STRUCTURE AND STRATIGRAPHY OF A PART OF KOHAT BASIN BETWEEN LACHI AND BANDA DAUD SHAH, N.W.F.P.

BY

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In the Name of
" ALLAH "

The Most Beneficient,
The Most Merciful.

DEDICATED TO MY BELOVED AND DEAR PARENTS

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AMJAD ALI KHAN
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ABSTRACT

The detailed mapping of the study area have resulted in establishing nine lithostratigraphic units which range in age from Eocene to Pliocene. These units fall within three groups which are from bottom to top as Chharat, Rawalpindi and Siwalik Groups. The Chharat group is represented by five formations in the area including Panoba shale at the base, overlain by Jatta Gypsum alongwith its lateral equivalent Sheikhan Limestone, Kuldana and Kohat Formations.

The Chharat group is unconformably overlain by the Murree and Kamlial Formations of the Rawalpindi group. The representative units of the Siwalik group in the area are Chinji and Nagri Formations.

The structural geometry of the area comprise large scale, east-west trending folds and thrust faults. The fold structures include narrow anticlines and anticlinoria mostly cored by thrust faults. The synclinal folds are open, with both their mbs overturned and reflect fan-geometry.

The faults include fore and back thrusts. The back thrusts are mostly overturned at their surface exposures and have changed their vergence from north to south.

The proposed structural model based on surface and subsurface seismic data shows a series of large scale hinterland dipping listric thrust faults emerging from the basal decollement. All these faults are steeply dipping at surface and becomes gentle with depth. Other prominent features are associated pop-ups and triangle zones which are the result of north verging splays from the listric thrust faults. The presence of triangle zones bounded by thrust faults of opposing vergence have resulted in the tectonic overprinting and delamination of different horizons at various levels. All the above mentioned features are characteristics of the foreland fold and thrust belts in different parts of the world.

The basal detachment is located at the base of Salt Range Formation at a depth of around 8 km and 8.4 km in the southern and northern parts of the study area respectively. The restored version of the deformed state cross-section shows about 19.5 km shortening for the mapped area with maximum structural relief of about 4000 meters above the regional level.

CHAPTER-1

INTRODUCTION

1.1: GENERAL DESCRIPTION

The study area is a part of Kohat quadrangle and lies within the survey of Pakistan topographic sheet No.38 0/3 (Fig. 1.1).The area covered in the map (Fig.1.2) is about 586 square Kilometers and restricted between the longitudes 71-00 , 71-15 East and latitudes 33-17 N, 33-31 North. The mapping has been carried out on a scale of 1:50,000.

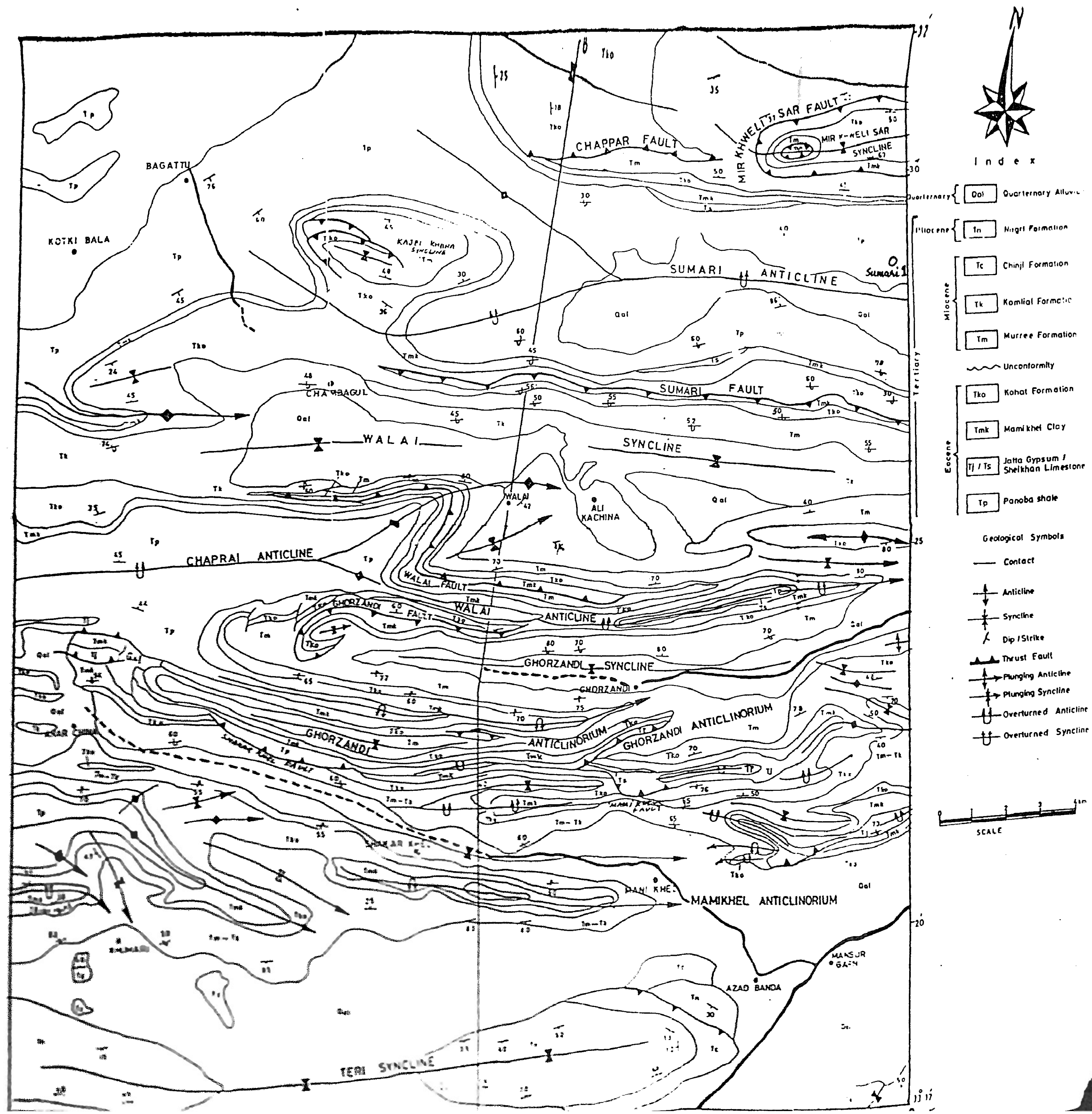
The area where present work is carried out is easily accessible from the Bannu-Kohat road, which run all along its eastern periphery. Several metalled and unmetalled side roads run east-west in the area which provide excellent sectional views. Besides side roads many stream courses and paths connecting 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.

The relief of the area is moderate with alternate valleys and ridges. The ridges have been formed by resistant limestone and sandstone beds whereas the valleys are the result of deep cuts by erosion of shale/clay of various units in the area.

Fig. 1.1 **Index map of Pakistan. The black square "A" shows location of the study area.**

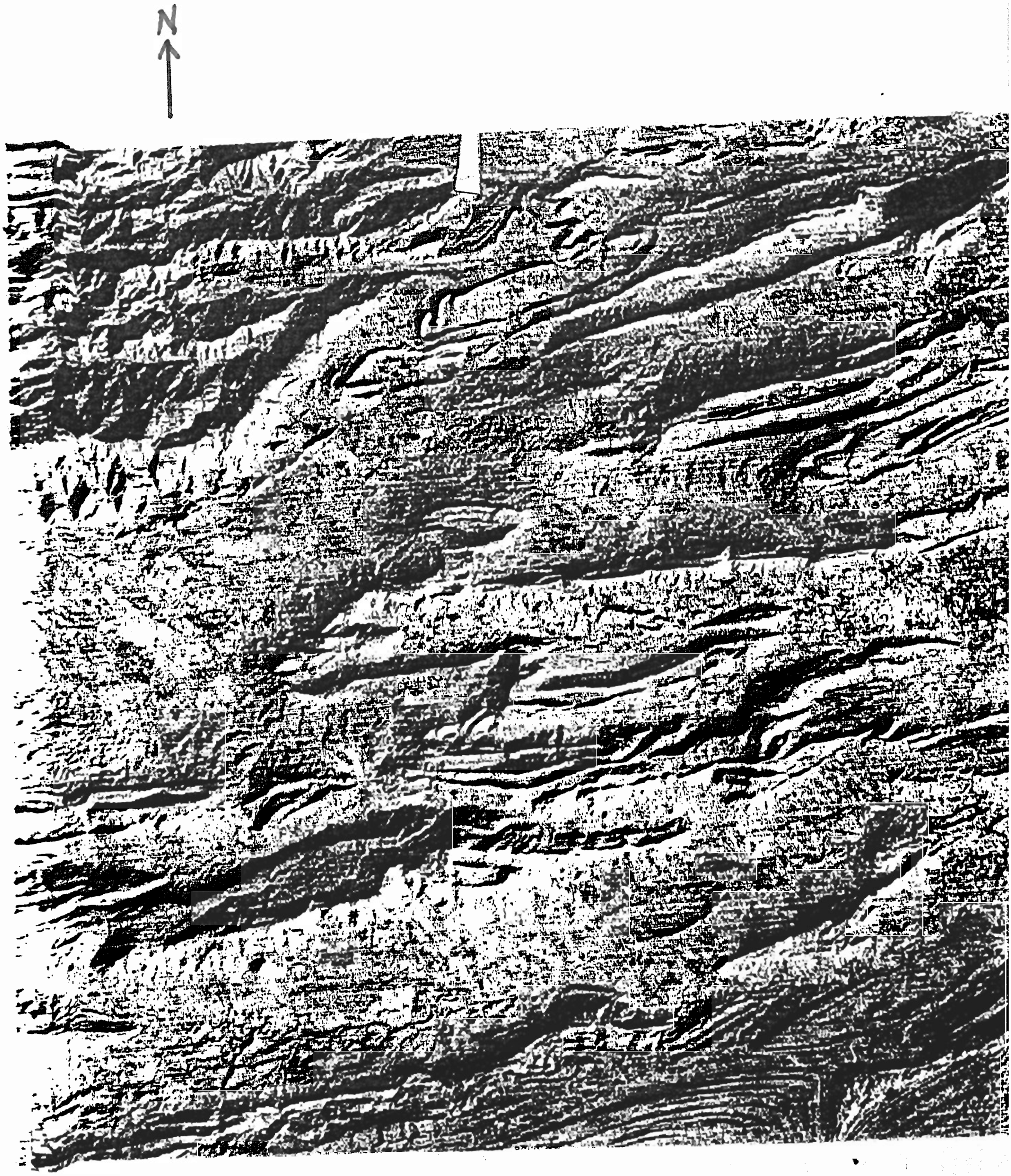

USSR
CHINA
Gilgit
Peshawar
KASHMIR
Kohat
Islamabad
AFGHANISTAN
A
Lahore
Quetta
Indus River
INDIA
IRAN
Karachi
400 km
74°
76°
72°
36°
70°
34°
68°
32°
62°
64°
66°
30°
28°
26°
24°

Fig. 1.2 Geological map of the study area.



N
Index
Quaternary
Qal Quaternary Alluvium
Pliocene
Tn Nagri Formation
Miocene
Tc Chinji Formation
Tk Kamlial Formation
Tm Murree Formation
Unconformity
Tertiary
Eocene
Tko Kohat Formation
Tmk Mamikhel Clay
Tj / Ts Jatta Gypsum / Shekhan Limestone
Tp Panoba shale
Geological Symbols
Contact
Anticline
Syncline
Dip / Strike
Thrust Fault
Plunging Anticline
Plunging Syncline
Overturned Anticline
Overturned Syncline
SCALE
MIR KHWELI SAR FAULT
MIR KHWELI SAR SYNCLINE
CHAPPAR FAULT
BAGATTU
KOTKI BALA
KAJRI KHAHA SYNCLINE
SUMARI ANTICLINE
Sumari 1
SUMARI FAULT
CHAMBAGUL
WALAI
SYNCLINE
ALI KACHINA
CHAPRAI ANTICLINE
WALAI FAULT
WALAI ANTICLINE
GHORZANDI FAULT
GHORZANDI SYNCLINE
GHORZANDI
GHORZANDI ANTICLINORIUM
MAMIKHEL FAULT
MAMIKHEL ANTICLINORIUM
MANSUR GARH
AZAD BANDA
TERI SYNCLINE

Fig. 1.2(a) **Part of the Kohat Plateau comprising study area as seen on satellite imagery.**


N

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.3.2). 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 (Seebar 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 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 stratigraphic units of the area fall within the following three major groups :

1) Siwalik Group - Pliocene

2) Rawalpindi Group - Miocene

3) Chharat Group - Eocene

The Chharat Group is represented by the marine clay and sandstone of Kuldana Formation and the massive limestone of Kohat Formation. The Chharat Group has at its base the Panoba shale of Early Eocene age in the area. The Rawalpindi Group is represented by the Murree and Kamlial formations of Miocene age. The Kamlial Formation is overlain by Chinji Formation of Siwalik Group. The formation is dominantly composed of sandstone, clay and siltstone of grey to brownish grey colour.

The structure of the area is greatly influenced by the regional tectonics which is dominated by large scale thrusting and right lateral and left lateral strike-slip movements. The general trend of the major structures like thrust faults and large scale folds is east-west. Correlation of surface structural style with the sub-surface seismic data indicates that the area is represented by listric fore thrusts and back thrusts having gentle dips near the surface and become steeper with depth resulting in the formation of pop-ups and triangular structures.

1.2: 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. Finfold (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) has produced an excellent piece of work by establishing the lithostratigraphic units of the Kohat region. The first systematic geological mapping of the Kohat Plateau was carried out on 1:250,000 scale by Meissner et al. (1974) with the help of aerial photographs. This work included the stratigraphy, description of rock types and structure 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 Adem Khel and adjoining areas outlining the stratigraphy and facies changes. Ghauri et al. (1983)

have mapped the southern part of the Kotal pass and divided the area into different structural domains. Wells (1984) carried out detailed sedimentalogical studies on the Early ocean sediments of Kohat basin. McDougal (1985 and 1989) described the structural features related to the Kalabagh lateral ramp structure.

1.3: EXPLORATION ACTIVITIES IN THE REGION

Petroleum interest in the area was first stimulated by the oil seeps around the edges of the Salt Range and Bannu Trough. One of the first exploration wells in the world was drilled in 1866 by the Punjab Government near the Kundal oil seep and further attempts at providing a commercial resource were made sporadically, but without any notable success, during colonial times at Kundal (early 1900's, Punjab Government), Jaba (1905, Townsends), Dalwati-1 and 2 (1927-1932), and Babai (1932, Indo Burma Petroleum Company).

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 licenced a large area located over the Kohat Plateau and undertook an extensive investigatory campaign, 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).

PPL have had a long involvement in the area from the drilling of Domanda-1 in 1959 on a large Eocene anticline in the northern Sulaiman Ranges, continuing through the 1960s with wells in the Bannu/Tank area at Kundian (1965), Pezu (1968), and Marwat (1970), and culminating with the Kundi well in 1995. The only 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.

Thus, although activity has occurred over a period of 100 years, the Bannu/Tank area has been only lightly explored and there has been no systematic invetigatory campaign. Most participants have drilled one or two wells and then retired from the area, which has then remained unlicenced for long periods. Hydrocarbon occurrences abound and structures are evident, but the potential of the area has remained elusive.

1.4: PURPOSE OF 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. In the regional tectonic frame work, this area plays a pivotal role because the major faults of the region either pass through the area or lie in its close vicinity. Having thoroughly examined and reviewed the geological work done so far, the author is of the opinion that the study area needs further investigations 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.

The following are the main objectives of the present geological work:

1) To carryout 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 interpret and understand the structural configuration, evolution of structures and their sequential development; estimate shortening and establish a consolidated structural model of the area.

CHAPTER-2

STRATIGRAPHY

2.1: STRATIGRAPHY OF THE KOHAT AREA

Exposed rocks in the area under study ranging in age from Eocene to Pliocene. Sumari-1 well drilled in the first quarter of 1993 by AMOCO in the north eastern portion of the area represents the deepest penetration of the stratigraphic sequence of the region (Table-1). A composite stratigraphic correlation (Table-2) based on the wells drilled in the Kohat Plateau and adjacent areas shows thickness and facies 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:

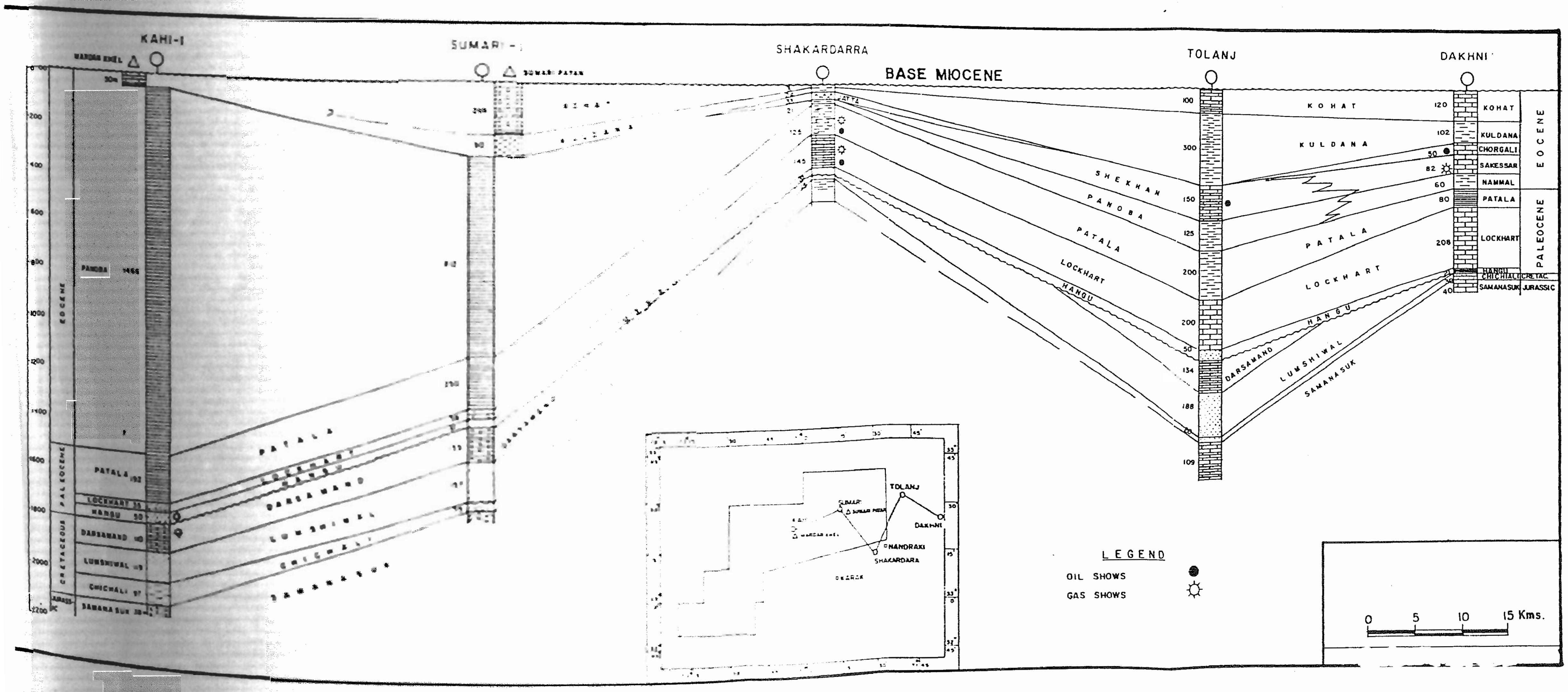
2.2: JURASSIC SUCCESSION

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 traces of micro stylolites with argillaceous/bituminous infilling. The base of the SamanaSuk Formation was not reached and the well was abandoned at a total depth of 1466 M.

SYSTEM	AGE	FORMATION: GROUP	FORMATION	LITHOLOGY	THICKNESS IN STUDY AREA (METERS)
PLEISTOCENE AND PLIOCENE		SIWALIK	NAGRI FORMATION		3000-3500
MIOCENE	LATE	SIWALIK	CHINGI FORMATION		900
MIOCENE	MIDDLE	RAWALPINDI	KAMLIAL FORMATION		526
MIOCENE	EARLY	RAWALPINDI	MURREE FORMATION		9-120
EOCENE	MIDDLE		KOHAT FORMATION		100
EOCENE	EARLY		KULDANA FORMATION		50-60
EOCENE	EARLY		JATTA GYPSUM / SHEIKHAN LIMESTONE		45 / 65
EOCENE	EARLY		PANOBA SHALE		622
PALEOCENE	LATE		PATALA FORMATION		443
PALEOCENE	EARLY		HANGU FORMATION		41
CRETACOUS	LATE		DARSAMAND LIMESTONE		132
CRETACOUS	LATE		LUMSHIWAL FORMATION		157
CRETACOUS / JURASSIC	LATE / MIDDLE		CHICHALI FORMATION		81
JURASSIC	MIDDLE		SAMANASUK FORMATION		33+

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

Table 2 Composite stratigraphic correlation of the Kohat Plateau.


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

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 grey to brownish grey in colour, glauconitic with common pyrite crystals. Traces of carbonaceous materials were noted in the well cuttings. Claystone is poorly indurated, soft and crumbly. Siltstone and sandstone are gray-green to greenish 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 belongs to 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 consisting of light to medium gray, very five to course-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 quartzone sandstone. Sandstone 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. Laminations are present but are typically highly bioturbated. 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 coloured microcrystalline. It is slightly dolomitic and partially argillaceous. 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 siltstone is dark grey in colour. It is blocky, hard, brittle and very calcareous.

The shale is greenish grey to bluish grey in colour. There are visible slickenside striations showing displacement along fault planes. It is moderately calcareous and grading to claystone. The total thickness is about 133 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 non-deposition 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 subaugular to rounded quartz grains. Cementation is dominantly siliceous, but locally slightly calcareous. Pores contain interstitial white clay matrix. The Hangu Formation displays an overall fining-upward textural profile. It represents near shore to shallow marine environments and was deposited during a major regional transgression (Sumari Well Completion Report 1993). Towards the base the well cuttings samples suggest higher porosities with abundant loose sand grains. It recorded a total thickness of about 41 meters.

2) **Patala Formation**

At Sumari well No.1, drilling started in the Eocene Panoba Shale and the same fotmation continued down to 622 meters. At this depth the Patala Formation was encountered and it was confirmed by analysing the samples (Amoco report 1993). 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 cemented siltstone and calcareous mudstone.

Traces of vein calcite occur in microfractures and random benthic forams are present. Shales contain abundant block 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 443 meters.

2.5: EOCENE SUCCESSION

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

1) **Panoba Shale**
2) **Sheikhan Limestone**
3) **Jatta Gypsum**
4) **Kuldana Formation**
5) **Kohat Formation**

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

Fig. 2.1 Olive-green outcrop of the Panoba shale located south-west of Boraka Village.

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 colloidal limonite, which is dispersed throughout the soft shale giving it a rusty colouration which marks its original green colour (PPL report, 1986),(Fig. 2.1). 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 thick at the Panoba section proper. It recorded a thickness of 622 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 foraminifers 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) Sheikhan Limestone

The term "Sheikhan Limestone" of Davies (1926) has been formalized by the Stratigraphic Committee of Pakistan as Sheikhan Formation to represent the "Gypsiferous 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 to 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 area proper, 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 Foraminifers which include Alveolina oblonga, Assilina daviesi, A.laminosa, Nummulites atacicus and orbitolites complanatus. Besides these foraminifers, corals, mulluscus 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) Jatta Gypsum

Jatta Gypsum is exposed in few localities in the southern part of the area under study. It seems to be the lateral facies of the Panoba Shale and Shekhan Limestone (Meissner et al., 1974). Jatta Gypsum was previously considered as part of the Bahader Khel Salt and was included in "Kohat Saline Series" of Gee (1945). It was renamed as Jatta Gypsum and believed to be the upper part of the "Kohat Saline Series" from exposures in Jatta Ismail Khel gypsum quarries (Meissner et al., 1974). The formation predominantly consists of gypsum with interbeds of gypsiferous shale and bentonitic clay. The gypsum is white, greenish white to grey in colour. It is massive to thick bedded. Grey and white bands with rugged and sharp edges are the characteristic feature of the outcrops of this formation. In some parts, gypsum is dark grey to black due to the hydrocarbon coating on the fractured surfaces giving distinct petroliferous odour. The clay is greenish grey to bluish green in colour and is plastic and greasy in nature. An average approximate thickness of 45 meters is estimated in the area. A number of small scale asymmetrical folds of various shapes and sizes have developed in the gypsum beds due to the tectonic activities in the area.

In the study area, the lower contact of the Jatta Gypsum is not exposed whereas its upper contact with the Kuldana Formation is conformable.

No fossils have been reported from Jatta Gypsum, however it conformable contacts with the Eocene formation above and below indicate an early Eocene age (Meissner et al., 1974).

4) Kuldana Formation (Mami Khel clay)

The formation was named as "Kuldana beds" by Wynne(1874)., the "Kuldan 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. 2.2). It forms conspicuous red coloured gullies because of being soft as compared to the Kohat Formation and other formations 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

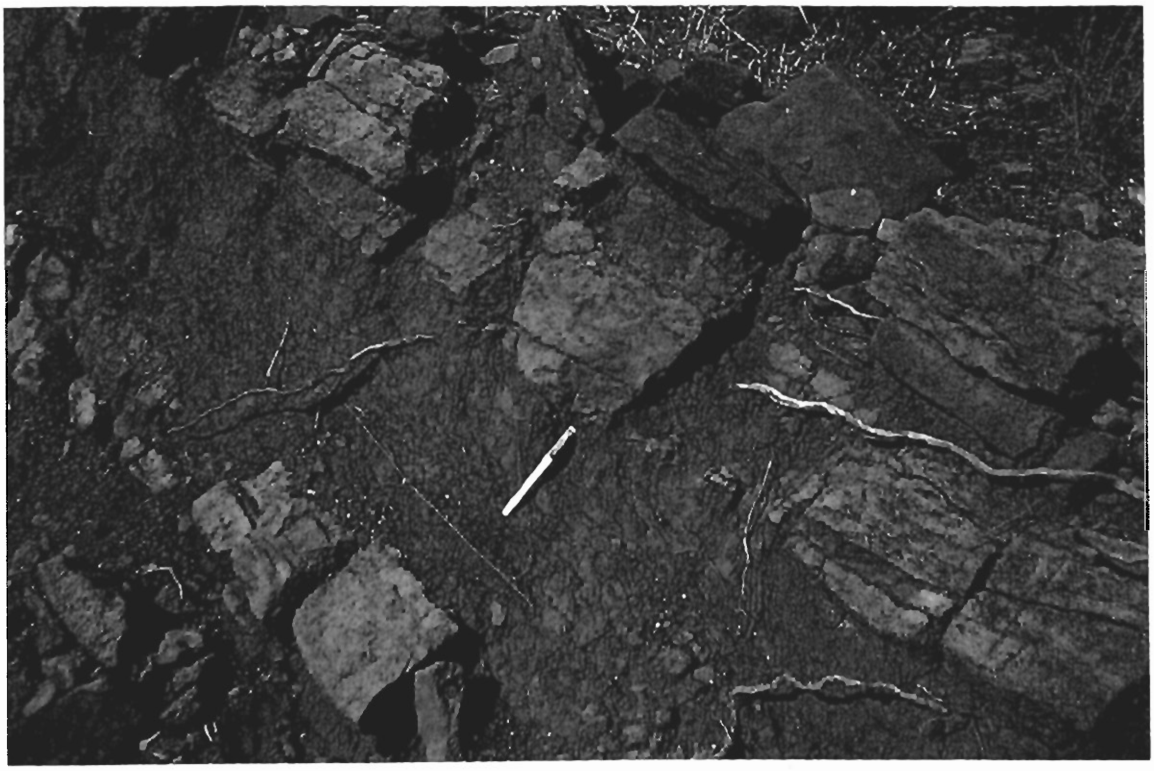


Fig. 2.2 An outcrop of Kuldana Formation showing interbedded sandstone and clay.

Formation has a continental 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), Dehm et al.(1958), Latif(1970) and Meissner et al. (1974) have reported foraminifers, gastropods, bivalves and some vertebrate fossils from different parts of the formation. These fossils indicate early to Middle Eocene age.

5) 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 the 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 abut 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 foraminifers and various species of Nummlites.

2.6: MIOCENE SUCCESSION (Molasse Sedimentation)

Molasse sedimentation in 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**

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.

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 Shakardara area (Abbassi, 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 syntaxis (Bossart and Ottigar, 1989) whereas 28-18 Ma old and of fluvial origin in the Kohat-Potwar Plateaux (Shah, 1977).

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

Muree Formation unconformably overlies the Kohat Formation whereas its upper contact with the Kamlial Formation is transitional.

2) **Kamlial Formation**

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

At Banda Daud Shah, the Kamlial Formation 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.

II. Siwalik Group

The name Siwalik was first used by Meddlicott(1864) from the Siwalik Hills of India. Pilgrim (1913) proposed a three fold division of the Siwalik System, which included the Lower Siwalik (Kamlial and Chinji zone), Middle Siwalik (Nagri and Dhok Pathan Zone) and Upper Siwalik (Tatrot, Pinjor and Boulder Conglomerate Zone). Cotter(1933) suggested that the Kamlial Stage should be grouped with the Murree Formation as the boundary between the two units is quite arbitrary, which was accepted by the Stratigraphic Committee of Pakistan. Ultimately, the Stratigraphic Committee of Pakistan substituted the "Siwalik Group" for the "Siwalik System" comprising the following formations:

4) **Soan Formation**

3) **Dhok Pathan Formation**

2) **Nagri Formation**

1) **Chinji Formation**

The Siwalik Group represents a coarsening upward mollase sequence in the Indo-Pakistan sub-continent and has a thickness of several thousands meters. The group has yielded rich vertebrate fauna (Pilgrim, 1913; Pascoe, 1963), which indicates Middle Miocene to Early Pleistocene age.

In the study area, however, only the Chinji and Nagri Formations are exposed in the extreme south.

1) Chinji Formation

Lewis (1937) used the name "Chinji Formation" for the "Chinji Stage" of Pilgrim (1913) which was accepted by the Stratigraphic Committee of Pakistan (Shah,1977). In the study area, the Chinji Formation is exposed only in the south near Banda Daud Shah in the form of patches. It is mostly covered by the alluvium. The formation is about 900 meters thick at Banda Daud Shah (Meissner at al,. 1974). The formation is mainly composed of sandstone interbedded with clay and siltstone. Thin lenses of intraformational conglomerates are also present. The sandstone is grey to brownish grey, soft, cross-bedded and medium grained. The silty clay is brown-red to greenish red and nodular in character. The siltstone is brownish grey and is interbedded with laminated silt and clay. A number of small scale tight folds of different shapes and sizes have developed in the Chinji Formation during thrusting and folding. The formation overlies the Kamlial Formation conformably with a sharp contact. The upper contact with the overlying Nagri Formation is also distinct and conformable. The Chinji Formation is rich in vertebrate fossils(Pascoe, 1963), indicating a Middle Miocene age.

2) Nagri Formation

Lewis (1937) renamed Nagri Stage of Pilgrim (1913) as Nagri Formation which was approved by the stratigraphic Committee of Pakistan (Shah, 1977. The formation is mainly composed of sandstone interbedded with clay. Intraformational conglomerate beds are also found at different horizons. The sandstone is greenish grey, medium to coarse-grained, cross-laminated, massive to thick bedded and well jointed. At weathered surfaces it is grey to greenish grey, and occasionally gives the appearance of old lichen-covered brick wall from a distance. At places spheroidal type of weathering has also been observed. The clay is silty, chocolate-brown or reddish brown in colour and contains occasional siltstone interbeds. At Totaki section, the Nagri Formation is 4225 meters thick (Meissner et al., 1974) which is enormous as compared to the other sections.

The formation lies conformably over Chinji Formation and is overlain transitionally by Dhok Pathan Formation. The formation has yielded fairly rich assemblage of vertebrate remains as recorded by Pilgrim (1913), Anderson (1928), Colbert (1933) and Lewis (1937). The fauna indicates Early Pliocene age of the formation.

CHAPTER-3

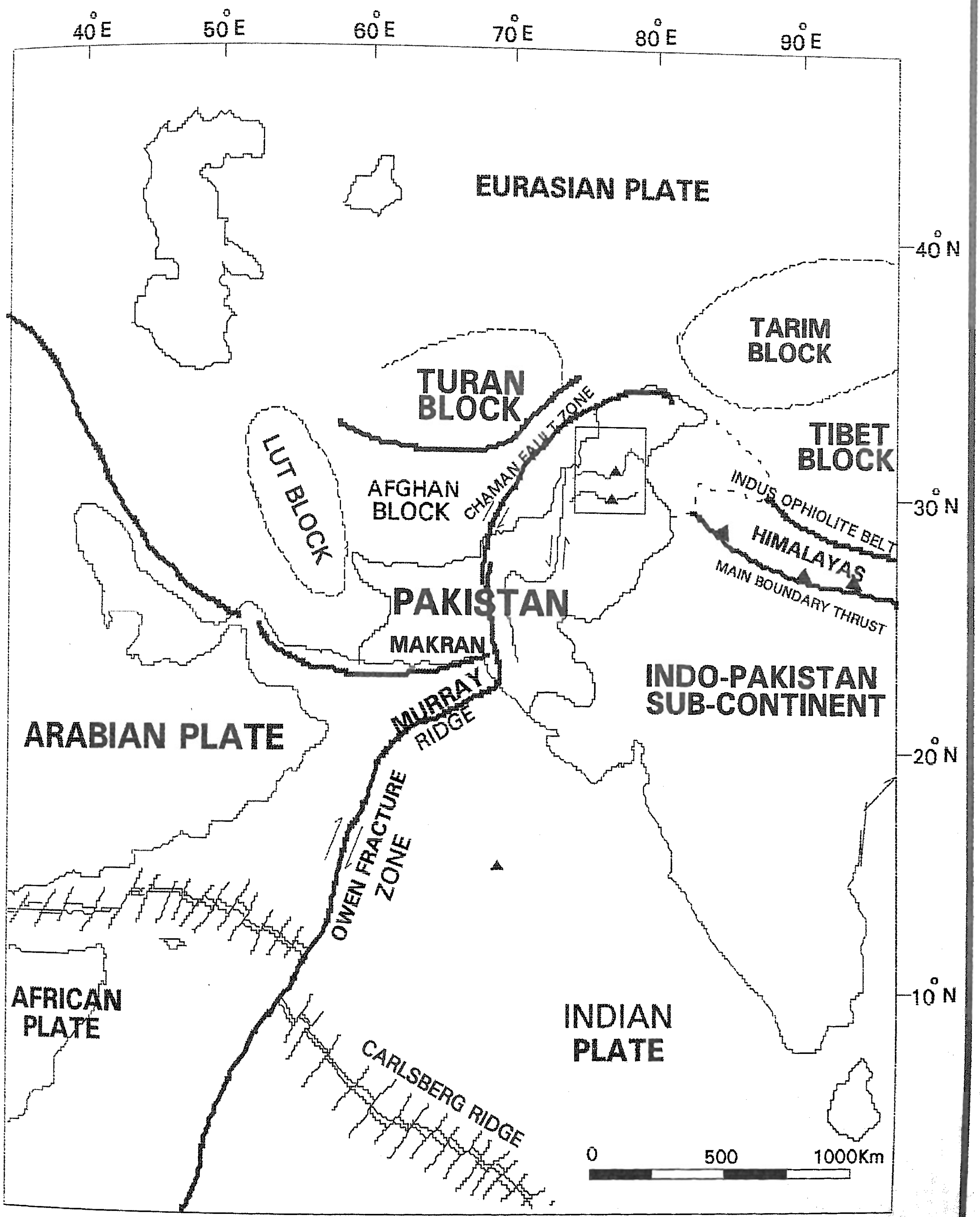
REGIONAL TECTONIC SETTING AND STRUCTURAL GEOMETRY

3.1: REGIONAL TECTONIC SETTING

The Himalaya-Karakoram-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 Karakoram plate, Afghanistan block and the Kohistan island arc developed to the north of the Indian continent during the Mesozoic Era. The first block to collide with southern margin of the Eurasian plate was Karakoram 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 subducion in Late Cretaceous to Late Jurassic time (Petterson and Windley, 1985).

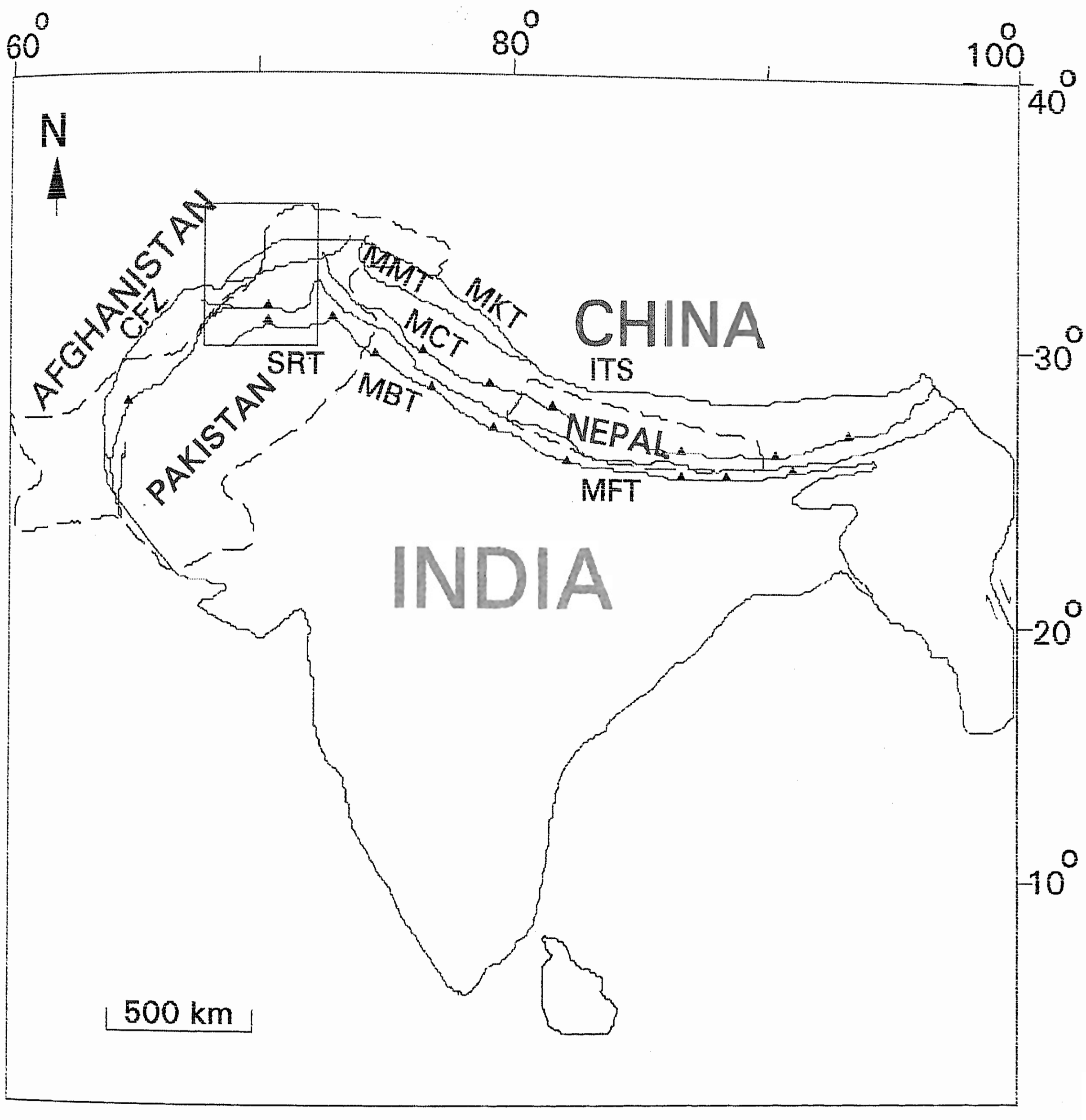
The Kohistan Island arc (Fig.3.2) is bounded to the north by Main Karakoram Thrust (MKT) and to the south by the Main Mantle Thrust(MMT).

The Main Karakoram Thrust (MKT) which is a major tectonic feature in northern Pakistan has been formed as a result of collision between the Karakoram plate in the



Regional Setting

Fig. 3.1 Generalised tectonic map of the Himalayan orogenic belt (After Peter Blisniuk,1994). Inset shows area of Figure 3.2


60°
80°
100°
40°
30°
20°
10°
N
AFGHANISTAN
CFZ
SRT
PAKISTAN
MMT
MKT
MCT
MBT
CHINA
ITS
NEPAL
MFT
INDIA
500 km

north and Kohistan island arc in the south (Tahirkheli, 1979; 1982; 1983). It was named as Northern Suture by Pudsey et al.(1985). According to Coward et al.(1986), it was formed during Late Cretaceous. The Main Mantle Thrust (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; Gansser, 1981).In India and Tibet, the MMT and MKT join together as the Indus-Tsangpo Suture (ITS) of the central Himalaya (Fig.3.1).

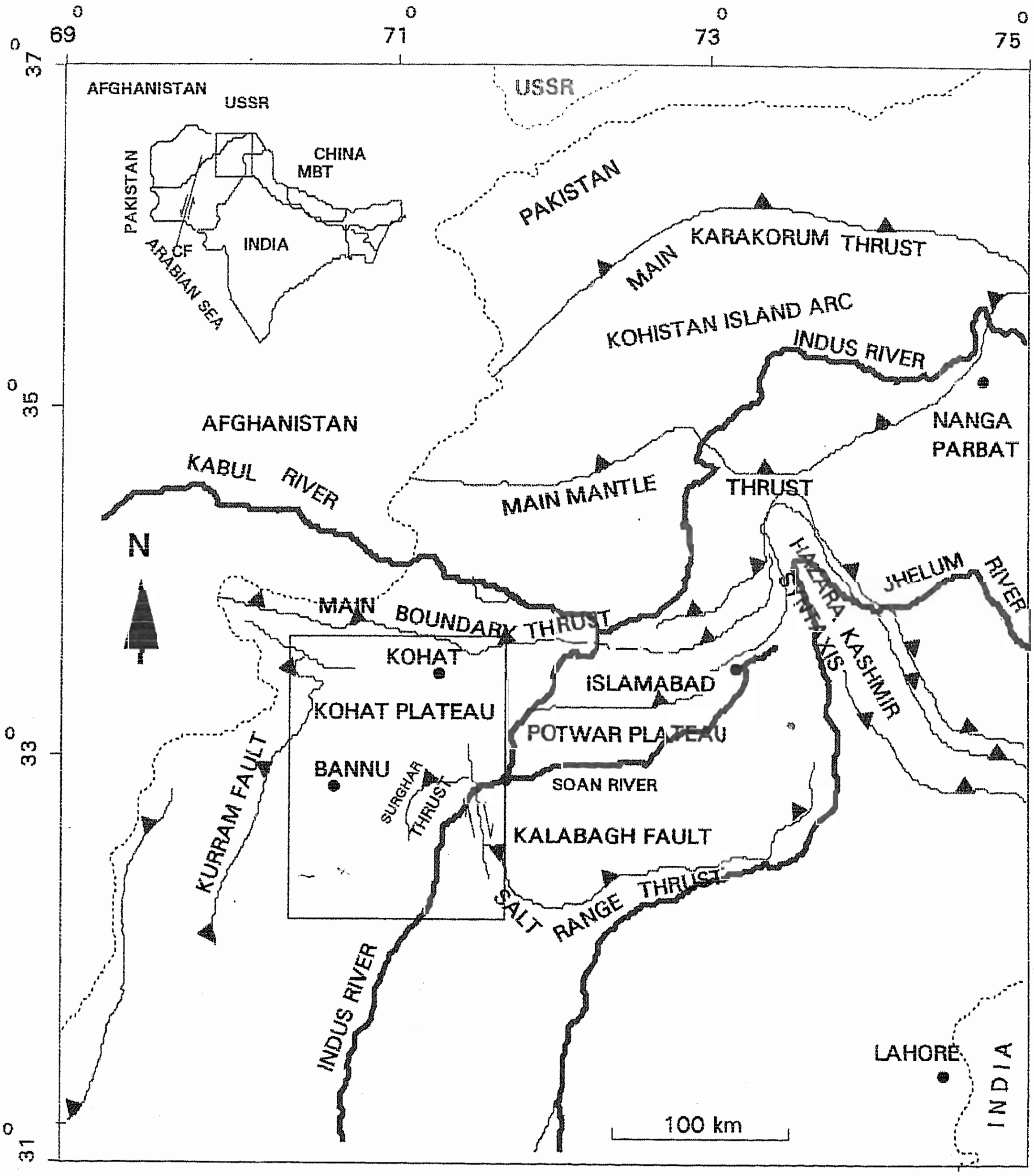
The Karakorum plate to the north of MKT is composed of high grade metamorphic rocks with granitic intrusions (Searle, 1991). To the south of MKT lies the metamorphic basic and ultra basic rocks of the Kohistan Island Arc (Bard et al. 1980; Bard, 1983).

The ocean between the Karakorum 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 arc and the Indian plate produced an extensive intrusive body called Kohistan batholith. The ocean between the Indian plate and the 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.3.1).

The convergence which resulted in continent-arc- continent collision (KaraKorum-Kohistan-India), however, did not cease with the 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 the MMT and is about 300 km wide (Fig.3.1). As a result of this gradual southward propagation of deformation, a system of south younging faults has developed. The major members of this fault system are the Main Boundary Thrust (MBT) and the Salt Range Thrust (SRT) (Zeithler et al. 1982; Zeithler, 1985; Yeats and Hussain, 1987).

The Salt Range Thrust (SRT) in the south western part of the Pakistani Himalaya is the lateral equivalent of the Main Frontal Thrust (MFT) of the central Himalaya (Fig 3.1). In the central Himalaya the foreland fold and thrust belt is internally sub-divided by two major north dipping thrust faults 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 a major bend known as the Hazara Kashmir Syntaxis (Fig.3.2). The Panjal and Nathiagali faults mark the western limit for the Hazara Kashmir syntaxis.

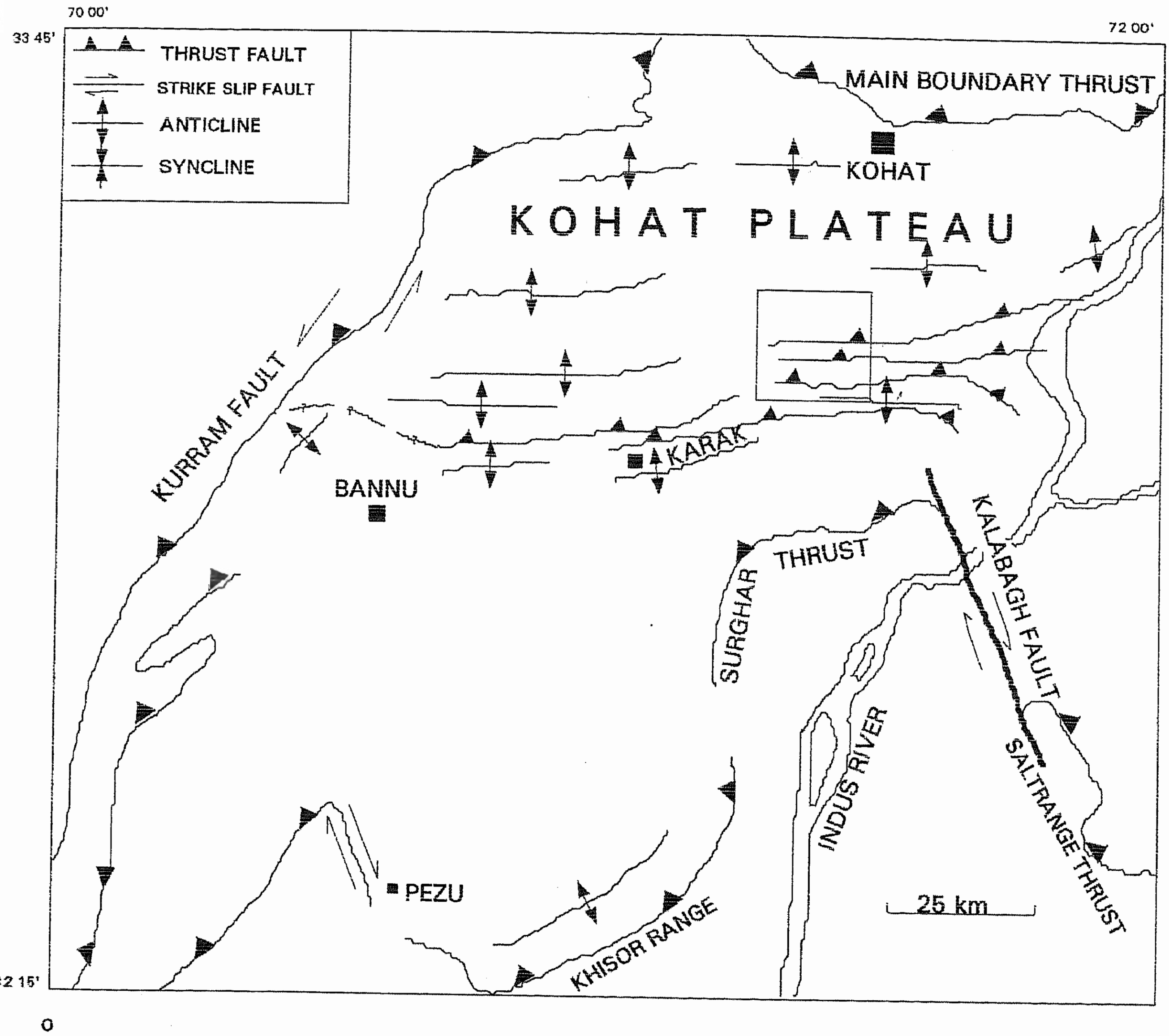
Fig. 3.2 Regional sketch map showing major tectonomorphic terrains (After Kazmi & Rana 1982). Inset shows area of Figure 3.3.


69°
71°
73°
75°
37°
35°
33°
31°
AFGHANISTAN
USSR
CHINA
MBT
PAKISTAN
INDIA
CF
ARABIAN SEA
USSR
PAKISTAN
MAIN KARAKORUM THRUST
KOHISTAN ISLAND ARC
INDUS RIVER
NANGA PARBAT
AFGHANISTAN
KABUL RIVER
MAIN MANTLE
THRUST
N
HAZARA KASHMIR SYNTAXIS
JHELUM RIVER
MAIN BOUNDARY THRUST
KOHAT
ISLAMABAD
KOHAT PLATEAU
POTWAR PLATEAU
BANNU
SURGHAR THRUST
SOAN RIVER
KURRAM FAULT
KALABAGH FAULT
SALT RANGE THRUST
INDUS RIVER
LAHORE
INDIA
100 km

The Kohat-Potwar fold and thrust belt is the western deformed terrain of the Himalayan foreland basin. This foreland basin can be 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. 3.2). The Potwar plateau 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 the Harara/Kalachitta Ranges (Fig. 3.2). 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 Himalyan fold and thrust belt and is approximately 70 km wide in north south direction (Fig.3.3). It is bounded to the north by the MBT, to the south by the Surghar Range Thrust which is separated 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 pleatu whereas towards the west it is truncated by the Kurram Fault (Fig. 3.2). In the Kohat plateau, the MBT brings Mesozoic and 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.3.2). Kalabagh Fault trends N15W and is characterized by transgressive right lateral strike-slip movement (McDougal, 1985).

Fig. 3.3 Tectonic map of the Kohat Plateau (After Meissner et al., 1975). Inset shows area of Figure 1.2.


70 00'
72 00'
33 45'
32 15'
THRUST FAULT
STRIKE SLIP FAULT
ANTICLINE
SYNCLINE
MAIN BOUNDARY THRUST
KOHAT
KOHAT PLATEAU
KURRAM FAULT
BANNU
KARAK
SURGHAR THRUST
KALABAGH FAULT
INDUS RIVER
SALTRANGE THRUST
PEZU
KHISOR RANGE
25 km
0

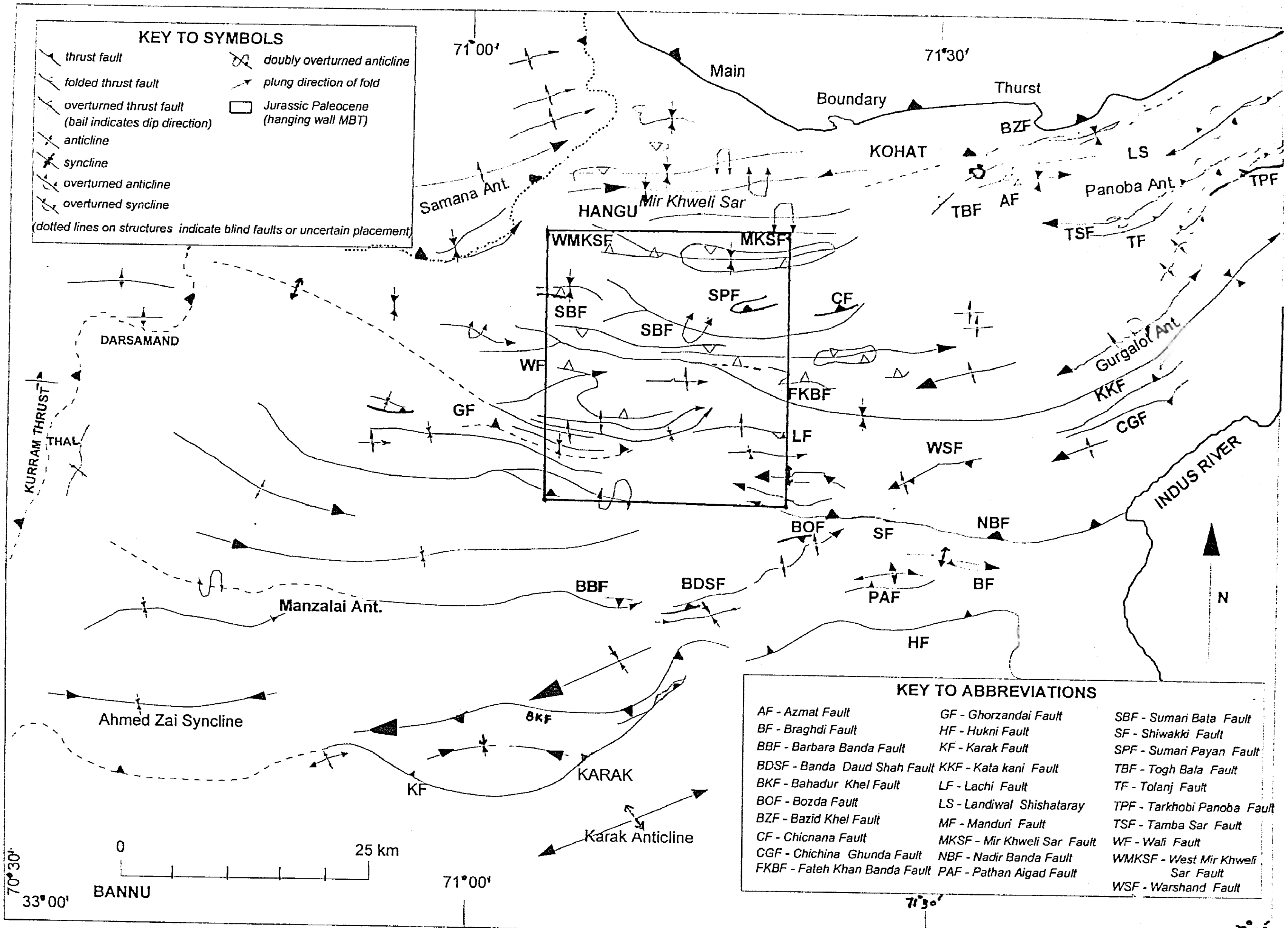


Fig- 3.3 : Tectonic map of the Kohat Plateau showing major structural features and towns after D.A. Pivnik and W.J. Sercombe, 1994. Inset shows area of figure 1.2

3.2: STRUCTURAL DATA

As a result of the present investigations it has been found that the structure of this part of the Kohat plateau is dominantly controlled by large scale folds,thrusts and back-thrusts (Fig. 1.2). All the major folds trend approximately in latitudinal fashion, i.e east-west and comprise large scale narrow anticlinal trends mostly truncated by east-west trending thrusts and back-thrusts. In between the anticlinal folds large scale intervening synclines are present most of which have both the limbs overturned and clearly show fan-folded geometry in cross-sectional view (Fig.3.3b). In addition to fan-folded synclines several fan-folded anticlines are also mapped. At the extreme southern margin of the map, two broad anticlines are observed (Fig. 1.2). These structures are in fact large scale anticlinoria on the basis of the systematic development of intermediate amplitude anticlines and synclines on their limbs. The southern most anticlinorium is named as Mami Khel-anticlinorium whereas the other one, which lies immediately north of it is named as Ghorzandi anticlinorium. In the northern part of the mapped area a suite of sedimentary rocks from Panoba Shale upto Murree Formation are exposed. At places, complete stratigraphic section from Kuldana Formation upto Murree Formation is repeated. This repetition is because of south verging thrust faults and south verging back thrusts.

For comprehensive explanation of the structural geometry of the area the folds are grouped as under:

a) **Anticlinoria**

b) **Fan folds**

c) **Overturned and Upright folds**

The thrust faults of the area are arranged as:

a) **Thrust faults**

b) **Back thrusts**

a) Anticlinoria

Two large scale anticlinoria have been mapped near the southern margin of the area which are from north to south as under:

Ghorzandi Anticlinorium

It is exposed all along the east west extension of the studied area. The map width of this anticlinorium ranges between 0.75-1.25 km (Fig. 1.2). The anticlinorium consists of numerous overturned anticlines and syclines both at its northern and southern flanks (Fig. 3.4). All these small amplitude overturned folds form a general arch of anticlinal shape. The oldest rocks exposed in this anticlinonium belong to the Panoba shale and Jatta Gypsum. Most of the associated small amplitude folds are cored by Panobe Shale, Jatta Gypsum and Kuldana Formation (Figs. 3.5 & 3.6). Looking at the sectional symmetry of this structure it is quite obvious that the highly plastic Panoba Shale, Jatta Gypsum and Khuldana Formation have induced a fan geometry to this

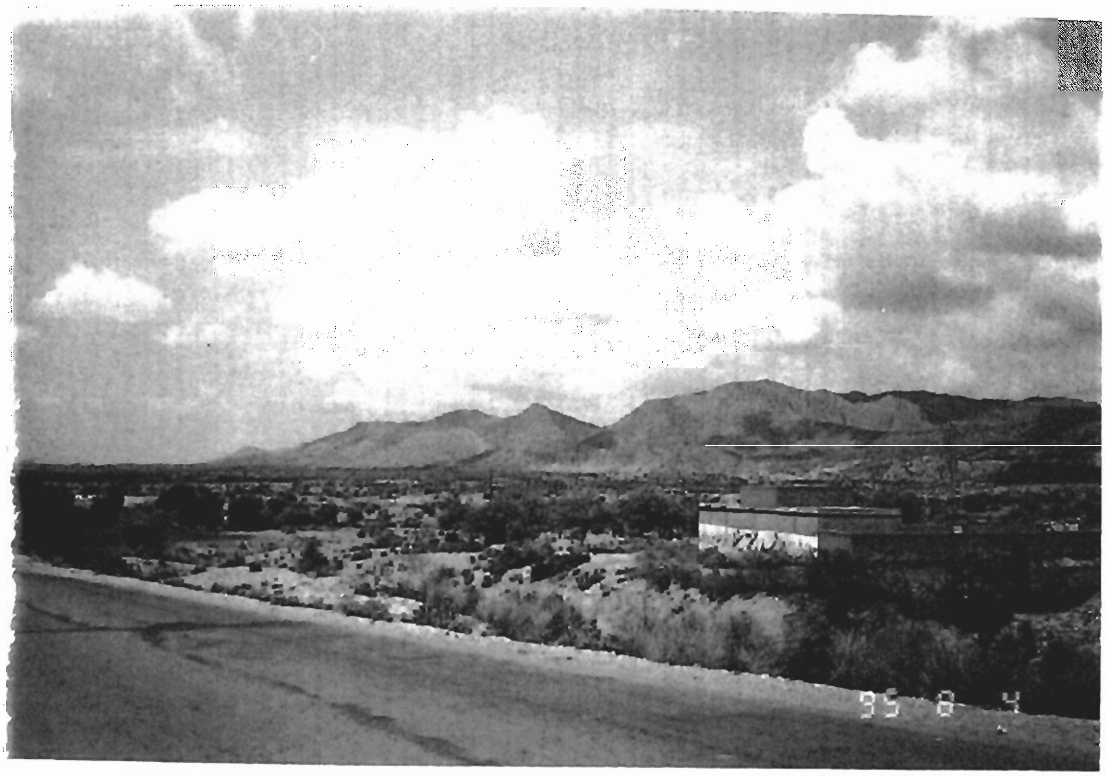


Fig. 3.4 Ghorzandi anticlinorium as viewed westward near Jatta village.

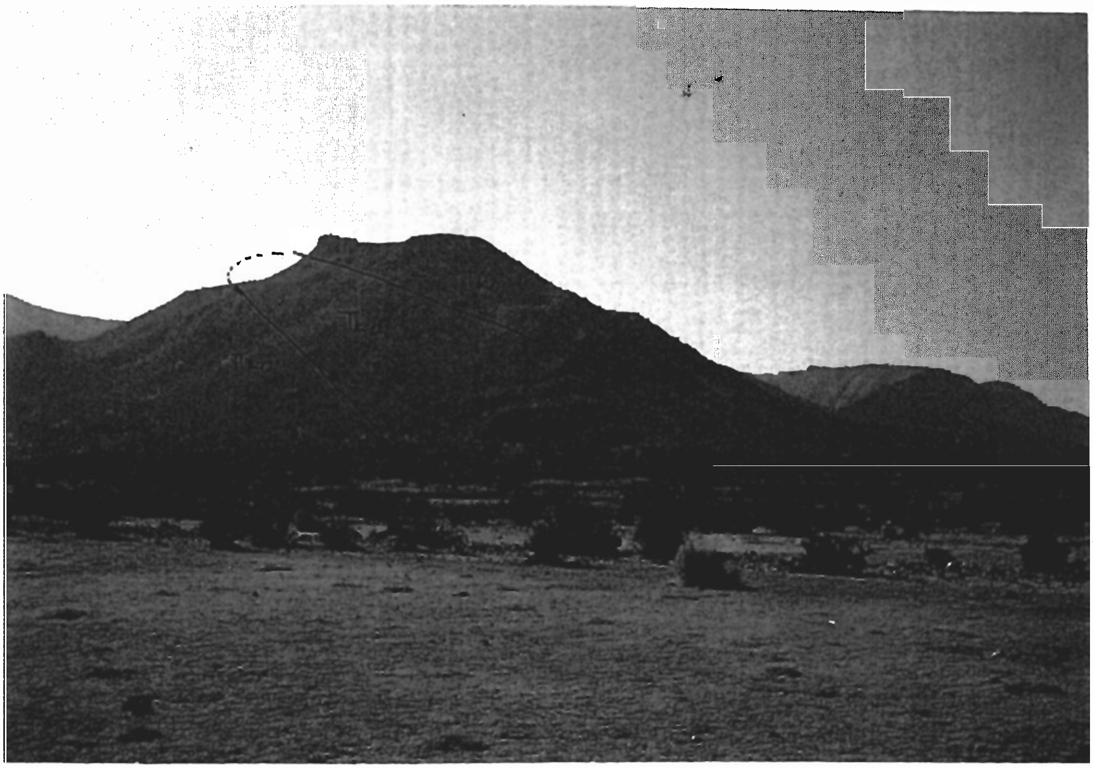


Fig. 3.5 View of a small anticline within Ghorzandi anticlinorium showing Kuldana Formation in its core.

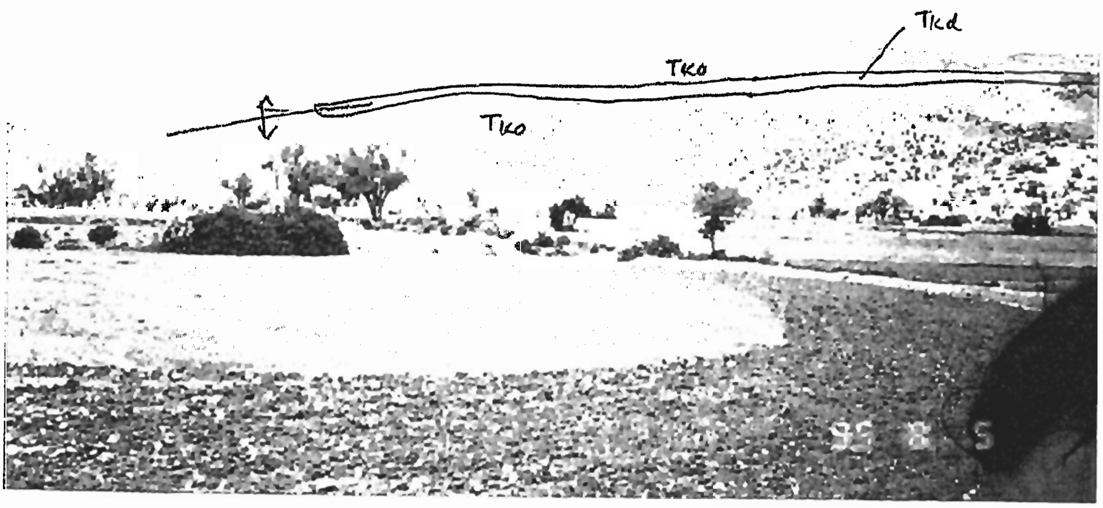


Fig. 3.6 A small scale anticline showing Kuldana Formation in its core at the southern limb of the Ghorzandi anticlinorium

structure. The smaller folds on the northern and southern flanks of the anticlinorium are overturned.

Mamikhel Anticlinorium

It is located south of the Ghorzandi anticlinorium. The nose of this Structure plunges into the alluvium near Mamikhel village and runs east-west upto the western margin of the mapped area. The map width of this anticlinorium ranges between 0.5-3.25 km. From Mamikhel village westward up to the Shaker Khel village the structure is a simple overturned anticline with the northern limb overturned towards south and exposes the Jatta Gypsum in its core. However, further west of Shakar Khel it incorporates numerous small amplitude overturned anticlines and synclines and represents anticlinorium structure (Fig. 3.7). The southern limb of the anticlinorium is overturned towards north in the western part. Towards the western margin, the anticlinorium exposes the oldest rocks of the region i.e Panoba Shale in its core. The axial trend of this structure at the western and eastern margin is east-west whereas at the central portion the smaller folds trend northwest. The overturned limbs of the structure clearly indicate the role of the diaparic flow of the weaker rocks i.e Jatta Gypsum and Panoba Shale.

b) Fan Folds

The area exposes several large scale fan-folded broad synclinal valleys in between the

Fig. 3.7 A view of the eastern closure of Mami Khel anticline.

tightly folded anticlinal ridges. These are from north to south as under:

Walai Syncline

South of the Sumari Fault and north of the Walai anticline a large scale intervening synclinal trend is mapped. It is oriented east-west and is exposed in the entire mapped area. It has a broad & flat trough and its both limbs are overturned.

The syncline exposes the Miocene molasse of the Kohat Plateau in its core and exhibits fan geometry in cross-sectional view.

The north-eastern part of its limb is truncated by the Sumari Fault whereas the central part of its southern limb is truncated against the Walai Fault.

Ghorzandi Syncline

It is located south of the Walai anticline and north of the Ghorzandi anticlinorium. It is oriented east-west and exposes the Miocene mollase in its core. Both of its limbs are overturned at steep angles. The map width of this syncline is around 2 km and appears to have flat bottom in the subsurface. The western part of its northern limb is truncated by Ghorzandi Fault.

Shaker Khel Syncline

It is the third major fan folded synclinal valley of the region and is located south of the Ghorandi anticlinorium and north of the Mamikhel anticlinorium. It is exposed in the entire mapped area in latitudinal fashion.It is identical to the other two fan-folded synclines mentioned earlier in the sense that both of its limbs are overturned at steep angles and is covered by the Miocene mollase of the Kohat plateau. However, none of its limbs are truncated by the faults like the other two synclincal folds.

c) Overturned and Upright folds

There are several large-sale folds in the area which exhibit a geometry different from those folds described above. These are either overturned folds verging south or are upright folds. The overturned folds are dominantly present in northern part of the area while upright folds are few and can be seen in central and southern parts of the mapped area (Fig. 1.2).

Anticlinal Folds

Sumari Anticline

It is the northern most and prominent anticline of the area. This east west trending structure is about 22 km long and 4.5 to 5 km wide. It bifurcates into two small scale anticlinal structures at the western termination of the Sumari valley. The southern limb of the anticline is overturned towards north with dip angle of about 58° . The structure exposes the oldest rocks of the region i.e Panoba shale in its core. Miocene Murree and Eocene Kohat Formations constitute the northern and southern limbs of the anticline respectively.

Chaprai Anticline

It is well developed in the western half of the mapped area and is located south of the Walai syncline. This fold, about 20 km long and 3.5 km wide exposes Panoba shale in its core. It seems to have been formed by the unification of Walai anticline in the south and another anticlinal structure terminating in the alluviam near Walai village.

Walai Anticline

As already mentioned it branches out from the Chaprai Anticline exactly south of the Walai village. It is tight, assymmetrical and both of its limbs are Juxtaposed along thrust fault in places(Fig. 3.8). In cross-sectional view it is overturned towards north. The southern limb has a dip value of 40° whereas the northern limb has dip value of 25°. Its nose plunges into the alluvium at its eastern termination. The axial trend is identical to the other major fold structures of the region i.e. east west.

Synclinal Folds

From south to north the following are the synclinal folds of the area:

Teri Syncline

It is the largest synclinal structure located at the southern margin of the study area (Fig. 1.2). Its axial trace is oriented east-west and is an open asymmetric syncline in sectional view. The dip angles of its northern and southern limbs are 27° and 16°

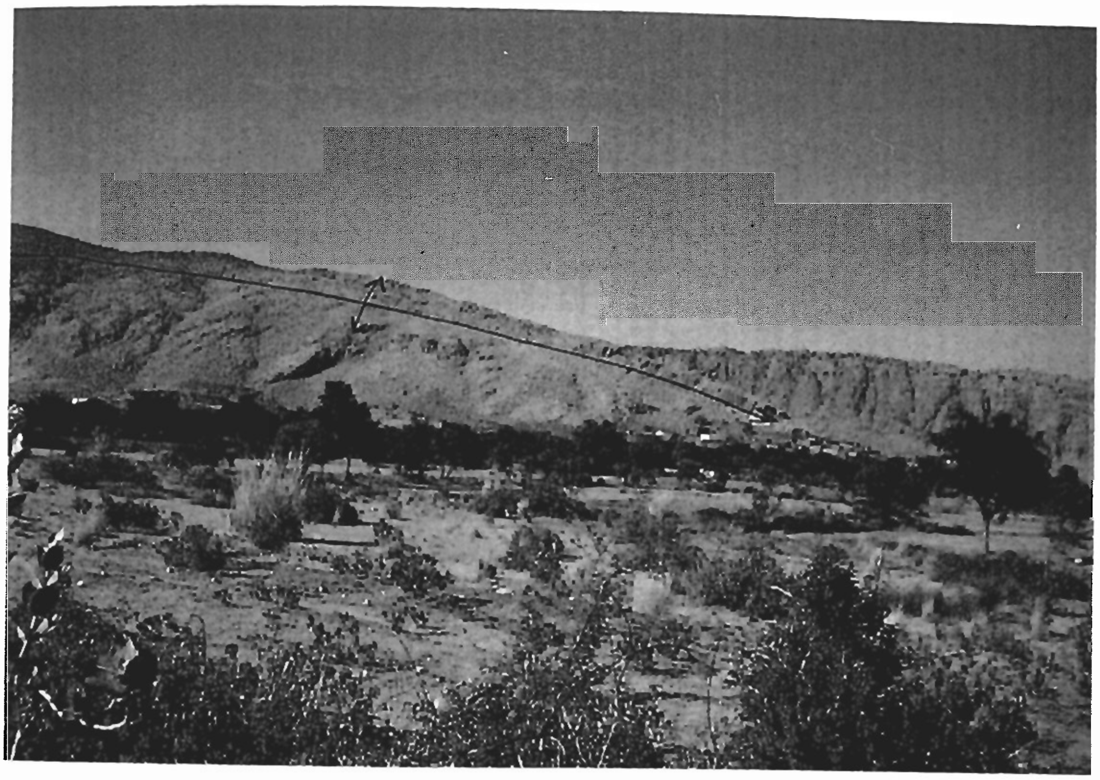


Fig. 3.8 Eastern closure of the Walai anticline.

respectively. It exposes the Nagri Formation of the Siwalik Group in its core (Fig. 3.9). It is truncated by a small scale thrust on its eastern side. This synclinal structure is about 25 km long and 5.5 km wide.

Kajbi Khana Syncline

It is located west of the Sumari valley and is oriented east-west. It exposes the Murree formation of the Rawalpindi Group in its core (Fig. 3.10). Two small out of syncline thrusts emerge from its core.

Mir Khweli Sar Syncline

It is the northern most synclinal fold of the area and is oriented east west. It is symmetric in sectional view and folds two thrust sheets in its core and limbs. Murree Formation of Miocene age forms the core of the syncline (Fig. 3.11).

Faults

The mapped area comprises large scale fore and back thrusts. The back thrusts are mostly overturned at their surface exposures and have changed their vergence from north to south. The faults are assigned different names after the local villages for simplicity. Thrust faults of the study area are as follows:

a) Thrust Faults

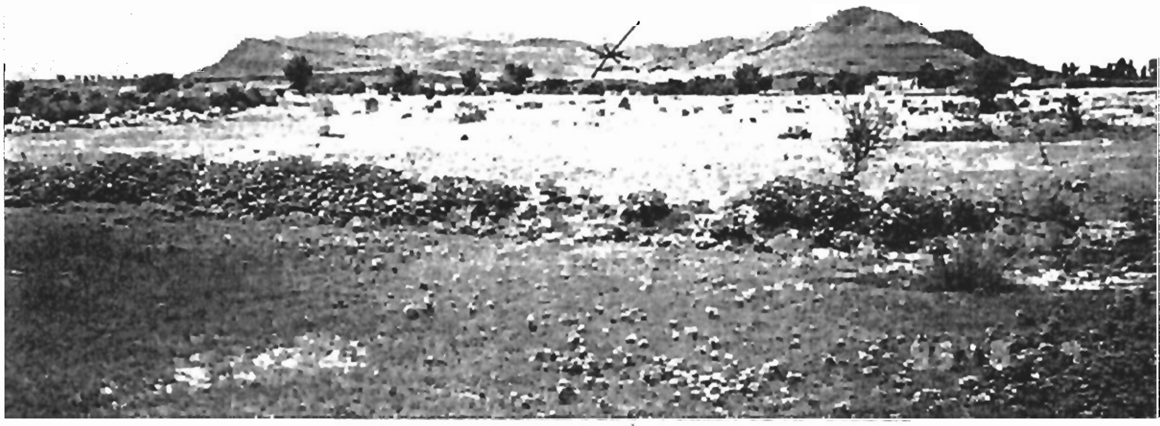


Fig. 3.9 Photograph of the Teri syncline with Nagri Formation in its core.

Fig. 3.10 Eastern closure of the Kajbi Khana syncline showing Murree Formation in its core.

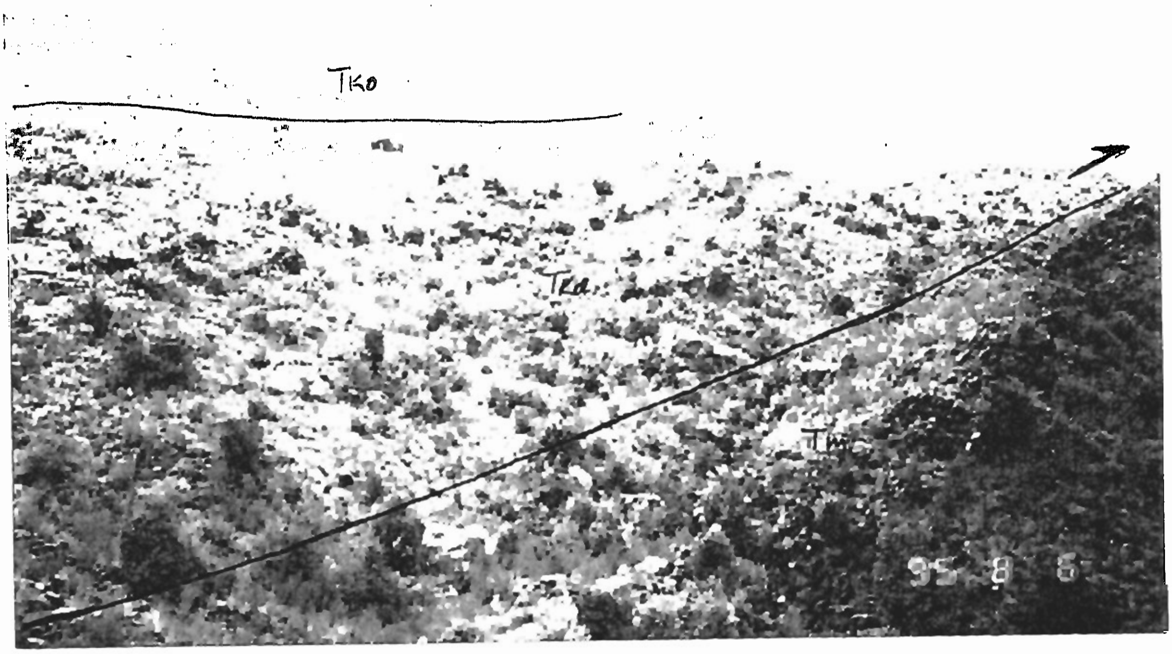


Fig. 3.11 Western closure of the Mirkhweli Sar syncline and Mirkhewli Sar fault.

Mir Khweli Sar Fault

Chappar Fault

Walai Fault

Shaker Khel Fault

Mami Khel Fault

Mir-Khweli Sar Fault

It is the northern most structural discontinuity of the region. It occurs as an isolated klippe of Kuldana (Mami Khel clay),Kohat and Murree Formations sitting on the top of the Murree Formation. The fault is subparallel to the bedding and has been folded with the entire Eocene package. In the sectional view it can be demonstrated to have been involved in the folding of the Mir Khweli Sar syncline. The northern segment of this fault dips gently southward whereas its southern segment dips northward moderately. Along this fault, Kuldana and Kohat Formations are thrust over the Murree Formation (Figs. 3.12 & 3.13).

Chappar Fault

It is developed on the western end of the Mir-Khwali Sar syncline. The fault is oriented east west and moderately dips towards north. Along .the fault Kohat Formation is thrust southward over the Murree Formation present in the footwall (Fig. 1.2). On the basis of the stratigraphic sequence involved and sectional view it is an out of syncline thrust.

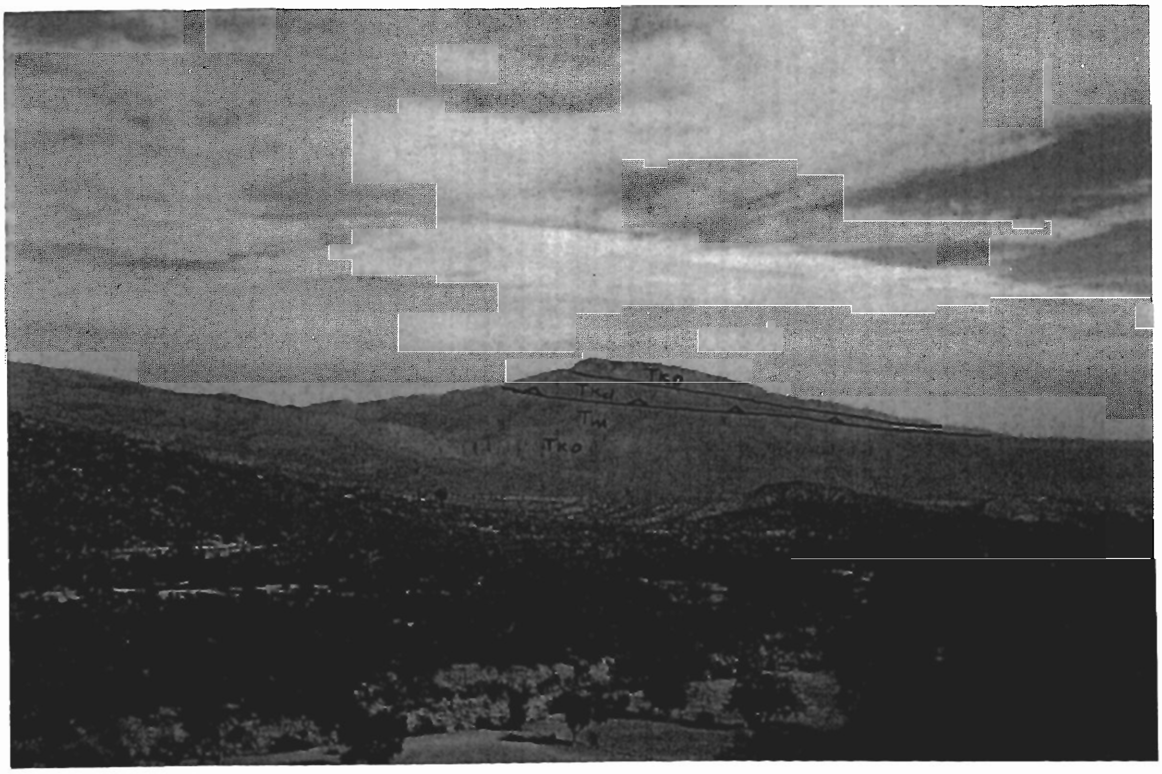


Fig. 3.12 A view of the Mir Khweli Sar Thrust along which Kuldana Formation is thrust over Murree Formation as viewed from south of the Sumari Bala Village.

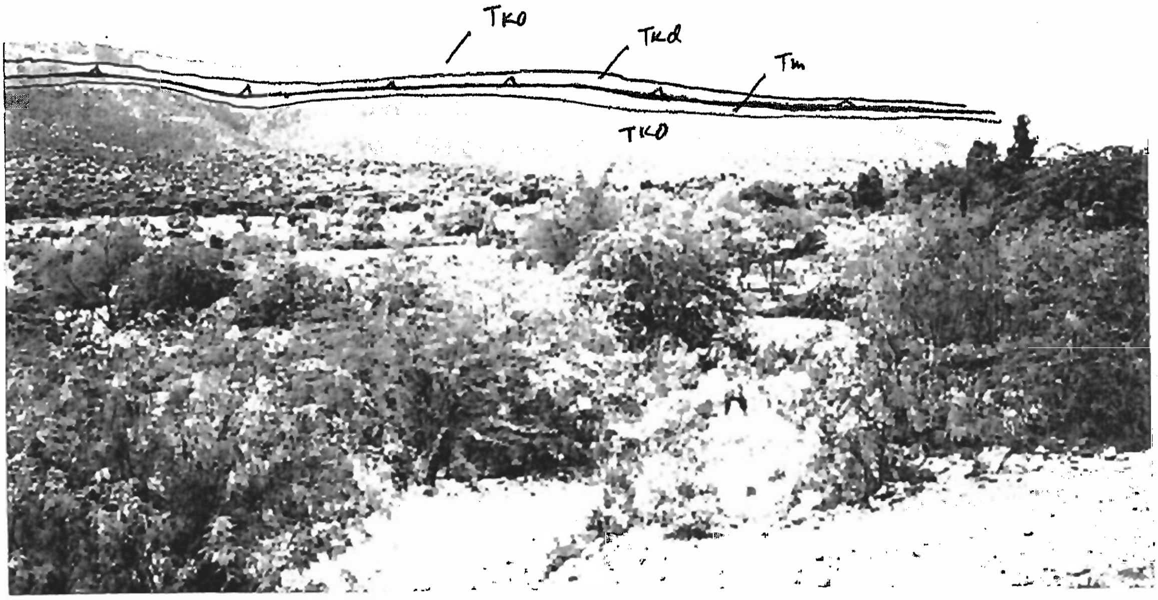


Fig. 3.13 A south looking view of Mir Khweli Sar Fault along which Kuldana Formation is thrust over Murree Formation.

Walai Fault

It lies north of the Chaprai anticline. Its surface trace is folded around the northern limb of the Chaprai anticline. Along this fault, Kuldana Formation is thrust over the Murree Formation (Fig. 3.14). Along the northern limb of the Chaprai anticline its trace is overturned towards south and along the northern limb of the Walai anticline it steeply dips northward.

Shahakar Khel Fault

This fault crops out on the southern limb of Ghorzandi anticlinorium and lies north of the Shakar Khel village. Its east-west map extension is very small. The fault trends east-west and dips steeply towards north. The Panoba Formation in the hanging wall has been thrust over the Murree Formation in the footwall.

Mami Khel Fault

It has small east-west map extension and is located in the southern limb of the Ghorzandi anticlinorium north of Mamikhel village. It is oriented east-west and is steeply dipping towards north. At its eastern exposure the Jatta-Gypsum is thrust over the Kuldana Formation present in the footwall, whereas its westward extension is burried under the alluvium, However, its extension to the west is confirmed from the interpretation of seismic line No.YXT-13.

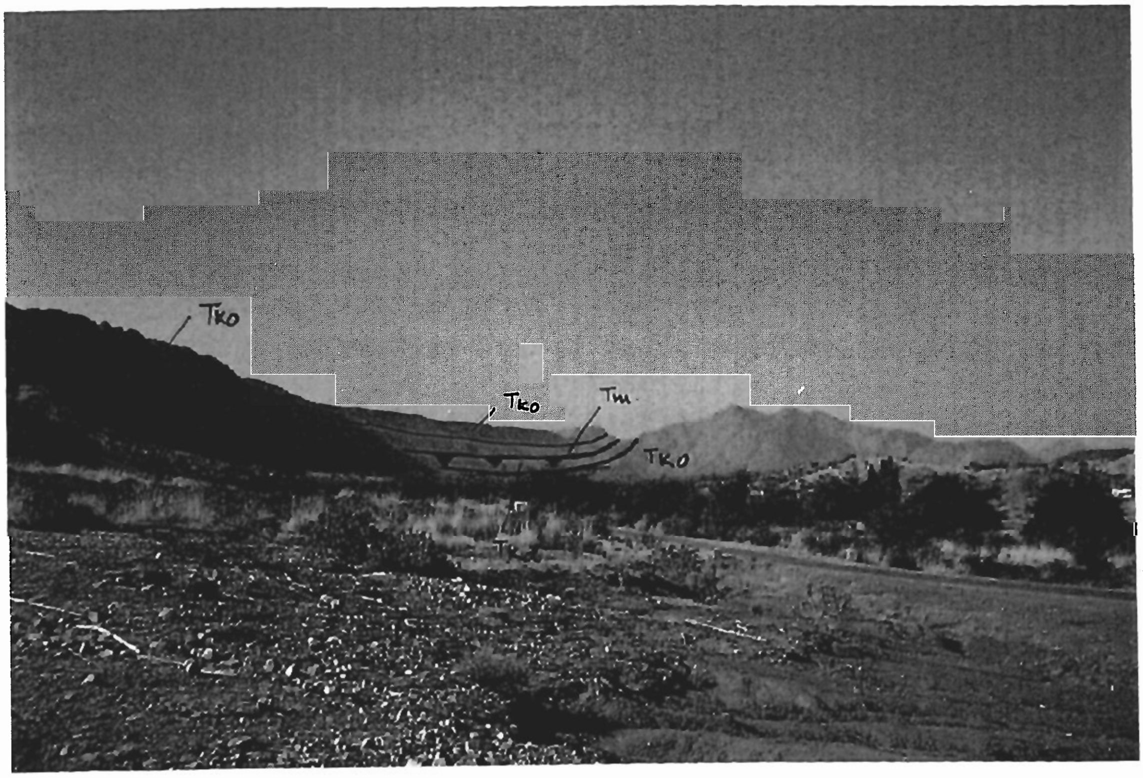


Fig. 3.14 A photograph of the Walai Fault showing the juxtaposition of Kuldana Formation with Murree Formation.

b) Back Thrusts

Sumari Bala Fault

Ghorzandi Fault

Sumari Bala Fault

It trends east-west and dips moderately toward north. On the basis of the stratigraphic succession and dip direction it is overturned towards north (Fig. 3.15). It runs along the entire length of the southern limb of the Sumari Anticline. Along this fault, Mamikhel Formation is thrust over the Kohat Formation.

Ghorzandi Fault

It is located north of the Ghorzandi syncline and truncates the western closure of this syncline. In the map (Fig. 1.2) it can be seen folded around the nose of the Ghorzandi Syncline. Along this fault the Kuldana Formation is thrust over the Murree Formation (Fig. 3.16). All along its trace the fault is overturned.

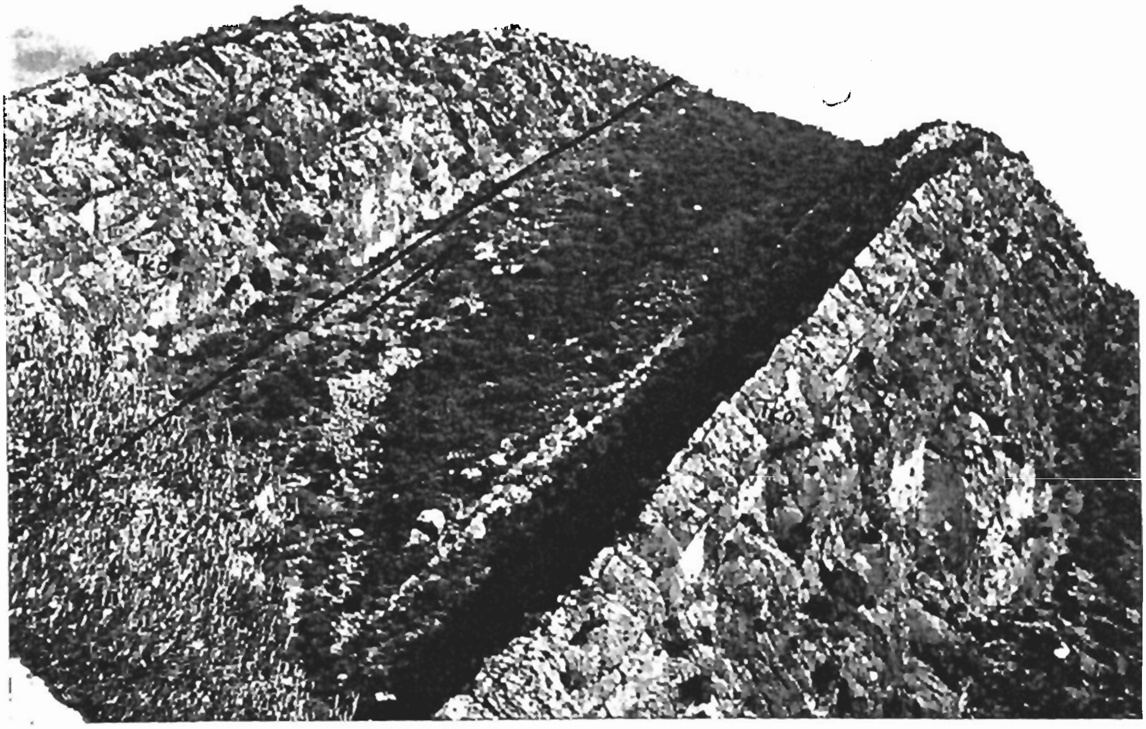


Fig. 3.15 Northward dipping, overturned Sumari Bala Fault along which Kuldana Formation is thrust over Kohat Formation.

Fig. 3.16 Western closure of the Ghorzandi Fault along which Kuldana Formation is thrust over Murree Formation.

CHAPTER-4

SYNTHESIS OF STRUCTURAL DATA AND PROPOSED STRUCTURAL MODEL

4.1: SYNTHESIS OF STRUCTURAL DATA

Representative structural cross section has been constructed with the help of the surface traverses and seismic data in order to determine the structural style of deformation and kinematic development of this part of the Kohat plateau.

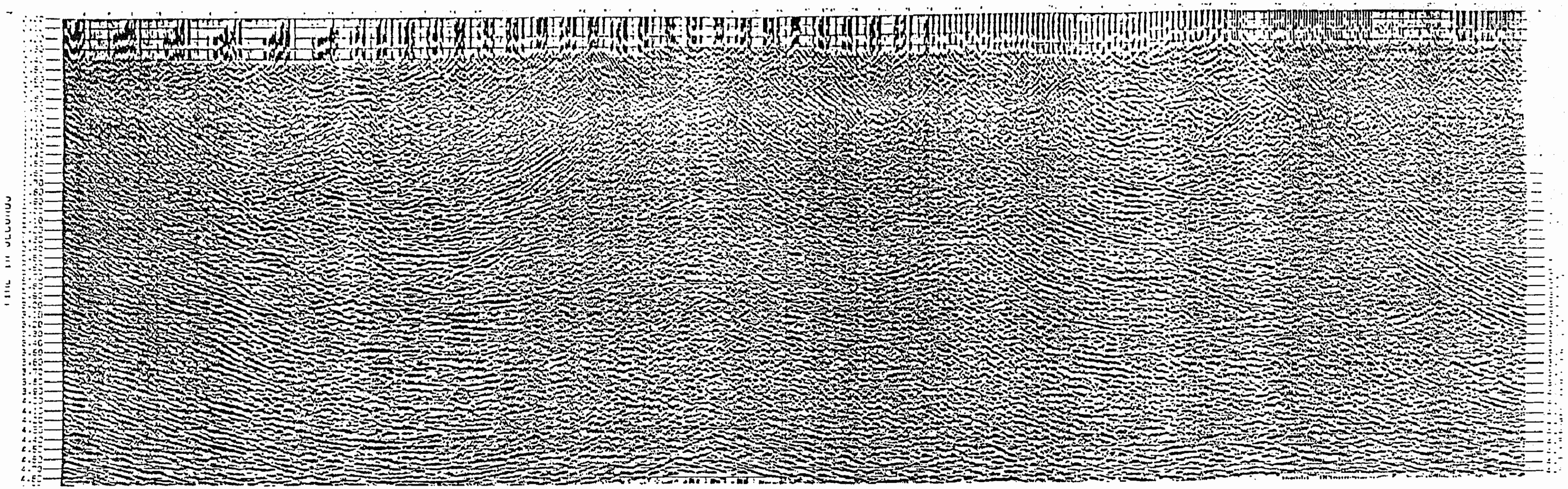
A geological map of the area has been prepared on 1:50,000 scale. The structural cross-section is co-axial with the seismic line No. YXT-13 (Fig. 4.1). This seismic section is within a range of about 5° to the regional tectonic transport direction.

4.2: INTERPRETATION OF SEISMIC SECTION

A cross-section along the available seismic line has been constructed and interpreted. This interpretation is well-supported by information obtained from a well drilled in Sumari Bala by AMOCO in early 1993. The well data has been used to identify the subsurface stratigraphic horizons and determine the exact thicknesses of various formations. The depth to the detachment is calculated using the velocity data. The top of nearly flat basement at 4.0 seconds, two-way time, is interpreted on migrated seismic line YXT-13 that extends across the study area all the way from north to south (Figs. 1.2 and 4.2). By applying the velocity data, the top basement has been worked-out to be at a depth of 8000 meters in the southern part and about 8400 meters in the northern part of the study area(Fig.4.3).

Fig. 4.1 **Migrated seismic line No. YXT-13 of AMOCO which passes along line AB of Figure 1.2.**

YXT-13



Mc Dougall and Hussain (1991) have plotted the top basement in the Kohat Plateau at a depth of about 8.5 km whereas Abbassi and Mc Enroy (1991) have estimated the top basement at a depth of about 6 km in the Shakar Darra area. The decollement has a regional dip of about 3° towards north. This part of the Kohat plateau has some of the characteristic features of the foreland fold and thrust belt. The maximum structural relief is about 4000 meters for the different horizons at regional level.

The section (Fig 4.2) shows a series of large scale, hinterland dipping thrusts emerging from the basal decollement. All these faults are steeply dipping at the surface and become gentle at depth. These faults are founded to be emergent blind at places. The other prominent feature is the associated pop-ups which are the result of the north verging splays from the large scale fore-thrusts. All these observed features are the characteristics of regions with prevalent thin-skinned deformation.

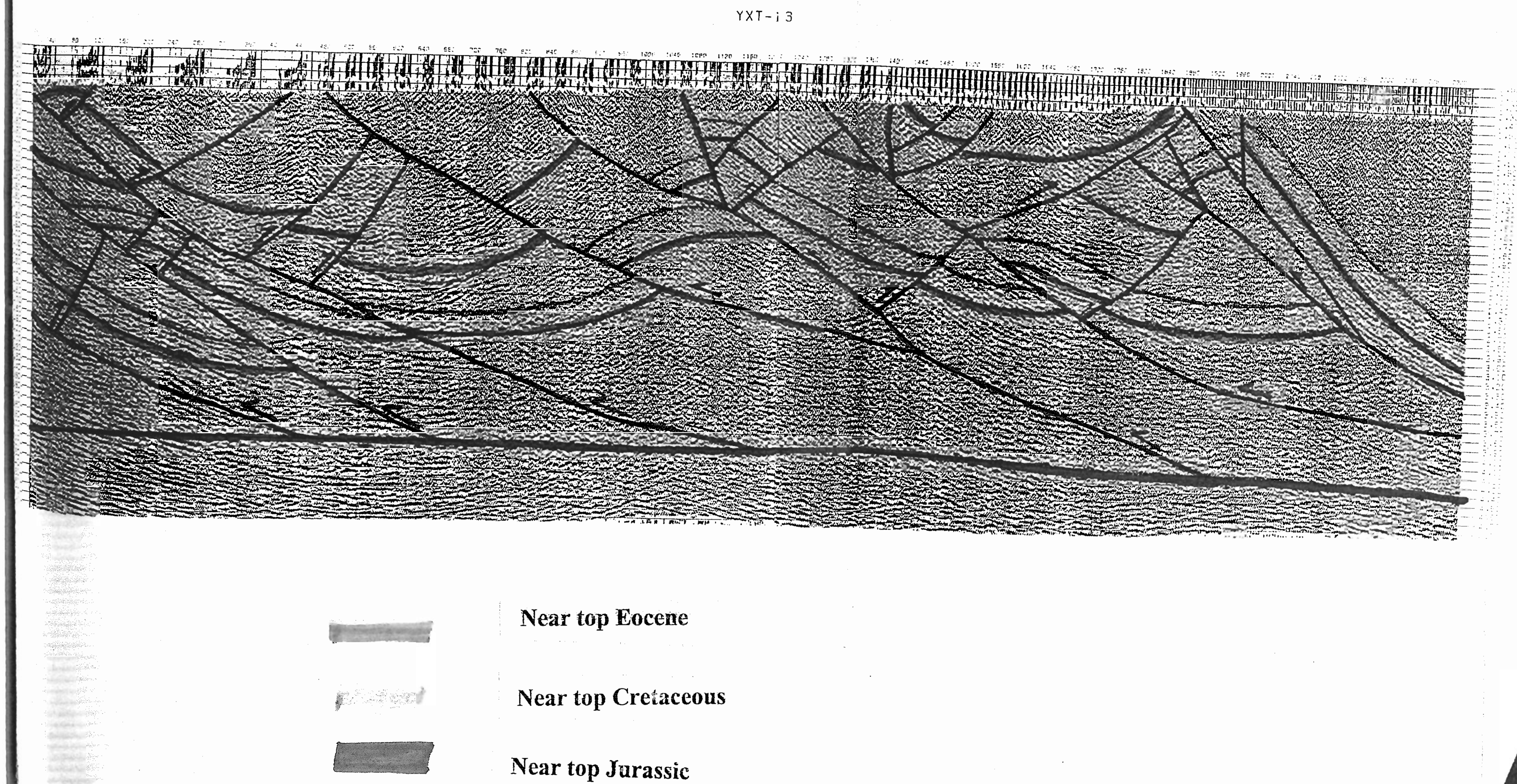
4.3: INTERPRETATION OF GEOLOGICAL CROSS-SECTION

A cross-section has been constructed for a better understanding of the subsurface behaviour of various formations and to facilitate working-out a structural model for the area. The section is oriented parallel to the direction of tectonic transport.

The cross-section depicts that the structure of the area is largely controlled by south verging thrust and north verging overturned back-thrusts. Along most of these faults the Eocene sucession is repeated in the outcrops. In addition to faults, several large scale anticlinal trends can be seen in the section (Fig. 4.4). As the main anticlinal

Fig. 4.2 **Interpreted seismic line No. YXT-13 of AMOCO.**

Interpretation is based on surface geological data from Figure 1.2 & drilling information of Sumari well # 1.


YXT-i3
Near top Eocene
Near top Cretaceous
Near top Jurassic

trends incorporate several small amplitude folds, these are regarded as anticlinoria. The limbs of these anticlinoria are truncated by north and south verging back-thrusts and fore-thrusts forming pop-ups beneath them. From north to south the Mir Khewli Sar, Chappar, Walai, Shakar Khel and Mamikhel faults are the surface exposures of north dipping fore-thrusts and Sumari Bala and Ghorzandi faults are the surface exposures of north dipping overturned back-thrusts.

In addition, the diapirism has played an important role in the development and modification of all the large scale anticlinoria and fan-folded anticlines and synclines. The small amplitude folds which have been developed at the flanks of these major folds have variable and often opposite vergence which is the evidence of the role of shale diapirism in the formation of these structures.

4.4: RESTORATION OF SEISMIC SECTION

In order to check the validity of the deformed state cross-section, restoration has been carried out upto the top of Cretaceous horizon (Fig. 4.4). The formations above the top of Cretaceous are not restored because the area is not conserved during deformation as significant amount of thinning and thickening can be seen in the Eocene succession. The regional dip is within 5° range and the regional level lies at about 8000 meters depth. The maximum structural uplift above regional level is upto 4000 meters. The restoration is based on area and bed length conservation and constant slip along the faults. The younging sequence of faulting is from hinterland to foreland which is the well-documented sequence of faulting in the foreland fold and thrust belts of this region. The folds are interpolated as segments of parallel concentric arcs.

The restored version of the deformed state cross-section (Fig. 4.4) shows about 19.5 kms shortening for the mapped area.

4.5: PROPOSED STRUCTURAL MODEL

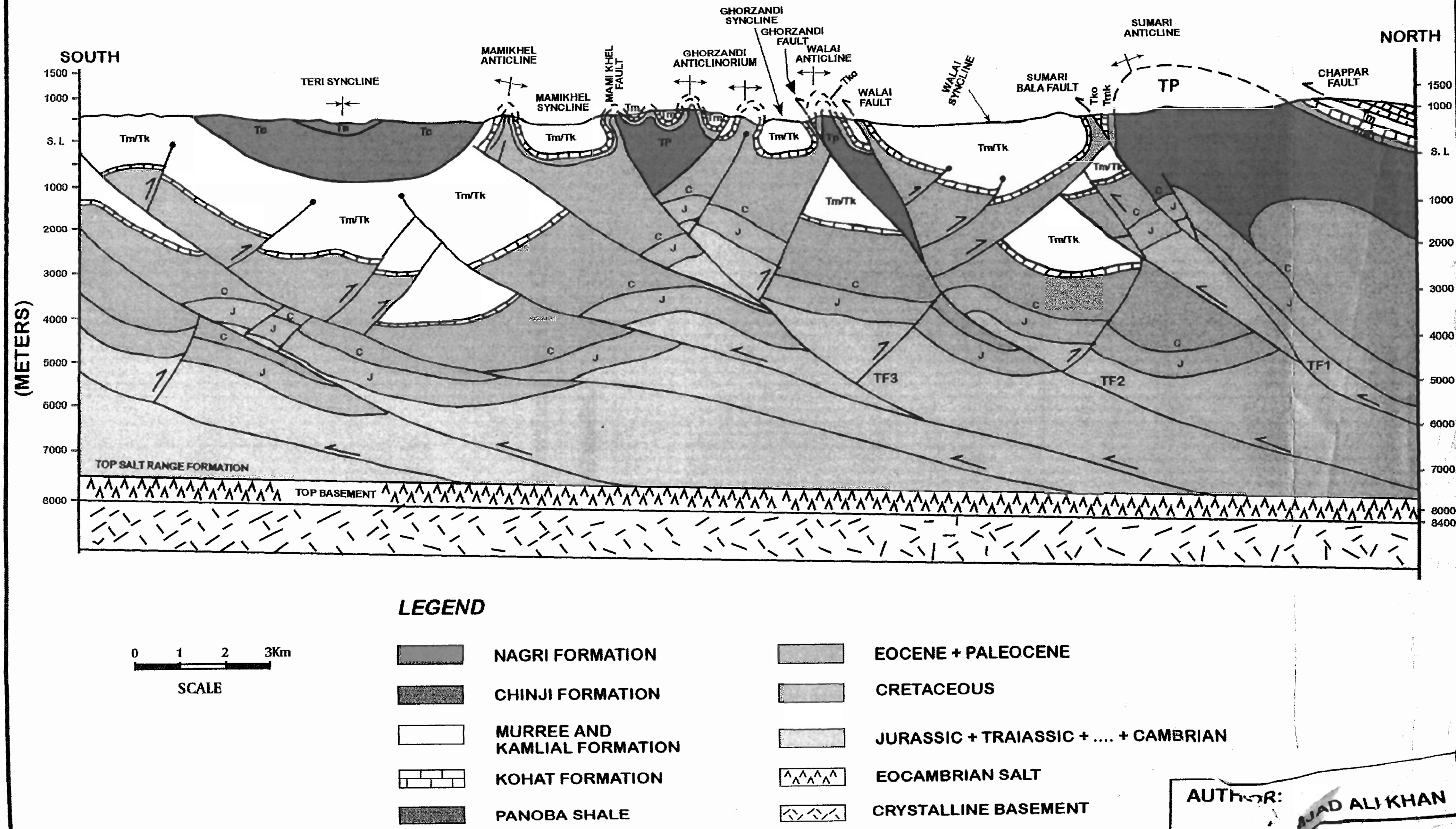
The studied area exposes a suite of structures which are characteristic of the Alpine and Himalayan foreland fold and thrust belts. This combination of ductile and brittle structures on several different scales is the result of poly phase deformational episodes and minor pulses. A structural model has been proposed by ploting the surface geological data along interpreted seismic line (Fig. 4.3). The sectional line drawn on the topographic map is the same as the seismic line.

The main structural features of the model are as follow:

1) North dipping listric thrust faults
2) North dipping overturned back-thrusts exposed at surface
3) South dipping blind back-thrusts
4) Fault propagated anticlinal folds
5) Open flat-bottomed fan-folded synclines
6) Anticlinoria

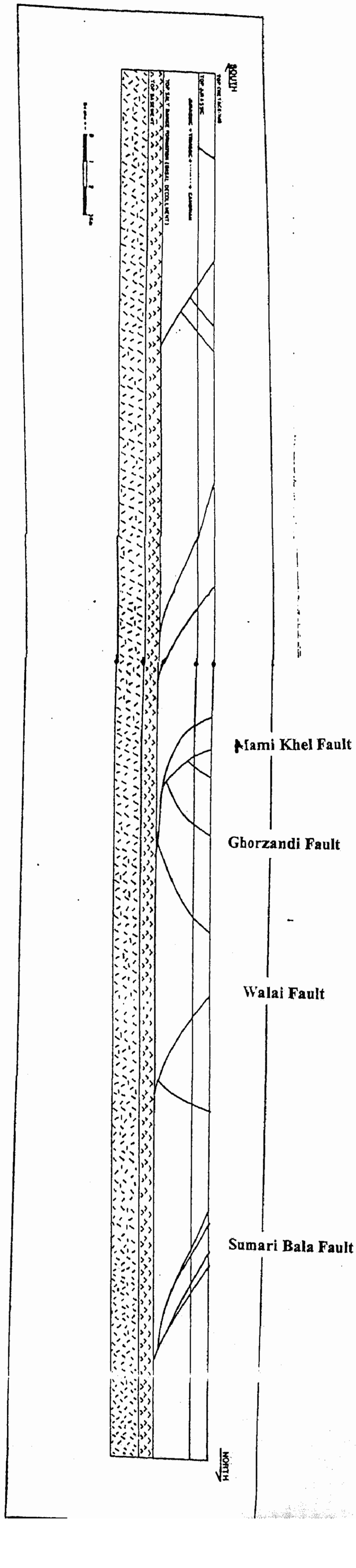
The proposed model (Fig. 4.4) includes several large scale south verging listric thrust faults which emerge from the basal detachment. Out of these faults some are emergent at the surface whereas some are blind thrusts with tip lines terminated in the subsurface.

Fig. 4.3 **Proposed structural model of the study area along line AB of Figure 1.2.**



AUTH–R: …JAD ALI KHAN

Fig. 4.4 Restored version (upto top Cretaceous level) of the proposed structural model.



SOUTH
Mami Khel Fault
Ghorzandi Fault
Walai Fault
Sumari Bala Fault
NORTH

Looking at the model it is clear that out of these faults, three faults play important role in the manifestation of the surface geometry. These faults are from north to south named as TF1,TF2 and TF3. The TF1 and TF2 were formerly exposed at the surface but at present their surface expressions are modified by a set of back thrusts which splay from the next fore thrusts. The surface expression of TF1 is modified and obliterated by the south verging, overturned Sumari Bala Fault which has emerged from TF2. As a result a triangle zone has been developed beneath the Sumari Bala structure at a depth of about one kilometer. South of the Sumari Bala structure is the Walai anticline where similar situation exists. The surface expression of TF2 is also obliterated by a south verging, overturned back thrust namely Ghorzandi Fault. Ghorzandi Fault splays as a back thrust from the Shakar Khell Fault which is the southern most emergent thrust fault. Below the Walai anticline a triangle zone has developed as a result of the opposite dipping Ghorzandi Fault and TF2. thrust fault.

TF3 is emergent at the surface and truncates the southern limb of the Ghorzandi anticlinorium (Fig. 1.2). It is named as Mamikhel Fault.

In addition to the above mentioned listric thrust faults several north verging back thrusts are present in the model which splay from the major thrust faults. Out of these back-thrusts, two are most prominent and are exposed at the surface. The Sumari Bala Fault initiated as a north verging back thrust from TF2 and at the intersection with TF1 its vergence is changed from north to south because right from the intersection it has followed the trace of this listric thrust fault. As a result it has obliterated the surface expression of this listric thrust fault.

South of the Sumari Bala Fault is another back thrust named as Ghorzandi Fault. The Ghorzandi Fault runs along the southern limb of the Walai anticline and it has been initiated as north verging back thrust from the Mamikhel Fault and has changed its vergence to south at its intersection with TF2. As a result it has obliterated the previous surface expression of the TF2.

In addition to the emergent back-thrusts, the model incorporates numerous north verging blind back-thrusts which have developed as a result of stress release and have formed several pop-up structures and triangle zones at various levels.

From north to south three major anticlinal trends are present namely Sumari Bala anticline, Walai anticline and Ghorzandi anticlinorium. All these structures are the result of fault propagation and constitute the hanging walls of the three major listric thrust faults of the region.

Another prominent structural feature in the model is the fan-geometry of folds in sectional view. From north to south, the Walai syncline, Ghorzandi syncline, Mamikhel syncline, Ghorzandi anticlinorium have fan geometries. The reasons for the fan geometry of these structures is that all these structures are controlled by pop-ups in sub surface which are responsible for the overturning of the limbs of these folds. In addition to the sub-surface pop-ups, the shale diapirism has also played important role in the modification of the shape of these structures. The base of the

Eocene succession is dominated by highly plastic shales of Panoba and Kuldana Formations. The diapiric flow of these shale can also be attributed to the development of fan geometries of these folds.

The kinematics of the various structures occurred such that in the initial stages shortening was achieved by folding. Later on, south-verging listric thrust faults emerged from the basal decollement with break forward sequence of faulting. During the progressive deformation the back thrusts were developed as splays from the fore thrusts and resulted in the formation of pop-ups and triangle zones. The presence of the triangle zones have complicated the structural geometry of the area as the back thrusts have mostly disturbed the footwall succession of the earlier formed fore thrusts.

CHAPTER-5

CONCLUSIONS

1. As a result of present investigation, nine lithostratigraphic units have been established in the study area ranging in age from Eocene to Pliocene. These units are listed below in the order of superposition:

   I) Nagri Formation

   H) Chinji Formation

   G) Kamlial Formation

   F) Murree Formation

   E) Kohat Formation

   D) Kuldana Formation (Mami Khel clay)

   B) Jatta Gypsum C) Sheikhan Limestone

   A) Panoba shale

2. The general trend of the major structures (fault traces and fold axes) in the area is east-west with north-south tectonic transport direction.

3. The maximum structural relief is around 4000 meters for different horizons above regional level.

4. A series of north-dipping listric thrust faults emerge from the basal decollement and various back thrusts splay from these faults.

5. Great displacement ranging from 3 to 4.5 km is associated with various faults mapped in the area.

6. The sequence of faulting is found to be south younging.

7. The surface geometry of structural elements along with seismic data indicates that the structure of the area is characterised by pop-ups and triangle zones.

8. Pop-up structures and shale diapirism is responsible for the attribution of fan geometries to the different fold structures of the area.

9. The presence of triangle zones have resulted in the complication of the surface geometry of the various faults mapped in the area.

10. The basal decollement located at the base of Salt Range Formation has a depth of around 8 km and 8.4 km in the southern and northern parts of the study area respectively.

11. The amount of shortening calculated for the area is 19.5 km based on the restoration of the deformed state cross-section.

CHAPTER-6

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