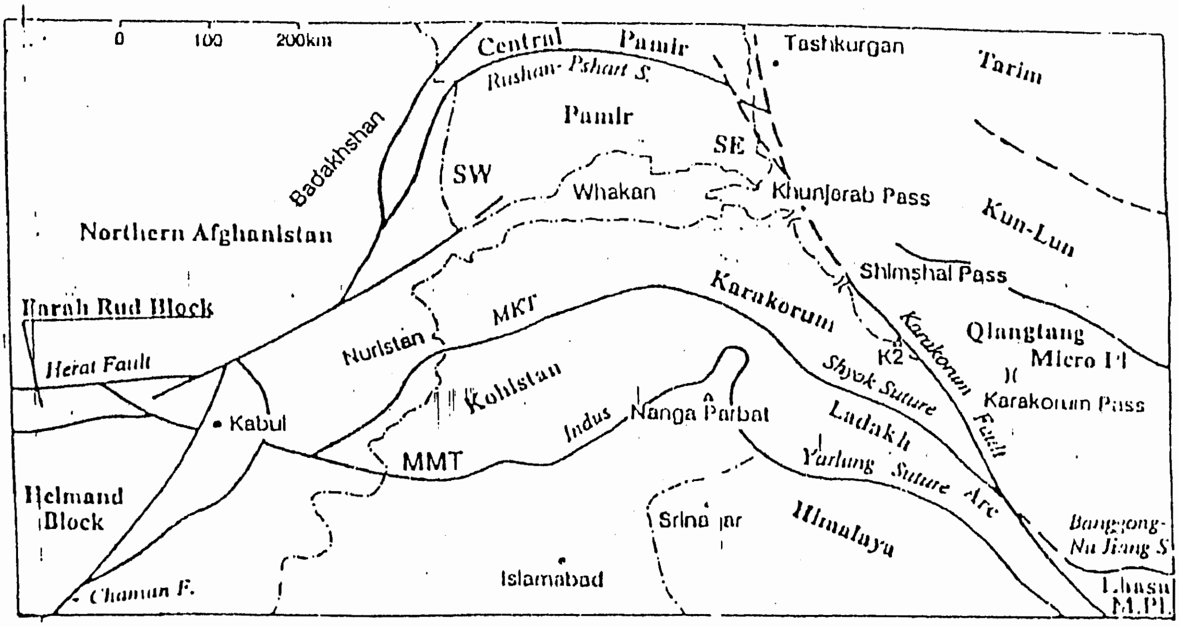


Fig. 3.2 Geotectonic Setting of Central Asia around Karakorum (After Gaetani et al., 1990).

et al. (1985). According to Coward et al. (1986), it was formed during Late Cretaceous. The Main Mantle Thrut (MMT) or Indus Suture zone was formed as a result of collision and subduction of Indian plate underneath the Kohistan island arc during Eocene time (Tahirkheli, 1979; 1982; Ganser, 1981). In India and Tibit, the MMT and MKT join together as the Indus-Tsangpo Suture (ITS) of the central Himalaya (Fig. 3.3)

The Karakuram plate to the north of MKT is composed of high grade metamorphic rocks with granitic intrusions (Searle, 1991). To the south of MKT lies the metamorphic basic and ultra basic rocks of the Kohistan Island Arc(Bard et al. 1980; Bard, 1983).

The ocean between the Karakuram plate and the Kohistan island arc was closed in Late Cretaceous (between 102 and 75 Ma) at the site of MKT (Coward et al. 1986). Continued subduction between the Kohistan island and the Indian plate produced an extensive body called Kohistan batholith. The ocean between the Indian plate and Kohistan island arc was closed in Eocene at the site of Indus Suture zone or Main Mantle Thrust (MMT) (Tahirkheli, 1979 a, 1979 b, 1982; Ganser, 1981) (Fig. 3.3).

The convergence which resulted in continent-arc-continent collision (Karakuram-Kohistan-India), however, did not cease with formation of MMT, but rather continued since Eocene at a rate of 5 mm per year (Patriat and Archache, 1984). This convergence resulted in the deformation of the Indian crust giving rise to the Himalayan foreland fold and thrust belt of the northern Pakistan. This belt is located to the south of MMT and is about 300 km wide (Fig. 3.3). As a result of this gradual southward propagation of deformation, a system of south younging fault has developed. The major members of this fault system are the Main Boundary Thrust (MBT) and the

Fig. 3.3 **Generalized tectonic map of the Himalayan Orgenic belt (After Peter Blisnivk, 1994). Inset shows area of Fig. 1.1**

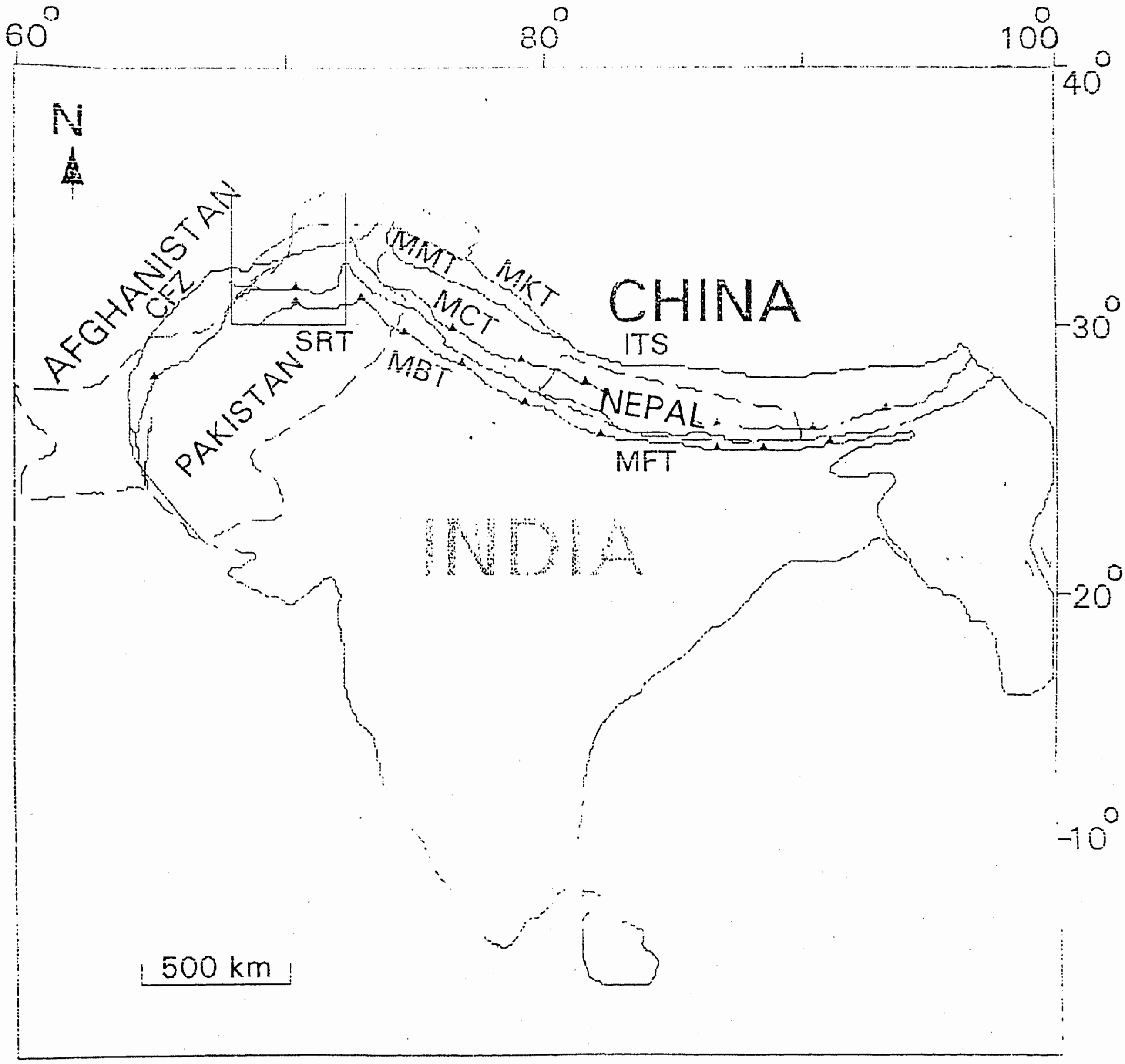


Fig. 3.3 **Generalized tectonic map of the Himalayan Orgenic belt (After Peter Blisnivk, 1994). Inset shows area of Fig. 1.1**

Salt Range Thrust (SRT) (Zeithler et al. 1982; 1985; Yeats and Hussain, 1987).

The Salt Range Thrust (SRT) in the south western part of the Pakistan Himalaya is the lateral equivalent of the Main Frontal Thrust (MFT) of the central Himalaya (Fig. 3.3). In the central Himalaya the foreland fold and thrust belt is internally sub-divided by two major north dipping thrust fault i.e. Early to Late Miocene Main Central Thrust (MCT) in the north and late Miocene Main Boundary Thrust (MBT) in the south. The MBT in the north western Pakistan runs east west along most of the foreland basin but turns northward west of the Jhelum River in the form of major bend known as the Hazara Kashmir Syntaxis (Fig. 1.1). The Panjal and Nathiagali faults mark the western limit for the Hazara Kashmir syntaxis.

The Kohat-Potwar fold and thrust belt is the western deformed terrain of the Himalaya forelanf basin. This foreland basin can de divided into two tectonic provinces; the Potwar plateau to the east and the Kohat plateau to the west of Indus river, in the Trans Indus Ranges (Fig. 1.1). The Potwar plateay is constituted by a less internally deformed fold and thrust belt having a width of approximately 150 km in north-south direction (Kazmi and Rana, 1982). It is bounded to the south by the Salt Range Thrust and to the north by Hazara/Kalachitta Ranges (Fig. 3.4). Most of the deformation is concentrated in the northern part of the plateau which is called as the Northern Potwar Deformed Zone (NPDZ) (Leather, 1987; Baker et al. 1988).

The Kohat plateau constitutes the western part of the Himalaya fold and thrust belt and is approximately 70 km wide in north south direction (Fig. 3.4). It is bounded to the north by MBT (Fig. 3.5), to the south by the

Fig. 3.4 Tectonic map of the Kohat Plateau (After Meissner et al., 1975 and Pivnik., 1994). Inset Shows area of Fig 4.1

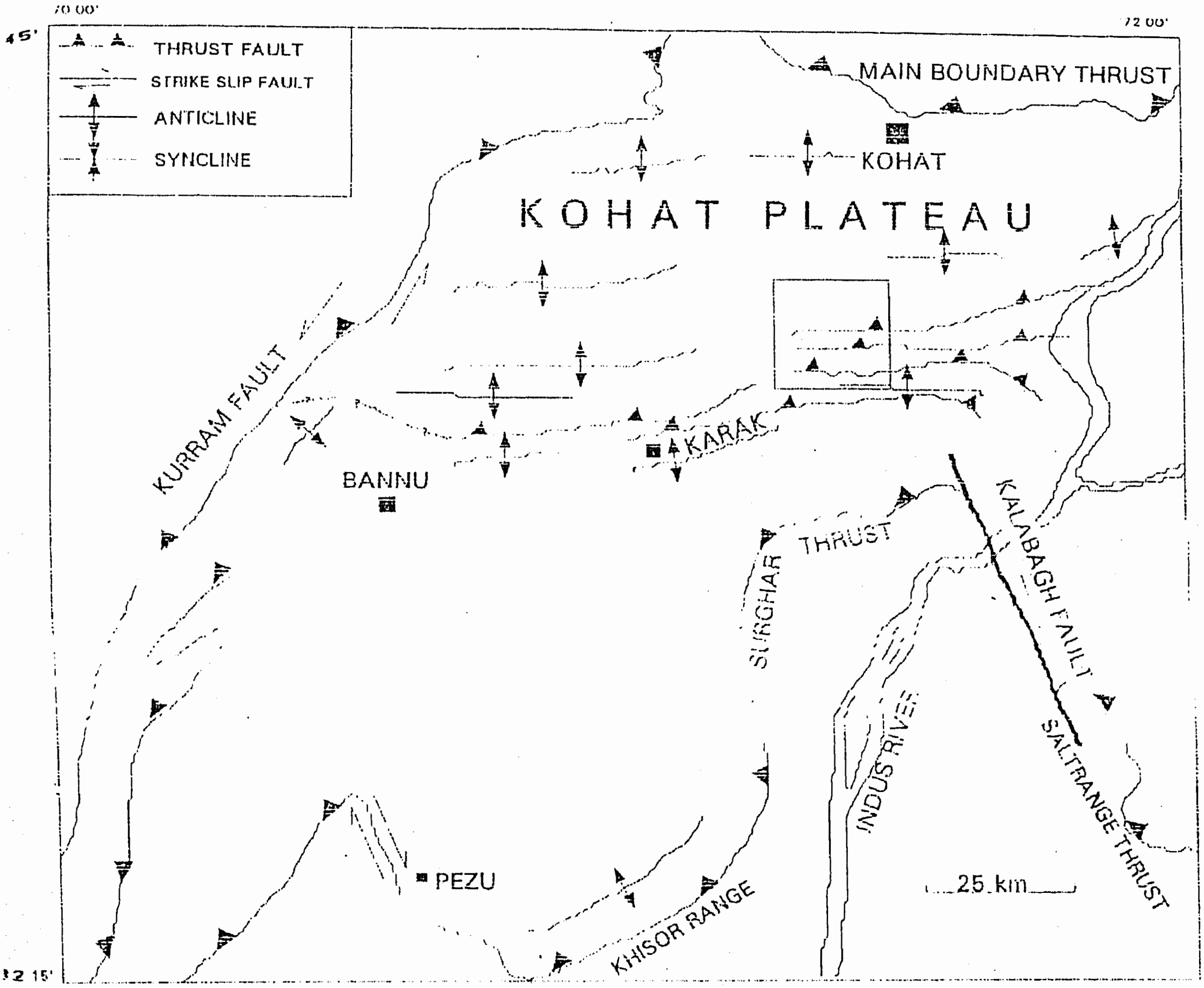


Fig. 3.4 Tectonic map of the Kohat Plateau (After Meissner et al., 1975 and Pivnik., 1994). Inset Shows area of Fig 4.1

Fig. 3.5 **Tectonic map of the Kohat Plateau showing major structural features (After D.A. Pivnik and W.J. Sercombe 1994). Inset shows area of Fig 4.1.**

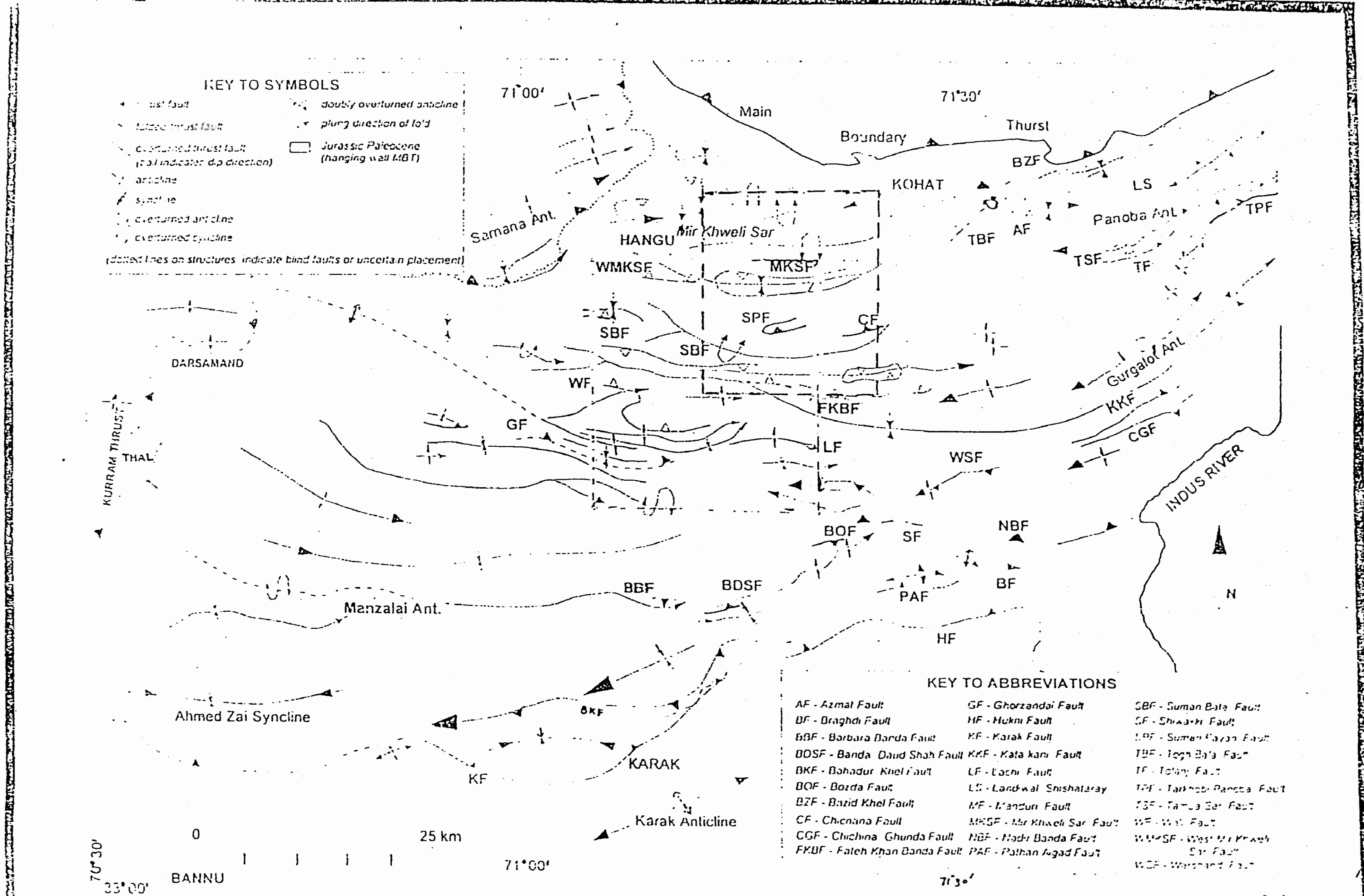


Fig. 3.5 Tectonic map of the Kohat Plateau showing major structural features (After D.A. Pivnik and W.J. Sercombe 1994). Inset shows area of Fig 4.1.

Fig. 3.6 Landsat image showing major structural provinces and geomorphic features of the northern Pakistan fold and thrust belt (After Leather, 1998).

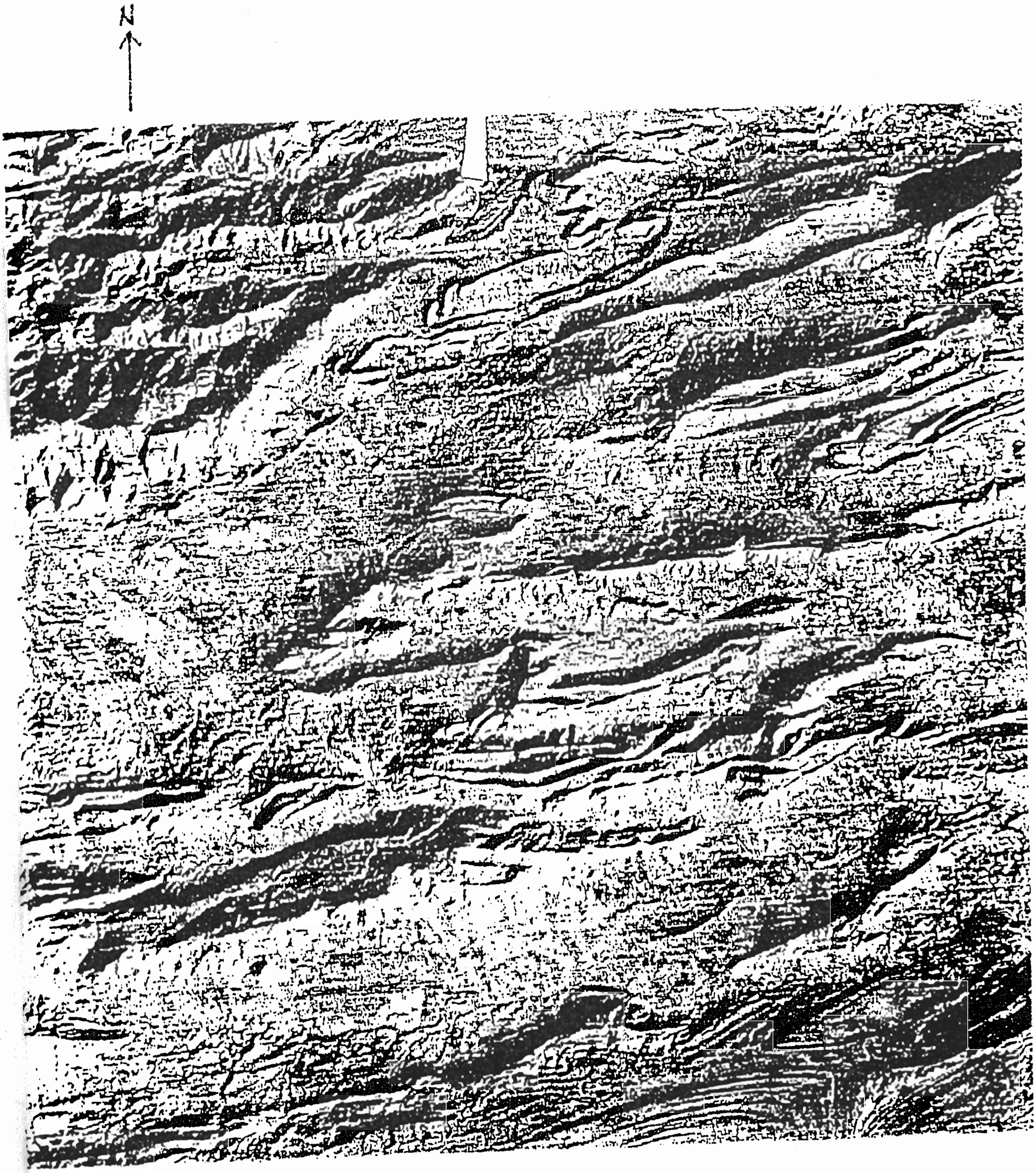


Fig 3.6 Landsat image showing major structural provinces & geomorphic features of the northern Pakistan fold & thrust belt (After Leather 1998).

Surghar Range Thrust which is separted from the Salt Range Thrust by Kalabagh strike-slip fault and in the south west it merges into Bannu Basin. Indus River marks its eastern limit which separates it from the Potwar plateau whereas towards the west it is truncated by the Kurram fault (Fig. 1.1). In the Kohat plateau the MBT brings Mesozoic andn younger strata over Neogene molasse sediments. The Kalabagh fault is the most prominent north south structural feature at the southern most fringe of the Kohat Potwar foreland fold and thrust belt and its trace on the surface runs for about 120 km (Fig. 1.1). Kalabagh fault trends N15W and is characterized by transgressive right lateral strike-slip movement (McDougall, 1985).

CHAPTER

NO. 4

STRUCTURAL GEOLOGY OF THE AREA SOUTH-WEST OF KOHAT

4.1 General Description

The study area is located immediately south of the MBT and constitutes the hanging rock sequences of the MBT. The southward propagation of Himalayan deformation associated with MBT is well recorded in the area, which is represented by tight, east-west trending anticlinal structures and open to tight, east-west trending synclinal folds. The folds are mostly south vergent but north vergent are also present. Additionally the area is well comprised by east-west trending thrust faults which includes fore and back thrusts as far as there vergence is concerned. The basal decollement for most of these thrust faults is located within Kuldana Formation.

At places, the study area is showing a complete stratigraphic sections of the exposed formations. The formations mainly exposed as Panoba shale, Sheikhan formation, Kuldana formation and Kohat formation of the Eocene Succession and Murree formation and Kamlial formation of the Miocene Succession.

For simplification purposes the mapped structures are subdivided as under.

1. Anticlinal Trends.
2. Synclinal Trends.

Fig. 4.1 Geological map of the project area.

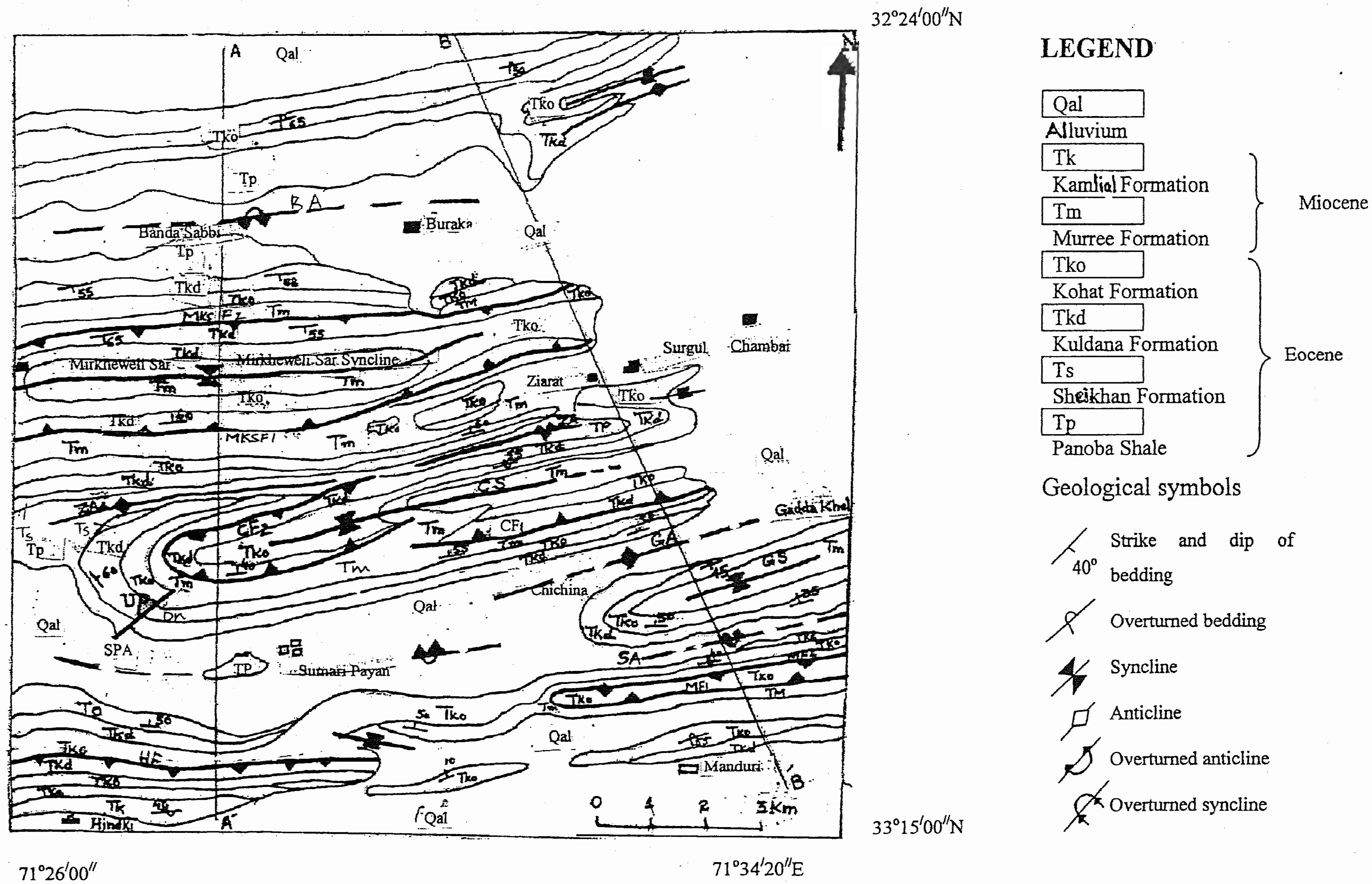


Fig. 4.1

BA = Buraka Anticline, MKS1 = Mir Khweli Sar Fault 1, MKSF2 = Mir Khweli Sar Fault 2, ZA = Ziarat Anticline, ·2 = Chichina Fault 2, CH = Chichina Syncline, SPA = Sumari Payan Anticline, GA = Gadda Khel Anticline, GS = Gadda khel Syncline ·F1 = Manduri Fault 1, MF2 = Manduri Fault 2, HF = Hindki Fault CF1 = Chichina Fault 1 SA = Spina Anticline.

3. Fore Thrusts. 4. Back Thrusts.

5. Normal Fault 6. Overturned Thrust Faults.

4.2. Anticlinal Trends:

Five prominent anticlinal structures are recognized and mapped in the investigated area (fig. 4.1) which are from north to south as under.

(a) Buraka Anticline

(b) Ziarat Anticline

(c) Sumari Payan Anticline

(d) Gadda Khel Anticline

(e) Spina Anticline

(a) Buraka Anticline:

It is the northern most structural feature mapped in the area. The axial trend of this fold is oriented east-west and exposes the oldest rocks of the region i.e. Panoba Shale in its core. It's northern limb is constituted by overturned, steeply south dipping rocks of Kuldana Formation, Kohat Formation, Kamlial Formation and Murree Formation (fig. 4.1). At the eastward termination of this limb it has developed to small scale east-north-east trending anticlines and synclines incorporating the rocks of Kuldana and Kohat Formations. The southern limb of this fold is steeply south dipping and include the rocks of Kuldana, Kohat and Murree Formations. This limb constitutes the foot wall strata of the Mir khweli Sar Fault 2 as well (fig. 4.1) along which the Kuldana Formation is thrust over the rocks of the southern limb of the Buraka anticline. Based on the attitude data of the limbs of this fold it is an overturned anticline.

(b) **Ziarat Anticline:**

It is a tight anticlinal fold of the region and is exposed in a 2 to 3 Km wide zone and has a lateral extension of about 10 Km (fig. 4.1). It is well exposed south of Ziarat village. It exposes the rocks of Panoba Shale and Kuldana Formation in its core (fig. 4.2). Towards its western termination its northern limb consist of steeply north dipping rocks of the Sheikhan, Kuldana, Kohat and Murree Formations. And its southern limb is occupied by the identical rocks to that of its northern limb except that these rocks steeply dip towards south. As we move eastward along the southern limb of this fold the rocks gradually change their dip from south to north and near its eastern closure of this fold, the rocks of its southern limb are moderately north dipping , overturned (fig. 4.3). So towards west it is an upright anticline whereas towards east it becomes overturned anticline.

The northern limb of this fold is marked by the Mir Khweli Sar fault 1 and its southern limb is demarcated by the Chichina fault 2 (fig. 4.1).

(c) **Sumari Payan Anticline:**

It is best exposed near the village of Sumari Payan and is oriented east-west, consisting the rocks of Panoba Shale in its core (fig. 4.1). It has a mapped width of about 4 Km and is extends for about 8 Kms in the E-W directions. Its northern flank is occupied by the moderate, north dipping rocks of the Kuldana, Kohat and Murree Formations. Its southern limb is occupied by the steeply, north dipping rocks

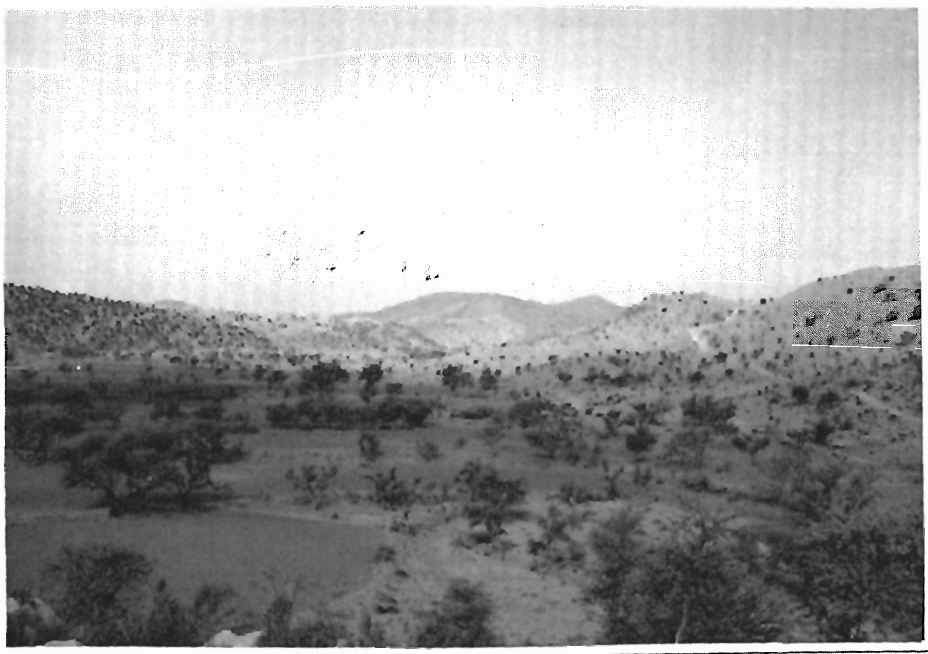


Fig. 4.2

Ziarat anticline showing Kuldana Formation in its core.

(Tkd = Kuldana Formation, Tko = Kohat Formation)

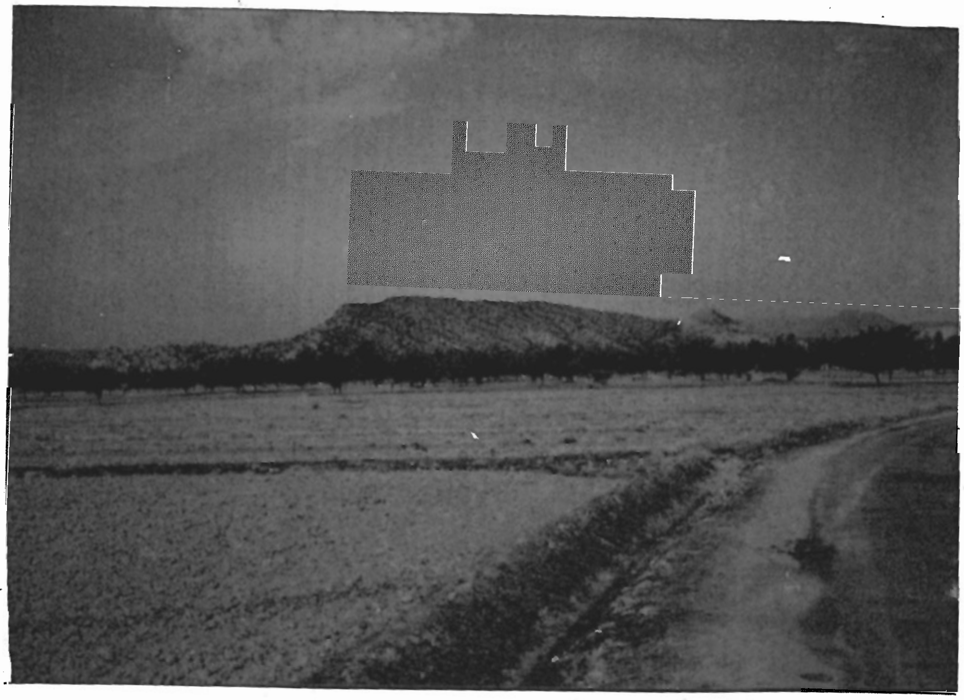


Fig. 4.3

The southern overturned limbs of the Ziarat anticline.

(Tko = Kohat Formation, Tm = Murree Formation) the Kuldana, Kohat and Murree Formations. The southern limb of this fold is overturned towards north, so is classified as an overturned anticline.

Its northern limb is truncated against the Chichina Fault 2 and its southern limb is truncated by Hindki fault (fig. 4.1).

(d) **Gadda Khel Anticline:**

It is well exposed west of Gadda Khel village and its axis oriented E-NE. Its core is mostly covered by Quaternary alluvium whereas its northern limb consists of moderately, north dipping rocks of Kuldana, Kohat and Murree Formations. Rocks of the southern limb of this anticline steeply dipping towards the south and consists of the same rock units as that of its northern limbs (Fig. 4.1). It has limited east-west map extension with width ranging upto 2 Kms.

(e) **Spina Anticline:**

Its axial trend is oriented ENE and is well exposed south of Gadda Khel Syncline (fig. 4.1). It exposes the rocks of Sheikhan and Kuldana Formation in its core. Its southern limb comprise the rocks of Kohat and Murree Formations which are steeply north dipping and is westward. Its northern limb is occupied by the same rock types and is gently north dipping. Thus this fold is overturned anticline.

4.3 **Synclinal Trends:**

The major synclinal folds of the region are as under from north to south.

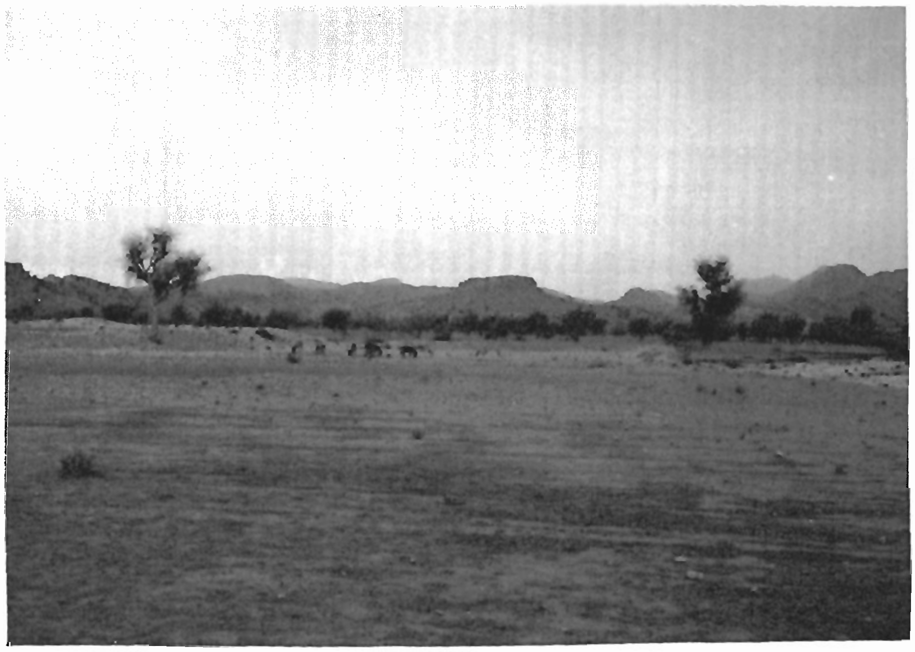


Fig. 4.4

Westward look into the tightly folded Mir Khweli Sar syncline.

(Tm = Murree Formation)

a- Mir Khweli Sar Synlcine

b- Chichina Syncline

c- Gadda Khel Syncline

(a) Mir Khweli Sar Syncline:

It is best exposed east of the rest house named Mir Khweli Sar and is oriented in latitudinal fashion i.e. east-west. It exposes the rocks of Murree Formation in its core. Its north limb is dipping and consist of the rocks of Kohat and Kuldana formations. The same rocks occupies its northern limb which is steeply north dipping (fig. 4.1 & 4.5). Both of its limbs i.e. northern and southern are truncated against Mir Khweli Sar fault 2 and 1 respectively.

(b) Chichina Syncline:

It is located south of Ziarat anticline (fig 4.1 & 4.6) having identical trend to it i.e. east-west core of this synclinal structure is occupied by Murree Formation (fig. 4.7). The outcrop attitude data along the limbs of this fold is an upright syncline with its northern limb steeply dipping towards south. Whereas its southern limbs moderately dips southward. However as we move eastward along its northern flank, the constituting rocks changes its dip from south towards north and becomes overturned, suggesting that towards its eastern termination it is an overturned syncline. Its southern limb is truncated against the Chichina fault 1 (fig.4.1).

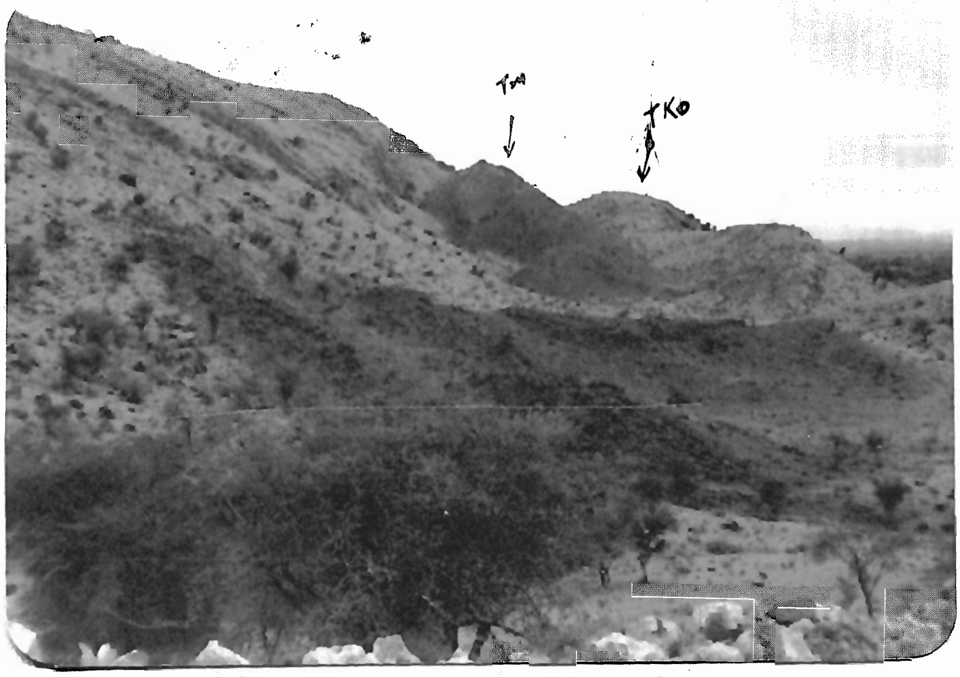


Fig. 4.5

Tightly folded Mir Khweli Sar syncline.

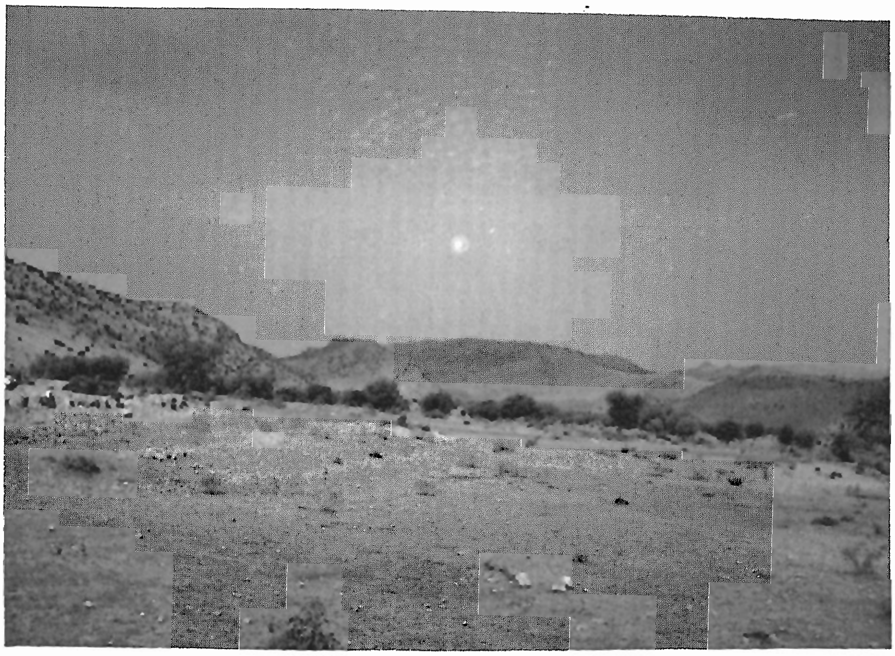


Fig. 4.6

A northward looking view of Chichina syncline.

Fig. 4.7 A view of the Chichina Syncline.

(c) Gadda Khel Syncline:

It is located south of Gadda Khel village and is oriented ENE (fig. 4.1). This fold exposes the rocks of Murree Formation in its core and is an upright syncline based on the attitude data along its limbs.

4.4 Fore Thrusts:

Several east-west folding fore thrusts were mapped during detailed fields traverses in the area which are as under from north to south.

a- Mir Khweli Sar Fault (1).

b- Chichina Fault (1).

c- Manduri Fault (1).

(a) Mir Khweli Sar Fault (1):

It is oriented east-west and steeply dips towards north. It occupies the southern limb of Mir Khweli Sar syncline and along it the rocks of the southern limb of this syncline are thrust over the Murree Formation the foot wall (fig. 4.1 & 4.8). The outcrop characteristics of this fault suggests that it is south verging fore thrust.

(b) Chichina Fault (1):

It is located north of Chichina village and is oriented east-west moderately dipping towards north (fig. 4.1). It occupies the southern limb of Chichina syncline and along this fault the rocks of

Fig. 4.8

Mir Khweli Sar fault along which Kuldana Formation is thrust over the Murree Formation in its core..

(Tkd =Kuldana Formation, Tko = Kohat Formation, Tm = Murree Formation)

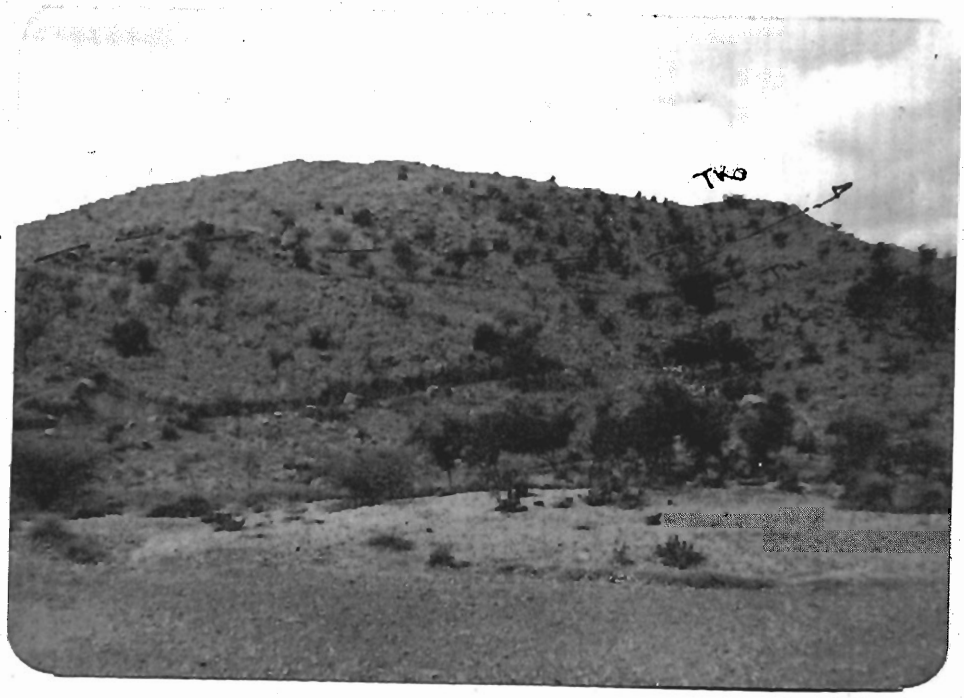
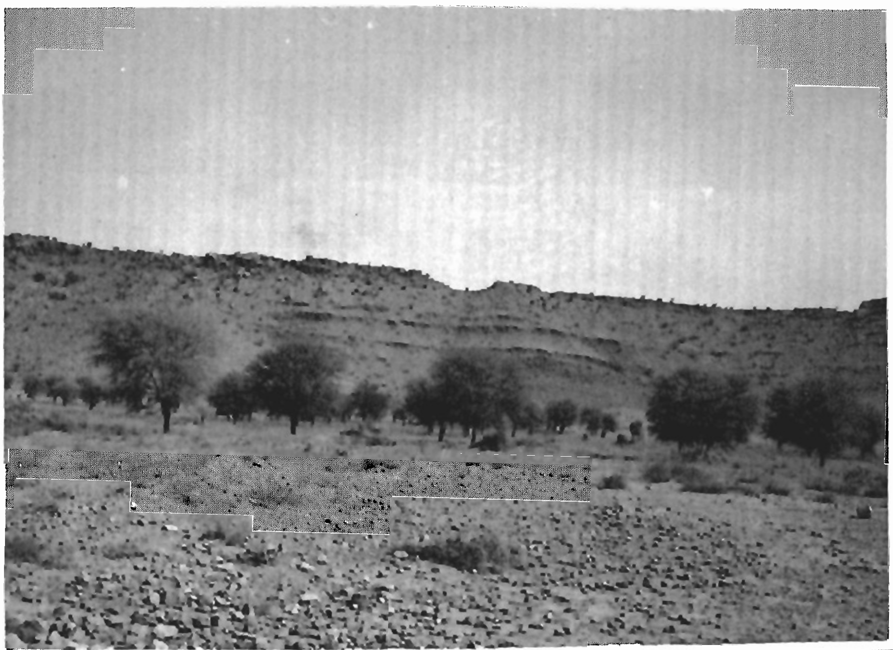


Fig. 4.9

North dipping, Chichina fault (1) along which Kuldana Formation(Tkd) is thrust over the Murree Formation (Tm) in the foot wall.

(Tko = Kohat Formation)



Kuldana Formation are thrust over the Murree Formation in its foot wall (fig. 4.9). The map trace of this fault is joined with Chichina fault (2) towards west.

(c) Manduri Fault (1):

It is oriented east-west and is moderately north dipping. Along this fault the rocks of Kohat Formation are thrust over the rocks of Murree Formation in its core. Its outcrop trace is folded westward and joins the Manduri fault (2). The outcrop data suggests that it is south verging fore thrust.

4.5 Back Thrust:

Based on attitude data along the outcrop trace, several north vergent back thrusts are mapped which are named as under.

a- Mir Khweli Sar Fault (2)

b- Chichina Fault (2)

c- Manduri Fault (2)

(a) Mir Khweli Sar Fault (2):

This fault is oriented east-west and is steeply south dipping. It occupies the northern limb of Mir Khweli Sar syncline and it brings the rocks of Kuldana Formation in its hanging wall, over the Murree Formation in its foot wall (fig. 4.10). The outcrop data suggests that it is a north vergent back thrust.

Fig. 4.10

South dipping Mir Khweli Sar fault (2) along which Kuldana Formation (Tkd) is thrust northward over the Murree Formation (Tm).

(Tko = Kohat Formation)

(b) Chichina Fault (2):

It is an east-west trending fault along which the rocks of Kuldana Formation is thrust over the Murree Formation in its foot wall. The attitude data along its trace suggests that it is steeply south dipping back thrust.

(c) Manduri Fault (2):

It steeply dips southward and can be classified as a back thrust based on its vergence. This fault is oriented east-west and it brings the rocks of Kohat Formation over the rocks of Murree Formation in its core.

4.6- Normal Fault:

A small scale normal fault is mapped north of Sumari Payan village which occupies the western closure of the Chichina syncline. It is oriented NE and along this fault the southern block is down faulted. It is the result of the collapse of the tectonically uplifted rocks of the region associated with thrust faulting and folding.

4.7- Overturned Thrust Fault:

An overturned thrust fault is mapped north of Hindki and is named as Hindki Fault. It is oriented east-west and its out crop data suggests that it is steeply north dipping and is being overturned (fig. 4.1).

Fig. 4.11-a	Shows the cross-sectional line along the line A-A′ of the fig. 4.1
Fig. 4.11-b	Shows the cross-sectional line along the line B-B′ of the fig. 4.1

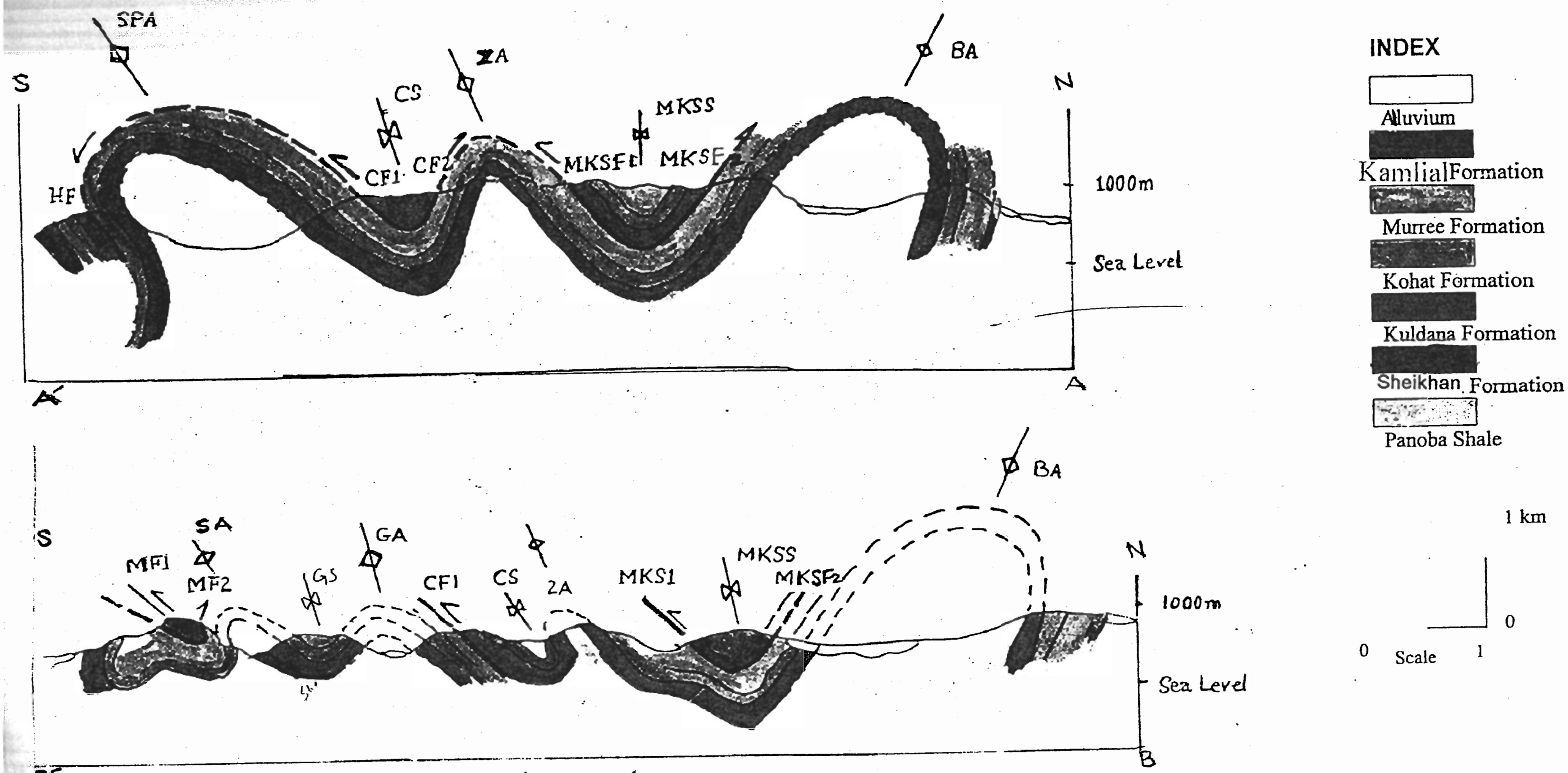


Fig. 4.11 Cross-sections along line A-Á and B-B´ of Fig. 4.1 BA = Buraka Anticline, MKSF1 = Mir Khweli Sar Fault 1, MKSF2 = Mir Khweli Sar Fault 2 , MKSS = Mir Khweli Sar Syncline, ZA = Ziarat Anticline CF1 = Chichina Fault 1, CHF2 = Chichina Fault 2, CS = Chichina Syncline MF2 = Manduri Fault 2, GA = Gadda Khel Anticline SPA = Sumari Payan Anticline, HF = Hindki Fault, MF1 = Manduri Fault 1 GS = Gadda Khel Syncline, SA = Spina Anticline.

CHAPTER NO. 5

SYNTHESIS OF STRUCTURAL GEOMETRY

The study area constitutes the south western most part of the Himalayan foreland-basin (fig. 1.1). The idea obtained from the present work and gathered from the previous Literature is all put together to construct the systematic development of structure in the project area.

The general strike of the entire study area is east-west with some minor deviation and dip towards north-south observed.

The hindward-paperward verging thrusts concentrated mainly in the central portion of the study area. The trend of these thrusts are east-west and dipping towards north-south.

The fold axes of the major folds recognized in the project area are orienting parallel to the regional strike.

5.1- Proposed Structural Model:

Two Geological cross-sections along A-Á and B-B́ of fig 4.1 have been constructed for the better understanding of the subsurface behavior of various Formations and to understand the Kinematics and relationship between the various folds and faults mapped during field investigations. Cross-section A-Á (fig. 4.11-a) is oriented N-S and is almost perpendicular to the direction of tectonic transport as inferred from the trends of the various structures developed in the area, whereas cross-section B-B́ (fig. 4.11-b) is slightly oblique to the direction of tectonic transport i.e. NNW. The folds and faults are interpolated and extrapolated based on the field data collected during the geological traverses. Both the geological cross-sections suggest that the dominant structures within the area is a series of south vergent, alternate anticlines and synclines. Besides these south verging folds, an opposite vergent fold structures i.e. Buraka anticline is also present. The folding incorporates a repeated sequences of Kuldana, Kohat and Murree Formations. In addition to the folding several south and north verging fore thrusts and back thrusts are present which are believed to be the remnant parts of an once united and quite extended thrust sheet as depicted on the cross-sectional area, which are exposed at various localities due to erosion and have different vergence due to folding.

5.2- <u>Kinematics</u>:

The mapped structural geometry suggests that the area has undergone several phases of deformation and is the result of compressional stresses which were oriented N-S as all the folds and faults trend in latitudinal fashion i.e. east-west.

Atleast three different phases of deformation can be inferred based on the different structural relationships. The earliest deformation to be responsible for the initial architecture of the area can be attributed to southward propagation of the rocks along the main boundary thrust which is located north of the study area. Initially a large overthrust sheet was formed having detachment horizon at the base of Kuldana Formation which is best glide horizon for the propagation of thrust faulting as it dominantly consist of shale. Thus thrusting resulted in the horizontal shortening and vertical thickening of the region as the stratigraphic sequence above Kuldana upto Murree Formation was doubled. This deformational phase was later on superimposed by a second phase of deformation which resulted in the folding of the entire stratigraphic horizon from Panoba at the base upto Murree Formation at the top, including the overthrust sheet as well. So it can be inferred that all the mapped faults are free folding phase and were later on synchronously folded with the folding of the autochthonous rocks sequences below. The rocks above the thrust sheet are believed to be allochthonous having a faulted relationship with the underlying autochthonous rocks.

A normal fault is mapped in the study area, NW of Sumari Payan village. This fault suggests the gravity collapse of the highly uplifted rocks associated with compressional deformation and it is believed to be the third phase of deformation which exhumed the uplifted rocks of the region. So it can be inferred that the studied area has undergone a D1, phase of faulting followed by D2 phase of folding and finally D3 phase of gravity collapse. Furthermore the role of shale diapirism can not be neglected in the study area, as the basal horizon of the Eocene succession i.e. Panoba shale is mainly shale which can behave in ductile manner. The role of diapirism could be responsible for the presence of north verging i.e. an opposite verging folds in the region.

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CHAPTER

NO. 6

CONCLUSIONS

As a result of present investigation, the following conclusions are drawn regarding the geology and structural setting of the area south west of Kohat Hill Range.

1- Six lithostratigraphic units have been established to the study area ranging in age from Eocene to Miocene. These units are listed below in order of superposition.

(A) Kamlial Formation (B) Murree Formation	Miocene Succession

.... Unconformity ....

(A) Kohat Formation (B) Kuldana Formation (C) Sheikhan Formation (D) Panoba Formation	Eocene Succession

Found the Kamlial Formation (Miocene) and Sheikhan Formation (Eocene) in the study area. These Formations have not been shown in the map of the same area by Meissner et al. 1974.

2- The general trend of the major structures (fault traces & fold axes) in the area is East-West, while the tectonic transport direction observed from North to South.

3- The structural geometry is represented by east-west trending, tight anticlinal and synclinal folds and thrust faults having north and south vergence.

4- Three distinct phases of deformation i.e. D1, D2 and D3 are recognized. The D1 phase is responsible for the development of an early thrust sheet having a basal decollement recognized within the Kuldana Formation. The D2 phase resulted in the folding of the autochthonous rocks underlying the thrust sheet and the thrust sheet itself. The D3 phase resulted in the gravity collapse of the structurally elevated rocks.

5- The orientation of the mapped structures suggest that both the compressional phases of deformation i.e. D1 and D2 have experienced a north- south compressional stresses.

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