A comparative study of structural styles in the Kohat Plateau, NW Himalayas, NWFP, Pakistan

By

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Thesis presented for the degree of Doctor of Philosophy at the University of Peshawar

National Centre of Excellence in Geology
University of Peshawar, Pakistan
2003

This work is dedicated to
my loving parents and
son Yahya Sajjad

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Abstract

Kohat Plateau is located in the northwestern apex of the southern deformed fold and thrust belt that borders the entire Himalayan foothills in India and Pakistan. Detailed mapping, combined with structural analysis throughout the Kohat Plateau, and critical reassessment of the previously published data have resulted in reinterpretation of the structural evolution of this important part of the active foreland fold and thrust belt of Northern Pakistan. The present study within the Kohat Plateau suggests that it is dominantly a thin-skinned deformed fold and thrust belt over its major part, superimposed by thick-skinned structures in the south and has been distinguished as the Northern, Central and Southern Kohat Plateau.

The thin-skinned structures are well developed within the outcropping rocks of the Northern and Central part of the plateau and exhibit a variety of structural styles that include macroscopic-scale doubly overturned disharmonic anticlinal folds, imbricate fans, pop-ups and triangle zones and relics of a folded thrust sheet. The macroscopic-scale doubly overturned disharmonic anticlinal folds are well exposed throughout the Northern Kohat Plateau and west of the longitude of the Jatta Ismail Khel in the Central Kohat Plateau. The imbricate fans, pop-ups and triangle zones are well depicted only east of the longitude of the Jatta Ismail Khel of the Central Kohat Plateau. Relics of a folded thrust sheet are observed in the Northern Kohat Plateau alone. The structural style within the non-outcropping rocks of the plateau is dominated by a series of thrust splays getting younger towards south from the basal decollement. The motion along these thrust splays give rise to fault propagation folds in the overlying strata. Remarkable structural contrast has been observed within the outcropping and non-outcropping rocks both laterally and vertically and is ascribed to a major rheological change.

The thick-skinned structures are confined to a zone (3-12 kilometer wide) in the south, stretching from Zarwam in the west up to Banda Lakhoni in the east. This zone is defined by a couple of east

west trending wrench faults that involve the basement as well. Deformational features related to this fault system include enechelon folds, steep to vertical dips and stratigraphic mismatch across the fault surfaces. The genesis of this wrench zone is related to the westward underthrusting of Kohat Plateau underneath the Sulaiman and Samana Ranges along the transpressional boundary called as the Kurram Fault.

Orientation of both large and small scale structures within the Kohat Plateau indicate that it has undergone deformation as a result of an earlier phase of compressional deformation related to north-northwest horizontal compressional stresses with the exception in the southwest. Towards the southwestern boundary of the Kohat Plateau along the Bannu Basin, the earlier compressional structures are overprinted by a later phase of transpressional deformation. The Kohat Plateau is dominantly a south-southeast vergent structural system impinging upon Bannu Basin in the southwest and Punjab Foreland in the southeast.

The Surghar Range in the southeast represents the active deformational front of the Kohat Plateau and is interpreted as a strong to weakly emergent thrust front along which Paleozoic rocks are thrust southwards over the Punjab Foreland .

ACKNOWLEDGMENTS

I am grateful to Almighty Allah, who bestowed me with the ability to successfully complete this thesis work.

I am highly thankful to my supervisor Professor Dr. S. Hamidullah, Director National Centre of Excellence in Geology, University of Peshawar for his painstaking efforts in completion of this thesis work. He is highly acknowledged for his full time guidance, technical help and keen interest in every phase of my studies.

I am deeply indebted to my co-supervisor Dr. Irshad Ahmad, Associate Professor, National Centre of Excellence in Geology, University of Peshawar for his untiring efforts in supervising this thesis. He is thanked for his guidance in the field, providing useful suggestions and thoroughly reviewing the manuscript.

Due regards are indebted to my Colleague Mr. Fayaz Ali, Lecturer Department of Geology, University of Peshawar for his assistance, encouragement and moral support through out this work.

Mr. Irshad Ahmad, Computer Technician, Department of Geology, University of Peshawar is highly acknowledged for setting-up the final manuscript.

Dr Robert D. Lawrence, Dr. Shafiqur Rehman and Dr. Mirza Shahid Baig are thanked for critical review of the manuscript and fruitful suggestions.

CHAPTER# 1

INTRODUCTION

1.1 General description

The mountain belt of North Pakistan lies at the western end of the main Himalayan chain in the apex of a major oroclinal deflection in structural trend from east-west to north-south. The Kohat Plateau lies in this apex, about 100 Km southwards of the main part of the western Himalayan foothills (Figure 1.1). It is believed to be the main depocenter of Himalayan shed during Miocene, now uplifted and deformed, to give rise to a typical foreland fold and thrust belt. It represents the southern margin of the collision zone in North Pakistan and has well preserved imprints of Himalayan orogeny.

The study area covers a major part of the Kohat Plateau and encompasses 9500 square kilometers area, consisting of rugged mountainous terrain with low topographic relief. It is located in the Northwest Frontier Province and related tribal agencies of Pakistan. The term Kohat Plateau has been traditionally used as a sack name in the existing literature though it does not strictly fulfill the definition of plateau. The geographic boundaries of it are marked by Kohat Range in the northeast, Indus River in the east, Surghar Range in the southeast, Bannu basin in the south and Samana Range in the northwest (Figure 1. 2).

The sedimentary record of Himalayan convergence in northwestern Pakistan is well preserved in the Kohat Foreland Fold and Thrust belt, which constitutes western part of the deformed foreland fold and thrust belt of northern Pakistan (Pivnik and Wells, 1996). The Kohat Foreland Fold and Thrust belt comprises Paleocene to Eocene sedimentary rocks in a complex assemblage of limestone, shale, evaporites, sandstone and conglomerates succeeded by an unconformity, which is overlain by Miocene terrestrial, synorogenic foreland basin deposits.

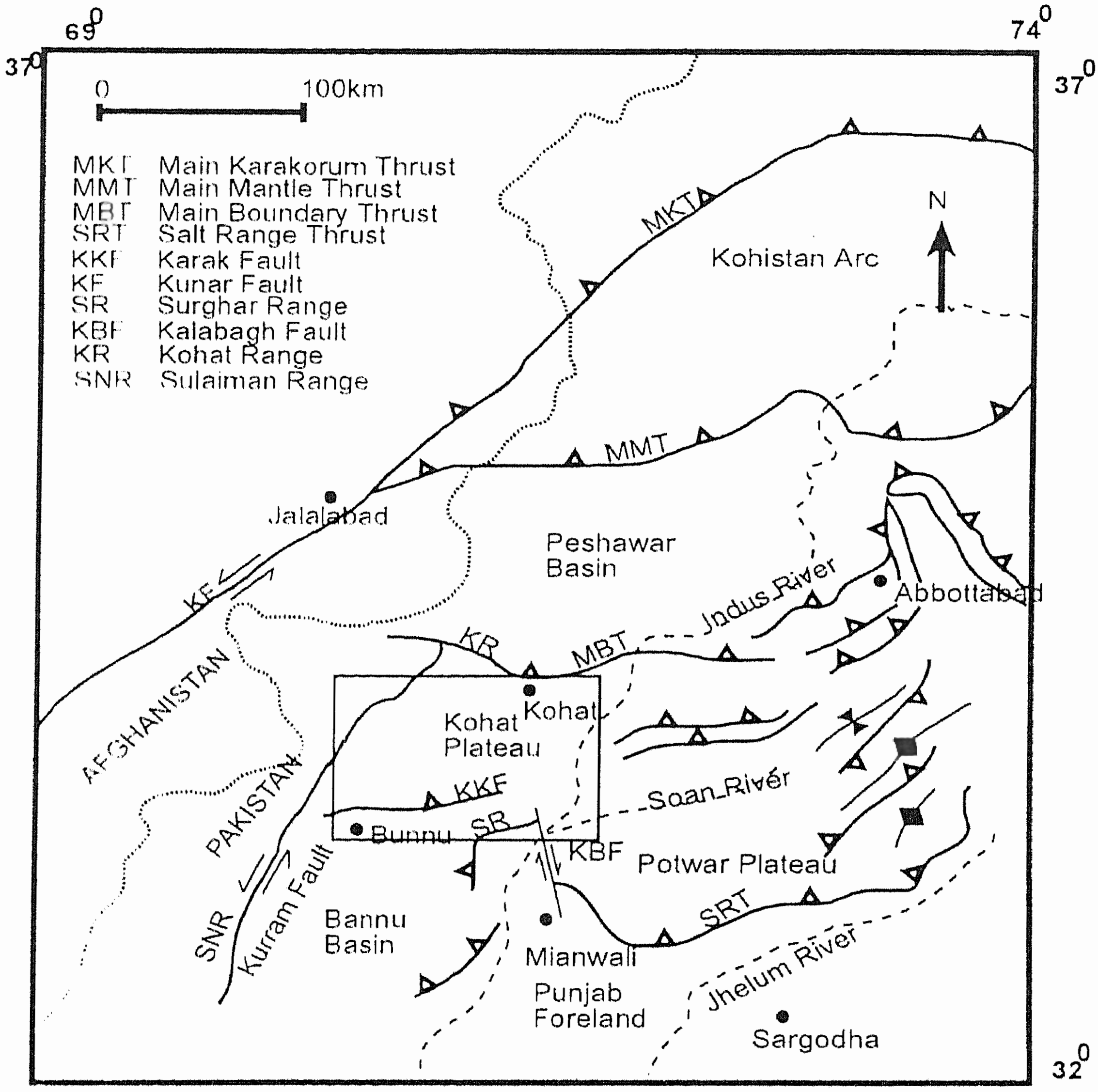


Figure 1.1. Tectonic map of North Pakistan, showing major structural features and towns (modified after Kazmi and Rana, 1982).

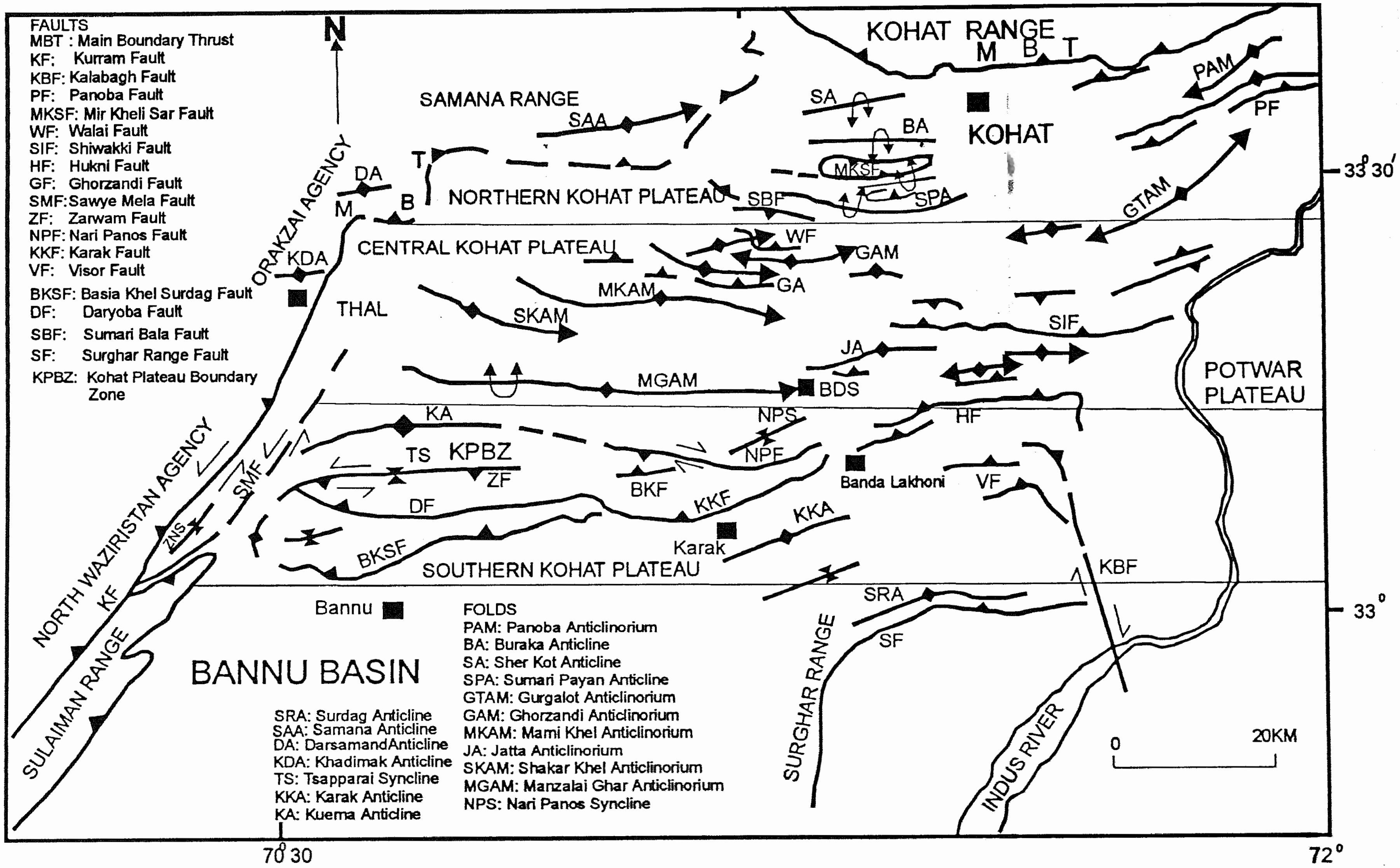


Figure 1.2. Structural Map of Kohat Plateau (Modified after Pivnik & Sercombe, 1993).

Importance of evaporites and shale sequences in the dynamic and kinematic evolution of foreland fold and thrust belts have long been suspected. The reason is that evaporites and shale have extremely low yield strengths compared to other lithologies and play an important role in controlling the structural geometry of the fold and thrust belts. Evaporites exposed in the south and shale in the north constitute the base of the Eocene rocks and is the oldest stratigraphic sequence in the Kohat Plateau. These lithologies have a strong impact on controlling the structural style of the plateau. The Kohat Plateau has been found to be a hybrid terrain of complex structural geometries, which can be attributed to salt and shale diapirism, thrust faulting and wrench faulting.

This study will help in understanding the tectonic evolution of an active foreland fold and thrust belt having evaporites and shale horizons at a shallow level. It will also help to work out processes involved in the development of variable structural suits within the Eocene and Miocene carapace of Kohat Plateau and whether these share an extensive and common detachment at the base of Eocene or to a basal detachment at deeper level.

1.2 Historical review

The Kohat Plateau has been frequently investigated by workers since Burnes (1832) reported the occurrence of salt in the Kohat Plateau. The salt deposits of Kohat Plateau have also been referred in various reports and articles by a large number of earlier geo-scientists of the Geological Survey of India (Oldham, 1890; Wynne, 1879; Pinfold, 1918 and Davies, 1926). Gee (1945) presented a regional overview regarding the age and stratigraphic relationship of the Salt Range and the Kohat salt deposits. Raza and Khattak (1972) of the Geological Survey of Pakistan published a useful report on the gypsum deposits of the Kohat area. Fatmi (1973) has produced an excellent piece of work by establishing the lithostratigraphic units of the Kohat region.

Significant contribution owes to Meissner *et al.* (1974, 75) regarding the geology of the Kohat Plateau. They conducted detailed geological investigations and prepared a geological map at a scale of 1:250,000, including the lithostratigraphic boundaries and structural details. Well (1984) worked out the depositional environments of the Cenozoic rocks in detail. McDoughall and Hussain (1991) prepared a balanced cross section through the eastern Kohat Plateau and Surghar Range to describe the fold and thrust propagation beneath the Kohat Plateau. Abassi and McElroy (1991) outlined a structural model for the plateau utilizing north-dipping, low-angle imbricate thrust faults underneath a Passive roof thrust. An alternate interpretation of the plateau suggests that it is a complex, hybrid terrain consisting of strike-slip and compressional features (Pivnik, 1992; Pivnik and Sercombe, 1993; Sercombe *et al.*, 1994 a, b). They suggested that the majority of early Cenozoic rocks exposed in the plateau crop out in the core of anticlines and forms detachment folds and pressure ridges above complex, positive flower structures that represents considerable amount of north to south shortening.

1.3 Aims and Problems

Some of the questions addressed in this study are:

1). What is the style of deformation? Is Kohat Plateau a typical foreland fold and thrust belt characterized by listric thrust faults, pop-ups and triangle zones or it is a hybrid terrain of compressional and transpressional related deformational structures?

2). What is the role of Eocene evaporites controlling the structural style of Kohat Plateau?

3). What is the nature of detachment at the interface between sedimentary carapace and basement? If we have the Eocambrian salt at the base, which is the case in the Potwar Plateau, then why do the structural geometries of the Kohat Plateau differ from the Potwar Plateau?

4). What is the geometric relationship between structures within the Eocene cover and underlying Mesozoic sediments?

5). What is the structural geometry of the Surghar Range front and how does the ramping mechanism vary along the strike of the range?

1.4 Objectives

The Kohat Plateau is important for the study of fold and thrust belt mechanism. Several studies of reconnaissance nature within Kohat Plateau have resulted in small-scale maps. The main aim of this study is to unravel the structures of the Kohat Plateau in detail. Following are some of the main objectives of this study.

1). To prepare a detailed structural map of Kohat Plateau with the help of aerial photographs and field traverses.

2). To correlate and synthesize the variety of structural suites with each other and structural style within adjoining Potwar Plateau in the east.

3). To develop a comprehensive structural model for the tectonic evolution of the region.

4). To study the kinematic relationship between the structural styles within the plateau and adjacent regional tectonic features.

1.5 Geological setting

The Kohat Foreland Fold and Thrust belt became part of the terrigeneous Indo-Gangetic foreland basin by early Miocene and is represented by sedimentary rocks, ranging in age from Paleocene to Pliocene. The oldest rocks exposed in the area belong to Paleocene and consist of limestone and shale. These rocks were deposited in a restricted fore deep marine environment due to the loading of the Indian plate margin and represent the first record of the

Himalayan convergence (Pivnik and Wells, 1996). This sequence is conformably overlain by a complex assemblage of shale, carbonate, evaporite and clastic rocks, which were deposited in a restricted marine basin and represent a tectonically isolated portion of the Tethys sea situated between northwestern Indian continental margin and the southern Asian margin (Pivnik and Wells, 1996). The Eocene sequence is in turn unconformably overlain by a thick succession of Miocene to modern molasse sediments of Murree and Siwalik Group. The molasse interval of sedimentation is lithologically represented by sandstone, shale and conglomerate. This sequence is believed to be the result of Himalayan exhumation.

The northern margin of the plateau is marked by Kohat Range trending east-west and is composed of Jurassic to Paleocene carbonate, sandstone and shale having a total stratigraphic thickness of 1300 meters. Towards west of the plateau, a series of right stepping enechelon anticlinal trends such as Khadimak, Darsamand and Samana Anticline (Samana Range) mark its geographic and stratigraphic boundary with Orakzai Agency (Figure 1.2). These structures expose about 1000 meters thick succession of Jurassic to Paleocene rocks comprising limestone, shale and sandstone.

The Surghar Range is located towards southeast of Kohat Plateau and represents its leading deformational front. It exposes about 1100 meters thick Triassic to Eocene rocks including carbonates, sandstone and shale. This sequence is unconformably overlain by a thick succession of middle Miocene to Pleistocene rocks of Siwalik Group. Towards southwest, the flat lying Bannu Basin, which is covered by recent sediments, borders the plateau. The western boundary of the plateau have a faulted contact with the north-south trending Sulaiman Range, which is a complex assemblage of sedimentary melange and Mesozoic to recent sediments.

CHAPTER # 2

TECTONIC AND STRUCTURAL SETTING

2.1 Tectonic setting

The world's spectacular mountain chains, the Himalayas are sandwiched between Eurasian plate in the north and Indian plate in the south. These mountains are characterized by oroclinal geometry having northwest trend in India, change to an east-west orientation in Pakistan and become more north-south along the western border of Pakistan (Figure 2.1).

The origin of Himalayan mountain chain can be attributed to the global plate kinematics and reconstruction when a plate of the earth's crust carrying Indo-Pakistan continent was separated from the mother Gondwana about 130 Ma ago and started northwards drift (Johnson *et al.*, 1976). As a consequence, the Neo-Tethys that was located between the Indian continent in the south and Asian plate in the north started shrinking. This shrinkage and continental drift was facilitated by the consumption of Neo-Tethy, opening up of Indian ocean behind, the transform motion along Owen Fracture Zone located towards southwest of the Indo-Pakistani subcontinent and Ninetyeast Ridge located towards southeast of Indo-Pakistani subcontinent (McKenzie and Sclater, 1976, Figure 2.2). During the closure of Neo-Tethys Ocean intraoceanic subduction generated a series of arcs, namely Kohistan–Ladakh, Nuristan and Kandhar (Searle, 1991; Treloar and Izatt, 1993). The arc magmatism occurred for a period of 40 Ma (Petterson *et al.*, 1985), after which the back-arc basin was finally closed and the Kohistan–Ladakh arc was accreted onto the Eurasian plate forming an Andean type continental margin. The collisional boundary is referred to as the Main Karakorum Thrust (MKT) where the collisional event began at 50-55 Ma (Powell, 1979 and Patriate and Achache, 1984). This collisional time is also supported by the fact that Indo-Pakistani subcontinent was rapidly drifting at a rate of 15 centimeter per year northwards relative to Australia and Antarctica

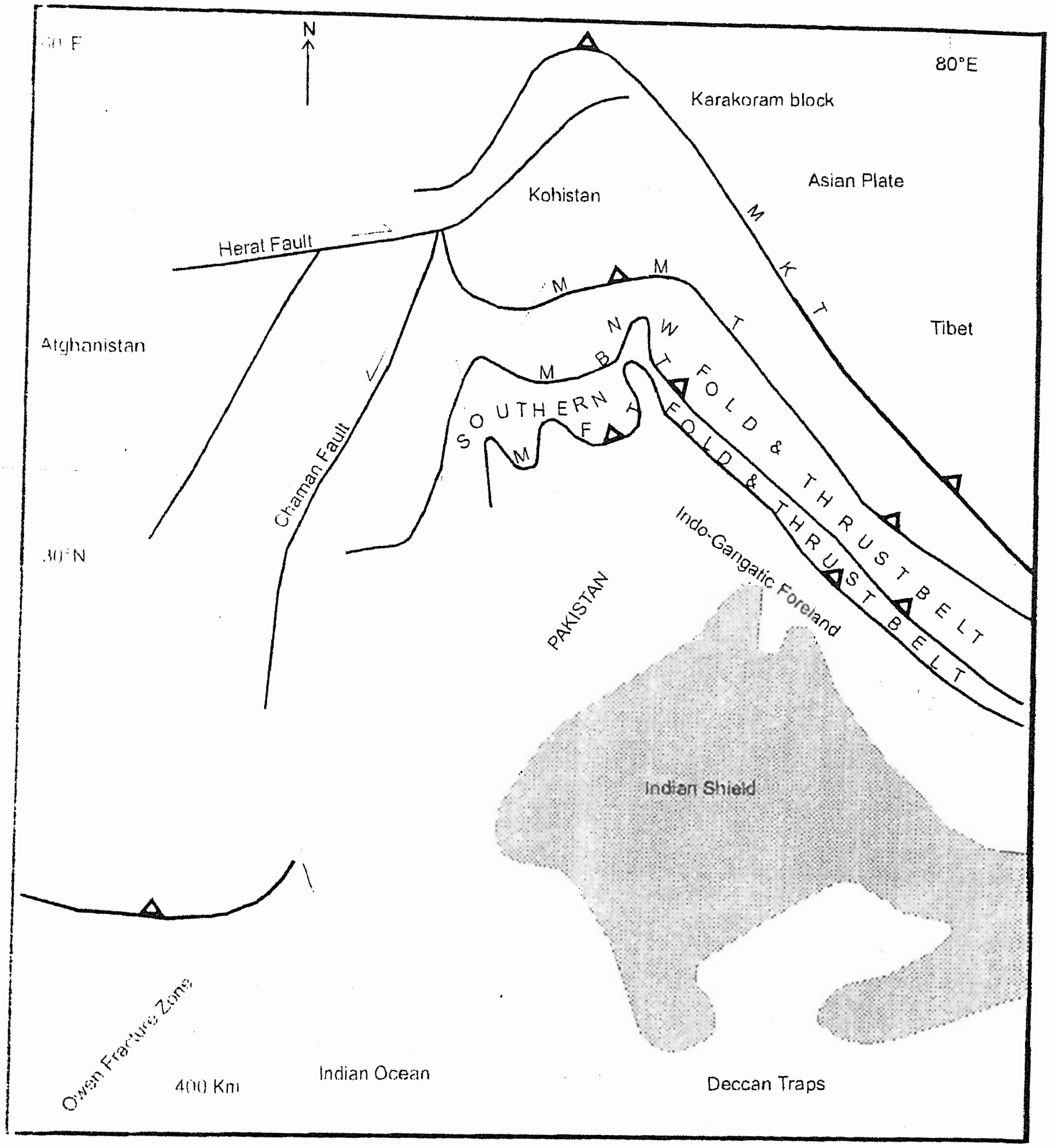


Figure 2.1. Tectonic map of northwest Pakistan (Modified after Powel,1979 and Treloar and Izatt,1993).MKT: Main Karakoram Thrust; MMT: Main Mantle Thrust; MFT: Main Frontal Thrust.

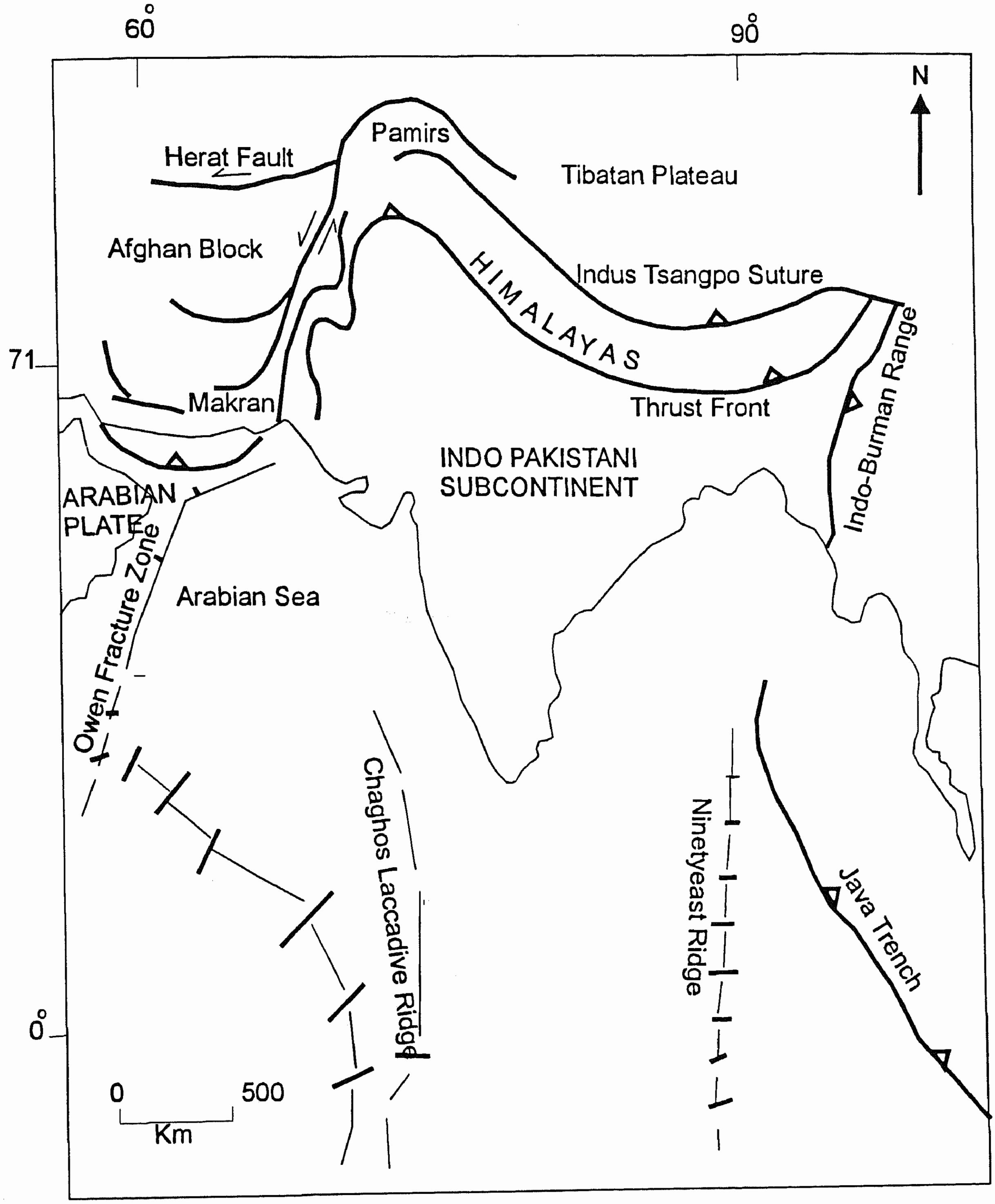


Figure 2.2. Tectonic map of India-Eurasia collision zone (Modified after Qayyum et al.,1996).

about 80 Ma ago. From 53 Ma to the present, Indo-Pakistani subcontinent seemed to have moved northwards at much slower rates of 4 to 6 centimeter per year (Powell, 1979). The abrupt slowing down is a consequence of the collision with Eurasia during the early Tertiary (LeFort, 1975; Molnar and Tapponier, 1975; Klootwijik *et al.*, 1992).

After the Kohistan–Ladakh arc was docked onto the Eurasian plate in the north, the subduction of Neo-Tethys beneath Kohistan–Ladakh arc was still continued and resulted in the complete consumption of the leading edge of the Indian plate that finally collided with the remnants of Kohistan–Ladakh arc (Powell, 1979). The collision between the Indian plate and the Kohistan–Ladakh arc occurred during Eocene and is marked by the Main Mantle Thrust (MMT) (Tahirkheli, 1979). The south migration of Himalayan deformation from the site of MMT is represented by the Main boundary Thrust (MBT) along which the northern deformed fold and thrust belt is thrust southwards over the molasse sediments of Potwar and Kohat Plateau.

The collision tectonics along western border of the Indian craton is highly controversial. The western boundary of the Indo-Pakistani plate is commonly taken as Chaman Fault, which extends from Kharan to Kabul for about 850 kilometers (Kazmi, 1979a; Lawrence *et al.*, 1979). It connects the convergence zones of Makran (in the south) with the Himalayan in the north. However, several cratonic blocks and plate margin indicators have been recognized about 100 to 300 kilometers southeast of its previously established plate boundary such as Chaman Fault. One of these cratonic blocks, the Kabul block located further east of Chaman Fault (Figure 2.3), has ophiolites on its eastern and werstern boundary. It has been interpreted as an isolated continental block, which was obducted onto the Indian plate during early Eocene, followed by collision of India with Asia during middle Eocene (Powell, 1979; Tappnier *et al.*, 1981a) or Paleocene (Treloar and Izatt, 1993). East of the Kabul block, highly deformed Mesozoic sedimentary rocks with scattered ultra mafic rocks of Waziristan igneous complex are present. These Mesozoic sediments are

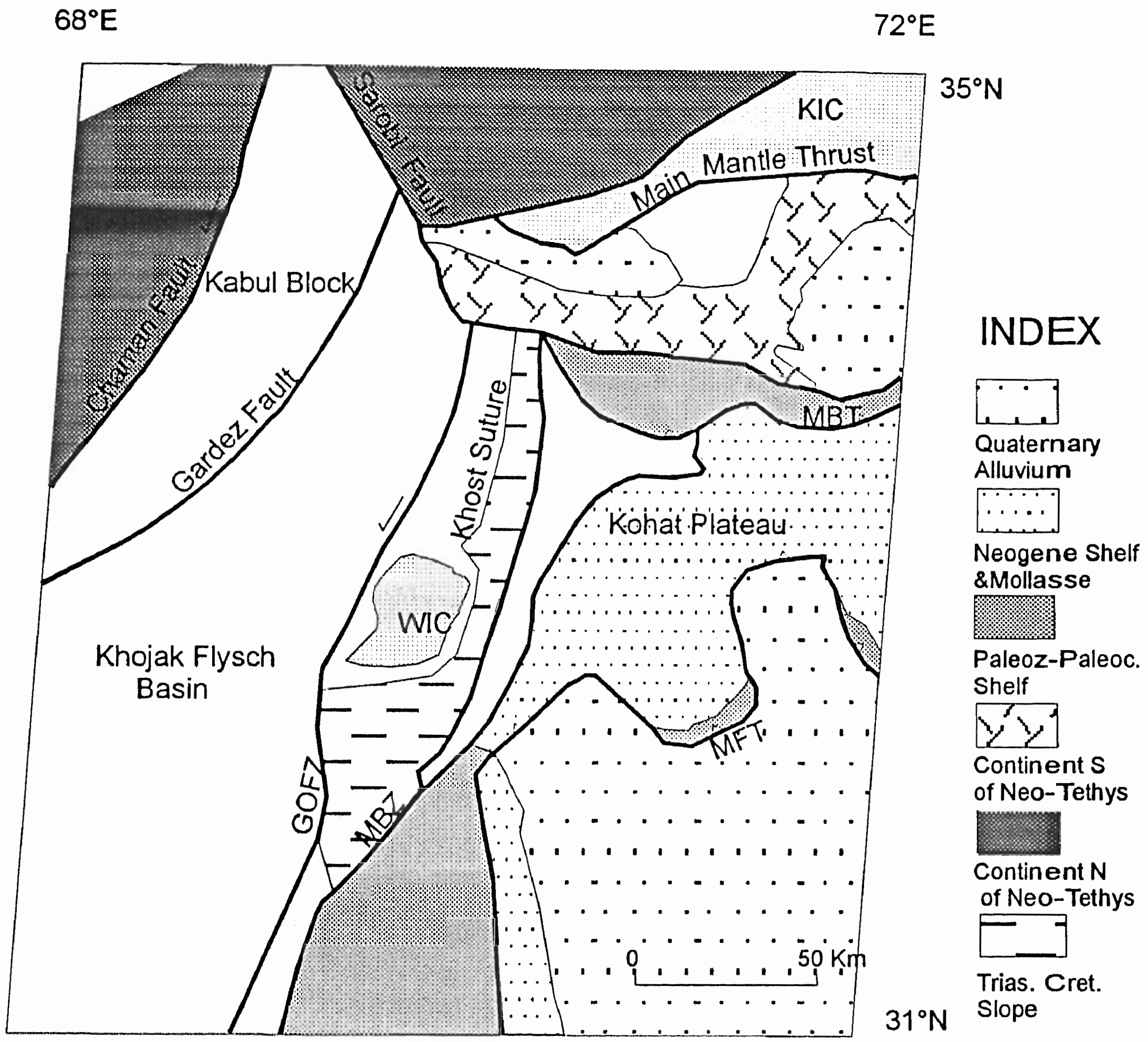


Figure 2.3. Tectonic map of northwestern Pakistan and eastern Afghanistan (Modified after Beck et al.,1995). GOFZ: Gwarar Oba Fault Zone, MBZ, Melange Boundary Zone, MBT: Main Boundary Thrust, MFT: Main Frontal Thrust, KIC: Kohistan Igneous complex, WIC: Waziristan Igneous Complex.

also characterized by Cretaceous to early Cenozoic ophiolites and accretionary arcs (Beck *et al.*, 1996; Treloar and Izatt, 1993). All these facts lead to the conclusion that the western plate boundary lies far east of its previously recognized location such as Chaman Fault.

2.2 Structural setting

The Pakistani Himalayas can broadly be subdivided into five tectono-stratigraphic terrains, delineated by regional fault boundaries (Figure 2.1). From north to south these are as under:

Karakorum block

------- Main Karakorum Thrust (MKT)-------

Kohistan Island arc

------- Main Mantle Thrust (MMT)------------

Northwestern deformed fold and thrust belt

------- Main Boundary Thrust (MBT)----------

Southern deformed fold and thrust belt

------- Salt Range Thrust (SRT) and Trans Indus Ranges Thrust (TIRT)------

Indo-Gangetic foredeep

The Karakorum block consists of complex assemblages of heavily deformed sedimentary, metasedimentary and igneous rocks of the southern Asian plate lies between Pamirs in the north and Kohistan–Ladakh arc in the south. Its southern boundary is marked by MKT, which separates the Paleozoic metasediments of Karakorum block from the Cretaceous–Tertiary Kohistan–

Ladakh arc. The MKT was closed in late Cretaceous (Tahirkheli, 1982; Coward *et al.*, 1986).

The Kohistan island arc developed in response to northward-directed subduction of Neo-Tethys underneath Asia during late Jurassic to Cretaceous time (Searle *et al.*, 1987). It covers 36000 square kilometer area in western Himalayas, Karakorum and eastern Hindukush. The arc is oriented east-west and comprises a variety of volcanic and plutonic rocks and subordinate sedimentary rocks that have undergone varying degree of deformation and metamorphism. It is divided into Ladakh and Kohistan arc by the north-south trending Nanga Parbat Haramosh massif and is underlain by the Indian crustal plate (Seeber and Armbuster, 1979). The arc is bounded by the MKT towards north and MMT towards south, which merges laterally in India and Tibet to form a single suture such as the Indus Tsangpo suture. In Afghanistan, towards west of the Kohistan arc the two bounding suture zones such as MKT and MMT join one another and merge with the left lateral Kunar Fault (Figure 2.4).

The northwestern deformed fold and thrust belt lies south of MMT and comprises festoon shaped belt of heavily deformed sedimentary, meta-sedimentary and igneous rocks. This belt stretches from Kurram area in the west near Afghan border up to the Kashmir basin in the east. The MMT, which borders its northern margin, exhibits major swing in its trend towards northeast giving rise to a reentrant within the Kohistan island arc sequence. This reentrant is called as Nanga Parbat-Haramosh massif and is composed of more than 15 km thick Proterozoic gneisses and schists (Madin, 1986). The MMT dips northwards, between 25° and 45° (Malinconico, 1986) and is the southern most thrust involving lower-crust crystalline rocks of the Indo-Pakistani shield (Lefort, 1975; Bard, 1983a). The MMT is possibly correlative with the Indus suture in India. The northwestern fold and thrust belt is bounded by MBT towards south and separate it from the southern deformed fold and thrust belt.

The southern deformed fold and thrust belt rims the Himalayan mountain belt from Gange delta in India up to the South Waziristan Agency in Pakistan (Figure 2.1). It is oriented east-west and is underlain by a thick pile of fluvial sediments. This belt was the main depocenter of the synorogenic sediments influx, which started in early Miocene. The Salt Range Thrust (SRT) and Trans Indus Ranges Thrust (TIRT) mark the southern boundary of this deformed fold and thrust belt, and separates it from the Indo-Gangetic foredeep in the south. The SRT and TIRT represent the active deformational front along which Cambrian to Paleocene rocks are thrust southwards on to the Indo-Gagentic foredeep.

The Indo-Gangetic foredeep rims the southern most extension of Himalayan mountain chain in India and Pakistan (Figure 2.1). It is overlain by unconsolidated Quaternary sediments and is the present day depocenter for the eroded debris from the Himalayan chains in the north.

The Kohat Plateau lies in the southern deformed fold and thrust belt and was located far off southwards of the shelf margin at the time of collision and suturing in the north. The area had been influenced by the southward progression of deformation during late Miocene. The plateau is bounded to the north by the MBT, which brings highly deformed Mesozoic rocks of Kohat Range over the Eocene-Miocene sediments of Kohat Plateau (Yeats and Hussain, 1987). Towards west, the Kurram Fault juxtaposes highly deformed Mesozoic rocks of Samana, Darsamand, Thal and North Waziristan Agency with the Eocene to Miocene sediments of the Kohat Plateau. The Kurram Fault is believed to be a left lateral transpressive boundary. The southeastern boundary of the Kohat Plateau is the Surghar Range with Mesozoic rocks emplaced southwards onto the Indo-Gangetic foredeep in the south. Toward south, the undeformed sediments of Bannu Basin form the southern boundary of the plateau.

CHAPTER #3

STRATIGRAPHIC FRAMEWORK

3.1 Introduction

The stratigraphic framework of the area can be grouped into four major units; (1) Paleocene sequence; (2) Eocene sequence; (3) Rawalpindi Group; and (4) Siwalik Group rocks respectively. The stratigraphic details are summarized in Table 1 and Figure 3.1. The oldest sediments belong to the Lockhart Limestone and Patala Formation of Paleocene age conformably overlain by the early Eocene to middle Eocene rocks. These are in turn unconformably overlain by the fluvial molasse sediments of the Rawalpindi and Siwalik Groups (Plate 1, in pocket). In this study the nomenclature used by Meissner et al. (1974, 1975), Shah (1977) and Pivnik and Wells (1996) has been followed.

3.2 Paleocene sequence

The Paleocene sequence within the Kohat Plateau is represented by Lockhart Limestone and Patala Formation. Their exposure is confined to the northeastern corner of the plateau, where this sequence forms the core of the Panoba Anticlinorium (Figure 1.2).

Lockhart Limestone

The Lockhrat Limestone of Davies (1930a) represents the base of Paleocene sequence and is composed of finely crystalline light gray to dark gray limestone. The limestone is massive to thick bedded and has rounded character (Figure 3.2). The formation contains abundant Forams. The thickness of the formation is not known because its base is not exposed within the Kohat Plateau. It lithologically grades upward into the overlying Patala Formation.

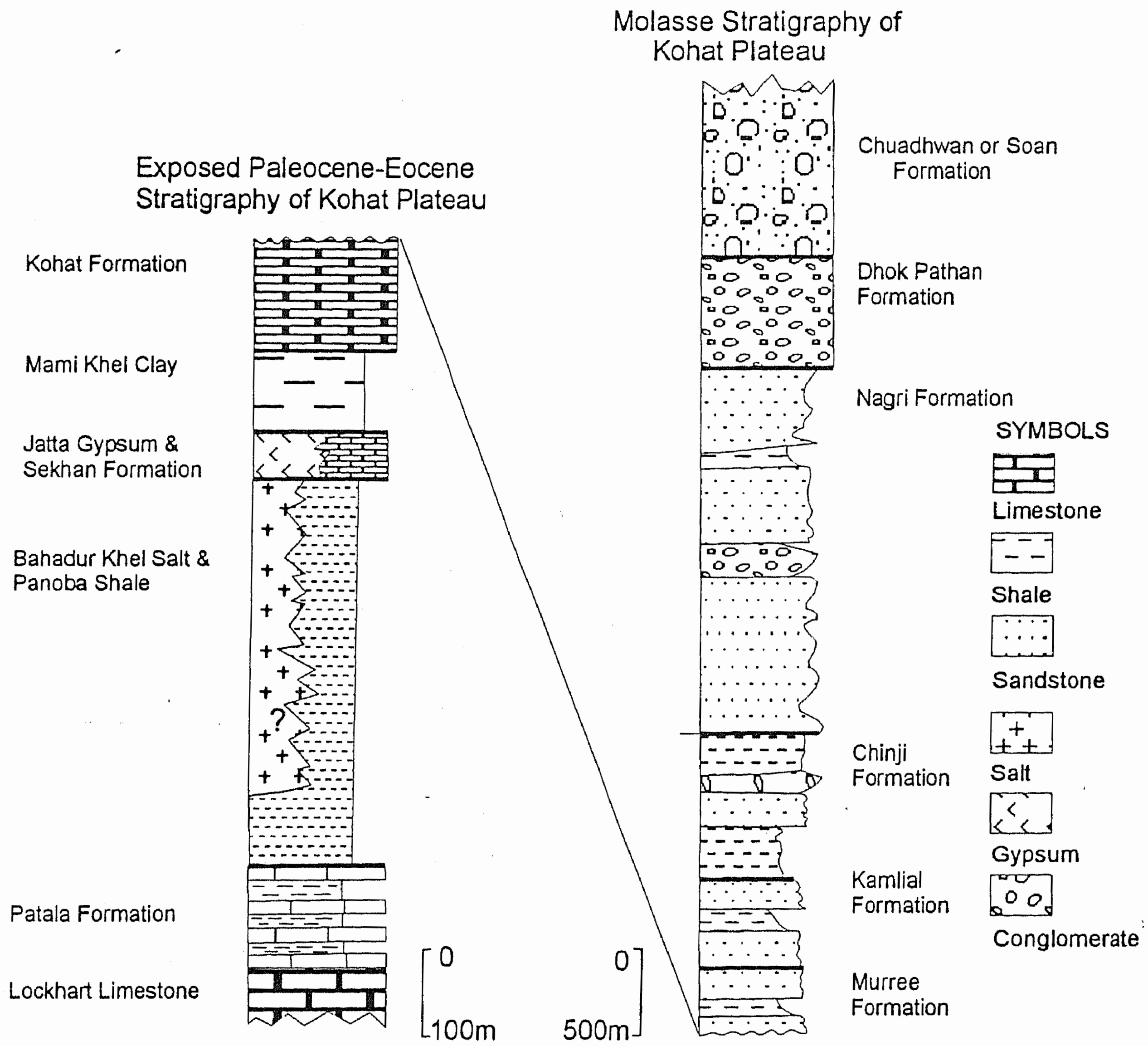


Figure 3.1. Composite stratigraphic column of the rocks of Kohat Plateau.

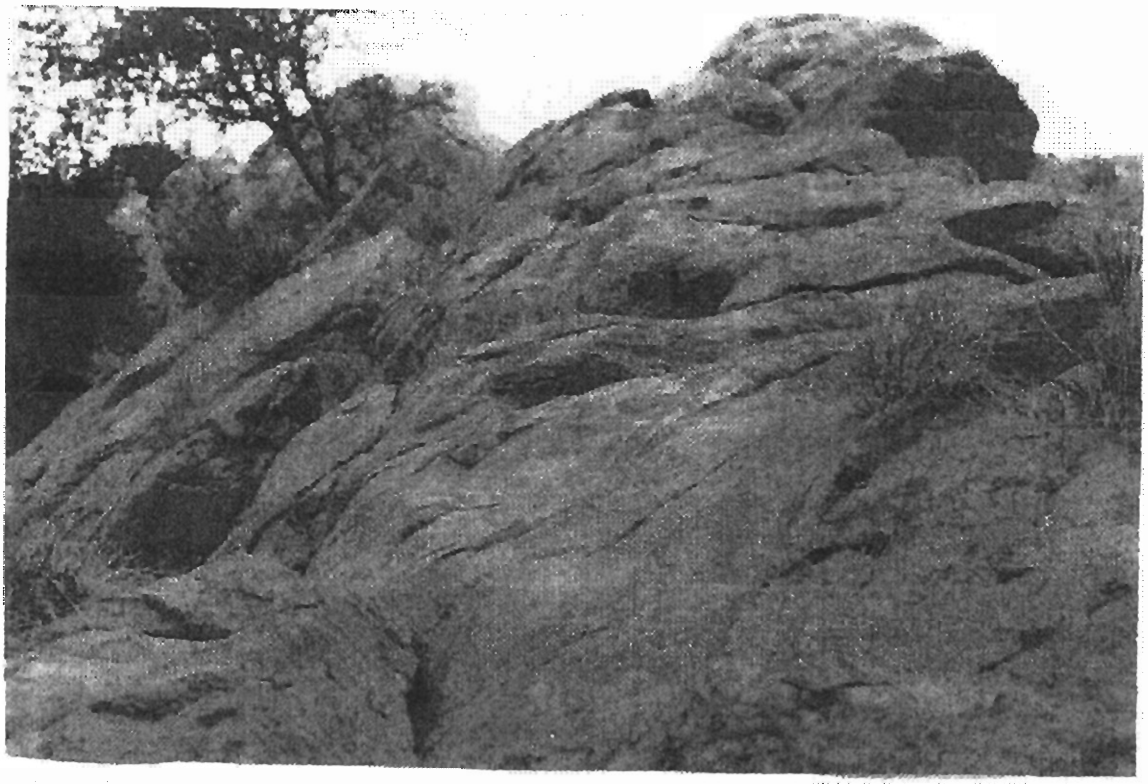


Figure 3.2. Outcrop of massive to thick- bedded Lockhart Limestone at Panoba section.

Table 1. Stratigraphic framework of the Kohat Plateau (Modified after Meissner et al., 1974).

Age	Units	Formation
Quaternary		Quaternary alluvial sediments (No formation name)
Plio-Pleistocene	Siwalik Group	Chuadhwan/Soan Formation Dhok Pathan Formation Nagri Formation. Chinji Formation
Miocene	Rawalpindi Group	Kamlial Formation Murree Formation
Eocene	Eocene Sequence	Kohat Formation Mami Khel Clay Shekhan Formation Jatta Gypsum Bahadur Khel Salt Panoba Shale
Paleocene	Paleocene Sequence	Patala Formation Lockhart Limestone

Patala Formation

The Patala Formation of Davies and Pinfold (1937) is composed of dark gray to maroon, splintery shale interbedded with argillaceous limestone (Figure 3.3). The limestone is gray to dark gray, thin to medium-bedded, whereas the shale contains limonitic concretion. Early Eocene Foraminifera have been found near the top of the formation at Tarkhobi section (south limb of Panoba Anticlinorium, Figure 1.2). The Patala Formation is 110 meters thick at Panoba and Tarkhobi sections and is conformably overlain by early Eocene Panoba Shale.

3.3 Eocene sequence

Panoba Shale

The Panoba Shale of Eames (1952) represents the base of the Eocene sequence within the Kohat Plateau. The shale is greenish gray to olive green and is found to be soft and slightly silty. At places the shale contains beds of arenaceous limestone and calcareous sandstone (Figure 3.4). The thickness of Panoba Shale varies at different localities. It is found to be thick in the eroded cores of Manzalai Ghar and Ghorzandi Anticlinorium and Kurma, Chaprai, and Sumari Bala anticlines and thins out in the northeastern direction in Gurgalot and Panoba Anticlinorium (Figure 1.2).

The Panoba Shale exposed in the Manzalai Ghar Anticline, interfinger with the Bahadur Khel Salt and is believed to be its southeastern equivalent within Kohat Plateau (Meissner et al., 1974). The Panoba Shale in the northeastern Kohat Plateau is conformably overlain by the Shekhan Formation and in the central plateau by Mami Khel Clay. It is unconformably overlain by the Kohat Formation in the core of Kurma Anticline and Manzalai Ghar Anticlinorium (Plate 1). The thickness of the formation is not known, because the base is not exposed along most of the outcrops within the Kohat Plateau.

Figure 3.3. Dark gray carbonaceous shale, interbedded with thin limestone beds of Patala Formation at Panoba section.

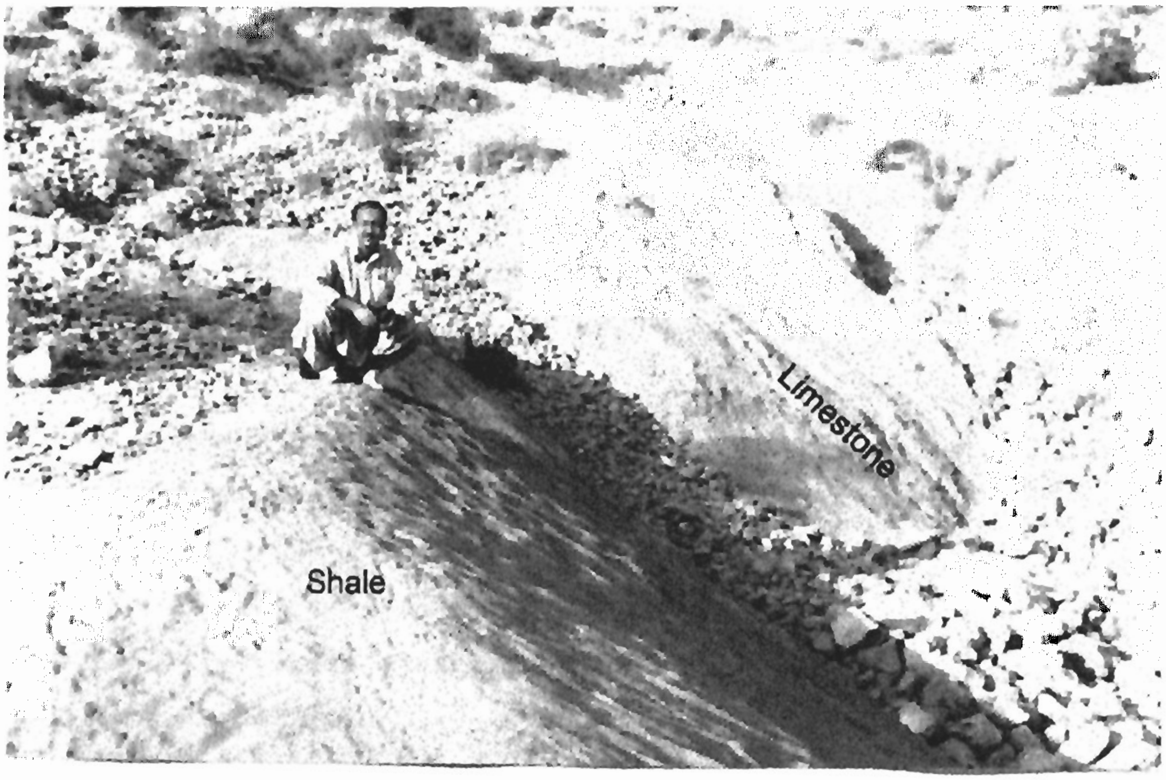


Figure 3.4. Greenish-gray shale with thin limestone beds of Panoba Shale at Panoba section.

Bahadur Khel Salt

The Bahadur Khel Salt of Meissner *et al.* (1974) consists light gray salt which is generally free of clay and calcareous material (Figure 3.5). The salt occurs as diapirs and is confined to the Southern Kohat Plateau where it is exposed in the core of Manzalai Ghar Anticlinorium (western half), and Bozda, Bahadur Khel and Cheshmai anticlines (Figure 1.2). The formation is believed to be the lateral equivalent of Panoba Shale of (Meissner et al., 1974) and is conformably overlain by the Jatta Gypsum.

Shekhan Formation

The Shekhan Formation of Davies (1926) dominantly consists yellowish-gray, nodular limestone. The limestone is massive to thin-bedded and nodular (Figure 3.6). The lower part consists planar, laminated, bioturbated foraminiferal limestone and green shale. It has yielded benthic forams such as Nummulites, Assilina, pelecypodes, gastropods, echinoids and bryozoa (Figure 3.7). The upper most 30 feet is mostly gypsiferrous shale. The formation is best exposed east of the Kohat city in Shekhan Nala, Panoba Anticlinorium, and northern flank of Sumari Bala Anticline and Mami khel Anticlinorium and is absent from the rest of the Kohat Plateau.

The Shekhan Formation is considered to be the lateral equivalent of Jatta Gypsum present in the Southern Kohat Plateau (Meissner et al., 1974). It has conformable contacts with the underlying Panoba Shale and overlying Mami Khel Formation. The formation has a maximum thickness (50 meters) in the Panoba Anticline.

Jatta Gypsum

The Jatta Gypsum (Meissner et al., 1974) is comprised of greenish-white to gray gypsum and is massive to thin-bedded (Figure 3.8a and b). It has thin reddish, purple and green clay partings at most of the exposures. It also contains

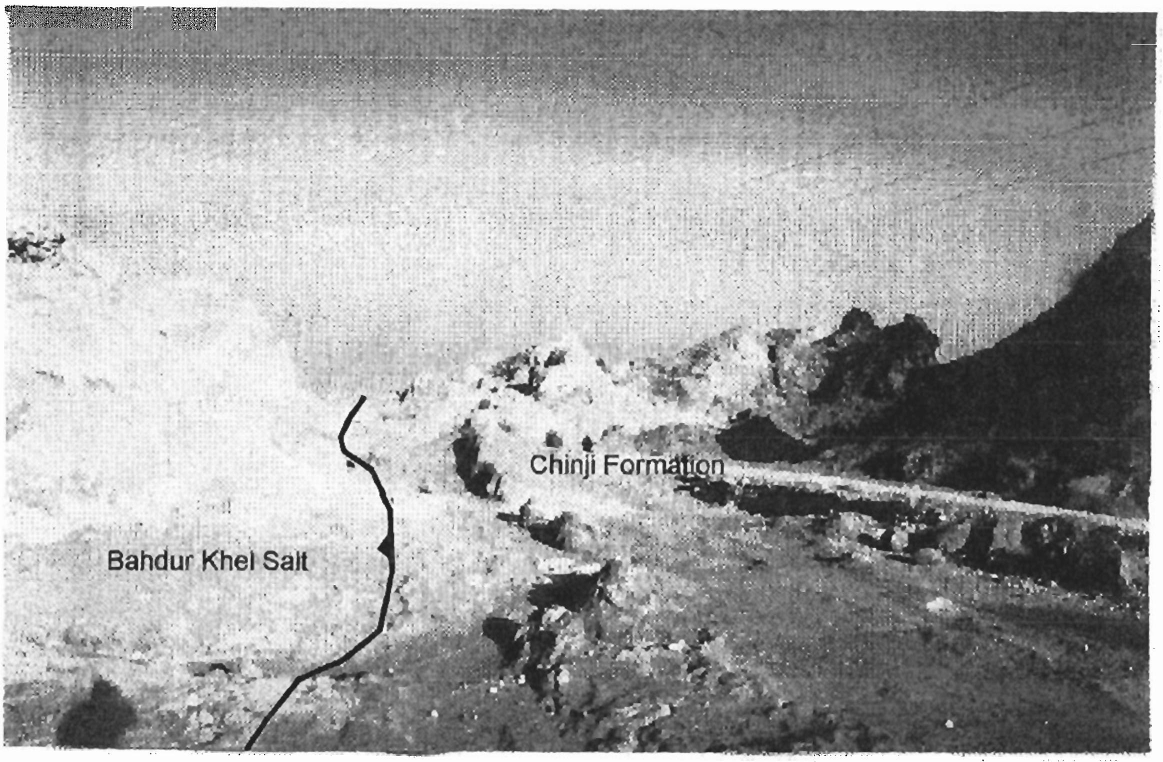


Figure 3.5. Outcrop of light-gray Bahadur Khel Salt exposed within the core of Bahadur Khel Anticline along the Bannu- Kohat road.

Figure 3.6. Yellowish-gray nodular limestone of Shekhan Formation interbedded with greenish shale at Shekhan Nala, east of Kohat city.

Figure 3.7. A view of a foram-rich limestone of Shekhan Formation exposed in Shekhan Nala.

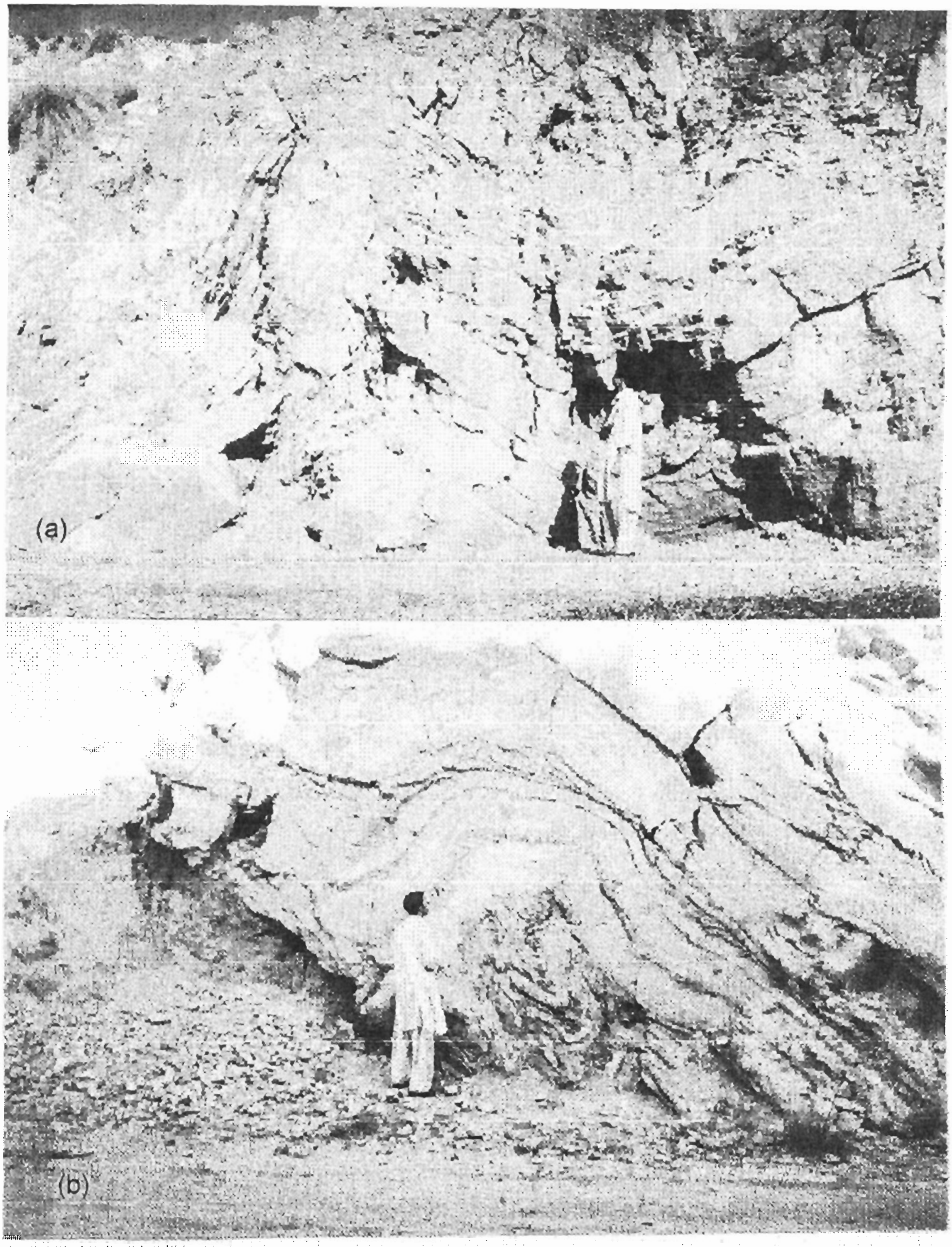


Figure 3.8 a & b. Greenish white to gray, thin to thick-bedded, highly contorted gypsum beds within Jatta Gypsum, along Karak-Nari Panos road.

White shale, chalky-dolomite, thin clay-rich carbonate and channel-filled sandstones at places. The thickness of the formation is variable between 20 to 30 meters at the type locality. The upper and lower contacts of the formation are conformable with Mami Khel Clay and Bahadur Khel Salt respectively. Its upper contact with the Mami Khel Clay is generally sharp but north of Karak along Karak–Nari Panos road, red shale is interbedded with gypsum in upper 2 meters. The formation is considered as lateral equivalent of the Shekhan Formation, which is developed within the Northern Kohat Plateau (Meissner et al., 1974).

Mami Khel Clay

The Mami Khel Clay of Meissner et al. (1974) consists of brownish red, soft, silty and calcareous clays (Figure 3.9). At places thin lenses of limestone and conglomerate are also present. The thickness of the formation is variable because of its plastic nature and is 125 meters thick at the type section along the flanks of Mami Khel Anticline. The Mami Khel Clay is well distributed through out the Kohat Plateau except the southwest, where it is absent from the core of Kurma and Manzalai Ghar Anticlinorium (western half, Figure 1.2). The formation has conformable contact with the overlying Kohat Formation through out the Kohat Plateau except in the west where the Kohat Formation overlies it unconformably (Pivnik and Wells, 1996). The Panoba Shale and Jatta Gypsum through out the Kohat Plateau conformably underlie the Mami Khel Clay.

Kohat Formation

The Kohat Formation of Meissner *et al.* (1974) represents the top of the Eocene sequence within the Kohat Plateau. The three-fold subdivision of Kohat Formation into various members by Meissner *et al.* (1974) does not persist through out the plateau. The formation attains maximum thickness in the Northern Kohat Plateau southwest of Kohat city (180 meters) and varies between1-5 meter in the Southern Kohat Plateau along the flanks of Kurma

Figure 3.9. Brownish-red Mami Khel Clay containing limestone lenses, exposed within the core of Ghorzandi Anticlinorium.

anticline. At its type locality (southwest of the of Kohat city) the Kohat Formation is composed of thin-bedded foraminefral limestone and yellow-green shale at the base (Kaladhand Member of Davies, 1926). In the middle part, the formation is dominantly foraminefral grainstone, which is consisted almost of nummulites (nummulitc shale of Pinfold, 1918). Towards the top it comprises thick-bedded limestone (Kohat Limestone of Davies, 1941), which makes ridges through out the Kohat Plateau (Figure 3.10). Its lower contact is conformable with the underlying Mami Khel Clay and is unconformably overlain by the Miocene series.

3.4 Miocene series

The Miocene series of Kohat Plateau includes Rawalpindi Group of Fatmi (1973), which comprises Murree and Kamlial Formation.

Murree Formation

The Murree Formation (Fatmi, 1973) is composed of red-purple sandstone and shale with white marl at places and is confined to the Northern and Central Kohat Plateau. It is absent south of Banda Daud Shah. The base of the Murree formation is marked by an unconformity with the underlying Kohat Formation. It contains oncolites, bivalves, gastropods and invertebrate bone fragments and is 250 meter thick near Kohat (Pivnik and Wells, 1996).

Kamlial Formation

The Kamlial Formation (Fatmi, 1973) dominantly consists greenish gray sandstone and red shale. It is 650 meters thick in the Kohat Plateau (Meissner et al., 1974) and is well developed through out the Kohat Plateau, occupying the cores of synclinal folds. The contacts with the underlying Murree Formation and overlying Siwalik Group rocks are conformable.

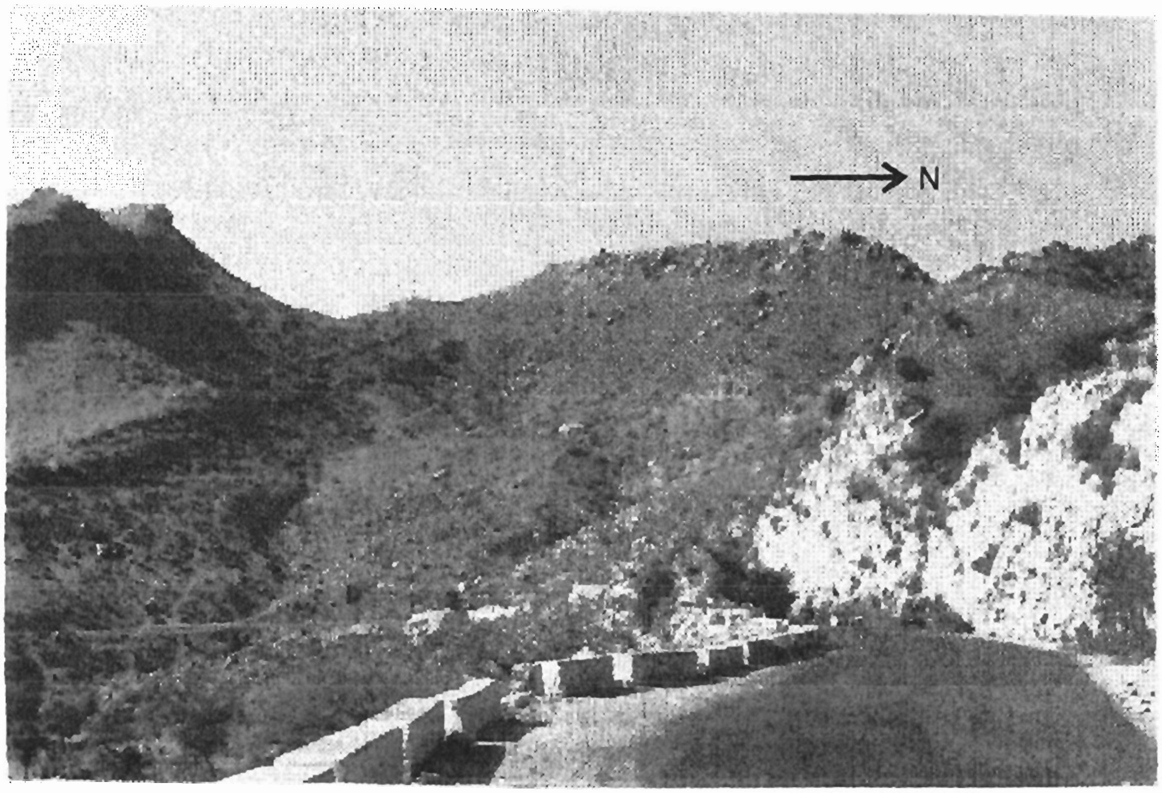


Figure 3.10. A ridge of the Kohat Formation exposed along Hangu-Kohat road, south of Jowzara rest house.

3.5 Pliocene-Pleistocene series

The Pliocene-Pleistocene series in the Kohat Plateau consisting of Siwalik Group rocks (Fatmi, 1973; Meissner et al., 1974, 75); is represented by Chinji, Nagri, Dhok Pathan and Chuadhwan/Soan formations. The name Chuadhwan Formation of Hemphil and Kidwai (1973) is retained herein for the upper Siwaliks, which are mapped in the core of Tsapparai Syncline (Figure 1.2). This sequence is similar in lithology to the Chuadhwan Formation exposed along the western flank of Bannu Basin (Figure 1.2).

Chinji Formation

The Chinji formation mainly consists red shale with frequent intervals of gray-green, soft sandstone. It is mostly confined to the synclinal valleys developed in the Southern Kohat Plateau. The formation is 1000 meters thick, measured along the northern limb of the Nari-Panos Syncline (Figure 1.2).

Nagri Formation

The Nagri Formation (Nagri Stage of Pilgrim, 1913; Chinji Formation of Lewis, 1937) is mainly composed of gray to greenish-gray sandstone with 30% of red shale and minor conglomerate in the Kohat Plateau. Its maximum thickness is recorded about 2500 meters in the core of Nari-Panos Syncline. The age of the Nagri Formation in the Kohat Plateau is not clear, however, in the Potwar Plateau, the formation has been assigned late Miocene age (Johnson et al., 1985).

Dhok Pathan Formation

The Dhok Pathan Formation (Lewis, 1937) is well developed south of Karak Anticline in the Banghar Range and along the flanks of Tsapparai Syncline in the southwest of Kohat Plateau. It represents the onset of conglomerate deposition in the Kohat Plateau and is 700-800 meters thick. The formation consists greenish-gray to white sandstone and conglomerate. The conglomerate contains clasts of metamorphic and igneous rocks with minor shale.

The formation is correlative with the Indus Conglomerate Formation Abbasi (1994), which is reported from the eastern Kohat Plateau. The age assigned to the Dhok Pathan Formation is late Miocene in the Potwar Plateau (Johnson et al., 1985).

Chuadhwan Formation

Chuadhwan Formation (Hemphil and Kidwai, 1973) is exposed in the southwestern corner of the Kohat Plateau, where it crops out in the core of Tsapparai Syncline (Figure 3.11). It is dominantly composed of cobble to boulder conglomerate. Clast types include metavolcanics, igneous rocks, quartzite and nummulitic limestone. Pivnik and Wells (1996) correlated it with the upper parts of Indus Conglomerate Formation of Abbasi (1994).

Figure 3.11. Conglomerate beds exposed in the core of Tsapparai Syncline of Chudwan Formation.

Chapter #4

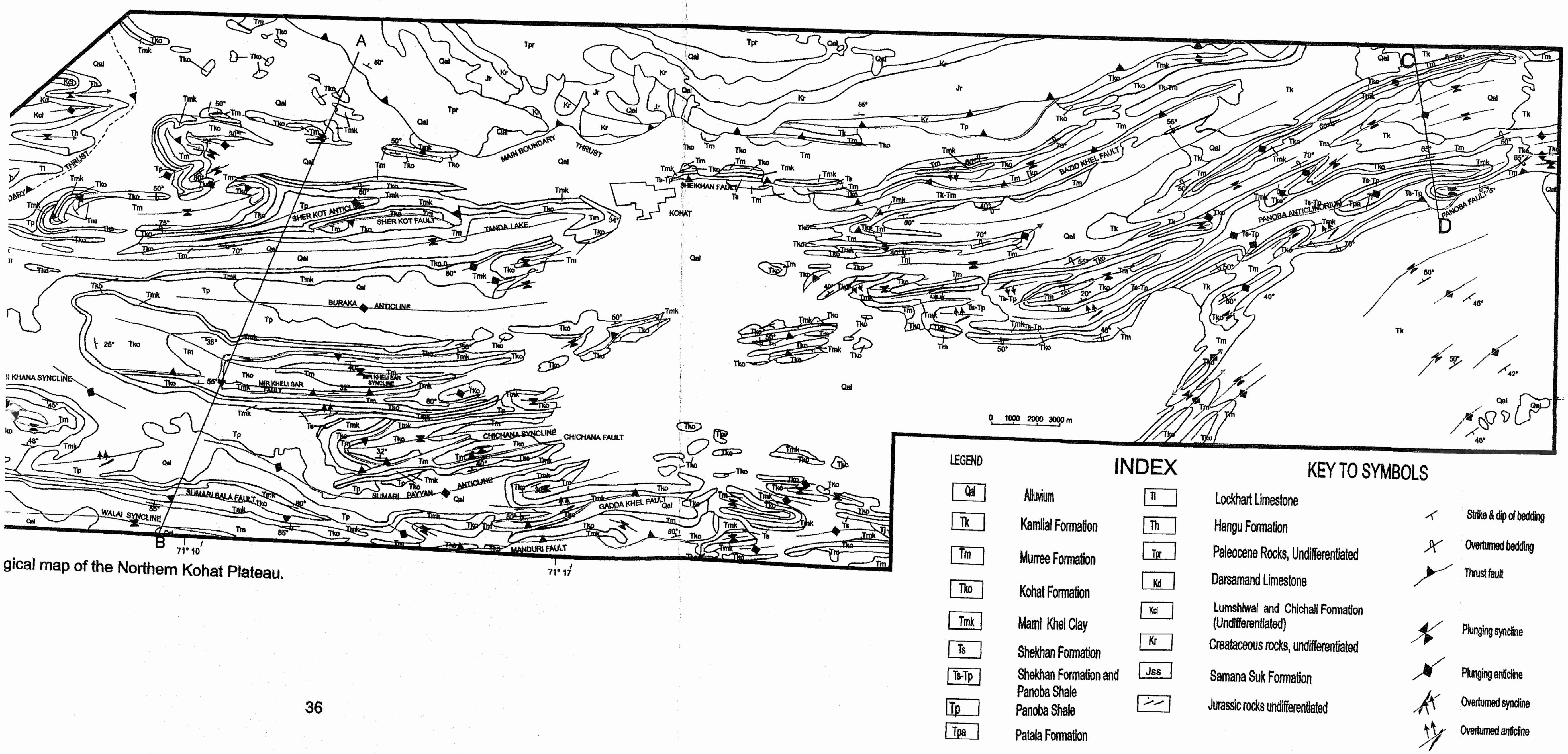
STRUCTURAL GEOMETRY OF NORTHERN KOHAT PLATEAU

4.1 Introduction

The Northern Kohat Plateau is marked by the Main Boudary Thrust (MBT) in the north and northwest and Sumari Bala Fault in the south (Figure 4.1). Being in close proximity to MBT, the Northern Kohat Fold and Thrust Belt was the first to experience the imprints of south migrating deformation. The MBT is a regional fault that brought the Mesozoic-Cenozoic shelf sediments of the Hill Ranges (Margalla, Kalachitta, Kohat and Samana Range) against a pile of molasse sediments, deposited in the foreland basins of Kohat and Potowar (Burbank, 1983 ;Yeats and Hussain, 1987). The stratigraphic record of Northern Kohat Fold and Thrust Belt shows that it was a restricted basin till the middle Eocene followed by a period of unconformity during late Eocene to Oligocene and became a synorogenic foreland basin since Miocene. Three major units that is Paleocene, Eocene and Miocene rocks represent the area. The Plio-Pleistocene Siwalik Group rocks are not exposed in this part of the Kohat Plateau because the foreland basin was migrating southwards in response to the uplift and tectonism associated with MBT, which started during Miocene (Burbank, 1983).

4.2 Surface Geology

The structure of the Northern Kohat Fold and Thrust Belt is dominantly controlled by eastwest trending folds, thrust faults, back thrust, and a large-scale overthrust sheet (Figure 4.1). The folds dominate the structural geometry, comprising tight anticlinal trends (Sher Kot, Buraka, Sumari Bala and Chaparai anticlines located southwest of Kohat city, (Figure 4.1), and broad intervening synclinal valleys with both the limbs overturned. Folds with broad anticlinoria (e.g. Panoba and Bazid Khel) are mapped as well (Figure 4.1). The Panoba anticlinorium is the most prominent structure located in the southwest and is



gical map of the Northern Kohat Plateau.

roughly oriented east west (Figure 4.1). The Bazid Khel Anticlinorium constitutes the footwall strata of MBT and trends east west. The anticlinorium has overturned limbs at its outcrop exposures.

Two major thrust faults, Bazid Khel and Panoba also dominate the structure of the area (Figure 4.1). They truncate the southern limb of Bazid Khel and Panoba anticlinoria respectively (Figure 4.1). The Bazid Khel Fault moderately dips towards north and is a south verging fore thrust (Figure 4.2). It brings the Kohat Formation over the Murree Formation in the footwall. The Panoba Fault has an east-west orientation and is a south verging fore thrust. It brings the Eocene rocks over the Miocene molasse sediments in the footwall (Figure 4.3). Southwest of the Kohat city, remnants of a large thrust sheet are exposed within the core of Mirkheli Sar, Chichana and Kajbi Khana Synclines (Figure 4.1). The Mirkheli Sar Fault is the most prominent of these relics and is observed to be bedding parallel (Figure 4.4). It is detached within the Mami Khel Clay and has been folded along with the underlying footwall sequence. Another prominent structural feature within the region is the east-west trending Sumari Bala Fault (Figure 4.5). At the outcrops, the fault is overturned and is steeply north dipping (Figure 4.1).

4.3 Structural Model

Geological cross sections along line A-B and C-D (Figure 4.1) illustrate the style, kinematics and structural geometries of the Northern Kohat Fold and Thrust Belt. The structures are projected to the basal detachment. The subsurface information regarding the depth of the detachment and pre-Paleocene stratigraphy along line A-B is established after Khan (1999) and AMOCO exploratory well drilled in Sumari Bala during 1993. The subsurface information along line C-D is based on the seismic information published by Mc Dougall and Hussain (1991). Considering the above-mentioned data, the basal detachement along line A-B and C-D is inferred to be located at the interface

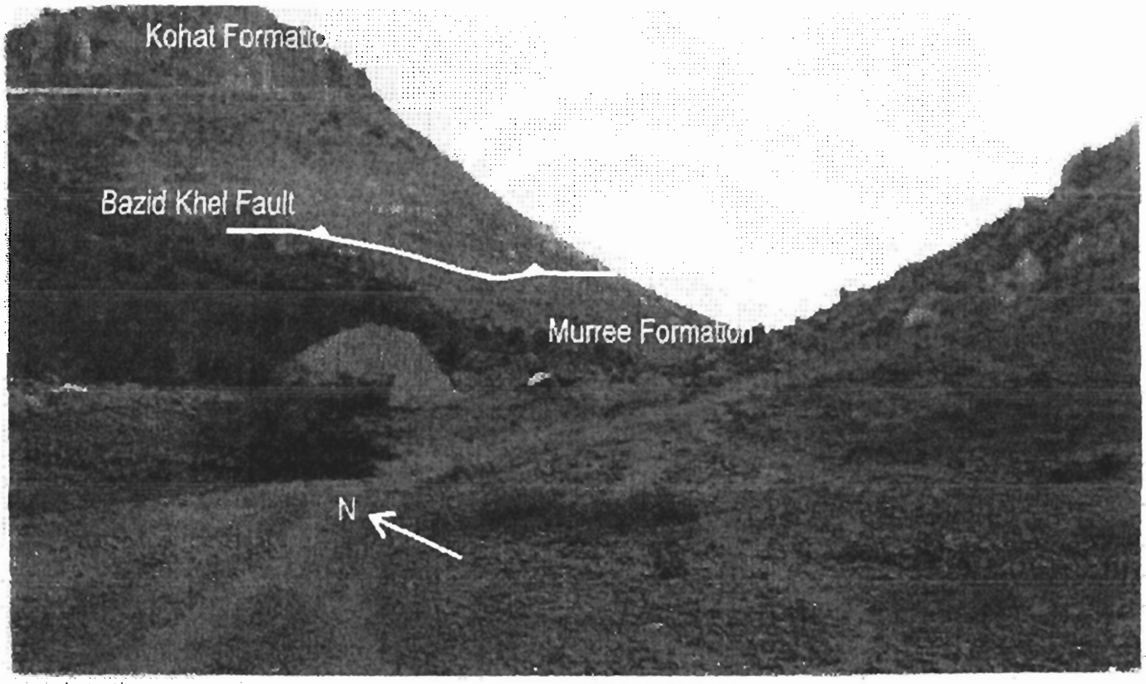


Figure 4.2. A view of north-dipping Bazid Khel Fault along which the Kohat Formation is thrust southwards over the Murree Formation .

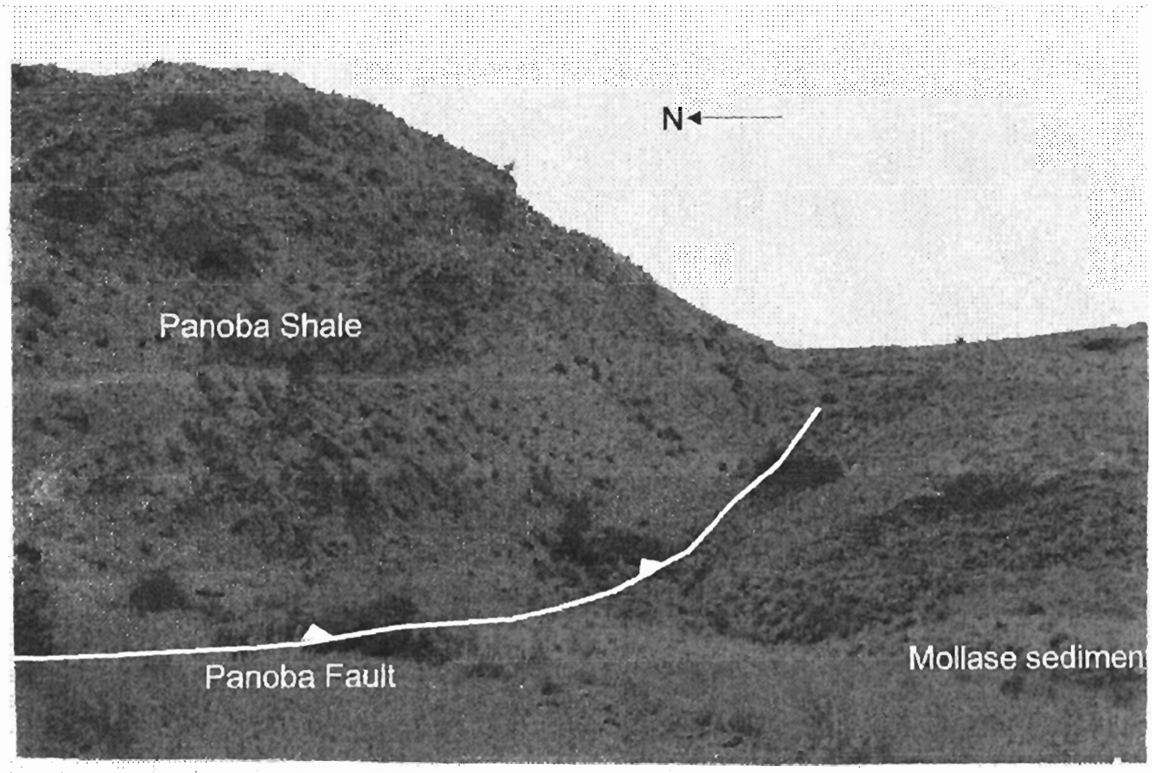


Figure 4.3. A view of Panoba Fault carrying Panoba Shale in its hanging wall over the mollase sediments along Tarkhobi section.

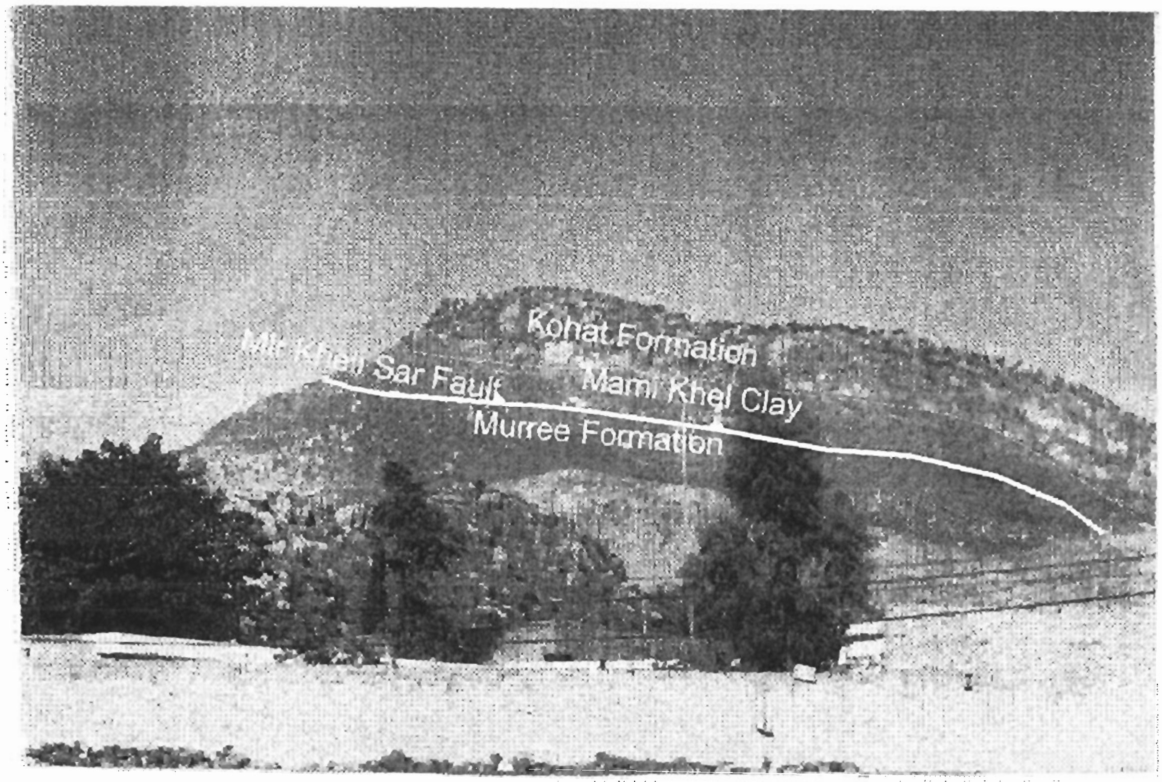


Figure 4.4. An eastward looking view of Mir Kheli Sar Fault exposed along the northern limb of Mir Kheli Sar Syncline bringing Mami Khel Clay over the Murree Formation.

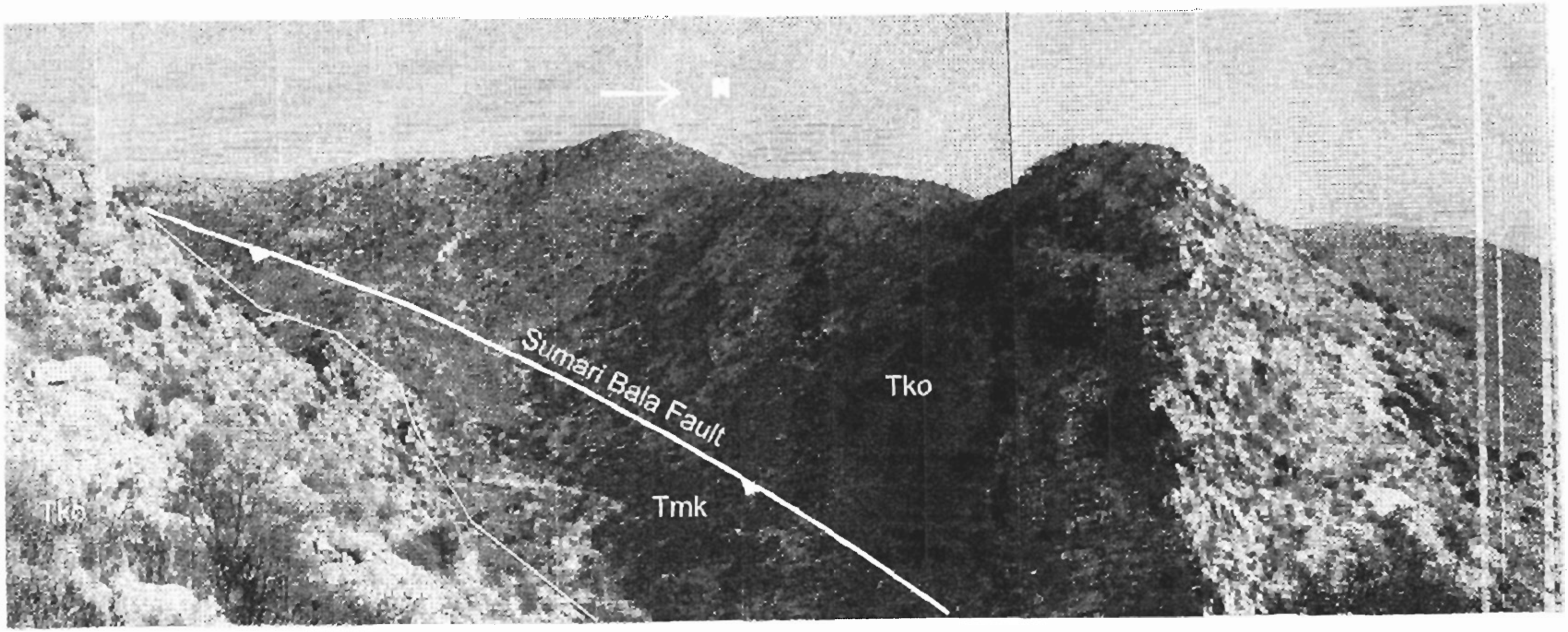


Figure 4.5. Overtutned Sumari Bala Fault along which Mami Khel Clay is thrust over the Kohat Formation in the footwall.
Tmk: Mami Khel Clay, Tko: Kohat Formation.

between the Paleozoic sedimentary cover and crystalline basement, at a depth of 8000 meters below the sea level.

The structural model constructed along line A-B suggests that within the Eocene carapace the disharmonic folds of varying amplitudes dominate the structural geometry (Figure 4.6). As the Panoba Shale occupies the base of the Eocene, its plastic nature has resulted in thickening of the anticlinal cores. Nearly all the folds are overturned at their limbs and exhibits fan geometries. The folds generally lack any vergence.

Another prominent structure in the section is a relict overthrust sheet, which occupies the core of Mirkheli Sar syncline (Figure 4.6). This thrust sheet is exposed in the form of a large klippen structure carrying Mami Khel Clay in its hanging-wall strata. Beside the folded thrust sheet another prominent fault is the Sumari Bala Fault that appears on the section south of the Mir Kheli Sar Fault. At the outcrops, the Sumari Bala Fault appears to be steeply north dipping and overturned.

The structures within the Mesozoic-Paleozoic succession beneath the Eocene cover are interpreted to be dominated by a series of north-dipping listric thrust faults. These faults exhibit curved fault plane geometries and share a common basal decollement at the sediments-basement interface. Most of these faults appear to be blind and tip out at the base of Eocene succession. Associated with these fore thrusts several back thrusts are also present in the subsurface, beneath Buraka Anticline. The structural complexities due to the geometric interaction of these faults have resulted in the formation of pop-up structure beneath Buraka Anticline and a triangle zone underneath the Sumari Payan Anticline (Figure 4.6).

Section along C-D (Figure 4.7) is drawn across the Panoba Anticlinorium, in the northeastern corner of the Kohat Plateau (Figure 4.1). From north to south along the section C-D, a fan-folded anticlinal structure crops out within the

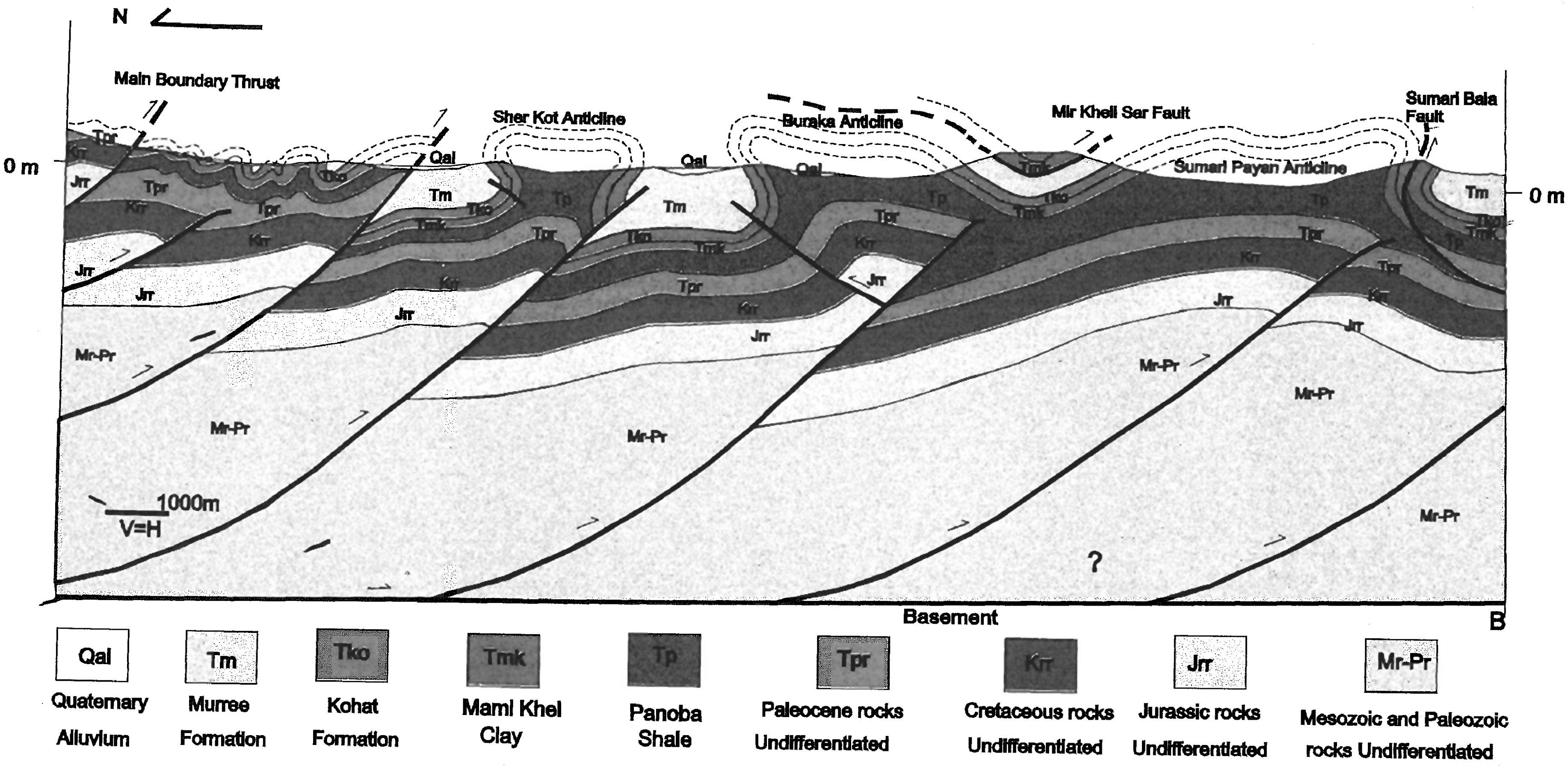


Figure 4.6. Geological cross section along line A-B of figure 4.1.

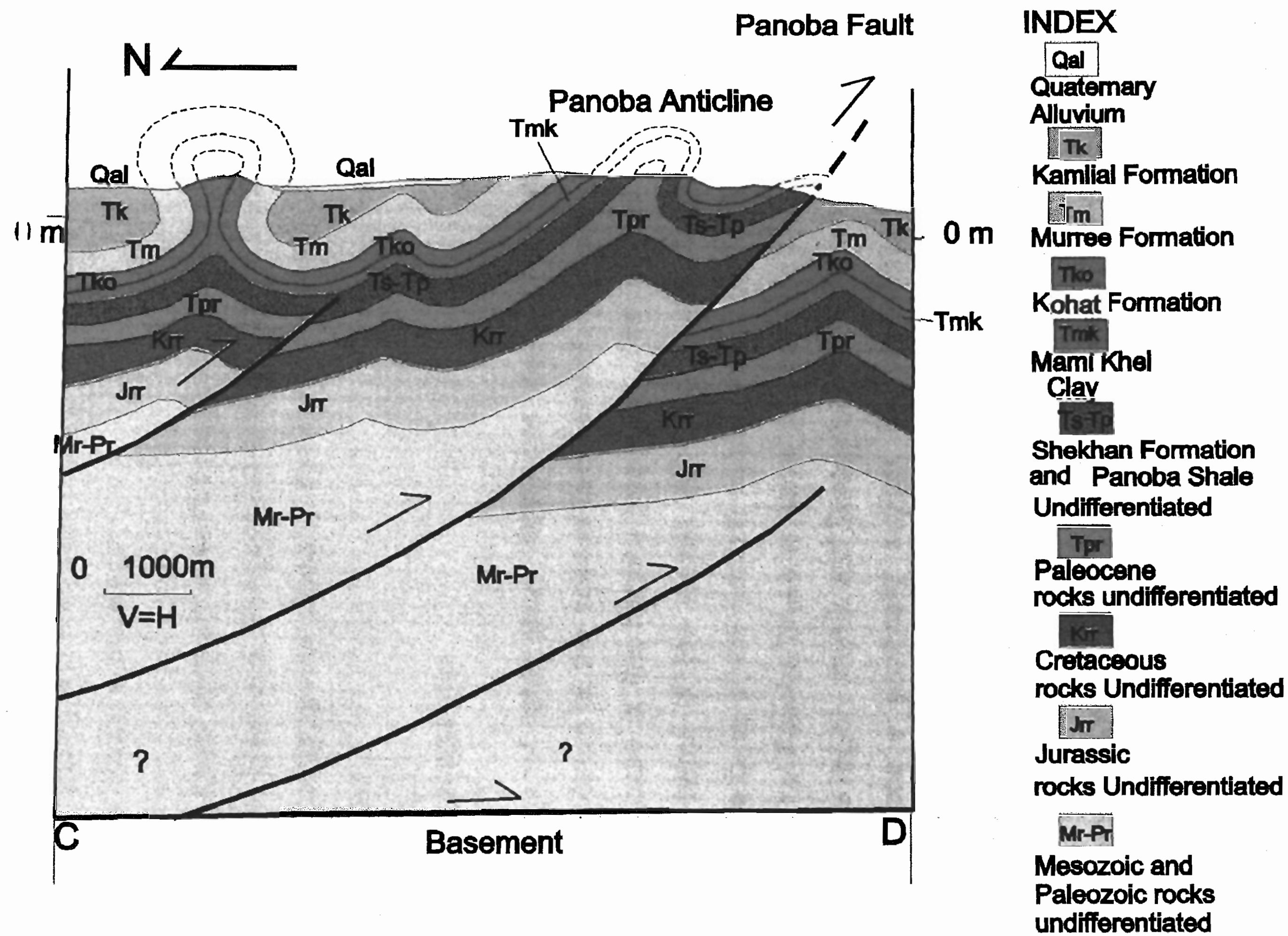


Figure 4.7. Cross section along line C-D of figure 4.1.

Eocene rocks. It has overturned limbs and is cored by the Mami Khel Clay. The other prominent structure is the Panoba Anticlinorium, which is cored by Paleocene rocks and is south facing in comparison to doubly overturned folding style of the region. Furthermore the southern limb of Panoba Anticline is marked by Panoba Fault and constitutes its hanging wall strata. The Panoba Fault is steeply north dipping and brings the base of Eocene and Paleocene rocks over the Rawalpindi Group in the south.

The structural style within the Mesozoic-Paleozoic sequence is interpreted to be a pair of blind and emergent listric thrust faults. Fault propagation folds illustrate the hanging-wall strata of these faults in the non-outcropping pre-Paleocene rocks.

4.4 Structural analysis

A series of listric thrust faults are identified as splays from a basal detachment located at the sediments-basement interface, which tip out while reaching the base of the Eocene sequence. This kinematic behavior can be explained in terms of the plastic behavior of a thick shale horizon which constitutes the base of the Eocene sequence in the Northern Kohat Fold and Thrust Belt. The Panoba Shale is about 2 kilometers thick and its base is not exposed in the region (Pivnik and Sercombe, 1993). This enormous thick pile of shale can behave plastically subject to appropriate burial and pressure temperature conditions. The stress build-up associated with splays cutting up section from the basal detachment is released while reaching Panoba Shale. The strain is distributed by the syntectonic flowage of shale into the anticlinal cores. This flowage of shale is responsible for the disharmonic folding style and the formation of shale-cored anticlines and shale-withdrawal synclines observed within the Eocene rocks (Figure 4.6). The folds wavelengths and their limb geometries suggest that the surface of decoupling is confined to the base of Panoba Shale. The proposed tectonic model indicates that the folds within the

Eocene rocks were formed as detachment folds in order to accommodate the shortening underneath the non-outcropping pre-Eocene rocks.

Another prominent feature of the region is the relics of a large overthrust sheet (Mirkheli Sar, Chichana and Kajbi Khana Fault) exposed southwest of Kohat city (Figure 4.1). The formation of this large overthrust sheet can be related to the insequence activation and uplift of Kohat Range along the Main Boundary Thrust, which relayed associated stresses towards Northern Kohat Plateau. The earliest response to this tectonic loading was the initiation of a shallow detachment within the base of the Eocene sequence where the south migration of deformation along the basal decollement was in progress (Figure 4.8 a). The shallow level decollement resulted in duplication of middle Eocene and lower Miocene rocks in the Northern Kohat Plateau. This overthrust sheet was later on folded with the underlying Eocene-Paleocene rocks, the remnants of which are still preserved in the Northern Kohat Plateau (Figure 4.8 b).

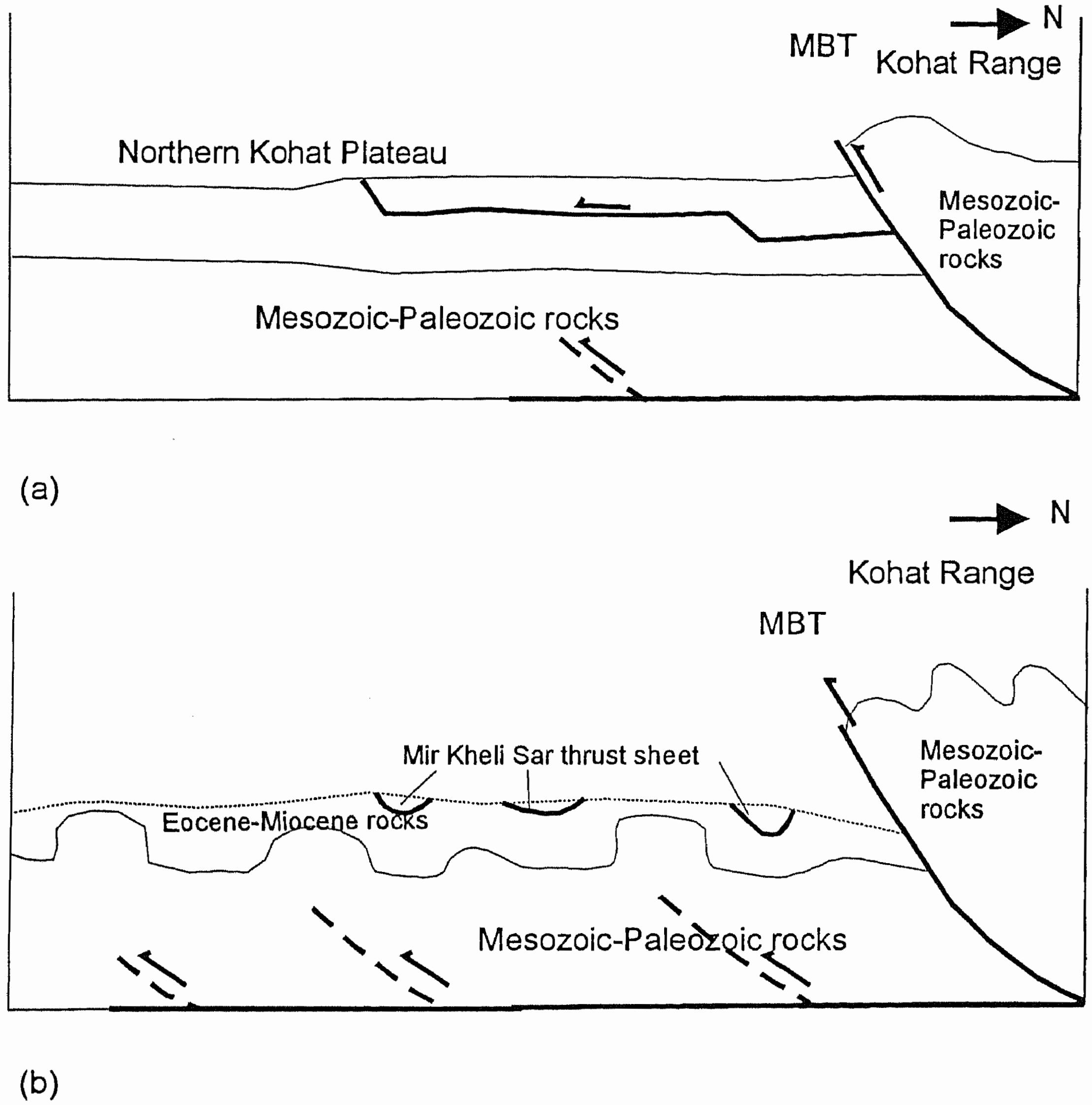


Figure 4.8 a,b. Schematic diagram showing sequential development of Mir Kh
thrust sheet in response to deformation along Main Boudary Thrus

CHAPTER #5

STRUCTURAL GEOLOGY OF THE CENTRAL KOHAT PLATEAU

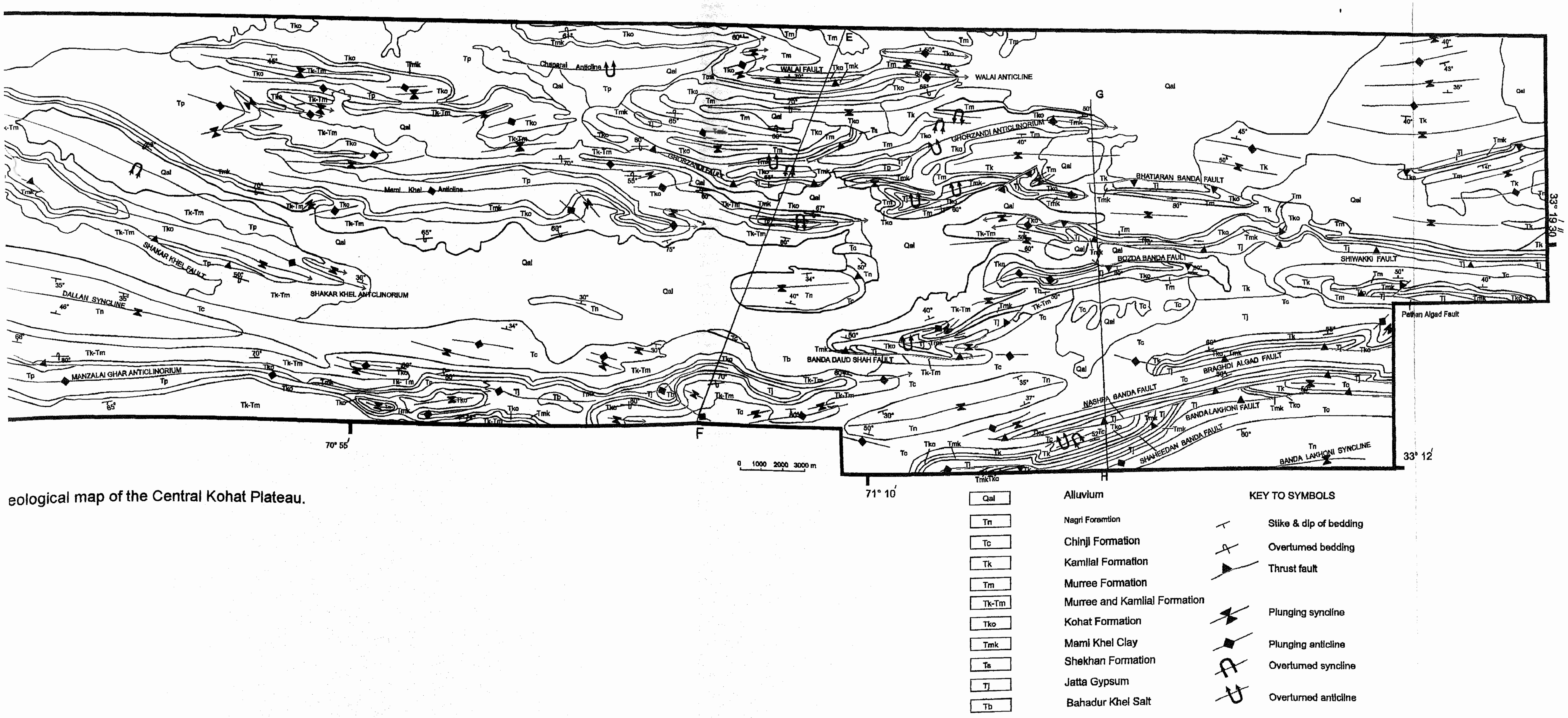
5.1 Introduction

The Central Kohat Plateau covers an area between Chapparai Anticline and Walai Fault in the north and Manzalai Ghar Anticlinorium in the south (Figure 5.1). No rocks older than Eocene crop out in this part of the Kohat Plateau. The Central Kohat Plateau consists Eocene-Pleistocene sedimentary rocks, including limestone, salt, gypsum, sandstone, shale and conglomerate. The facies record of the Central Kohat Plateau suggests that it was a restricted evaporite basin in the beginning of Eocene, evolved to an early terrestrial foreland basin followed by an open-marine basin and finally developed into a fully developed terrestrial foreland basin in the Miocene (Pivnik and Wells, 1996).

A number of publications have documented the structural styles and evolution of the Central Kohat Plateau (Abbasi and McElroy, 1991; Pivnik and Sercombe, 1993 and Sercombe et al., 1998). The early interpretations suggest multiple detachments horizons and Passive-roof duplex structural systems in the Kohat Plateau. This idea was followed by an alternate model, which implies major episodes of strike-slip faulting and minor thrust faulting.

5.2 Surface geology

The Central Kohat Plateau, based on the structural style can be divided into a western and eastern domain of the longitude of Jatta Ismail Khel (Figure.5.1). The surface geology of the western domain of the longitude of Jatta Ismail Khel is covered by east-west trending anticlinoria with associated small-scale folds (e.g. Walai, Ghorzandi, Mami Khel and Manzalai Ghar, Figure 5.1). These anticlinoria are commonly very wide, with approximate widths ranging from 2 to 6 kilometers. Generally both of the limbs of these anticlinoria are overturned and expose the base of the Eocene rocks in their core (Figure 5.2).



eological map of the Central Kohat Plateau.

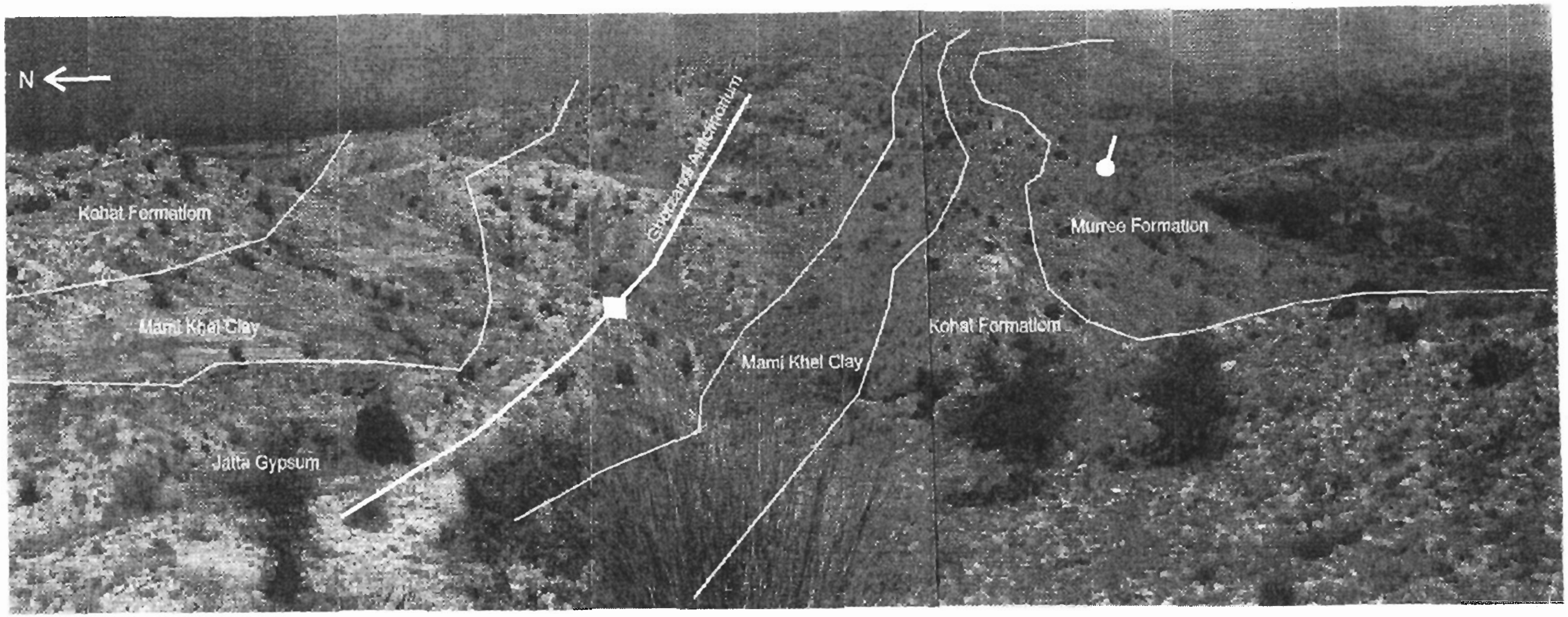


Figure 5.2. An east-west looking view of Ghorzandi Anticlinorium, showing typical anticlinal fold geometry in the central Kohat Plateau,which is cored by Eocene rocks with steeply overturned limbs.

Between these anticlinoria, broad synclinal structures are also mapped with their limbs overturned. The Rawalpindi and Siwalik Group rocks cored these synclinal structures (Figure 5.1). In addition, several thrust faults are mapped in the region as well. From north to south these faults include Walai Fault, along which the Mami Khel Clay is thrust over the Kohat Formation in the footwall. It is oriented east-west and is steeply north dipping (Figure 5.1). The Ghorzandi Fault marks the southern limb of the Ghorzandi Anticlinorium and is steeply north dipping. It has an east-west orientation and emplaces the rocks of Jatta Gypsum over the Rawalpindi Group towards south. The Shakkar Khel Fault dissects the southern limb of Shakkar Khel Anticlinorium, along which the base of Eocene sequence is thrust over the Rawalpindi Group in the footwall (Figure 5.1). A pair of south-verging fore thrusts are mapped along the southern flank of Dallan Syncline and emplaces Panoba Shale in its hanging wall above the Kohat Formation in the footwall (Figure 5.1).

The eastern domain of the longitude of Jatta Ismail Khel is dominated by east-west trending parallel enechelon folds and thrust faults. The folds mapped within this domain are generally asymmetrical with both their limbs overturned (Figure 5.1). The anticlines are commonly tight and their limbs are mostly characterized by thrust faults of opposing vergence. The geometric interaction of opposing vergence along various faults has resulted in the formation of pop-ups and triangle zones. The prominent structural discontinuity includes Bhatiaran Fault, which has an east-west trend, and is steeply south dipping (Figure 5.3). It has thrust over Jatta Gypsum on the Rawalpindi Group rocks in the footwall. The Bhatiaran Banda Fault is traceable for tens of kilometers along the strike. Another prominent discontinuity is named as the Shiwakki Fault, which is vertical to steeply dipping south vergent forethrust. It brings the rocks of Jatta Gypsum in its hanging-wall over the Siwalik Group rocks in the footwall (Figure 5.4). This fault is traceable for tens of kilometers along the strike. South of Shiwakki Fault, occurs the Bozda Banda Fault which is steeply south dipping in the east and changes its dip direction towards north in the west (Figure 5.5). South of

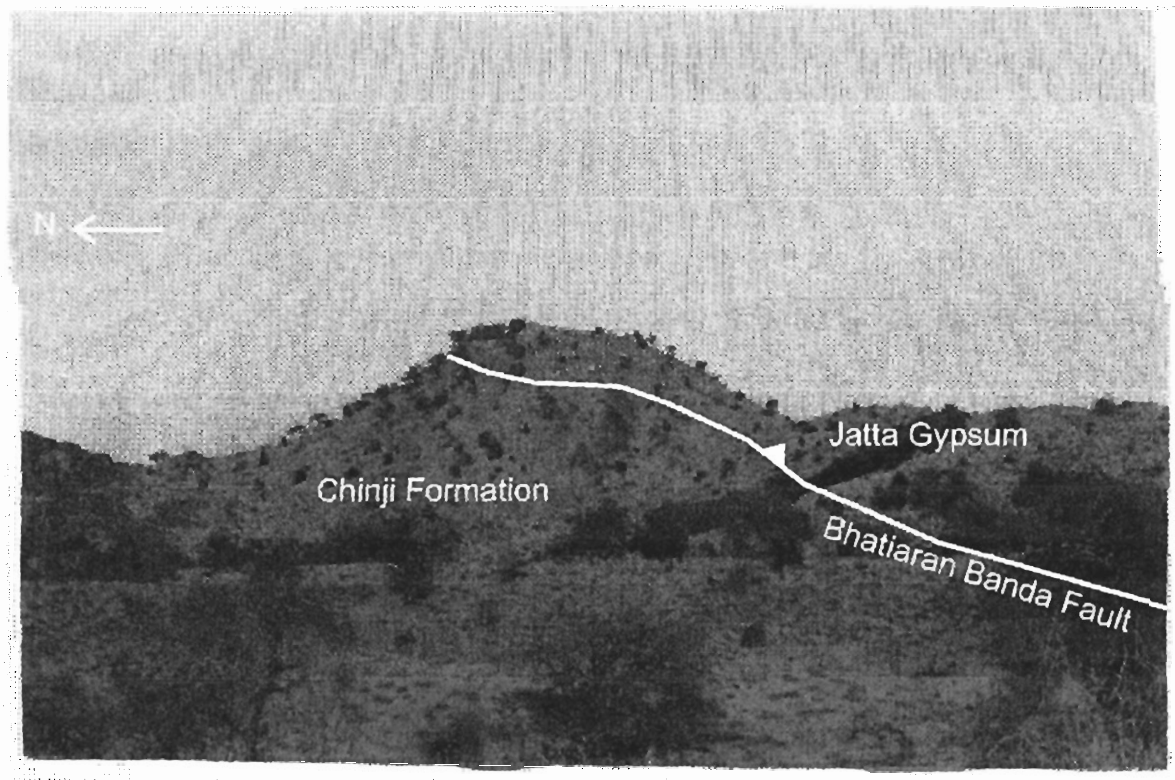


Figure 5.3. South-dipping Bhatiaran Banda Fault exposed along Bannu-Kohat road where Jatta Gypsum is thrust over the Chinji Formation in the footwall.l

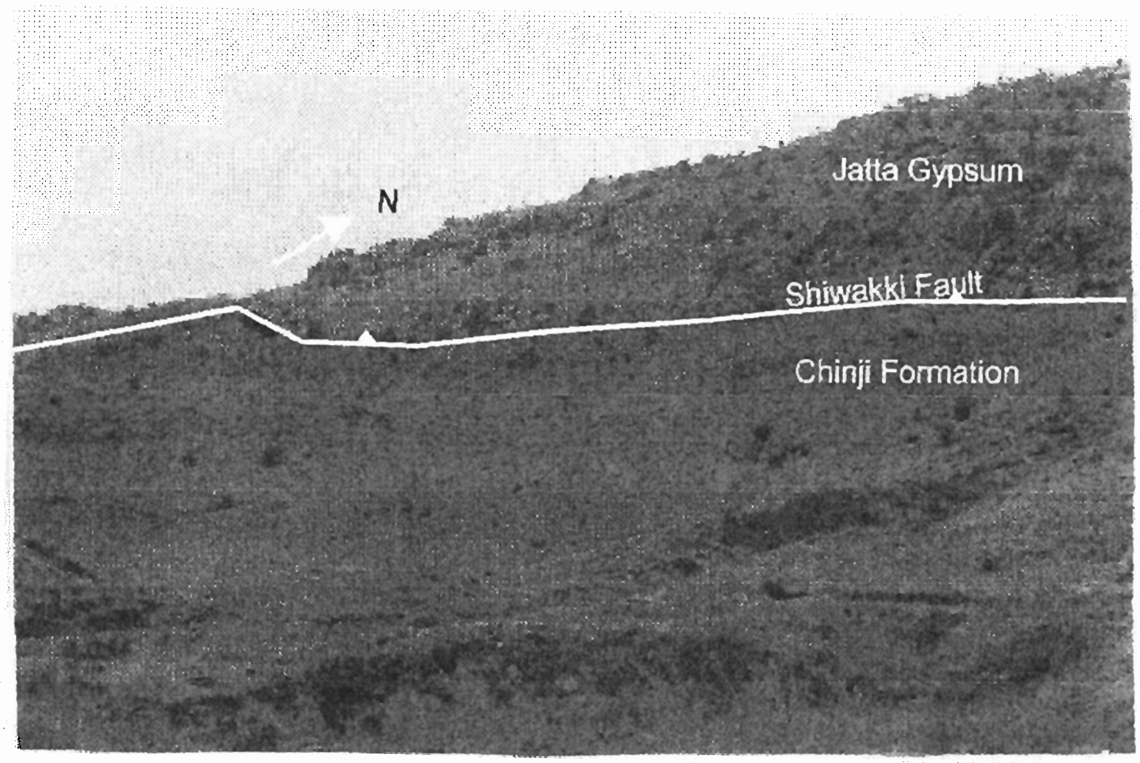


Figure 5.4. Shiwakki Fault exposed along Shakardara-Kharapa road which brings Jatta Gypsum above the Chinji Formation in the footwall

Bozda Banda Fault another prominent fault namely Braghdi Algad Fault crops out at the surface. It is steeply north dipping (Figure 5.1). The Jatta Gypsum is thrust over the rocks of Siwalik Group along this fault. The Nashpa Banda Fault is located southwest of Pathan Algad Fault and is south verging forethrust with an east-west trend. It brings the rocks of Jatta Gypsum in faulted contact with the Siwalik Group. The Shaheedan Banda Fault lies south of Nashpa Banda Fault and duplicate the Eocene strata. The Banda Lakhoni Fault is the southern most discontinuity of the area and brings the Mami Khel Clay over the Siwalik Group in the footwall (Figure 5.6).

5.3 Structural Model

Geological cross-sections along line E-F and G-H of Figure 5.1 are constructed to interpret the subsurface behavior of the mapped structures. The cross-section E-F is located west, whereas section G-H is located east of the longitude of Jatta Ismail Khel (Figure 5.1). The subsurface information regarding the Pre-Eocene stratigraphy, regional dip and the depth of detachment is inferred from the published data of Sercombe et al. (1998) and Khan (1997). The depth of the detachment is located about 7800 m at the contact between sediments and crystalline basement. The regional dip is 2° northwards.

Along line E-F from north to south (Figure 5.7), the structural geometry of the Eocene Carapace is characterized by a south facing forethrust, the Walai Fault. The footwall and the hanging wall strata of the Walai Fault are disharmonically folded into a series of anticlines and synclines. These are asymmetric and evolved at the surface of decoupling at the base of Panoba shale. Another emergent thrust fault such as the Ghorzandi Fault depict the southern limb of Ghorzandi Anticline along which the base of the Eocene is thrust over the rocks of the Rawalpindi Group. South of Ghorzandi anticline, the north facing Mami Khel Anticline occurs. It exposes the base of the Eocene sequence. South of the Mami Khel Anticline lies the Dallan Synclinorium, which incorporates

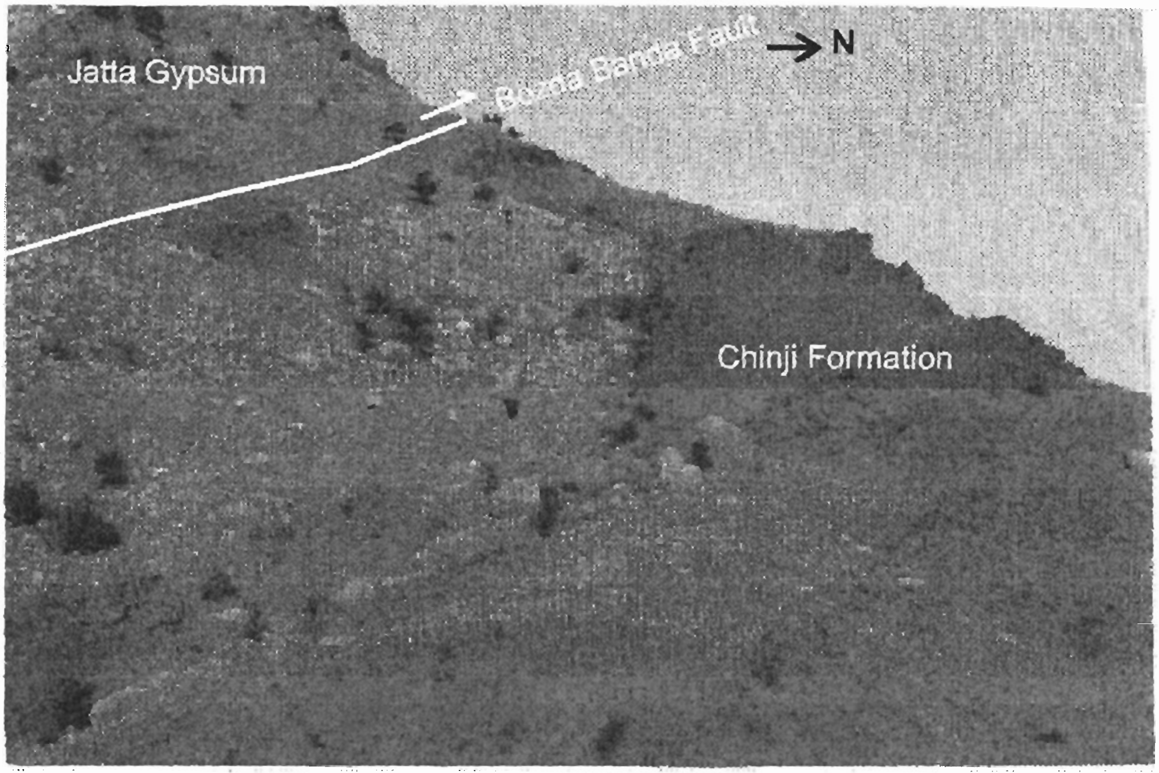


Figure 5.5. South-dipping Bozda Banda Fault expopsed along Kharapa-Karak road which emplaces Jatta Gypsum above Chinji Formation in the footwall

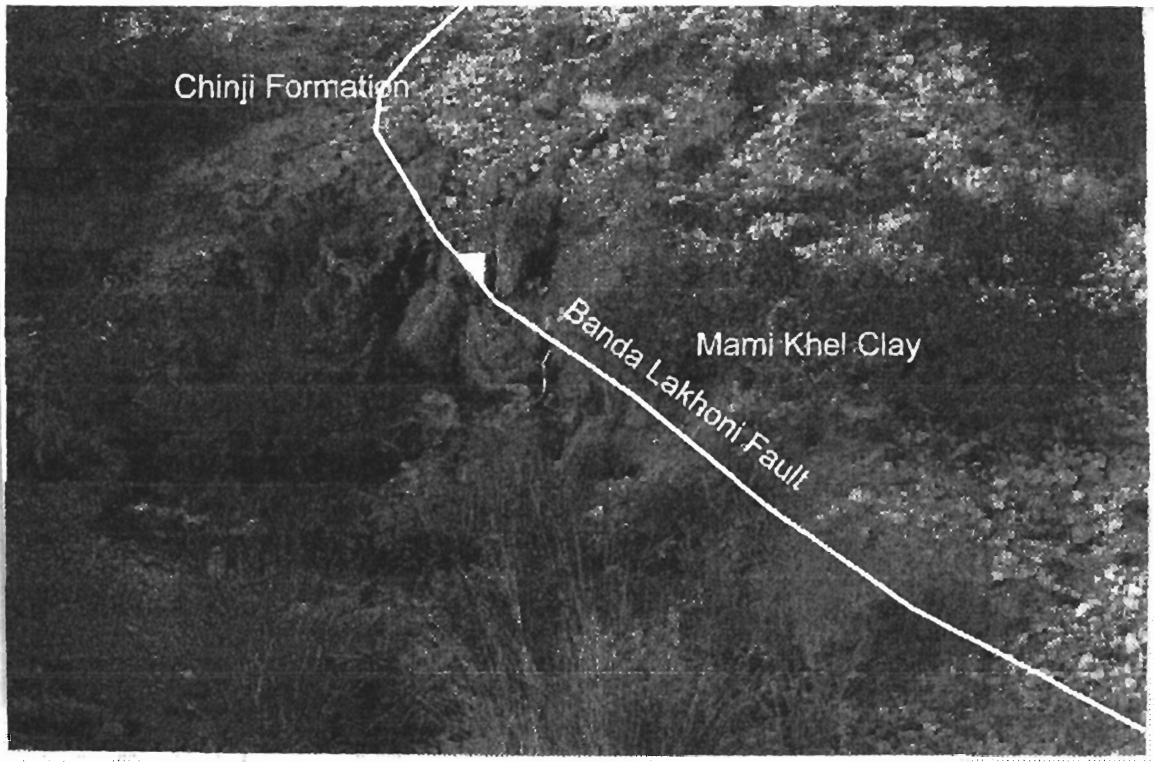


Figure 5.6. A close view of Banda Lakhoni Fault with Mami Khel Clay in its hanging wall, thrust over Chinji Formation in the footwall.

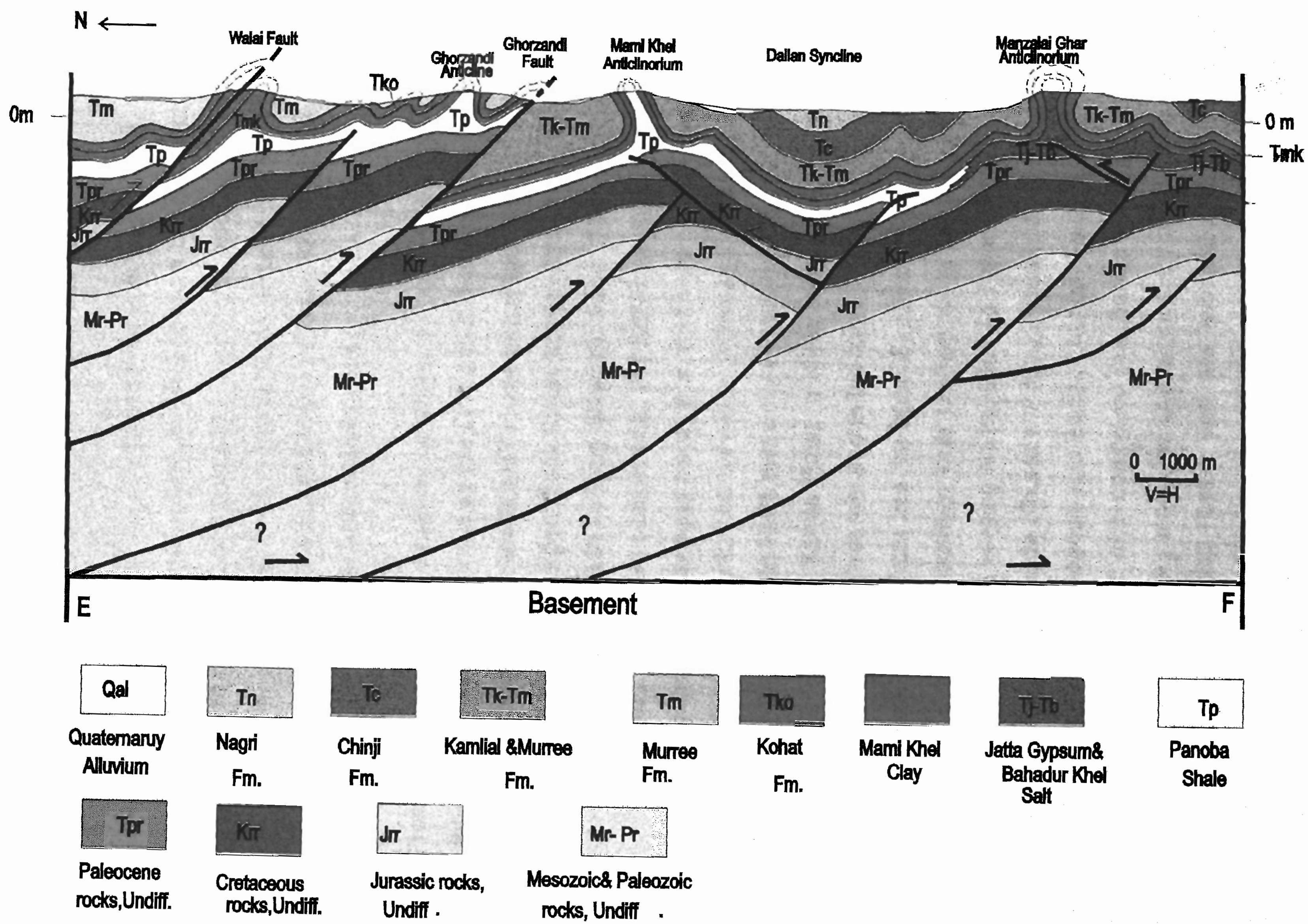
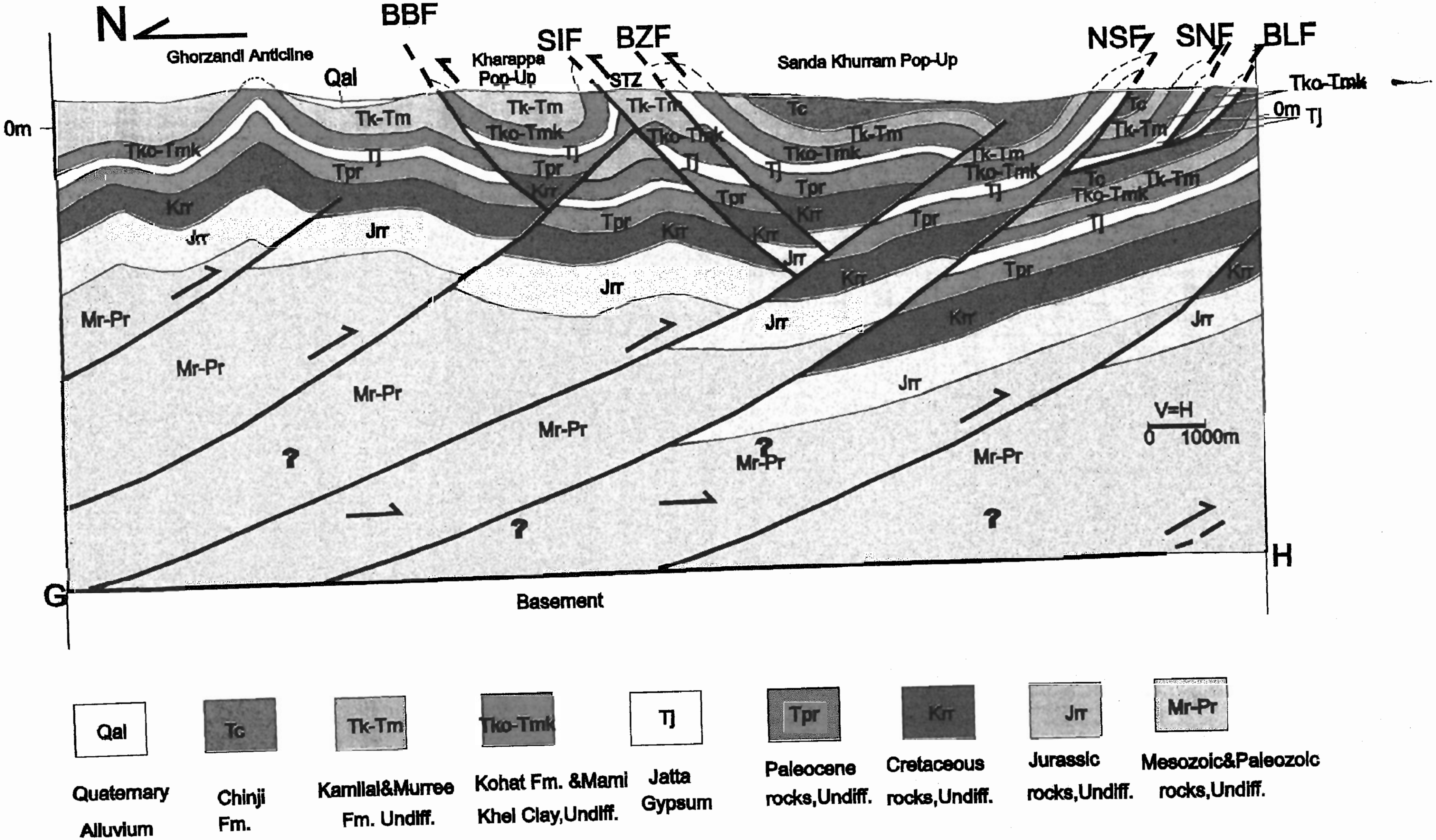


Figure 5.7. Geological cross section along line E-F of figure 5.1.

associated small scale folds in the limbs. The Siwalik Group rocks occupy the core of the Dallan Synclinorium. Another prominent feature, the Manzalai Ghar Anticlinorium south of Dallan Synclinorium has both of its limbs overturned and makes fan fold geometry. It is cored by the Jatta Gypsum and Bahadur Khel Salt.

The structural geometry of the Pre Eocene rocks is illustrated by a series of emergent and blind listric thrust splays emanating from basal detachment at the interface between Paleozoic and crystalline basement rocks. Associated with these forethrusts, a couple of north verging back thrusts splays are also observed. One of these thrusts tips out in the core of Mami Khel Anticline and the other one in the core of Manzalai Ghar Anticlinorium.

From north to south, the structural geometry along line G-H is marked by an upright anticlinal structure named as the Ghorzandi Anticline. It is cored by a blind thrust fault emanating from the basal detachment (Figure 5.8). South of the Ghorzandi Anticline lies an emergent back thrust such as the Bhatiaran Banda Fault, which splays from the south verging Shiwakki Fault. These faults bound the Kharappa Pop-up. Along the section line, the Shiwakki fault is overturned towards north, whereas along its map trace, it is south verging at most of the exposures (Figure 5.1). The overturned behavior of Shiwakki Fault is accredited to the motion along Bozda Banda Fault and a blind back thrust underneath. The geometric interaction of Bozda Banda Fault, a blind back thrust below Bozda Banda Fault and Shiwakki Fault has resulted in the formation of Shiwakki triangle zone. South of Bozda Banda Fault lies an open Synclinal structure within the Siwalik Group rocks with the southern limb marked by a couple of blind and emergent forethrusts. The south verging Nashpa Banda Fault and North verging Bozda Banda Fault bounds Sanda Khurram Pop up. South of Nashpa Banda Fault, two thrust faults i.e. Shaheedan and Banda Lakhoni Faults along with the Nashpa Banda Fault crop out and constitute the Banda Lakhoni Imbricate Structure, The structural geometry along the line suggests that all the emergent and blind thrust splays are deep rooted and are associated with the basal



BBF =Bhatiaran Banda Fault, SIF= Shiwakki Fault, BZF= Bozda Fault, NSF= Nashpa Banda Fault, SNF= Shaheedan Fault,
BLF= Banda Lakhoni Fault STZ= Shiwakki Triangle Zone

Figure 5.8. Geological cross section along line G-H of figure 5.1.

detachment. The fold structures within the Eocene and Paleozoic to Mesozoic rocks are related to the Kinematics of faulting in the region.

5.4 Analysis

Geological mapping and structural analysis of the Central Kohat Plateau, along with structural analysis suggests that it is underlain by a regional structural detachment, located at the contact between the crystalline basement and Paleozoic to Pliocene sediments. Projection of fold geometries within the Eocene rocks requires a decoupling surface at the base of Eocene sequence. The sectional geometries of the surficial folds indicate that these are detachment folds developed in response to the accumulation of shortening associated with the listric thrust splays cutting up section from the basal detachment. The subsurface fold geometries present within the Paleozoic–Mesozoic rocks are interpreted as fault propagation folds developed in response to the motion along the listric thrust splays from the basal detachment. The stratigraphy of the Central Kohat Plateau has played an important role in determining the contrasting structural styles within the exposed and subsurface rocks. It is believed that the presence of a thick sequence of shale and evaporites at the base of Eocene has defined the zone of strain partitioning between surface and subsurface structures where the subsurface structural system is migrating southwards in response to the Himalayan deformation. The Paleozoic to Mesozoic rocks are deformed by low angle listric thrust splays and give rise to fault propagation folds within the overlying rocks. At the base of Eocene the faults tips out and the overlying Eocene sequence is disharmonically folded along with the plastic flow of shale into the anticlinal cores and withdrawal from synclinal cores. This structural behavior is restricted to the area west of the longitude of Jatta Ismail Khel. In contrast, the area east of the longitude of Jatta Ismail Khel behaves differently. In this region, the base of the Eocene has experienced a lateral facies change such that Jatta Gypsum and Bahadur Khel Salt replace the Panoba Shale. This eastern facies is more capable of flow in solid state as compared to its lateral equivalent in the west. The difference in thickness between the two is responsible for the contrasting behavior of thrust splays. Most of the thrust splays emerge out at the surface and also have associated back thrusts. The geometric interaction of varying vergence on fault surfaces has resulted in the formation of pop-ups, triangle zone and imbricate fan (Figure 5.9). Virtually, every anticlinal trend is dissected by thrust or back thrust. Orientation of both small and large-scale structures indicates that it has undergone deformation as a result of north-south oriented horizontal compressional stresses. It is interpreted that the study area is dominantly a south-verging structural system that is propagating southwards.

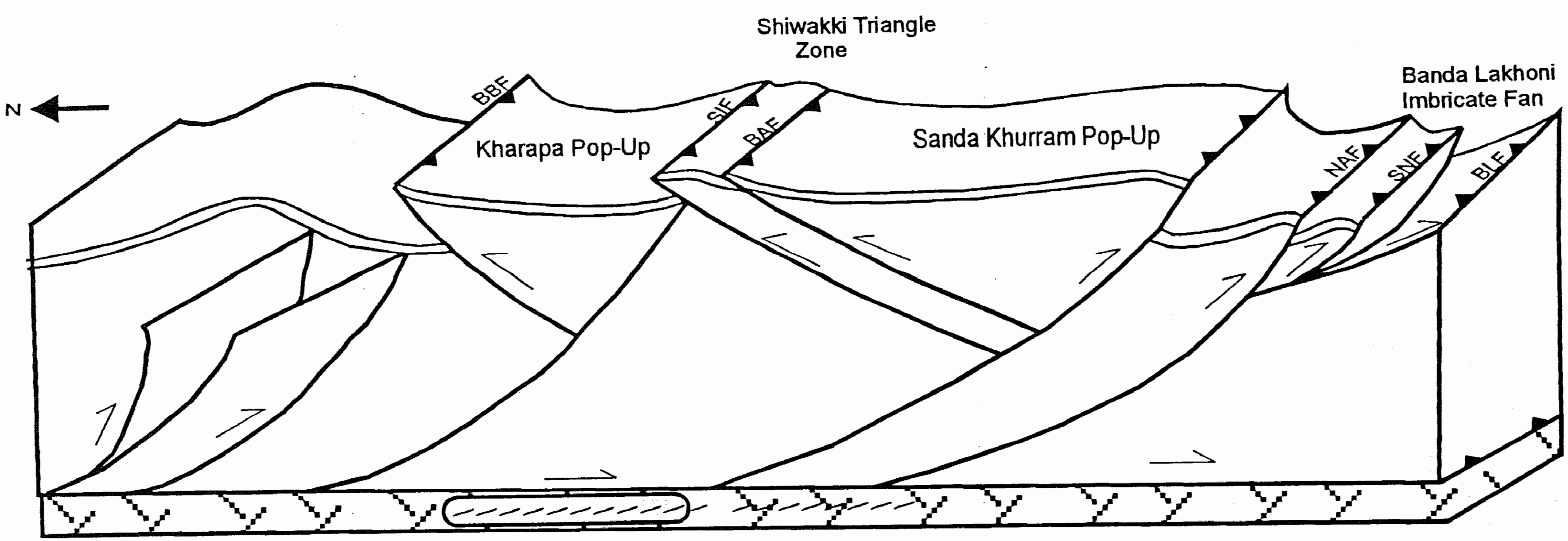


Figure 5.9. Schematic section showing thrust and folds relationship east of the longitude of Jatta Ismail Khel in the Central Kohat Plateau. BBF: Bhatiaran Banda Fault, SIF: Shiwakki Fault, BAF: Bozda Banda Fault, NAF: Nashpa Banda Fault, SNF: Shaheedan Fault, BLF: Banda Lakhoni Fault.

CHAPTER# 6

STRUCTURAL GEOLOGY OF THE SOUTHERN KOHAT PLATEAU

6.1 Introduction

The Southern Kohat Plateau covers the area marked by the Kurma Anticline in the north and Basia Khel-Surdag Fault in the south (Figure 6.1). This part of the plateau is characterized by south vergent folds and thrust belt that protrude into the Karak Trough in the east and Bannu Basin in the west (Figure1.2). Being in close proximity with the Kalabagh Fault in the east and Kurram Fault in the west, it has undergone significant amount of strike-slip adjustments along with contractile deformation. The Southern Kohat Plateau is underlain by the sedimentary rocks of Eocene age and exposes the rocks as young as that of the upper Siwalik Group. Tectonic deformation within the Southern Kohat Plateau is believed to be of Plio-Pleistocene to Holocene age, indicated by the tilting and uplift of the recent terraces along its southern topographic front.

6.2 Structural Data

Detailed field investigation has led to the identification of two distinct structural styles in the Southern Kohat Plateau. West of the longitude of Latamber, the surface geology is distinguished by east-west trending tight anticlinal trends, having both their limbs overturned. Broad intervening synclinal structures occur between anticlinal trends where their limbs and core are dissected by east-west trending faults. The Kurma Anticline marks the northern limits of the mapped area and is found to be roughly oriented east-west with Panoba Shale in its core (Figure 6.1). At the surface both of its limbs are steeply overturned. South of Kurma Anticline, the Tsapparai Syncline exposes the Upper Siwalik Group rocks in its core. It is east-west oriented and is the largest fold structure within the entire Kohat Plateau. Its limbs are characterized by steep dips, which progressively become gentle towards its core. Parallel to its axial

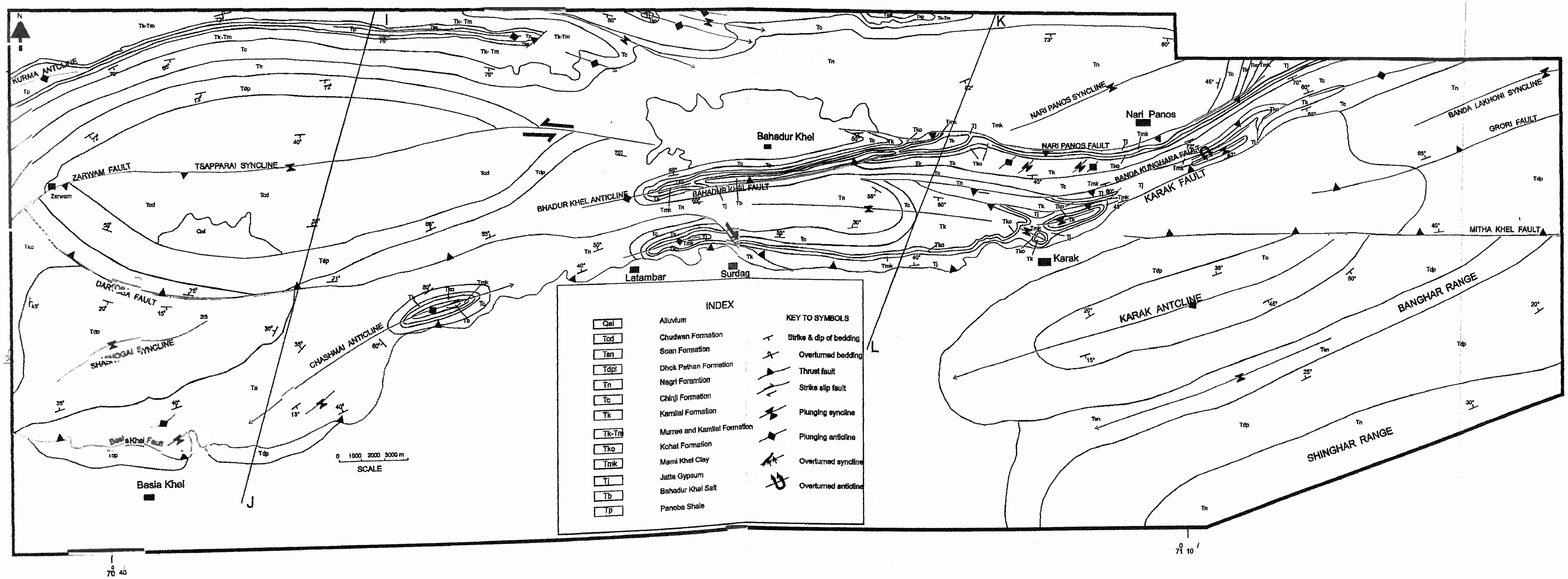


Figure 6.1. Geological map of the Southern Kohat Plateau.

trend, it is offset by an east-west trending strike-slip Zarwam Fault (Figure 6.1). The fault is vertical to sub vertical with sheared conglomerate and cherts at its surface exposure (Figure 6.2 and 6.3). At places horizontal slicks have been observed along the fault plane. The southern limb of Tsaparrai Syncline is also dissected by another regional scale Daryoba Fault. It is east-west oriented and joins the Zarwam Fault in the west and Karak Fault in the east (Figure 6.4). At the surface the fault is steeply north-dipping and brings the rocks of Nagri Formation in the west over the flat lying rocks of the Dhok Pathan Formation (Figure 6.1). Another prominent feature of the region is the Shashogai Syncline, which lies south of Daryoba Fault and has curvilinear axial trend. Its limbs are characterized by low dip angles and expose the Dhok Pathan Formation in its core. The southern limb of this syncline incorporates several en-echelon fold structures (Figure 6.1). The Basia Khel-Surdag Fault demarcates the southern limb of Shashogai Syncline in the west and the southern limb of Latamber anticline in the east. The Basia Khel-Surdag Fault is east-west trending and is gently north-dipping fore thrust (Figure 6.5).

Imbricate thrust splays contained along anticlinal limbs dominate the structural geometry east of the longitude of Latamber. The important structural features of the region include the Nari-Panos Fault in the north (Figure 6.1). At surface the Nari-Panos Fault is moderately south-dipping back thrust and brings the Jatta Gypsum over the Nagri Formaton in the footwall (Figure 6.1). The Banda Kunghara Fault lies south of the Nari-Panos Fault is steeply south-dipping back thrust (Figure 6.6). It brings the Jatta Gypsum in the hanging wall over the Chinji Formation in the footwall. South of Banda Kunghara Fault lies the north-dipping Karak Fault. It has moderate dip angles and emplaces the rocks of Jatta Gypsum over the Chinji Formation in the south (Figure 6.7). The Karak Fault represents the southern most extension of the evaporite facies exposed at surface within the Kohat Plateau. The Karak Trough lies between the Karak Fault in the north and Shinghar and Surghar ranges in the south. The Karak Trough is occupied by the Upper Siwalik Group rocks, which are gently folded into a series

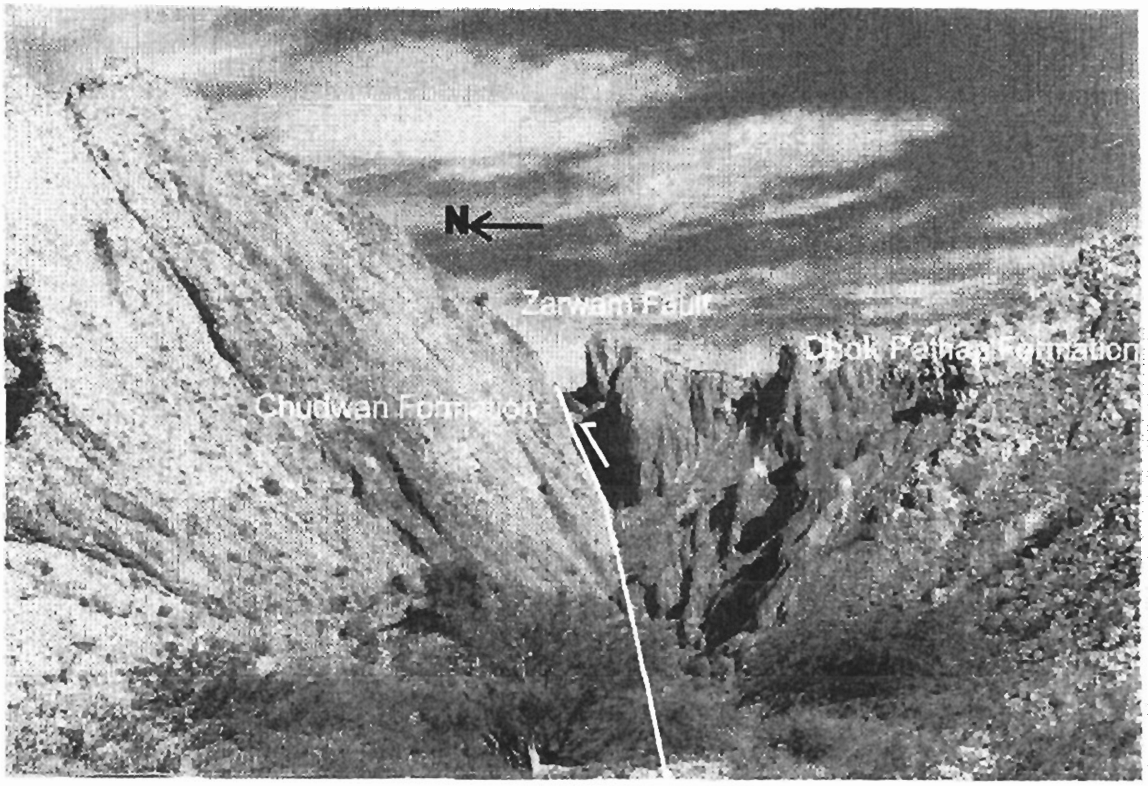


Figure 6.2. East looking view of Zarwam Fault exposed along Bannu-Zarwam road *has steep dips..*

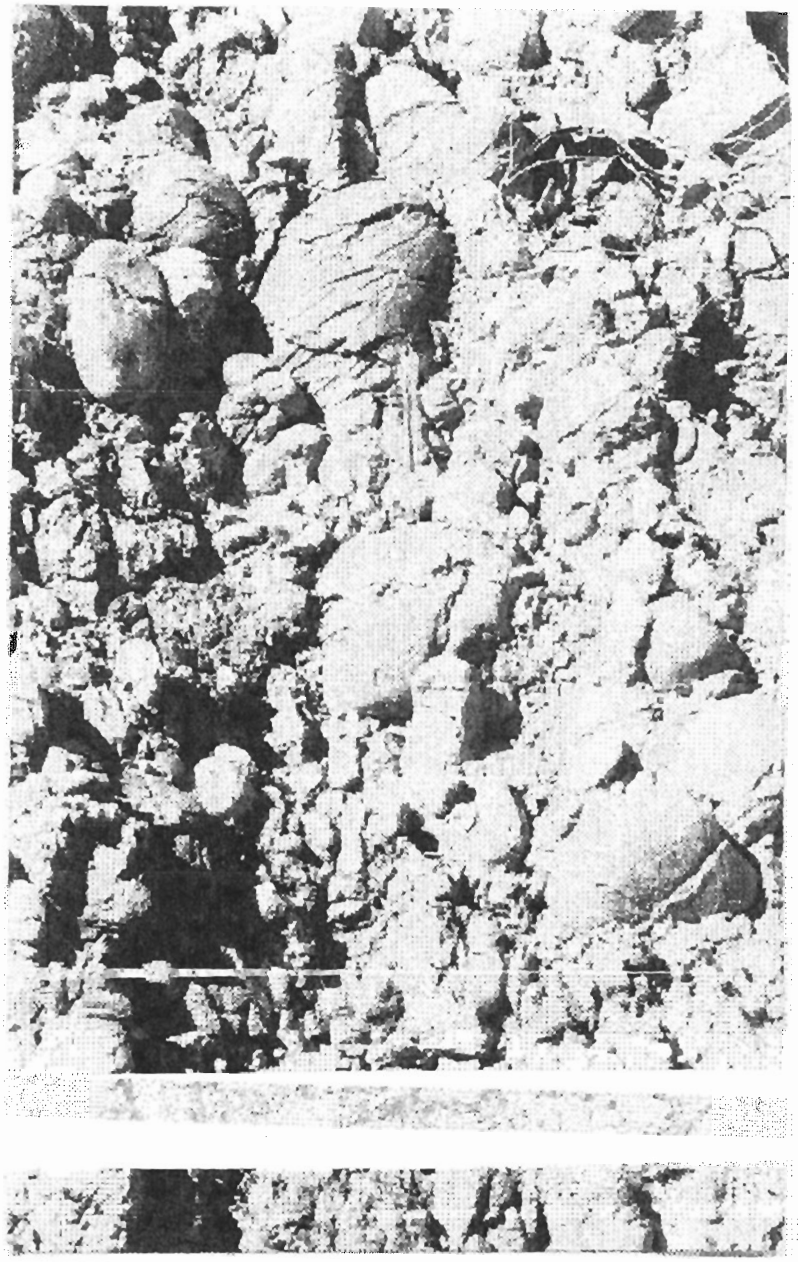


Figure 6.3. Sheared clasts of conglomerate that belongs to Chudwan Formation exposed along Zarwam Fault east of Zarwam village.

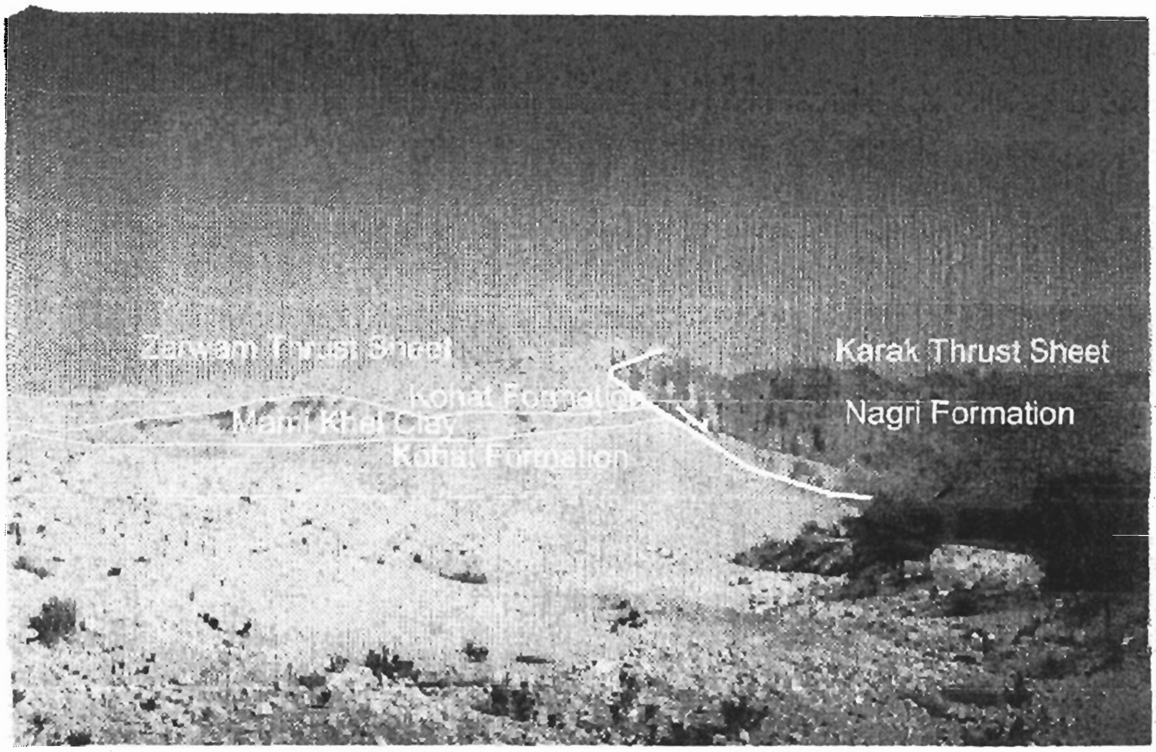


Figure 6.4. The eastern terminus of Zarwam Fault, north of Surdag village along Bannu-Kohat road.

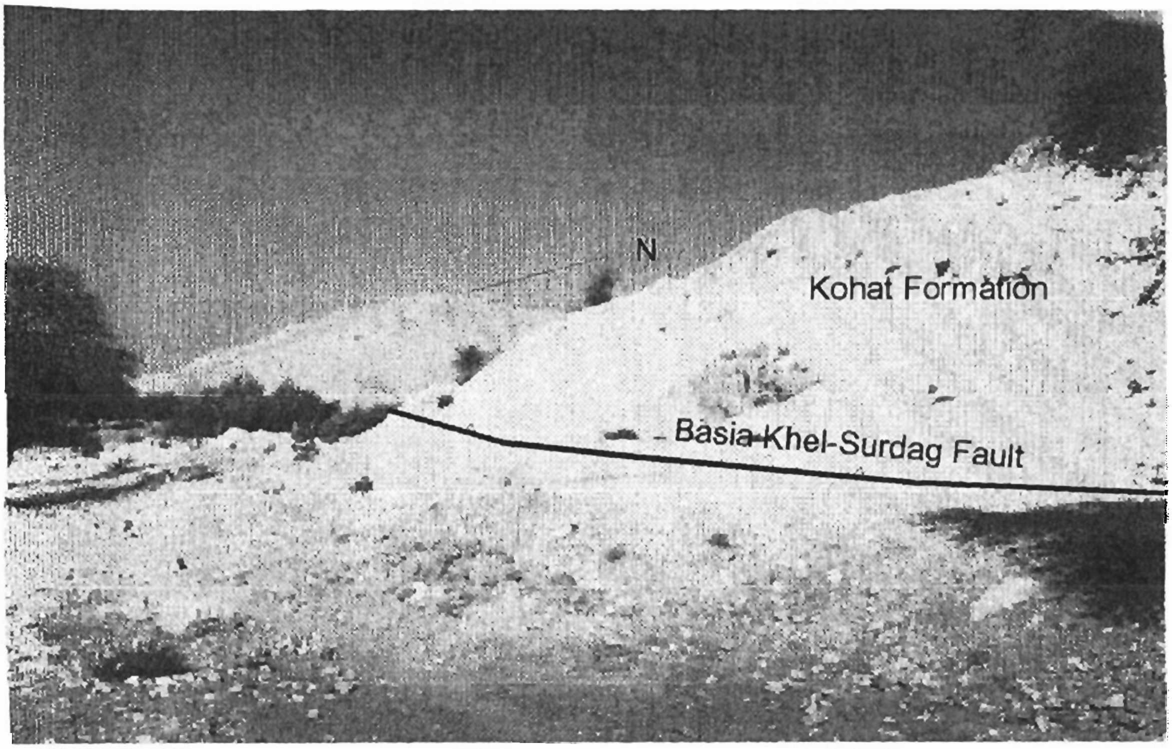


Figure 6.5. Basia Khel-Surdag Fault along Bannu-Surdag road which brings Kohat Formation over the sediments of Bannu Basin. .

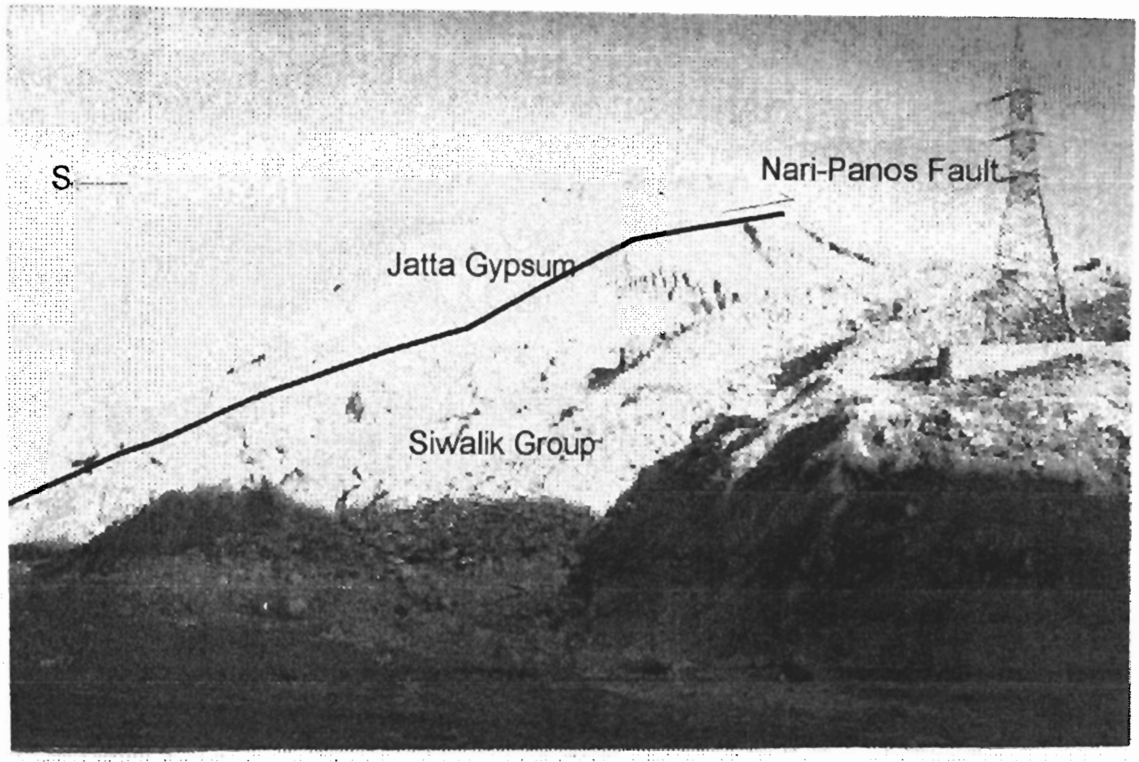


Figure 6.6. South-dipping Nari-Panos Fault exposed along Nari-Panos-Karak road, which brings Jatta Gypsum above the Siwalik Group rocks.

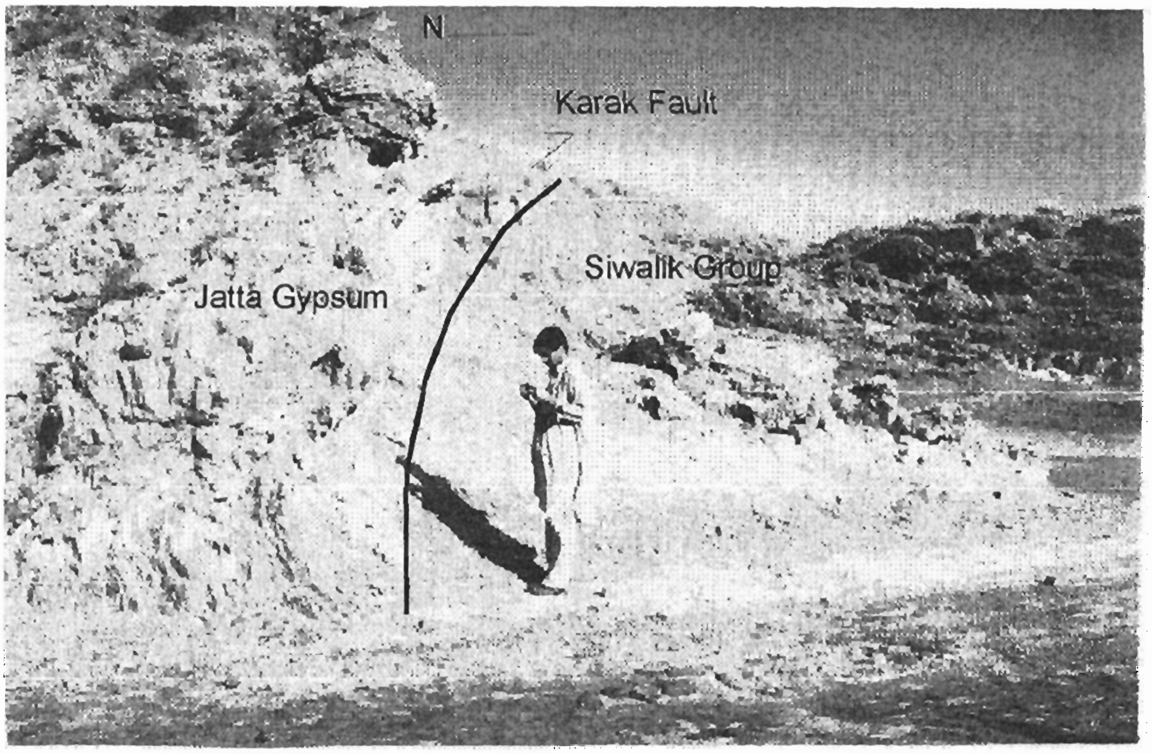


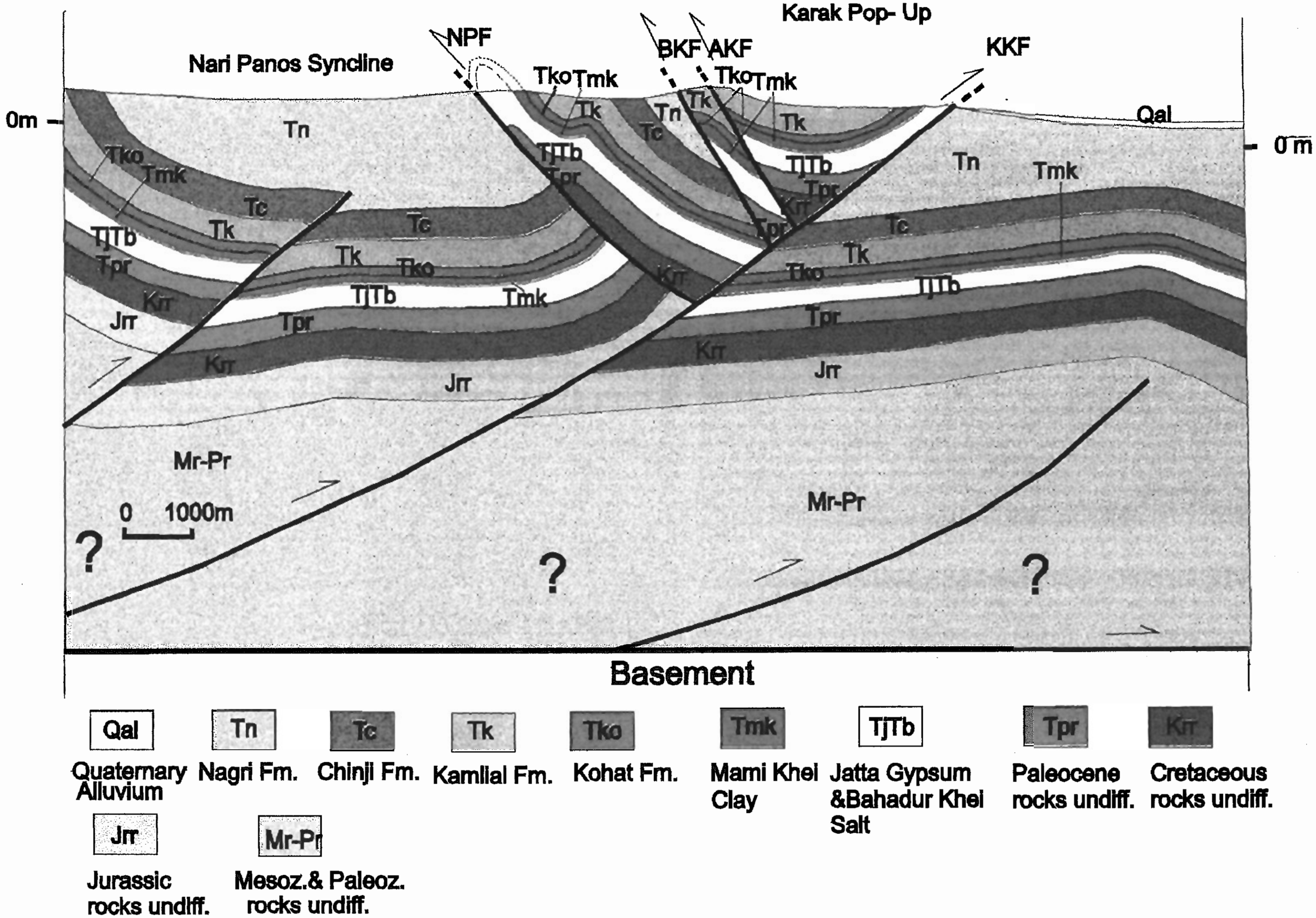
Figure 6.7. North-dipping Karak Fault exposed in the north of Karak Town that emplaces Jatta Gypsum over Siwalik Group rocks in its footwall.

of east-west trending folds (Banda Lakhoni Syncline, Karak Anticline and Banghar Syncline, Figure 6.1). Two regional scale faults such as Grori and Mitha Khel also dominate the region. The Grori Fault is roughly east-west oriented and steeply dipping towards north. It dissects the southern limb of Banda Lakhoni Syncline. The Mitha Khel Fault is located south of Grori Fault and marks the northern limb of Karak Anticline and Banghar Syncline. It has oblique relationship with the associated fold structures of the region (Figure 6.1).

6.3 Structural models

The structural style exhibited by the Sourthern Kohat Plateau east of the longitude of Latambar is dominated by thrust faults that are mostly bedding parallel in the hanging wall and stay within evaporite beds. From north to south along line K-L, the Karak Fault is believed to be a deep-seated thrust splay, emerging from the basal detachment (Figure 6.8). North of Karak Fault, a series of north-verging back thrusts are present representing the successive hanging wall collapse of the Karak Fault. All these faults are confined to the evaporite bed located at the base of Eocene succession. The zone between Karak Fault in the south and Nari-Panos Fault in the north is named as Karak Pop-Up. The Daggar Syncline is located north of Nari-Panos Fault and constitutes its footwall strata. A couple of south-vergent back thrusts are also inferred beneath the Daggar syncline (Figure 6.8).

The structural geometry portrayed along line I-J shows remarkable contrast to that along K-L. From north to south along line K-L, the Kurma Anticline is interpreted as a tight anticlinal structure (Figure 6.9) cored by a steeply south-dipping fault. South of the Kurma Anticline, the north limb of Tsapparai Syncline is steeply south-dipping and a vertical to sub-vertical Zarwan Fault offsets its core. The southern limb of Tsapparai Syncline is truncated by Darayoba Fault, which is steeply dipping reverse fault. The zone between Kurma Anticline and Daryouba Fault seems to be deformed by thick-skinned deformation style that involves the basement as well. South of Daryoba Fault the



KKF: Karak Fault, AKF: Andi Karak Fault, BKF: Banda Kunghara Fault, NPF: Nari Panos Fault

Figure 6.8. Geological cross section along line K-L of figure 6.1.

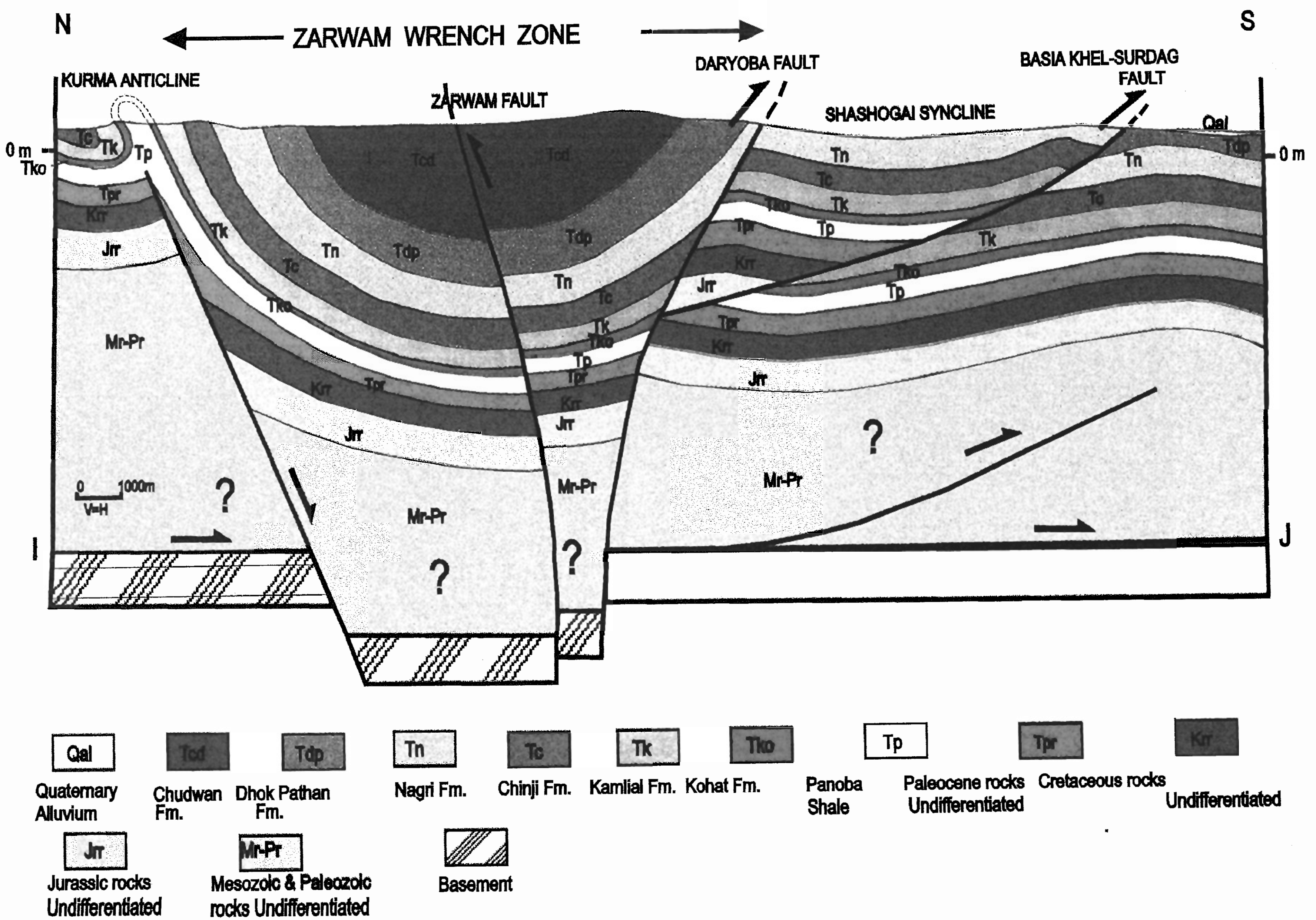


Figure 6.9. Geological cross section along line I-J of figure 6.1.

deformation style switches to thin-skinned mode and the Shashogai Syncline seems to be a flat-syncline sitting on top of the Basia Khel-Surdag Fault, which itself is north-dipping forethrust emplaced over the Bannu Basin.

6.4 Analysis

The map data, combined with subsurface interpretations of the exposed structures depicts that the geometry of Sourthern Kohat Plateau is a combination of thin and thick-skinned deformations style. The thick-skinned deformation is displayed in the section west of the longitude of Latamber, between the Kurma Anticline in the north and Daryoba Fault in the south. All the faults in this section are vertical to sub-vertical at the surface and are mostly non-parallel to bedding. Such a geometric amount of dip-discordance exists between fault planes and bedding surfaces and this relationship can only be produced in the fold and thrust belts subjected to strike-slip deformation (Sylvester, 1988). The vertical to sub-vertical dips of the faults are also an indication of the lateral motion along Daryoba and Zarwam Fault. The projection of Tsapparai Syncline and Kurma Anticline shows that the surface of decoupling lies at the base of Panoba Shale and leads to the inference of a blind normal Fault beneath Kurma Anticline. The sense of displacement in cross section for this fault suggests that it has an apparent normal sense of motion and appears that the northern limb of Tsapparai Syncline is down thrown. However, in a region subjected to a contractile deformation, normal sense of displacement is kinematically beyond question. Based on these observations it is inferred that the area between Daryoba Fault and Kurma Anticline has undergone strike-slip adjustments that involves the basement as well. The involvement of basement rock is inferred from the projection of the limbs of Tsapparai Syncline into the surface. To place in the stratigraphic sequence below the Tsapparai Syncline, it would require a deeper detachment level compared to the north and south of Tsapparai Syncline. The concept of strike-slip movement is also supported by the fact that the limbs of Tsappari syncline offsets in a lateral manner along Zarwam Fault (Figure 6.1). The geometric intersection of the faults within the Zarwam Wrench Zone and the area south and north of it suggest that the strike-slip faulting is a later activity superimposed upon the earlier contractile deformation.

The structural pattern switches to a thin-skinned deformation style east of the longitude of Latamber. In this part of the plateau a series of south verging listric thrust faults, partly blind and emergent are interpreted to be emerging from the basal detachment. In this section, the most prominent structural discontinuity is believed to be the Karak Fault, which marks the northern margin of the Karak Trough with the Southern Kohat Plateau. Along the Karak Fault, substantial vertical uplift is associated which is partitioned into a series of north verging back thrust system and bounds the Karak Pop-Up Zone.

CHAPTER # 7

STRUCTURAL GEOMETRY OF THE ACTIVE RANGE FRONT: SURGHAR RANGE

7.1 Introduction

The Surghar Range is an arcuate mountain belt, forming the southeastern proximity of Kohat Plateau. It has an east-west orientation, switching to a north-south trend while bordering the eastern flank of the Bannu Basin (Figure 7.1). It represents the leading deformational front of the Kohat Fold and Thrust Belt (KFTB) and is the southern most surface expression of tectonic uplift associated with Himalayan orogeny. Being an active frontal range, it has been tectonically uplifted and deformed, accommodating significant amount of shortening.

Little attention has been paid to the tectonic evolution of the Surghar Range, whereas its eastern analogue, the Salt Range is well studied and documented (Gee, 1980; Burbank and Raynolds, 1984; Yeats and Lawrence, 1984). Previous studies in the Surghar Range have been focused mainly on its stratigraphic framework. Significant contribution owes to Danilchik and Shah (1987) to produce a geological map of the north-south trending segment of the range. Most of the east-west trending segment of the Surghar Range remains unmapped except the northern Chichali Pass, which was mapped by Meissner et al. (1974) as part of the Kohat Quadrangle.

This study is oriented to work out the style of deformation, its lateral variation along the strike, the nature of frontal thrust, the amount of shortening and timing of deformation of this frontal thrust zone.

7.2 Geological setting

Beginning about 55 million years ago, the continent-continent collision of Eurasia and India produced the present day spectacular Himalayan arc of the

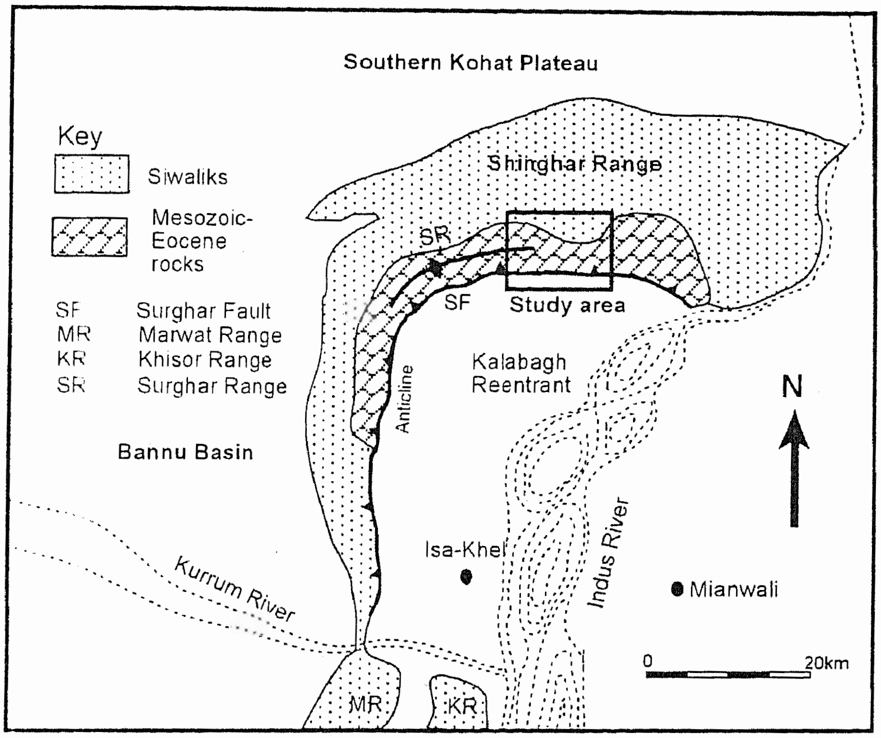


Figure 7.1. Generalized geological map of Surghar Range (Modified after Khan and Opdyke, 1993).

world (Molnar and Tapponier, 1975). In north Pakistan, the Himalayas and its associated mountain ranges trend east-west, switching to a north-south trend in the west (Figure 2.1). The Surghar and Salt Range are the southern most of these east-west trending ranges and represent the active deformational front. The Surghar Range is bounded in the north by the Kohat Plateau and separates it from the Kohat Range and in the west by the flat lying Bannu Basin, which separates it from the northern Sulaiman Range (Figure 1.2).

The exposed stratigraphic sequence of the range in the vicinity of Chichali Pass consists of about 735 m thick succession of Jurassic to Eocene rocks, which is unconformably overlain by the Chinji Formation of Lower Siwalik Group (Figure 7.2). The Datta Formation marks the base of the Jurassic sequence and contains red, gray and white sandstone with siltstone, shale, mudstone, marl and fire clay horizons. It grades upward into medium-bedded limestone, marl and sandstone of the Shinawari Formation, and is disconformably overlain by medium-bedded, gray limestone of Samana Suk Formation. The Samana Suk Formation is unconformably overlain by the Glauconitic sandstone and shale of the Chichali Formation, and is representing the upper part of the Cretaceous in the study area. Unconformably resting above the Cretaceous, the Paleocene is represented by 30 m thick beds of the Patala Formation, including sandstone, nodular limestone, carbonaceous shale and marl. This Paleocene sequence transitionally grades into a sequence of marl, limestone and shale of Nammal Formation. The Nammal Formation is conformably overlain by nodular to massive Sakessar Limestone, which is unconformably underlying the Siwalik Group rocks in the study area.

7.3 Structural geometry

The Surghar Range has an irregular map pattern with an east-west trend in general (Figure 7.3). Its structure is dominated by a south facing asymmetric Surghar anticline (Figure 7.3). The backlimb of this anticline is less deformed having shallow to moderate dip angles and covers the main topographic

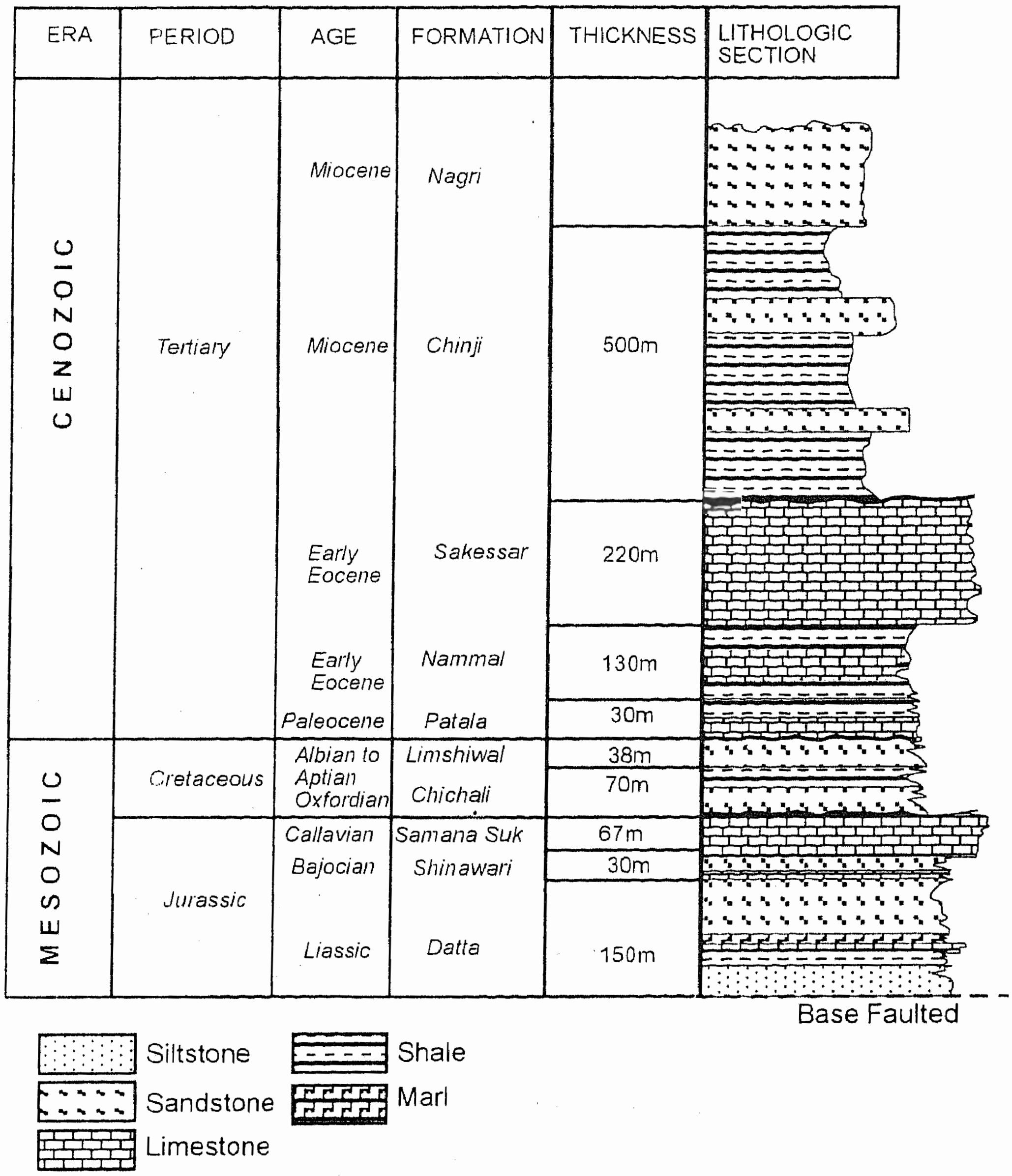


Figure 7.3. Generalized stratigraphic sequence of the Surghar Range in the vicinity of Chichali Pass area.

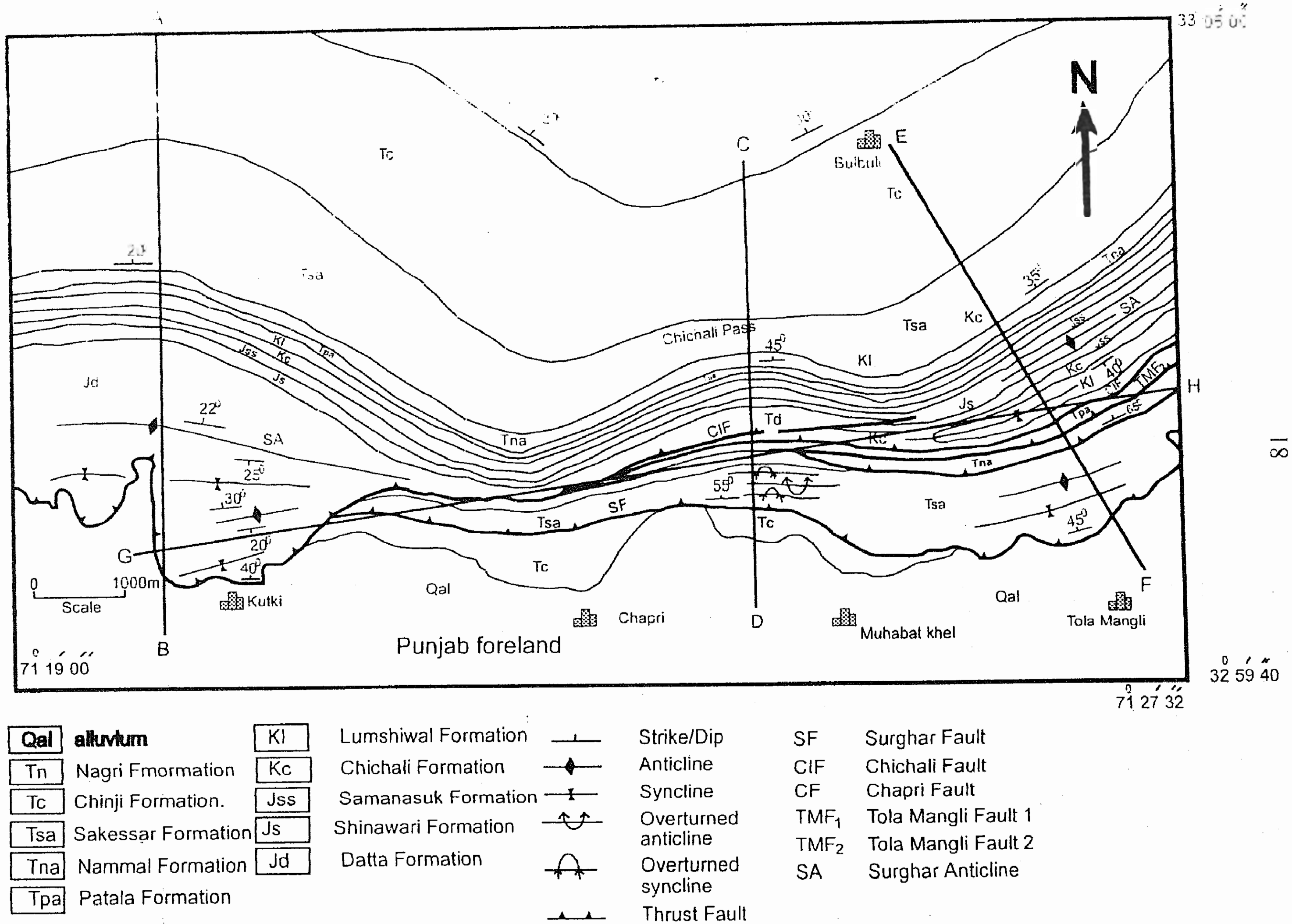
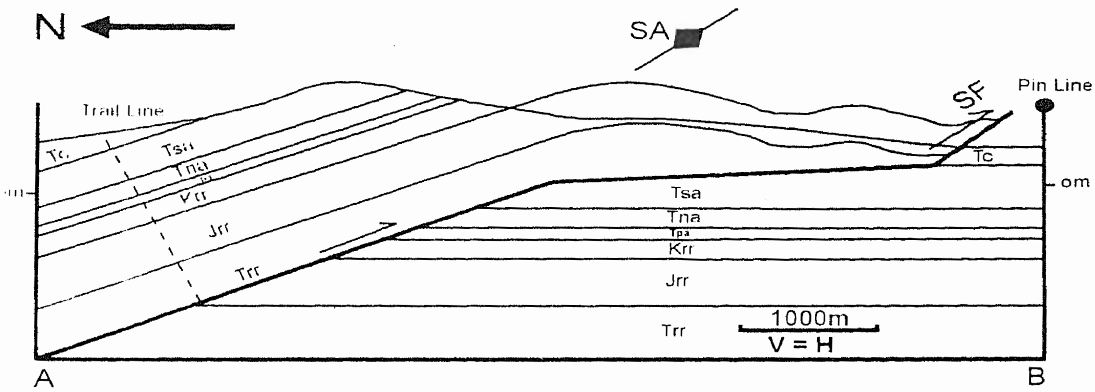


Figure 7.3. Geological map of Surghar Range in the vicinity of Chichali Pass area, Mianwali and Karak district of Punjab and NWFP Pakistan.

expression of the range. The forelimb of the Surghar anticline is moderately south dipping north of Kutki and Tola Mangli villages and is dissected by Chichali Fault north of the Chapari village. Jurassic rocks occupy the core of the Surghar Anticline. Surghar Fault along which Mesozoic rocks of the Surghar Range are thrust southwards over the Punjab foreland marks the range front. During field study it was noticed that contrasting geometric variations exist within the rocks along the strike. In order to understand these variations, cross-sections along line A-B, C-D, E-F and G-H of Figure 7.3 were constructed for detailed study.

From south to north along line A-B, the Surghar Fault brings the rocks of Datta Formation over the Chinji Formation in the footwall of Surhgar Fault (Figure7.4 and 7.5). The hanging wall sequence is shallowly folded into couple of south facing anticlines and synclines (Figure 7.6). The ramp is considered to be detached within or at the base of the Triassic sequence. Instead of cutting through Surghar anticline, it flattens at a shallow level and emerges at the surface about 2 km foreland ward, ahead of the bend in the major ramp. The structural style along the section shows a steady shortening and an easy propagation of thrust sheet towards the foreland.

Cross section C-D (Figure 7.7) represents the area in the vicinity of Chichali Pass and displays contrasting geometry as compared to the line A-B (Figure 7.4). From foreland towards hinterland, the shallowly folded Chinji Formation is thrust over by the Sakessar Limestone along the northerly dipping Surghar Fault (Figure 7.8). The hanging wall of this fault carries highly contorted Eocene strata. Further northwards the Chapri Fault has brought the Chichali Formation over the Paleocene rocks in the footwall (Figure 7.9). Immediately north of Chapri Fault, the Chichali Fault brings the Jurassic rocks in its hanging-wall over the Chichali Formation in the footwall (Figure 7.10). Most of the faults in this section are steeply north dipping. Here the displacement is distributed



INDEX

Qal	Alluvium	Tpa	Patala Formatiom
Tn	Nagri Formation	Krr	Cretaceous rocks undifferentiated
Tc	Chinji Formation	Jrr	Jurassic rocks undifferentiated
Tsa	Sakessar Formation	Trr	Triassic rocks undifferentiated
Tna	Nammal Formation		

SA Surhgar Anticline
SF Surghar Fault

Figure 7.4. Cross-section along line A-B of figure 7.3 through Chichali Pass.

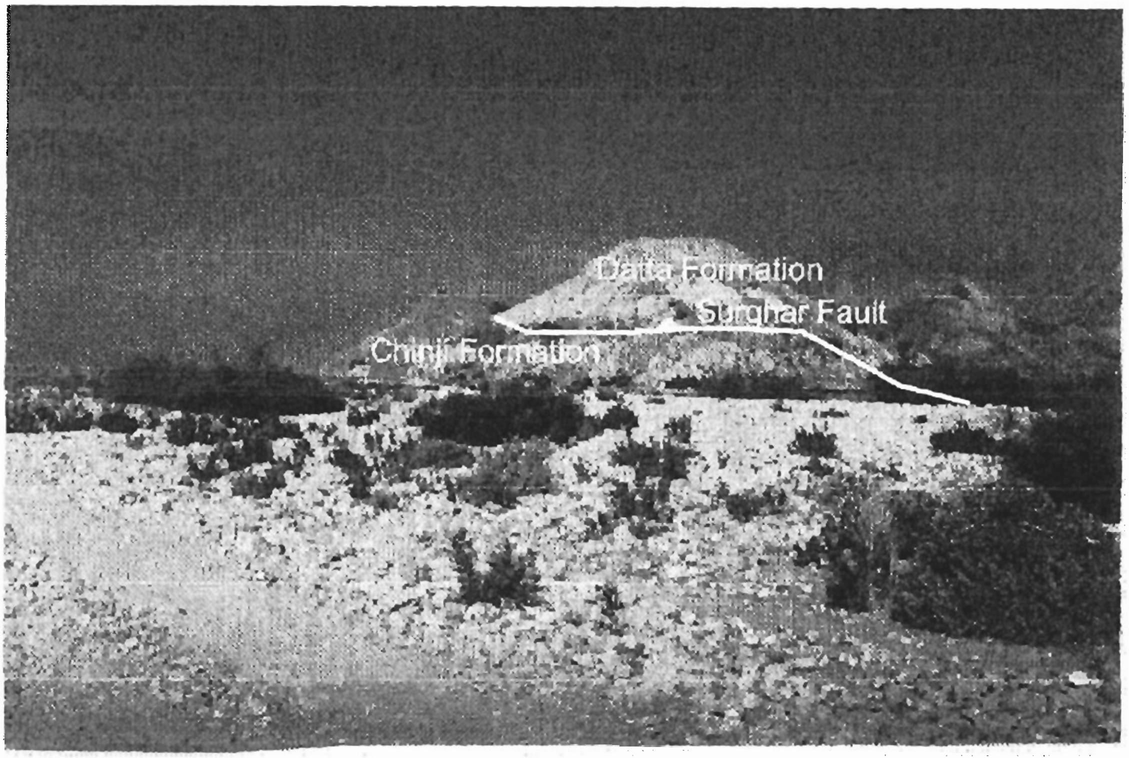


Figure 7.5. Northwest looking view of Surghar Fault north of Kutki Village, which brings Datta Formation over the Chinji Formation in its footwall.

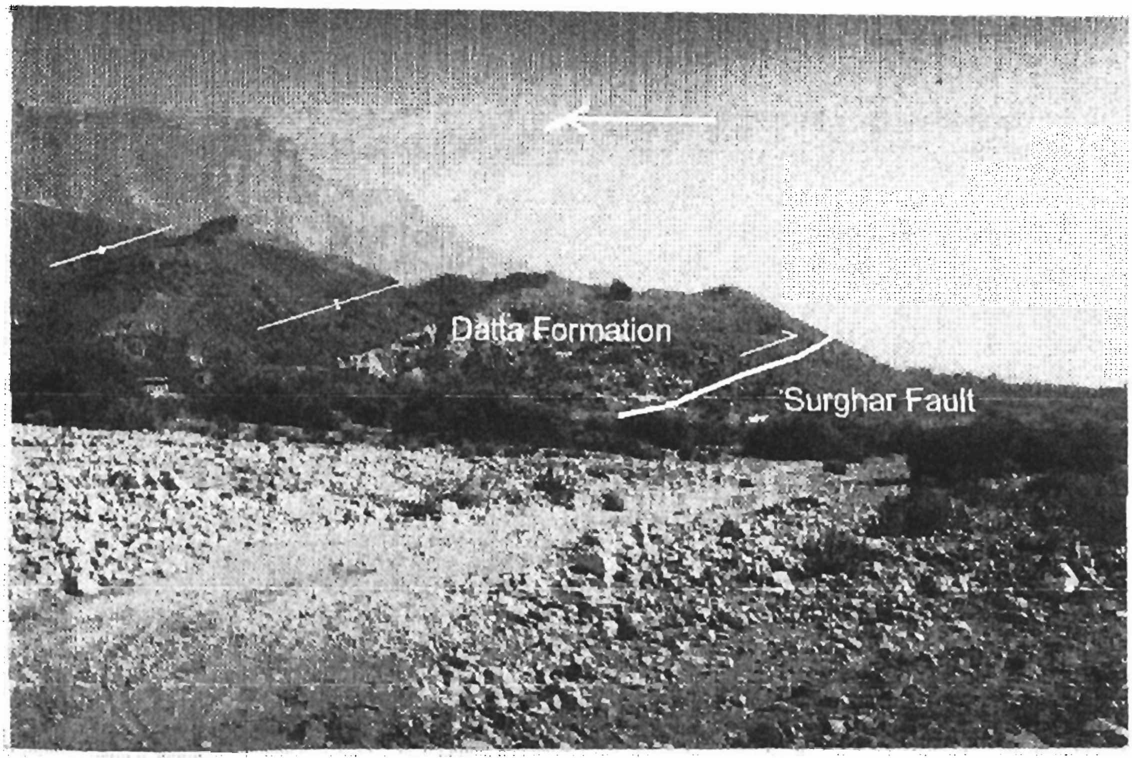
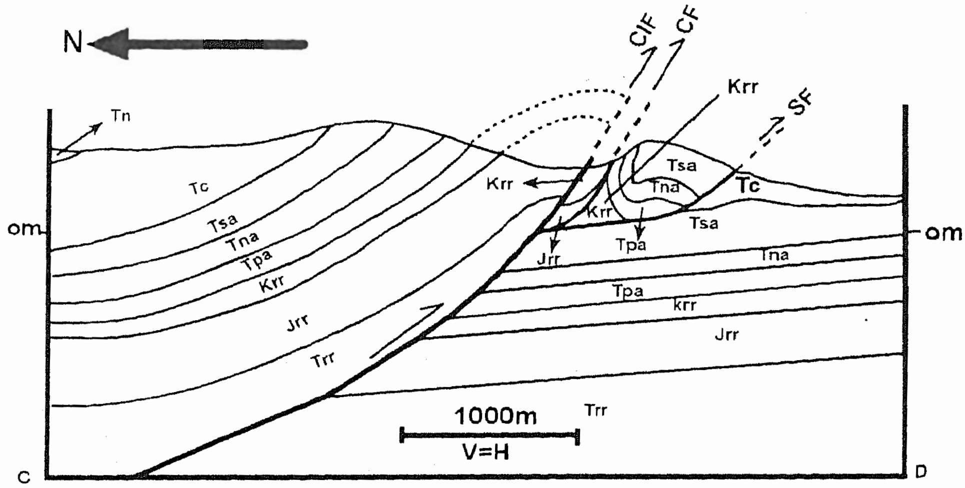


Figure 7.6. Shallowely folded thrust sheet of Surghar Fault, looking east along Kutki Nala.



Explanation

Qal	Alluvium	Tpa	Patala Formation	SF Surghar Fault
Tn	Nagri Formation	Krr	Cretaceous rocks undiff.	CF Chapri Fault
Tc	Chinji Formation	Jrr	Jurassic rocks undiff.	CIF Chichali fault
Tsa	Sakessar Formation	Trr	Triassic rocks undif.	
Tna	Nammal Formation			

Figure 7.7. Cross section along line C-D of figure7.3.

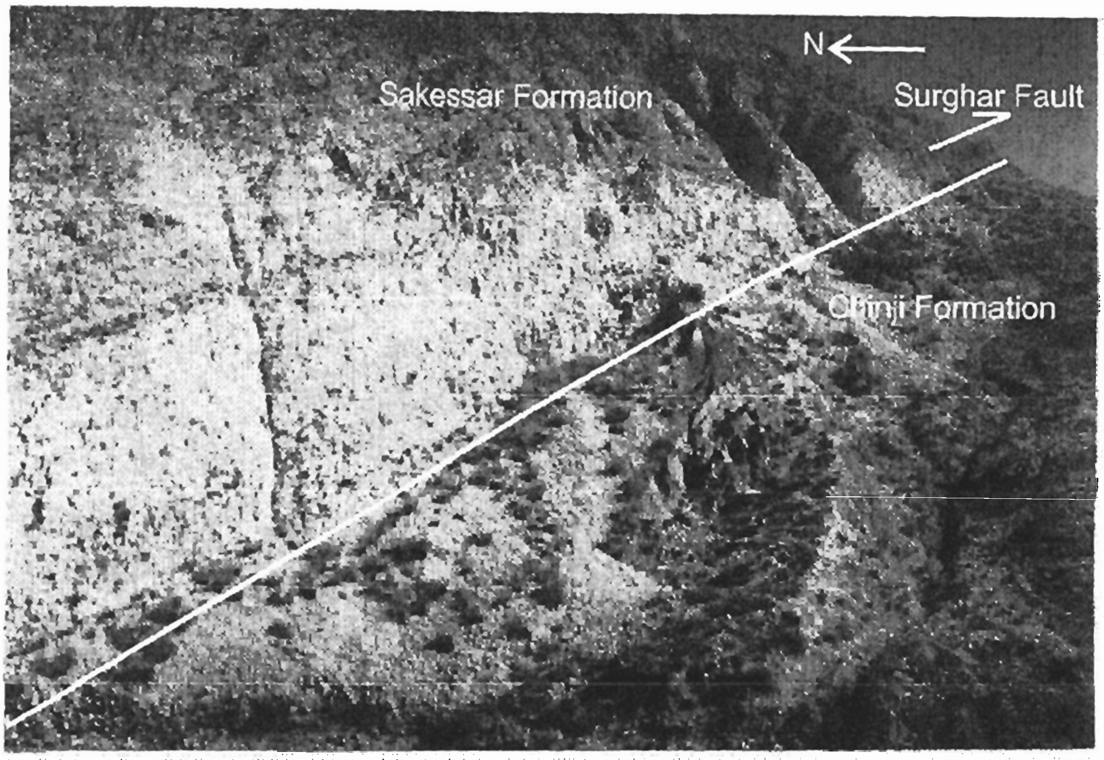


Figure 7.8. North-dipping Surghar Fault along which Sakessar Formation is thrust southwards over Chinji Formation in the vicinity of Chichali Pass.

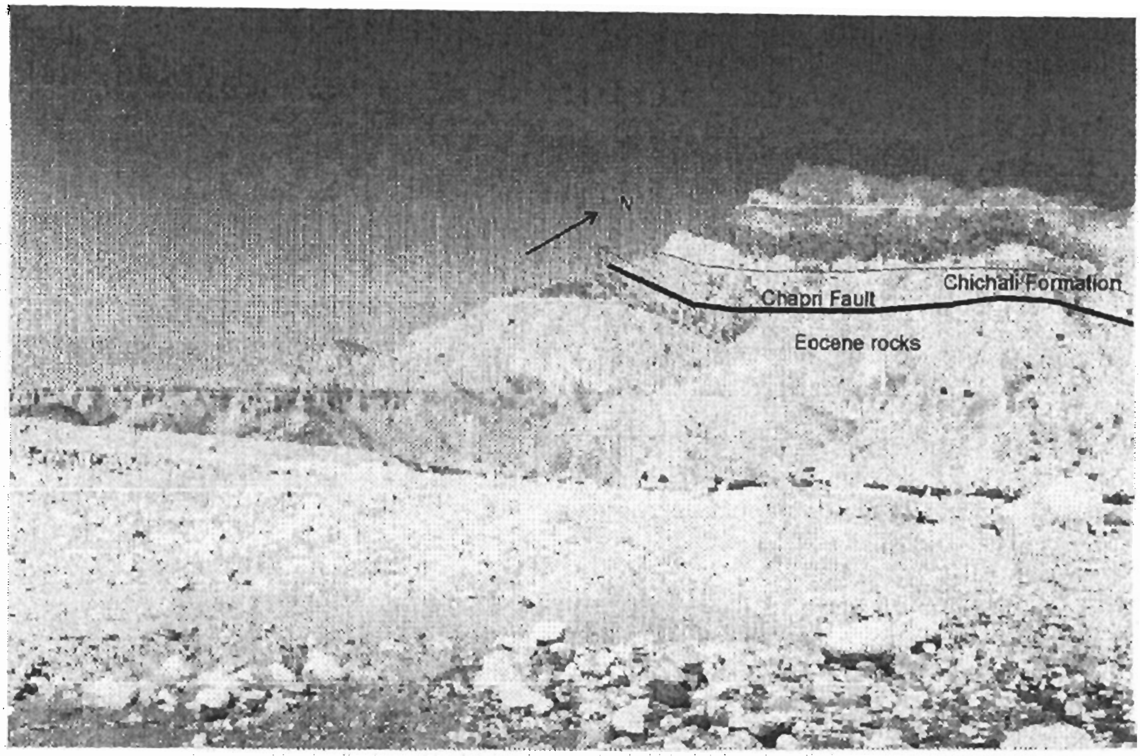


Figure 7.9. A north-west looking view of Chapri Fault exposed along Chichali Nala.

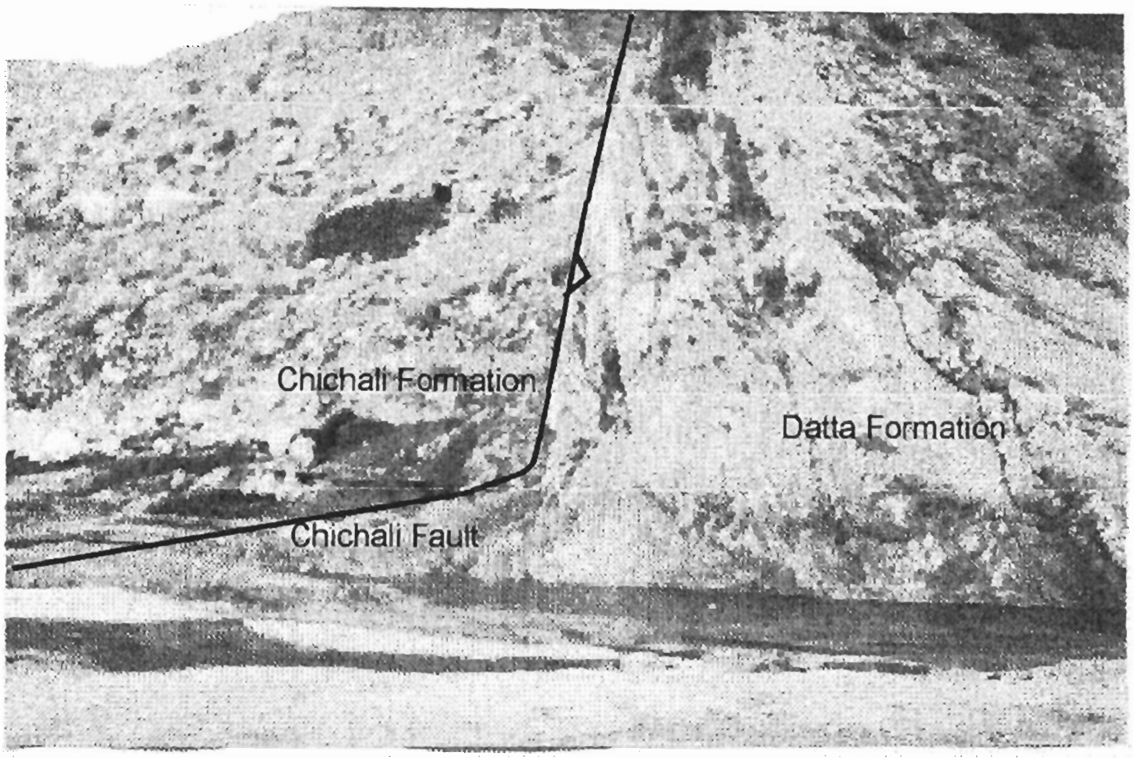
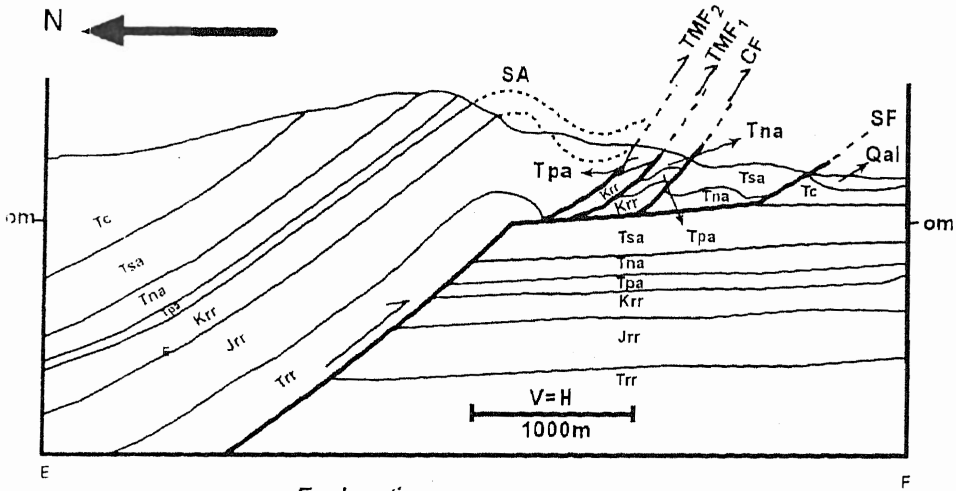


Figure .7.10. Eastward looking view of Chichali Fault along Chichali Nala.

through several thrust splays instead of a single frontal thrust, which is the case in the Kutki section (Figure 7.4).

Foreland to hinterland traverse along line C-D (Figure 7.11); the folded rocks of the Sakessar Limestone are thrust over the terrace deposits in the footwall of Surghar Fault. The hanging-wall sequence of this fault is shallowly folded and is thrust over by Nammal Formation along moderately north-dipping Chapri Fault. Immediately northwards the hanging wall rocks of Chapri Fault is thrust over by the Paleocene rocks along Tola Mangli Fault-1. Up section, another thrust splay, such as Tola Mangli Fault-2 brings the Cretaceous rocks over the Paleocene sequence in the footwall. The hanging wall of Tola Mangli Fault-2 is shallowly folded into a south facing anticline (Surghar Anticline) and syncline (Figure 7.12). The Surghar Anticline is cored by the Shinawari Formation of Jurassic age and both of its limbs are intact in this section. The ramp is interpreted to be detached within or at the base of Triassic sequence and flattens at a shallow level. The displacement is distributed through a series of thrust splays instead of a single fault.

Cross-section G-H has been drawn parallel to the strike of the range in order to study the lateral variations in the structural geometry (Figure 7.13). In the west, the Surghar Fault carries Datta Formation in its hangingwall over the Chinji Formation. The cross section illustrates that the thrust sheet was propagated easily in the west. Further eastwards it seems that the displacement along the Surghar Fault became stuck at some point and the hanging wall strata was deformed by the formation of another thrust splay towards the hinterland. In the extreme east of the section the displacement is distributed through four thrust splays, which indicate sequential failure of the hanging wall rocks in response to sticking of displacement along the Surghar Fault.



Explanation

Qal	Alluvium	Tpa	Patala Formation
Tn	Nagri Formation	Krr	Cretaceous rocks undifferentiated
Tc	Chinji Formation	Jrr	Jurassic rocks undifferentiated
Tsa	Sakessar Formation	Trr	Triassic rocks undifferentiated
Tna	Nammal Formation		

SA Surghar Anticline
SF Surghar Fault
CF Chapri Fault
TMF_1 Tola Mangli Fault
TMF_2 Tola Mangli Fault

Figure 7.11. Cross section along line E-F through Tola Mangli from figure 7.3.

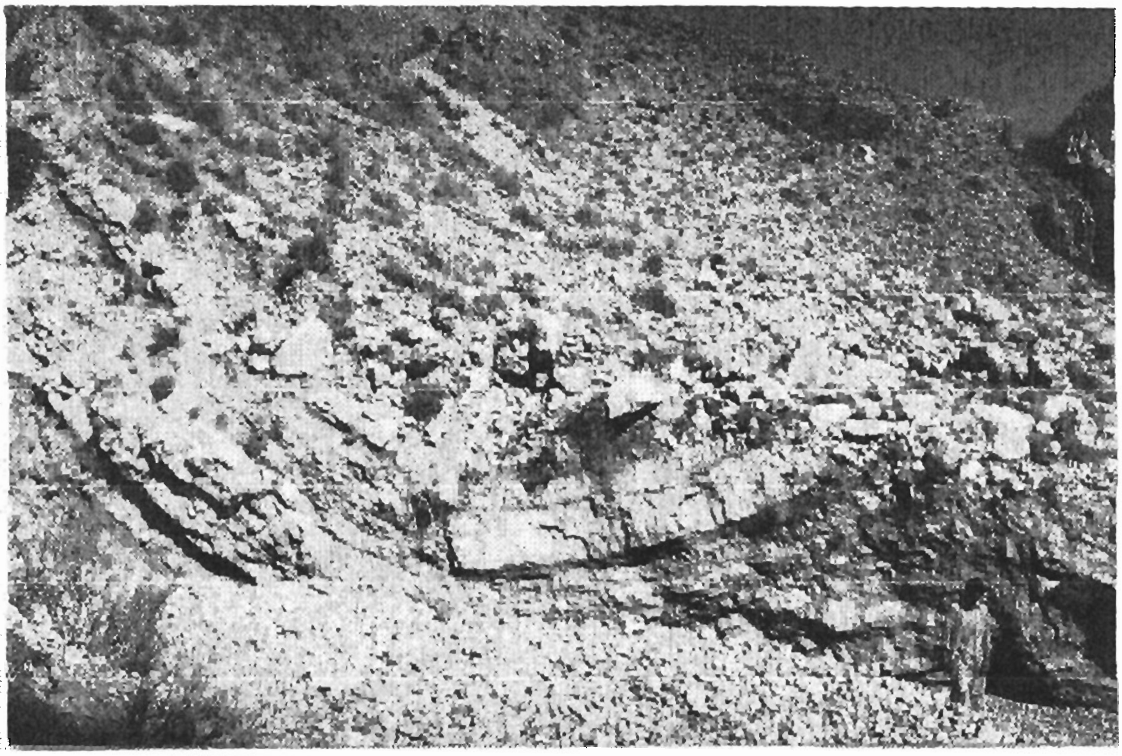
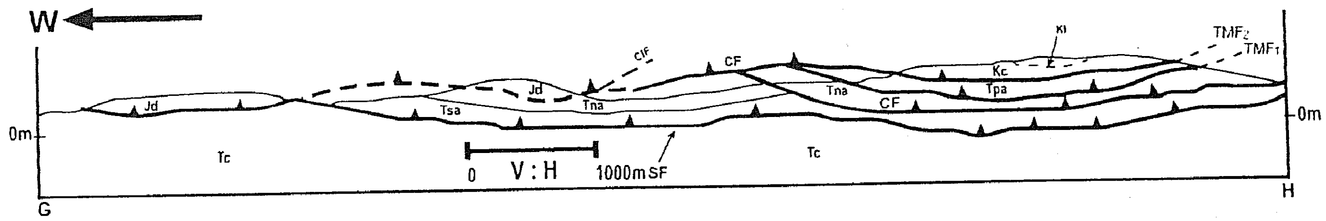


Figure 7.12. Shallowely folded thrust sheet of Tola Mangli Fault 2, exposed along Tola Mangli Nala.



Explanation

Qal	Alluvium	Tpa	Patala Formation	SF	Surhgar Fault
Tn	Nagri Formation	Krr	Cretaceous rocks undifferentiated	CF	Chapri Fault
Tc	Chinji Formation	Jrr	Jurassic rocks undifferentiated	CIF	Chichali Fault
Tsa	Sakessar Formation	Trr	Triassic rocks undifferentiated	TMF 1	Tola Mangli Fault
Tna	Nammal Formation			TMF 2	Tola Mangli Fault

Figure 7.13. Cross section along line G-H of figure 7.3 through Surghar Range.

7.4 Structural analysis

The variations in the structural geometry along the strike of the range can be well explained in terms of motion along the thrust sheet. The style of deformation in the west of the mapped area is typical of a thrust sheet that has propagated freely towards foreland with most of its shortening taken up by the frontal fault and the thrust sheet is gently deformed by shallow folds (Figure 7.4). It bears close similarities with the Morely (1986) thrust sheet development, where the sole thrust propagates rapidly to the surface instead of dying out periodically into the zones of high strain. The style of deformation changes rapidly eastwards in the Chichali area (Figure7.7) and display stick-slip style of deformation. The Surghar Fault, which marks the range front, represents the early stages of faulting. It was stuck at a shallow level after initial displacement and uplift. The associated thrust sheet of Surghar Fault was Passively folded, as is the case in Kutki section. The tightening of folds within the thrust sheet accommodated the incremental strain that later on sequentially failed giving rise to a north younging imbricate fan. The notion of stick-slip displacement is also supported by the development of low amplitude folds within the Siwalik rocks, located south of the Surghar Fault (Figure 7.14). Based on these observations it is noted that the range front is a weakly emergent thrust front in the vicinity of Chichali area. The stick-slip style of deformation continues eastward up to Tola Mangli area with the exception that the hanging wall anticline, such as the Surghar Anticline remained intact and the strain build-up got concentrated in a wider zone within the Surghar thrust sheet. The restored cross-sections along Kutki section reveals that overall 5.6 km shortening has taken place along the frontal Surghar Fault (Figure 7.15).

According to Khan and Opdyke (1993), the present site of Makarwal Anticline (Surghar Anticline) was occupied by Paleo-Indus River flowing west to east during 2.3-7 Ma that was later on displaced, indicating the start of tectonic activity at the site of Surghar Range.

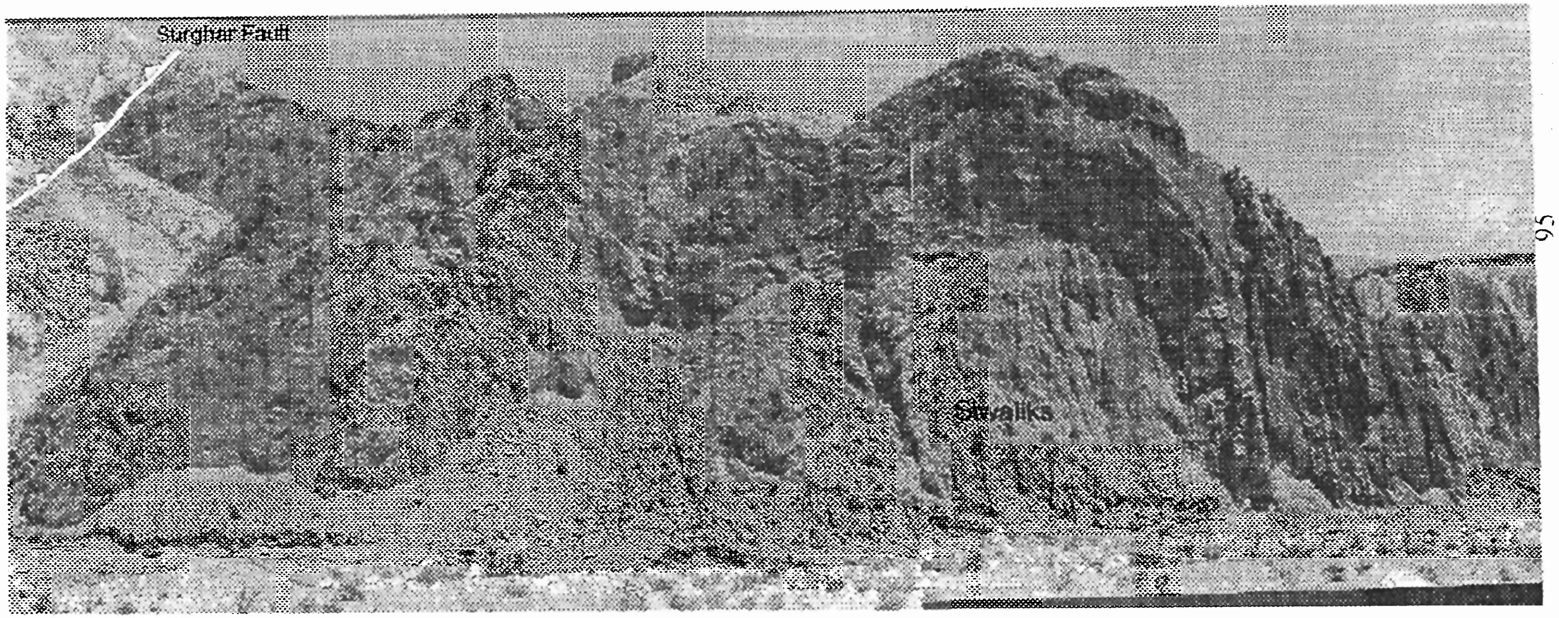
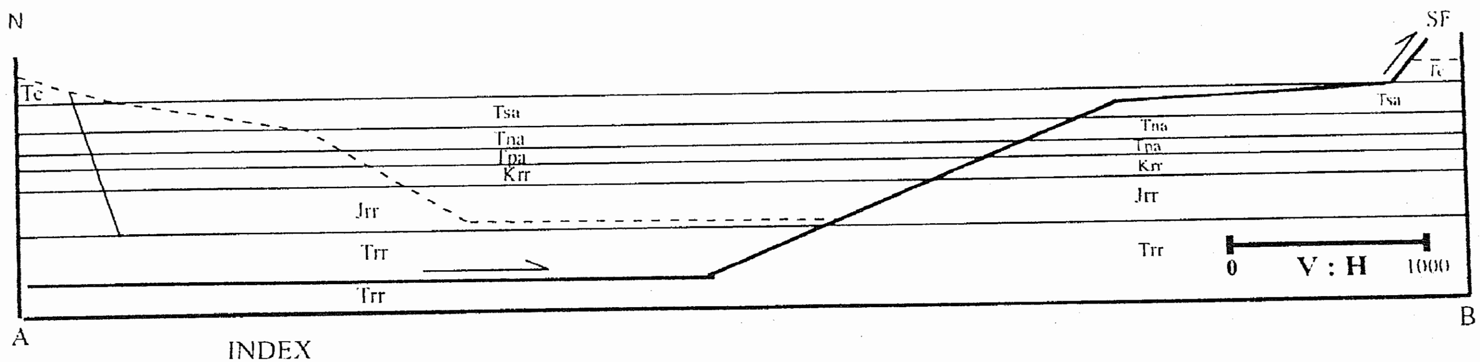


Figure 7.14. Low amplitude folds exposed in the foot wall of Surghar Fault within Siwalik rocks along Chichali nala.



INDEX

Qal	Alluvium	Tpa	Patala Formatiom
Tn	Nagri Formation	Krr	Cretaceous rocks undifferentiated
Tc	Chinji Formation	Jrr	Jurassic rocks undifferentiated
Tsa	Sakessar Formation	Trr	Triassic rocks undifferentiated
Tna	Nammal Formation		

SF Surghar Fault

Fig. 7.15 Restored cross-section along line A-B from Figure 7.3.

CHAPTER # 8

DISCUSSION AND CONCLUSIONS

8.1 Structural style and geometry

The present study within the Kohat Plateau suggests that it is dominantly a thin-skinned deformed fold and thrust belt, superimposed by thick-skinned structures along its southern boundary marked by the Bannu Basin and Karak Trough. The thin-skinned structures are well preserved throughout the plateau within the Eocene cover. These structures portray a variety of structural styles that include disharmonic anticlinal folds, relics of a large overthrust sheet, north and south verging thrusts associated with pop-ups and triangle zones (Plate 1, in pocket). The following discussion of the structural style is described analytically from north to south in order to highlight the aerial variations.

8.1.a. Northern Kohat Plateau

The surface structures within the outcropping Eocene rocks in the Northern Kohat Plateau are dominated by east-west trending macroscopic-scale anticlinal and synclinal folds. The anticlinal folds mostly display greater structural relief above the adjacent synclines and overturned limbs. Generally all the folds lack a unidirectional vergence, however, south vergence is observed at places. In cross-sectional view most of the folds exhibit **fan geometry.** The Panoba Shale generally cores these anticlines. The anticlinal trends incorporate low amplitude folds associated along their limbs and flanks. Relics of a large-scale overthrust sheet are mapped in the Northern Kohat Plateau as discontinuous patches. Deeper level fault exposures at the surface are rare.

Two contrasting models have explained previous account of the structural genesis of the outcropping rocks in the Northern Kohat Plateau. One of these models depicts that the structures within the exposed rocks are part of a Passive roof thrust that is translating northwards in a thin-skinned fashion. This Passive roof thrust is underlain by an active wedge of south-directed thrust slices of Pre-Tertiary stratigraphy that form a passive roof duplex (McDougall and Hussain, 1991; Abbasi and McElroy, 1991) (Figure.8.1 a, b and 8.2 a and b). If the outcropping strata within the Northern Kohat Plateau, regarded as a Passive roof sequence then it must be characterized by a) hinterland-facing isoclinal folds, b) overstep sequence of foreland-dipping passive back thrusts and, c) foreland ward-dipping monoclinal range front (Banks and Warburton, 1986). In fact none of the above mentioned structures are found in the Kohat Plateau to support the idea of passive roof thrusting. Majority of the folds mapped in the region display fan geometries without any facing direction. Though back thrusts are mapped in the area but are genetically related to the south-facing forethrusts without any overstepping. The Surghar Range, which represents the leading front of the Plateau, is weakly to strongly emergent thrust.

The second model suggests that the structural evolution of the Northern Kohat Plateau has been greatly influenced by strike-slip faulting related to thick-skinned deformation. These strike-slip faults are not recognizable at the surface but are deep-rooted in the basement and expose themselves as anticlinal trends in the Eocene cover (Pivnik and Sercombe, 1993; Sercombe et al., 1994 a, b; Sercombe et al., 1998) (Figure, 8.3 a, b). However, the present structural data mapped do not coincide with this interpretation. If the anticlinal trends at the surface are rooted by basement related strike-slip faults, it is surprising that not at a single locality evidences of lateral off set are found. Also, the tectonic setting of the Northern Kohat Plateau does not support this because it is located in close proximity to the MBT and constitute its foot wall stratigraphy. The MBT is a well documented south directed thrust system (McDougal and Hussain, 1991). Further, the region entirely lacks any of the characteristic features related to strike-slip faulting such as transtensional and transpressional bends, en-echelon array of faults and folds (Sylvester, 1988).

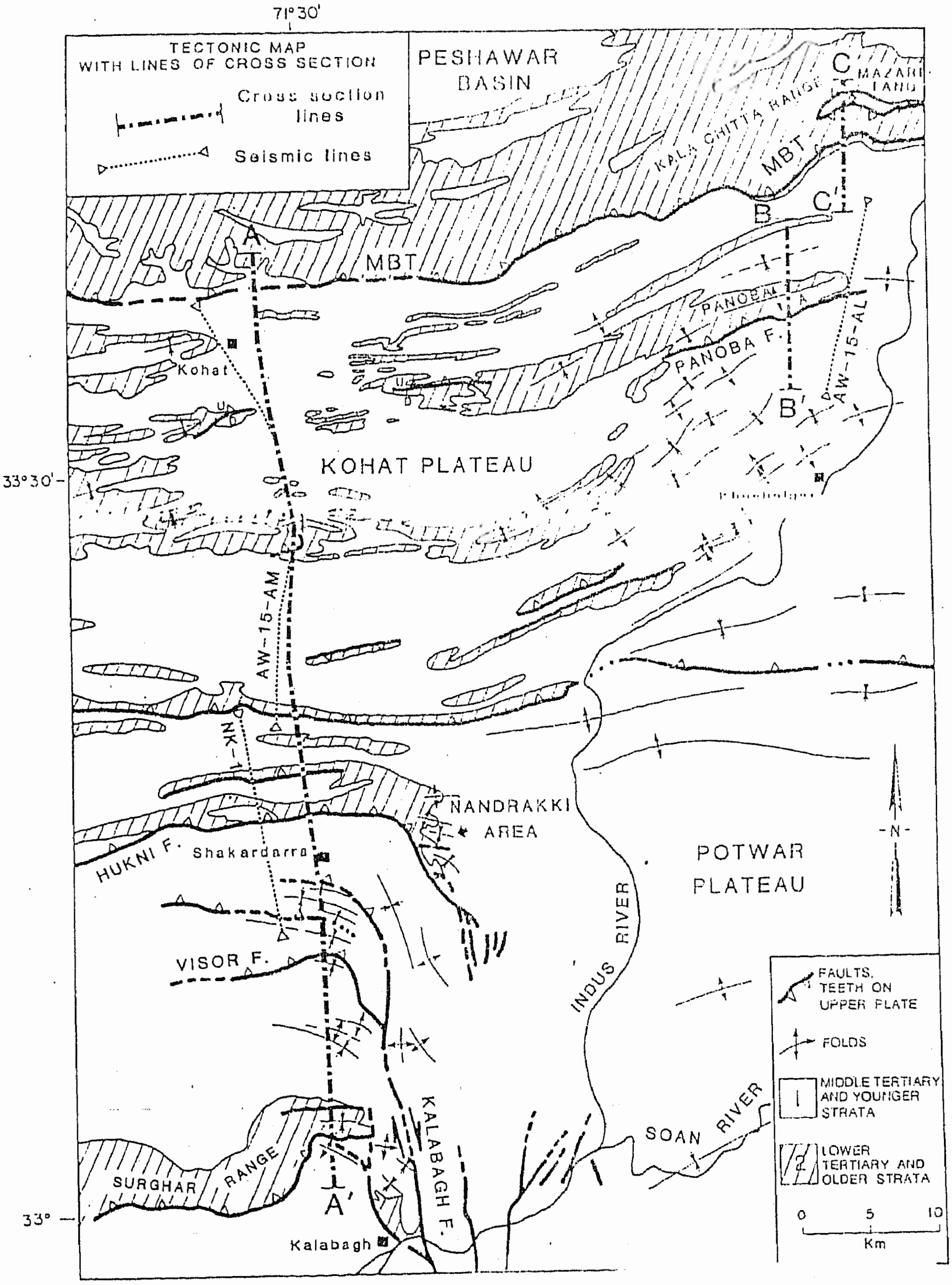


Figure 8.1a. Tectonic map of the Kohat Plateau (After McDougal and Hussain, 1991).

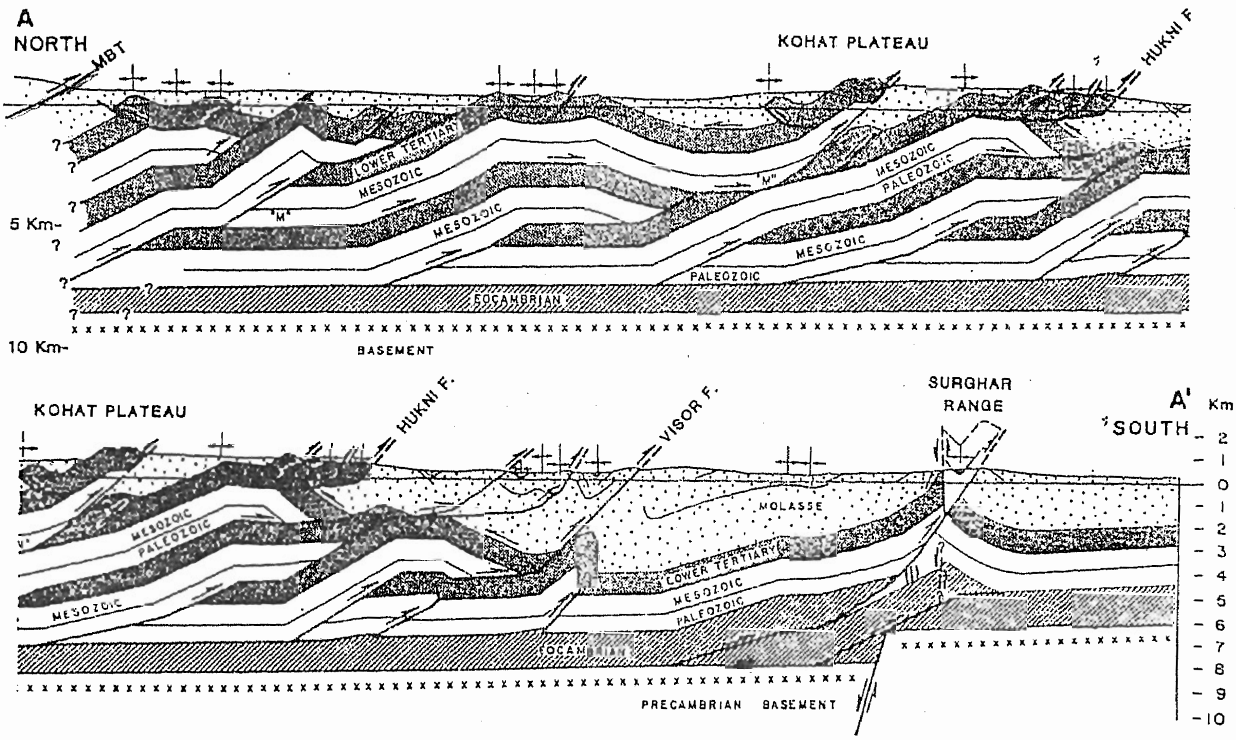


Figure 8.1b. Cross section A- A/, south of MBT up to Surghar Range, located on figure 8.1.a (After McDougal and Hussain, 1991).

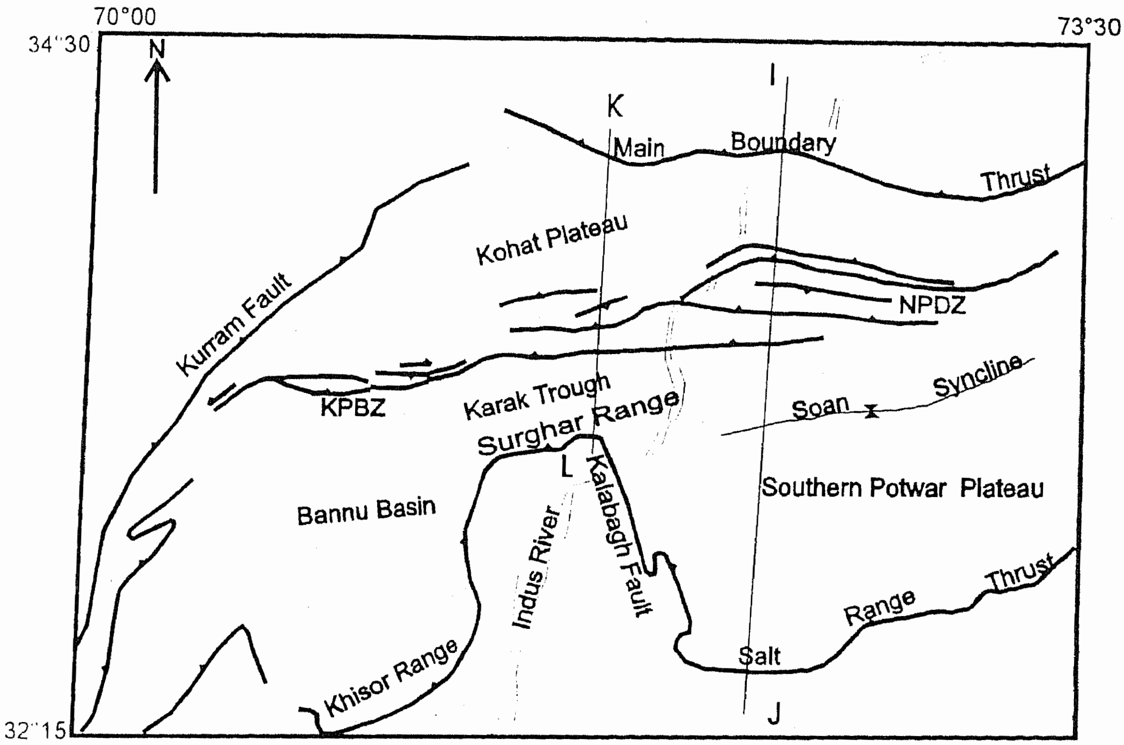


Figure 8.2 a. Structural map of Kohat Plateau (After Abassi and Mc Elory, 1991). KPBZ: Kohat Plateau Boundary Zone, NPDZ: Northern Potwar Deformed Zone.

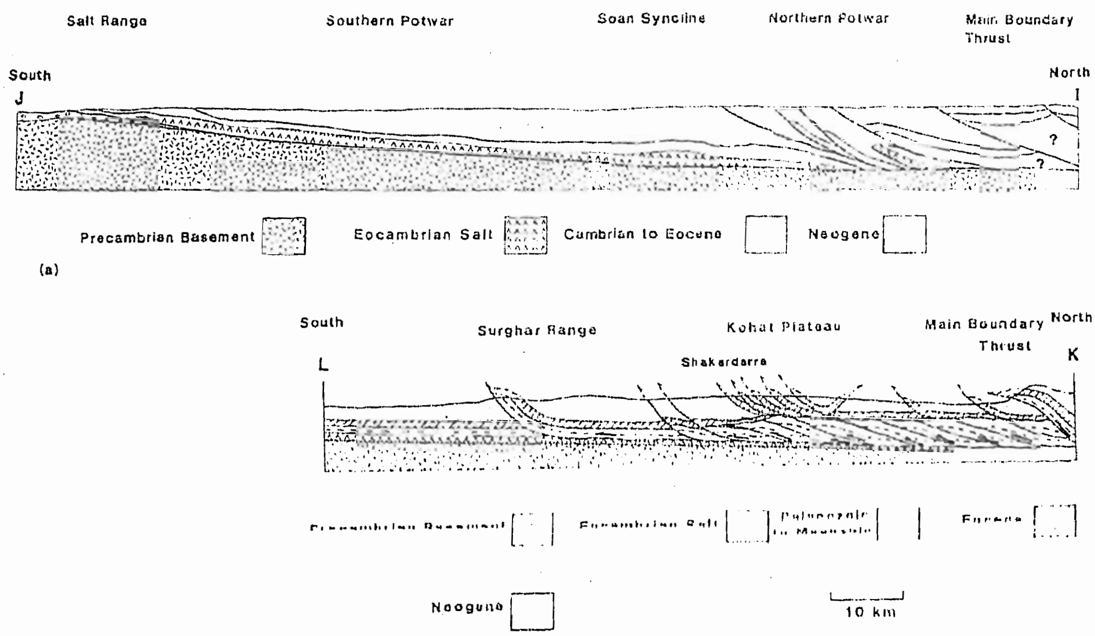


Figure 8.2b. Cross section I-J (Figure 8.2a) through western Potwar Plateau (After Leathers, 1987) and cross section L-K (Figure 8.2a) through Kohat Plateau (After Abassi and McElory, 1991).

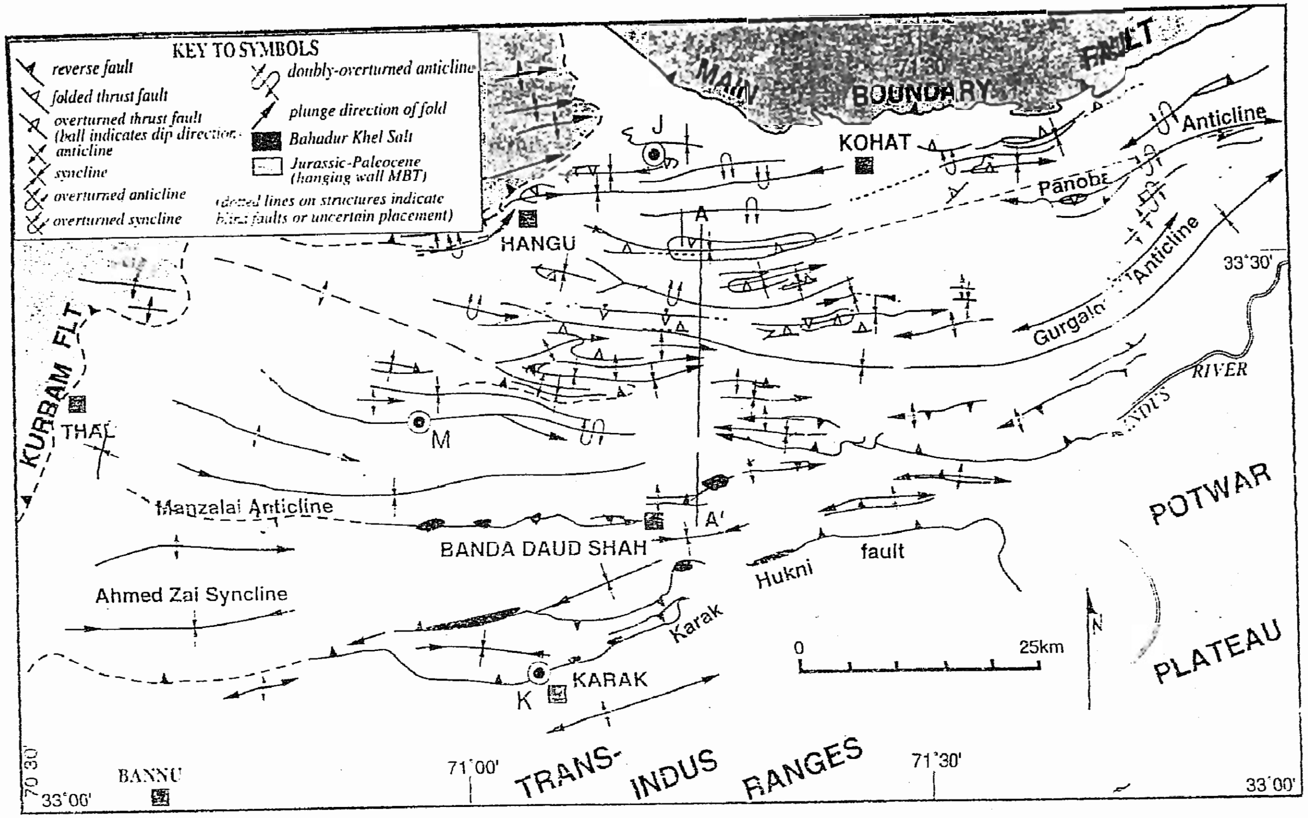


Figure 8.3a. Generalized geologic map of Kohat Plateau (After Pivnik and Wells, 1996).

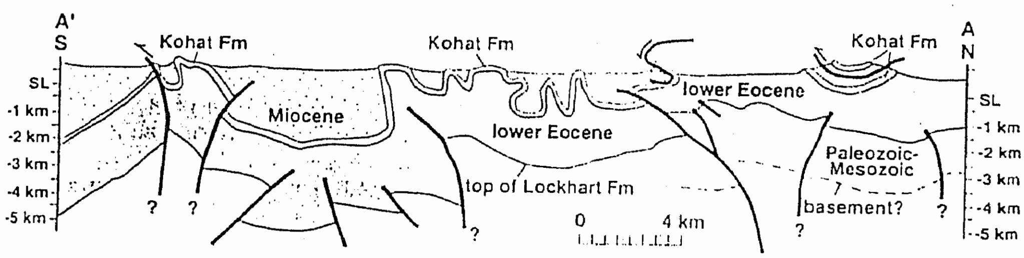


Figure 8.3.b. Structural cross section across Kohat Plateau along line AA of

Figure 8.3a (After Pivnik and Wells, 1996).

The present account of geometric data along the anticlinal trends within the Northern Kohat Plateau suggests that the genesis of these folds is neither related to translation along subsurface Passive roof thrust and not these folds are cored by deep-rooted strike-slip faults, but are detachment folds, which are decoupled at the base of Panoba Shale. The fan geometry of the folds in the region is attributed to the process of shale diapirism and is believed to be the only mechanism, which can explain the overturned nature of these mapped folds. Due to the enormous thickness and plastic behavior of Panoba Shale It is interpreted that it has flowed into the cores of anticlines and away from the cores of synclines.

Deformation of non-outcropping rocks in the subsurface is much more simpler as compared to the outcropping rocks. The structural style in the subsurface is mainly controlled by a series of south-verging listric thrust faults that are partially emergent and blind. These faults emerged as thrust splays from a basal decollement, which is located at the contact between sediments and basement rocks. The translations along these faults have resulted in fault propagation folds within the subsurface Pre-Eocene rocks and as disharmonic detachment folds in the Eocene rocks at the surface.

The vertical structure contrast between the surface and subsurface can be credited to a major rheologic change between the two successions such as a thick evaporite and shale horizon, which forms the base of Eocene succession in the plateau. This horizon has served as a decoupling surface for the folds within the Eocene rocks. It is believed that the thrust splays which sole out from the basal decollement mostly lose their displacement upon encountering the base of Eocene sequence. The shortening associated with the thrust splays is distributed within the Eocene rocks resulting in disharmonic folds. These folds generally lack unidirectional vergence and display fan geometries.

8.1.b. Central Kohat Plateau

Similar structural style like that of Northern Kohat Plateau has been observed in the Central Kohat Plateau west of the longitude of Jatta Ismail Khel. However, in the area east of the longitude of Jatta Ismail Khel substantial contrast in the surficial structures exists as compared to that of Northern Kohat Plateau. In this region the surface geometry is dominated by east-west trending macroscopic-scale anticlines that are mostly characterized by faulted limbs. This structural contrast between the Northern Kohat Plateau and the Central Kohat Plateau is related to a facie change at the base of Eocene stratigraphy, from shale in the north to evaporites in the south. This facies change has greatly facilitated the translation along thrust splays cutting up section from lower decollement. Most of these faults upon encountering the evaporite horizon at a higher level get branched to give rise to imbricate structures, triangle zones and pop-ups.

Contrary to the Northern Kohat Plateau, the deep-rooted faults behave differently in the Central Kohat Plateau. A logical explanation for this contrast is the difference in the thicknesses of the northern and southern facies. The thickness of the Panoba Shale is greater than 600 meters (Sumari well No. 1 APEC, Pakistan, (Khan,1999) whereas the Jatta gypsum is 30 meters thick at its type locality. It is inferred that due to the enormous thickness of the shale in the Northern Kohat Plateau, the deep-rooted faults lose their displacement upon encountering the shale horizon. Whereas in the Central Kohat Plateau, the deep-rooted faults encounter thin gypsum horizon and instead of losing displacement they get branched and emerge out at the surface.

8.1.c. Southern Kohat Plateau

While the major part of the plateau is dominated by compressional structures, strike-slip faulting is noticeable in the south of the region. The strike-slip faulting is confined to a zone that is 3-12 kilometers wide, stretching from

Zarwam in the west to Banda Lakhoni in the east. This distinctive structural domain is named as the **Kohat Plateau Boundary Zone** (KPBZ) and can easily be differentiated from the other widespread compressional features distributed through out the plateau. The KPBZ forms tectonic boundary between the Kohat plateau in the north and Bannu Basin and Karak Trough in the south (Figure 8.2a). It is defined by a couple of east-west trending fault systems that is the Zarwam-Nari Panos Fault system in the north and Basia Khel-Surdag-Karak Fault system in the south. The **KPBZ** typify strike-slip deformational features that include steep dips along the faults, stratigraphic mismatch across the faults, horizontal slicks along the fault surfaces and stepped arrangement of small-scale folds. The older compressional structures mapped in the **KPBZ** are influenced due to the motion along younger strike-slip faults. The present account of structural styles in the Southern Kohat Plateau to a greater degree acknowledges the early model of wrench faulting presented for the entire Kohat Plateau (Pivnik and Sercombe, 1993). Despite the fact, that the entire Kohat Plateau shares almost similar rheologies and tectonic environments, queuing that why the southern part of the plateau behave differently. It is suggested that the genesis of the strike-slip faulting in the **KPBZ** is related to the westward underthrusting of the Southern Kohat Plateau rocks underneath the Sulaiman and Samana Ranges in the west along the transpressional boundary called as the Kuram Fault (Pivnik and Sercombe, 1993). The transpressional deformation associated with the Kurram Fault has been transmitted to the **KPBZ** and the strike-slip faults of the **KPBZ** are believed to be rheidal shears associated with the major principle displacement zone that is the Kurram Fault.

8.1.d. Range Front: Surghar Range

The surface outcrop within Kohat Plateau only depicts the structural style of the Paleocene-Pliocene sequence as no rocks older than the Paleocene are mapped. The Surghar Range that forms the leading deformational front of Kohat Plateau provides opportunity to understand the structural style of deformation within the Mesozoic-Paleozoic rocks that is non-outcropping in the internal parts of Kohat Plateau. The detailed investigations in the Surghar Range suggests that it is dominantly a south verging thrust front detached at the base of Triassic sequence that is emplaced onto Punjab Foreland in the south. The structural data in the Surghar Range provides clear evidences that the Kohat Plateau is a thin-skinned tectonic feature that has developed as a response to southward migration of deformation above a regional basal decollement at the Paleozoic-Mesozoic sediments and basement interface.

The deformation within the Surghar Range can also be used to test the validity of the previous models proposed for the tectonic evolution of the Kohat Plateau. It does not support the earlier model of passive roof thrusting for the Kohat Plateau (McDougal and Hussain, 1991; Abbasi and Mc Elory, 1991) because for this kind of kinematics the deformation within range fronr would require a foreland ward-dipping monocline that is not the case. Furthermore, the Surghar Range includes typical compressional structures and does not support the wrench faulting style of deformation for the entire Kohat Plateau (Pivnik and Sercombe, 1993).

8.2 Relationship of deformation within Kohat and Potwar plateaus

The Potwar plateau is the eastward geographic extension of the Kohat Plateau, which is separated by the Indus River tributary (Figure8.2a). The Potwar plateau is a well documented thin-skinned fold and thrust belt underlain by a regional decollement at the contact between the Eocambrian evaporites and crystalline basement (Seeber and Armbruster, 1979; Jaume and Lillie, 1988). The south propagation of deformation along the regional basal decollement is greatly facilitated by the presence of evaporite horizon, which as a consequence emerges at the surface along the Salt Range Thrust (SRT). The Eocambrian-Cenozoic succession is emplaced over the Punjab foreland along the SRT in the south (Lillie et al., 1987). Based on the deformation style, the Potwar Plateau can be subdivided in to the northern and southern Potwar Plateau. Much of the southern Potwar Plateau is internally less deformed and has been pushed 20 kilometers southwards as a coherent block with the thrust sheet being gently folded. In comparison, most of the deformation is concentrated in the northern Potwar Plateau called as the Northern Potwar Deform Zone (Figure 8.2 a).

The NPDZ is a belt of Neogene deformation extending south of the MBT up to the northern limb of Soan Syncline (Jaswal et al., 1997) (Figure 8.2 a). It is severely folded and faulted and consists of compressed faulted folds, which are separated by wider synclines and have undergone 55± 5 kilometers of shortening between the MBT and the northern limb of Soan Syncline, whereas shortening estimate for the entire Potwar Plateau is reported as 65± 5 kilometers (Baker et al., 1988). The presence of Salt underneath the northern Potwar Plateau has long being suspected and the distribution of salt underneath the Potwar Plateau could be a well controlling factor for the contrasting structural behavior in the north and south of the Plateau.

The present account of the structures within the Kohat Plateau and its comparison with that of the Potwar Plateau suggests that the NPDZ is a true structural analogue of the Kohat Plateau. The Northern Potwar Deformed Zone and Kohat Plateau bears close similarities that include blind to partially emergent thrust faults giving rise to characteristic foreland structures such as triangle zones and pop ups. These structural similarities could be ascribed to the similar sort of rheologies at the basal decollement underneath the Kohat Plateau and the NPDZ. It is inferred that the basal decollement underneath the Kohat Plateau lacks salt horizon, which is the case underneath the NPDZ. The shortening estimates for the NPDZ (55± 5) and that of the eastern Kohat Plateau (55± 5) are correlative, and accommodate almost in the same aerial distance. Furthermore, structural trends in the NPDZ are consistent with that of the Kohat Plateau suggesting a structural analogy (Figure 8.2 a).

However, underneath the Bannu Basin, south of the Kohat Plateau Boundary Zone, it is interpreted that the basal decollement encountered an easy glide horizon. For instance the Eocambrian Salt where the thrust wedge was easily and rapidly pushed southwards. This basal decollement finally emerged at the site of Khisor Range, ponding the Bannu Basin behind. The indication of salt basin underneath the Bannu Basin is supported by the presence of Salt Range Formation that constitute the base of stratigraphic succession outcropping in the Khisor Range (Shah, 1977).

Orientations of both the large and small scale structures within the Kohat Plateau indicate that it has undergone deformation as a result of NNW-SSE oriented horizontal compressional stresses with the exception towards its southwestern boundary with the Northern Sulaiman Range, where the plateau has experienced eastward directed compressional stresses associated with left-lateral Kurram Fault. It is dominantly a SSE-vergent structural system impinging upon Punjab foreland basin in the southeast and Bannu Basin in southwest.

The present relation of the structural geometries within the surficial Eocene carapace and subsurface Paleozoic sequence.

.00 underneath the Kohat Plateau leads to the conclusion that two distinct styles of deformation characterize the region; 1) strike slip faulting is confined to the Southern Kohat Plateau, and 2) a relatively older compressional deformation over the rest of the plateau. The adjacent tectonic features and rheological variations within the plateau rocks at various stratigraphic levels mainly control the difference in the structural style.

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