THE GEOLOGY AND TECTONIC SETUP OF A PART OF THE DARRA ADAM KHEL - KOTAL PASS TRANSECT (KOHAT HILL RANGE), KOHAT DIVISION, N.W.F.P., NORTHERN PAKISTAN.

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By
KARAMAT ALI

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APPROVED

Dr. M. Asif Khan
(Supervisor)
Asstt; Prof. NCE Geology
University of Peshawar.

Dr. Ishtiaq A. K. Jadoon
(External Examiner)
Lecturer Earth Sciences
Quanid-e-Azam University, Islamabad.

Member Thesis Commottee
Dr. Iftikhar Ahmad Abbassi
Asstt; Prof. Department of Geology
University of Peshawar.

Dr. M. Qasim Jan
(Director)
NCE Geology
University of Peshawar.

Dedicated to my mother (Late).

ABSTRACT

This study describes the geology and structural set-up of a 168 km^2 area along the Darra Adam Khel-Kotal pass transect in the Kohat Hill Range. The area comprises, from bottom to top, the Jurassic Samana suk, the Cretaceous Chichali, the Lumshiwal, the Kawagarh, the Palaeocene Lockhart and Patala, (Palaeocene), the Eocene Kohat and the Miocene Murree Formations. The area is deformed into complex structures. The principal structure is a "pop-up". It comprises a south verging thrust (Main Boundary Thrust) at the southern flank against the Kohat plateau and a pair of north verging back thrusts at the northern flank against the Peshawar plain. Between these divergent thrusts , there are large scale fold structures (some with half-wave lenght > 7 kms) which have a fan shaped geometry, conforming to the pop-up style of deformation exhibited by the thrusts.

Overall four phases of deformation are recognized in the studied part of the Kohat Hill Range. D1 phase of deformation resulted in local duplex structure, just to the south of the Kotal pass. At least two horses have been recognized each with a stratigraphic range between the Samana suk and Kawagarh Formations, stacked below a roof thrust in the Kawagarh Formation. D2 is the principal phase of deformation related with the development of Main Boundary Thrust (MBT), the back thrusts and fan-shaped folding and pop-up shape of the Hill range thrust sheet. D3 is post folding and is represented by out-of-the-syncline thrusts in the southern limb of the Wahabian valley syncline. D4 is marked by low angle normal faults, which represent gravity collapse of the abnormally uplifted Hill range in the latest stages of deformation. The deformation in the Kohat Hill Range started after the deposition of the Miocene Murree Formation and probably continued until recently.

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CHAPTER I

1.1 INTRODUCTION

The Kohat Hill Range is a part of the Himalayan mountain belt, located in the N.W.F.P. province of North Pakistan. It is continuous with the Kalachitta Range in the east and the Samana Range in the west and is bounded by the Peshawar and Kohat plains on the northern and southern sides respectively.

The Himalayan foreland fold and thrust belt of northern Pakistan is being underthrust by crystalline basement along a single detachment surface (Seeber et al., 1981; Lilli et al., 1987). The Main Boundary Thrust (MBT) is a regional fault that brings the MesozoicCenozoic shelf sediments of the hill ranges (Margala, Kala chitta, Kohat, Samana and Safed Koh) to lie tectonically over a pile of molasse sediment, deposited in the foreland basins of Potwar and Kohat, (Yeats and Hussain, 1984). Disruption along the MBT zone started probably around early Miocene times as suggested by the involvement of the Miocene Murree Formation in deformation (Burbank, 1983; Yeats and Hussain, 1987). Structures associated with this major fault, include duplex systems, back thrusts (Ghauri et al, In press) and divergent folds (Khan et al. 1990). These structures are spread over an approximately 22 km wide zone in the Kohat Hill Range.

Earlier accounts of the MBT and its associated structures are given by Cooter, (1933). Various segments of the MBT zone have been subsequently mapped in relatively greater details, resulting in the recognition of a large number of folds and thrust structures associated with it (Gardezi, 1974; Gardezi et al., 1976; Ghauri et al., 1983; Akhter et al., 1984; Izat, 1990; Khan et al, 1990).

This project involves the reinvestigations of the structures in the hangingwall of the MBT along the Darra Adam Khel Kotal pass transect in the Kohat Hill Range.

The Kohat Hill Range is mainly deformed by popup style, both by imbricate thrusts, forming a local duplex zone and by folding including large divergent or fan shaped anticlines and broad box shaped synclines. The youngest phase of the tectonic activity associated with the MBT, has resulted in the development of outofthesyncline thrusts and normal faults, which have not been previously recognized.

1.2 GEOGRAPHIC DESCRIPTION

Much of the Kohat Hill Range, including the study area is a tribal territory which is known for its gun manufacturing town of Darra Adam Khel. The tribal areas of N.W.F.P. are not covered by the laws of the Government of Pakistan. However, the Government has a liaison with the tribal administration through an Assistant Political Agent who sits in Kohat F.R. house. Within the area itself more than one tribal jurisdictions exist.

The Kotal pass connects the Peshawar and Kohat plains by an 8 km metaled road.

The study area encompasses 168 Km^2 of the Kohat Range. It lies in the Survey of Pakistan topographic sheets no 38 O/6 and 38 O/10 between latitudes 33° 35' 20" and 33° 45' 0" N and longitudes 71° 25' 7" and 71° 30' 40" E. The base map was prepared by enlarging two times the quarter degree sheets (Fig. 1.3a).

The study area is accessible by the metaled PeshawarKohat road which passes through Kotal pass and Darra Adam Khel. This work was restricted to 6 km on the either side of the road in east west direction. Several secondary unmetaled roads run eastwest in the area, providing good access. However, most of the traverses in the interior parts of the study area were made on foot.

The study area consists of moderate to high relief, ranging from 527 meters above sea level at valley floors to about 1647 meters above sea level at Mirwal Sar, the highest summit in the study area.

1.3 PREVIOUS WORK

The Kohat region has received the attention of geologists for a long time probably because of its salt deposits (Burnes, 1832 b; Oldham, 1886; Gee, 1935). Khan, M. A., (1968) established the stratigraphic sequence on the southern slope of the Kotal pass, which is a lithlogical description of different rocks.

Fatmi (1973) described the lithostratigraphy of the Kohat area. Meissner et al. (1973), mapped the entire Kohat quadrangle on the scale of 1:2,50, 000, mostly with the help of air photographs. Gardezi et al. (1976), carried out first detailed work in the study area.They produced a map on the scale of 1:50,000, for the Darra Adam Khel area, outlined the stratigtraphy and studied the facies changes. Rabbani and Mazhar, (1978) have mapped and discussed the geology of Orakzai Agency.Gilmour et al. (1981) have concentrated on the carbonate petrography and microfacies of the Samana Suk Formation from the southern slope of the Kotal pass.Ghauri et al. (1983) have mapped the southern slope of the Kotal pass and divided the area into three structural domains. The dominant structure within the first domain is a refolded recumbent fold with the Patala Formation in its core. Multiple repetition of the Samana Suk and Chichali Formation are shown in second domain. The structure has been explained by tight overturned folds.

1.4 Present work

The present work is restricted to the vicinity of the metaled PeshawarKohat road in the Kohat Hill Range which was previously mapped by Gardezi et al. (1976) and Ghauri et al. (1983).

1.4.1 Objectives of the investigation

This study was carried out with objectives of local and regional implication in the field of structural geology. On a local scale the objectives are:

1) to remap the study area at 1:25,000 scale with the help of aerial photographs and surface toposheets.

2) to update the stratigraphy of the study area. Chapter 2 describes various startigraphic units of the area in detail.

3) to recognize the style of deformation of the Kohat Hill range, i.e., whether the Kohat Hill range has been deformed mainly by faulting or folding.

4) to clarify the repetition of the Samana Suk, Chichali, Lumshiwal and Kawagarh

Formations as well as that of the Lockhart and Patala Formations, i.e., whether these repetitions are due to tight folding or imbrication. Chapter 3 describes various structural pattern in detail.

5) to determine successive phases of deformnation, and position of various structures in this sequence.

on regional scale the objectives are:

1) to clarify the stratigraphic and structural relationship between the Kohat Hill Range and adjoining Hill Ranges(Kalachitta and Attockcherat and Samana ~~Suk~~).

2) to provide data that will further constrain models of the tectonic development of the Hill Ranges of north Pakistan.

CHAPTER 2

2.1 Stratigraphy of the Kohat Hill Range.

The rocks ranging in age from Jurassic to Miocene are exposed in the studied area. They were divided into nine formations by Gardezi et al.(1976),i.e., the Samana Suk, Chichali, Zarghun Khel, Lumshiwal, Kawagarh, Hangu, Lockhart, Patala and Murree Formations. No rocks younger than Miocene in age are exposed in the studied area (Table. 2.1). However, the present investigations, shows that the Zarghun Khel and the Hangu Formations are not exposed in the studied area as described by Gardezi et al.(1976). The Lumshiwal Formation, 6 meters thick is restricted to the southern part of the studied area. About 12 meters thick Kohat Formation was also found in the southern part of the studied area which has a faulted contact with the Samana Suk Formation. In addition to my own observations, the formation names and descriptions used here, are derived from the work of Meissner et al. (1974), Gardezi et al. (1976), and Shah (1977).

2.2 Jurassic succession

2.2.1 Samana Suk Formation

Davies (1930) introduced the name "Samana suk" for the Jurassic limestone in the Samana Range. The name is extended to include similar limestone sequence in the Salt Range, Trans-Indus Ranges and Hazara areas (Shah 1977).

In the studied area, it is thin to thick bedded, light to medium gray, well jointed limestone and dolomite with pitted surfaces. In lower parts, the formation is composed of highly sheared calcareous shale, followed by grayish fine grained sandy limestone and orange brown coarse limestone in the upper parts (Fig. 2.1). Dark brown coloured dolomatic bands are interbedded with yellowish to gray coloured limestone (Fig. 2.2). The butcher chop structure is the common weathering phenomena of the dolomite beds. There are some beds which show well developed cross bedding (Fig. 2.3)

In the studied area, thickness of the formation is difficult to measure due to intense folding and faulting, however, 186 meters thickness is observed at the type locality. The lower contact is not

Table2.1 The stratigraphy of the Darra Adam Khel-Kotal pass transect (Kohat Hill Range).

AGE	FORMATIONS	abb	LITHOLOGY
MIOCENE	MURREE	Tm	
	UNCONFORMITY		
EOCENE	KOHAT	TKo	
PALAEOCENE	PATALA	TPa	
PALAEOCENE	LOCKHART	TL	
CRETACEOUS	KAWAGARH	KKg	
CRETACEOUS	LUMSHIWAL	KL	
CRETACEOUS	CHICHALI	KC	
JURASSIC	SAMANA SUK	JSS	

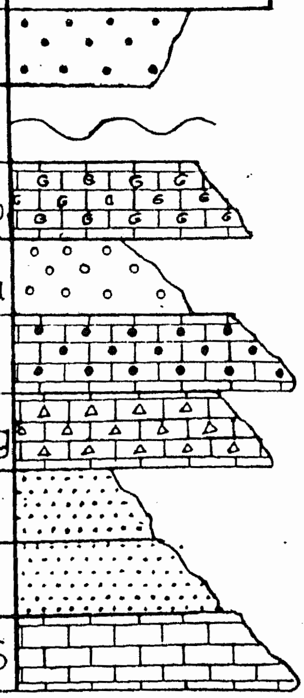


Fig 2.1 Grayish fine grained sandy limestone (at the left side) and orange brown coarse grained limestone (at the right side) of the Samana Suk Formation. The length of the pen is 14 cm.

Fig 2.2 Dark brown coloured dolomitic bands interbedded with yellowish to gray coloured limestone of the Samana Suk formation.

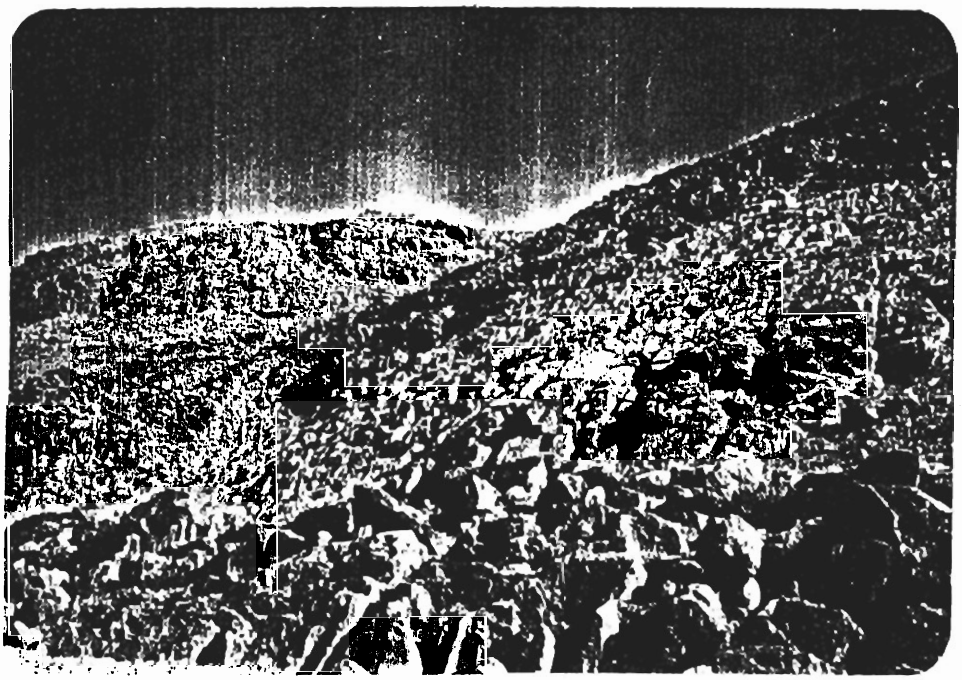


Fig 2.3 Excellent cross bedding have development in the Samana Suk Formation. The length of the pen is 14 cm, (bottom right of the photograph).

exposed. The upper contact is disconformable with the Chichali Formation (Shah, 1977).

The formation is oolitic at places and contains Foraminifera and megafossil fragments, including, Belemnopsis grantana, Protocardia, Eomiodon indicus and Corbula lyruta (Shah, 1977).

2.3 Cretaceous succession

2.3.1 Chichali Formation

The Belemnite beds of Spath (1938), Gee (1945) and Spiti shale of Middlemess (1896), Cotter (1933) were formally renamed the Chichali Formation by the Stratigraphic Committee of Pakistan (Shah 1977).

In the studied area, the formation consists of glauconitic, sandy shale. It contains 7 cm thick bands of dark unfossiliferous limestone (Fig. 2.4). It is 7 meters thick in the studied area.

The upper contact with the Lumshiwal Formation is sharp (Fig. 2.5), and the lower contact with the Samana Suk Formation is disconformable.

It is fossiliferous, containing, Ammonoids, Crinoid spicules and abundant Belemnites.

2.3.2 Lumshiwal Formation

The name Lumshiwal Sandstone of Gee (1945) was formally amended by the Stratigraphic Committee of Pakistan. The name is extended to Hazara, Kalachitta and Kohat areas.

In the studied area, it is composed of dark glauconitic and calcareous sandstone in the lower part, with dark rusty brown weathering colour, which is overlain by thin to thick bedded, argillaceous, orange yellow limestone (Fig. 2.6).

In the studied area, it is 6 meters thick. The lower contact with the Chichali Formation is sharp and the upper contact with the Kawagarh Formation is disconformable (Fig. 2.7). In the studied area the formation is poor in megafossils.

2.3.3 Kawagarh Formation

The "Kawagarh marls" of Day (in unpublished Attock Oil Companys'report), for the upper Cretaceous rocks, exposed in the Kawagarh hills, north of Kalachitta Range, was formally renamed

Fig 2.4 Apart of the Chichali Formation containing glauconitic sandy shale with abundant Belemnites, interbedded with bands of 7 cm thick dark unfossiliferous limestone. The length of the hammer is 22 cm.

the Kawagarh Formation by the Stratigraphic Committee of Pakistan (Shah 1977).

In the studied area, it is composed of light to medium gray, finely crystalline to aphanitic limestone which weathers to dirty gray and yellowish gray colour. It has got the intercalation of shale. Upper and lower parts of the formation are thin to medium bedded, whereas the middle part is medium to thick bedded. It breaks with a conchoidal fractures and when struck with the hammer breaks into splinters and sharp angular fragments with a metallic tone.

On account of intense folding in the studied area, the thickness is difficult to measure. At type locality the thickness varies from 40 to 70 meters. In the studied area, the formation has disconformable and conformable contacts with the underlying Lumshiwal and the Overlying Lockhart Formations respectively.

No mega fossils are found, however, microfossils are abundant. Globotruncana and Gumbelina are the most abundant of all the micro-fossils (Khan 1968).

2.4 Palaeocene succession

2.4.1 Lockhart Limestone

The term "Lockhart Limestone" of Davies (1930a) has been extended to similar units in other parts of the Kohat-Potwar and Hazara areas by the Stratigraphic Committee of Pakistan (Shah 1977).

In the studied area, it is composed of light to dark gray limestone which is yellowish brown to black on weathered surfaces. Medium to thick bedded, but generally massive, forming steep cliffs. The limestone shows well developed nodularity and the nodules vary in size. At places, the iron nodules are also present. It is generally bituminous and gives off fetid odor on freshly broken surfaces.

In the studied area, due to severe folding and faulting, the measuring of its thickness is not easy. However, at type locality it is 60 meters thick.

The formation disconformably and conformably overlies and underlies the Kawagarh and the Patala Formations respectively.

It contains abundant fossils, including Foraminifera, Coral, Lockhartia, Molluscs, Echinoids

Fig 2.5 Contact between the Lumshiwal (on the right) and the Chichali Formation (on the left), looking west at the gorge. (scale 1 cm=1 meter).

Fig 2.6 Interbedded dark rusty brown glauconitic sandstone (on the left) and orangeyllow argillaceous limestone of the Lumshiwal Formation. The length of the hammer is 22 cm.

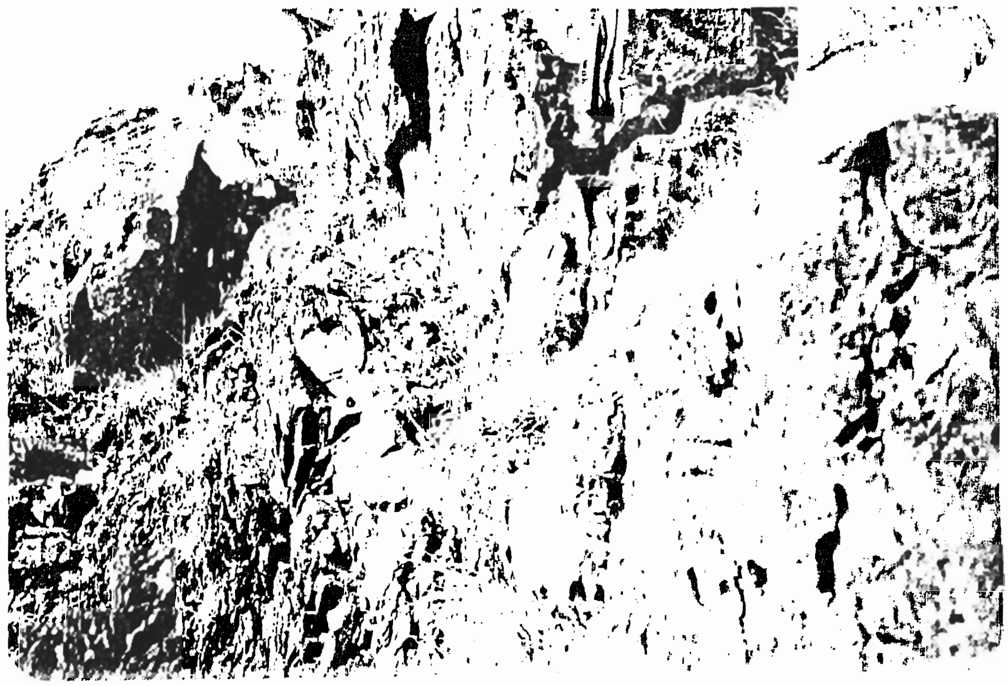
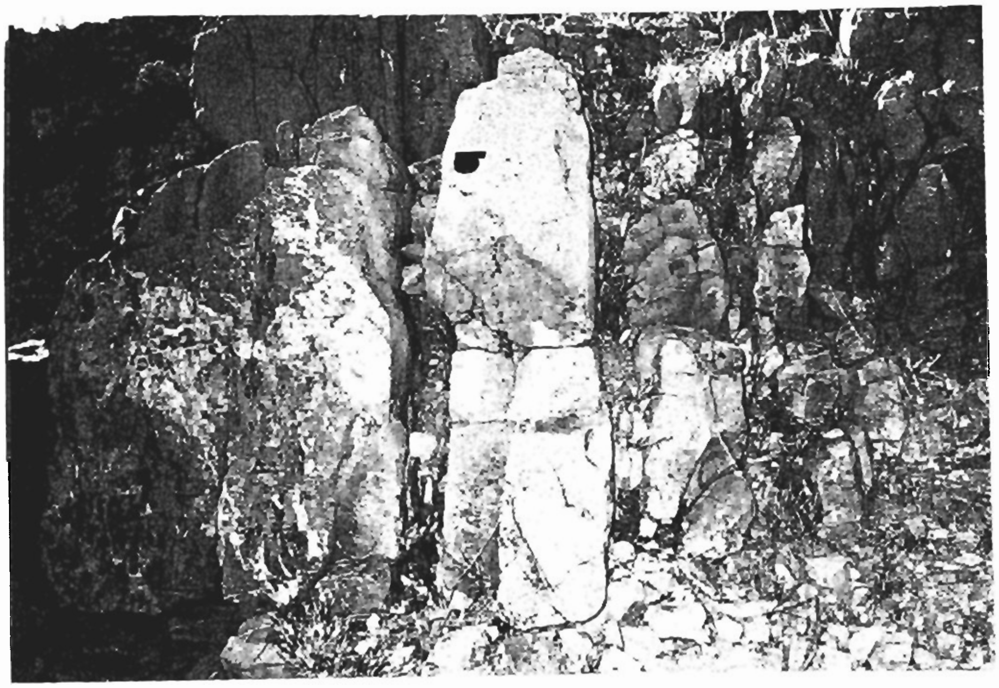


Fig 2.7 Contact between the Kawagarh Formation (on the right) and the orange yellow argillaceous limestone of the Lumshiwal formation. The scale is 4.5 cm.



and Algae etc (Shah 1977).

2.4.2 Patala Formation

The "Patala Shale" of Davies and Pinfold (1937) was formalized the Patala Formation by the Stratigraphic Committee of Pakistan (Shas 1977).

In the studied area, it consists of coarse grained mudstone, shale, marl, limestone, siltstone, sandstone and micro-conglomerate. the shale is greenish gray and khaki, at places having shades of purple, and splintery with subordinate marl. The limestone is nodular, arenaceous and yellowish gray in colour and is intraformational, while the sandstone is reddish in colour (Tanoli et al.1989). Size of conglomerate varies considerably. Big sized conglomerates are observed near Kotal check post (Fig. 2.8).

Due to distinctive lithology represented by the Patala shale, in the studied area, it has been named as "Kotal Member" of the Patala Formation.

In the studied area, intense folding and faulting make its thickness difficult to measure. At Patala Nala it is 90 meters thick.

In the studied area, it conformably overlies the Lockhart Limestone.

2.5 Eocene Succession

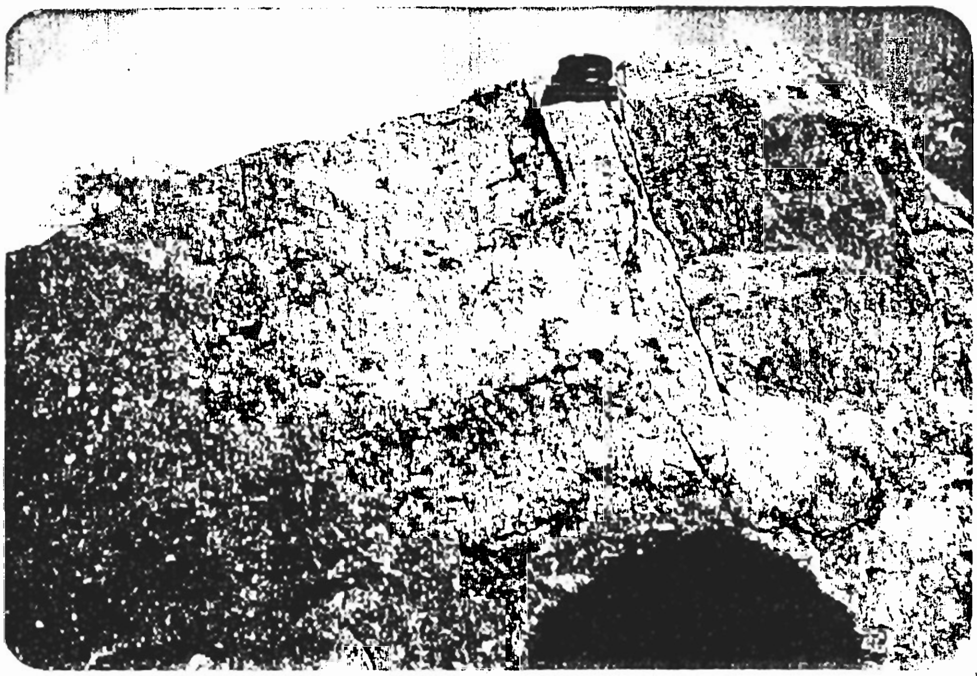
2.5.1 Kohat Formation

The Kohat Shales of Eames (1952) and the Kohat Limestone of Meissner et al. (1974) was formally renamed the Kohat Formation by the Stratigraphic Committee of Pakistan (Shah 1977).

It is composed mainly of interbedded dominant limestone and subordinate interbedded shale. The lower Kaladhand Member is composed predominantly of limestone which is light gray, hard, compact and thin bedded with shale intercalations, particularly in its the lower part. The Sadkal Member, in the northern Kohat, Kalachita and northern Potwar area is composed of greenish gray calcareous shale with subordinate light gray limestone. The limestone interbeds become dominant in the other parts of the Kohat area where they are characterized by an abundance of Nummulites.

The formation is confined to the Kohat, northern Potwar and Kalachitta areas.Its maximum

Fig 2.8 Big sized conglomerate of the Patala Formation near the Kotal check post. The scale is 4.5 cm.



thickness is 170 meters at Chilli Bagh (fig. 2.9). The lower contact with the Kuldana Formation is sharp and conformable. The upper contact in the Kohat area, with the Kirthar Formation is conformable. Elsewhere, the formation is unconformably overlain by the Murree Formation (Shah 1977). The formation has yielded abundant Foraminifers and various species of Nummulites.

2.6 Miocene succession

2.6.1 Murree Formation

The Mari Group of Wynne (1874), Murree Beds of Lede kher (1876) and Murree Series of Pilgrim(1910) were formally named the Murree Formation by the Stratigraphic Committee of Pakistan (Shah 1977).

In the studied area, it is composed of dark grayish brown, greenish gray and occasionally purple, medium to coarse grained sandstone, purple or reddish brown siltstone and shale and subordinate intraformational conglomerate.

It is well exposed in the northern Potwar, Kohat and in the Hazara-Kashmir-Syntaxes where an estimated thickness of 8 - 10 km has been reported by Bossart and Ottigar(1989). It is 120 meters thick in the Shakardara area (fig. 1.2) (Abbassi, 1990), but only 9 meters thick at Bonda Daud Shah (Fig. 2.9), (Shah 1977).

It is diachronous, estimated to be about 40 ma old and of shallow marine(tidal flat) origin in the Hazara-Kashmir-Syntaxes (Bossart and Ottigar 1989), whereas, 28-18 ma old and of fluvial origin in the Kohat - Potwar Plateaux (Shah 1977).

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

In the Kohat area, the upper and lower contacts, with the Kirthar and Kuldana Formation are conformable. In the northern part, i.e., in the studied area, the upper contact with the Samana Suk Formation is tectonic. It is up to 3,030 meters thick in the northern Potwar, but thins out to only 9 meters in western Kohat (Shah, 1977).

CHAPTER 3

Regional tectonic setting and structural geology.

3.1 Regional tectonic setting

The Himalaya of Pakistan is a product of collision between Indian and Karakoram plates. This continent-continent collisional event began in early Eocene or possibly late Palaeocene times (Stoneley, 1974; Molnar and Tapponnier, 1975). In India and Tibet, the Indus-Tsangpo suture marks the closure zone between the two plates (Ganssner, 1981), but this suture bifurcates into the Main Karakoram Thrust (MKT) and Main Mantle Thrust (MMT) in North Pakistan (TahirKheli et al., 1979). The rocks of the Kohistan Arc, a terrane now believed to have been formed as an Island Arc (TahirKheli et al., 1979; Jan and Asif, 1981; Tahirkheli, 1982; occurs to the north of the MMT, docked with the Karakoram plate along the MKT during late Cretaceous (Jan and Asif, 1983; Windley, 1983). The collision between the Indian plate and the Kohistan Arc occurred along thr MMT during Eocene (TahirKheli et al., 1979; TahirKheli, 1982).

The Karakoram plate is composed of gneisses, slates, marbles and quartzites which are probably Paleozoic or older (TahirKheli, 1979). The Kohistan island arc is a mass of dominantly amphibolites followed by diorites, metanorites and associated volcanic rocks (TahirKheli, 1979). The Indian comprises a Precambrian basement of gneisses overlain by slates, a cover of Paleozoic- Mesozoic carbonates, and a thick molasse succession of Tertiary age.

South of the MMT an estimated 500 Km shortening of the Indian plate (Coward and Butler, 1985; Coward et al., 1988) was either accommodated by under thrusting beneath the Kohistan Island Arc and Karakoram plate (Seeber et al., 1981; Ni and Barazangi, 1984) or by the development of an extensive southward directed thrust system and associated folding (crustal imbrication) over a broad zone (Molnar and Tapponier, 1975; Molnar and Qideng, 1984; Coward et al., 1982, 1988; Yeast and

Lawrence, 1984; Coward and Butler, 1985; Bossart et al., 1988; Greco et al., 1989).

At about 30 ma, the deformation front had shifted southward to the hill ranges, which were uplifted and deformed along the Panjal, Main Boundary Thrust (MBT) and the Salt Range thrust faults (Yeats and Hussain, 1987). The Gandhgar, Attock Cherat and Khyber Ranges were probably uplifted along the Panjal and Nathia Gali faults respectively (Fig. 3.1). The Panjal and Nathia Gali faults mark the western limit of the Hazara Kashmir Syntaxis. The MBT demarcates the southern limit of the Margala kalachitta, Kohat, Samana and safed Koh Ranges. Over an estimated 100 Km displacement has resulted in the development of the complex structures in the hangingwall of the MBT (C. Izatt, pers. communications). The MBT which strikes east-west along most of the foreland basin, turns northwards, west of the Jhelum River, forming a major bend known as Hazara Kashmir Syntaxis (3.1). The development of the syntaxis has taken place in three phases of deformation (Bossart et al., 1988), an early nappe development by southwards overthrusting of Himalayan rocks, followed by the formation of a large shear zone and then by the transport of overthrust sheet from north west to the south west. A single detachment surface which extends beneath the entire Kohat-Potwar plateau, surfaces south of the Salt Range as Salt Range Thrust (SRT), (Seeber et al., 1981). The Salt Range Thrust has brought the Precambrian Salt Range Formation to lie tectonically over its own alluvial and fan material (Yeat et al., 1984).

Fig 3.1 Regional geological map of the N. Pakistan, showing major tectonic features and tectonic position of the Kohat hill Range. (After Coward et al. 1988). The area in square is shown in Fig. 3.4a

3.2 STRUCTURAL GEOMETRY

The structural setting of the Kohat Hill Range in relation to the major tectonic features of north Pakistan is shown in figure 3.2, 3.3. The Kohat Hill Range is characterized by a complex set of structures. The MBT together with a major backthrust, delimits the Range at its southern and northern flanks, separating it, respectively, from the plains of Kohat and Peshawar (fig. 3.3). These structures divergently thrust the Samana Suk Formation of the Jurassic age over the Miocene Murree Formation on the southern flank and over the Palaeocene Patala Formation on the northern flank (Fig 3.4a). Within the Range, there is an interesting structural disposition of the stratigraphy. Except for a small outcrop of the Palaeocene Patala Formation on the northern flank, the Mesozoic strata including the Samana Suk, Chichali, Lumshiwal and Kawagarh Formations, are mainly exposed along the southern and the Samana Suk Formation along the northern flank of the Kohat Hill Range (i.e. in the immediate hangingwalls of the two faults, mentioned above, Fig 3.4a). The Palaeocene Lockhart and Patala Formations occupy the central part. The different structural features, responsible for the deformation of the study area are discussed here in detail.

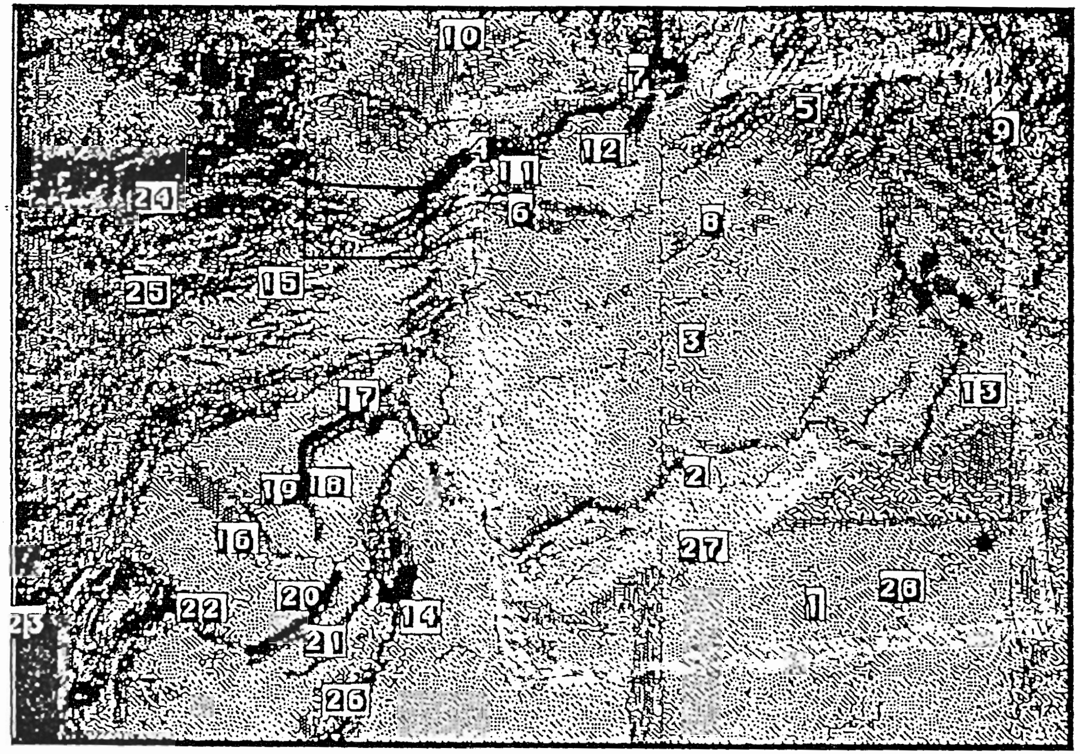
3.2.1 FOLDS

The Kohat Hill Range is mainly deformed by folding. A great variety of fold structures at different scales have been observed. As shown in the Figure 3.4b, fold structures in the study area can be classified into several types on the basis of their geometrical style. These include box or fan folds, domes, open folds, tight cylindrical, S and Z shaped folds and south-west plunging minor folds.

a) FAN FOLDS

The fan shaped folding style is very common in the Kohat Hill Range and is consistently repeated. The two limbs of these fan folds are mostly oppositely verging recumbent folds with intervening flat hinge zones. Various shape characteristics of fan folds

Fig 3.2 Landsat image showing major structural provinces and geomorphic features of the northern pakistan fold and thrust belt. scale is approximately 1:4,000,000. Outlined area is the Kohat Hill Range and a part of it is shown in figure 3.4a (after Leather, 1988).



1. JHELUM PLAIN
2. SALT RANGE
3. POTWAR PLATEAU
4. ATTOCK CHERAT RANGE
5. MARGALA HILLS
6. KALLA CHITTA RANGE
7. GONGAR RANGE
8. KHAIRI MURAT RANGE
9. PIR PANJAL RANGE
10. PESHAWAR BASIN
11. NIZAMPUR BASIN
12. CAMBELLPOR BASIN
13. JHELUM REENTRANT
14. KALABAGH REENTRANT
15. KOHAT PLATEAU
16. BANNU BASIN
17. TRANS-INDUS RANGE
18. SURGHAR RANGE
19. SHINGHAR RANGE
20. MARWAT RANGE
21. KHISOR RANGE
22. BHITTANNI RANGE
23. SULAIMAN RANGE
24. SAFRED KOH RANGE
25. TIRAH RANGE.
26. INDUS RIVER
27. JHELUM RIVER
28. CHENAB RIVER

0 50 100
Kilometers

Fig 3.3 Tectonic map of N. Pakistan, showing major structural boundaries. P=Peshawar; PB=Peshawar Basin; AB=Abbottabad; M=Murree; I=Islamabad; H=Haripur; HA=Hasanabdal; CB=Campbellpur Basin; K=Khanpur; ACR=Attock-cherat Range; KCR=Kalachitta Range; KH=Khanpur Hills; CF=Cherat fault; GR=Gandghar Rang; MH=Margala Hills; SR=Samana Range; SKR=Safed Koh Rangn; BB=Banu Basin; SRT=Surghar Range Thrust; NB=Nizampur Basin. The area A in square is shown in figure 3.4a. Modified after Hylland, 1988.

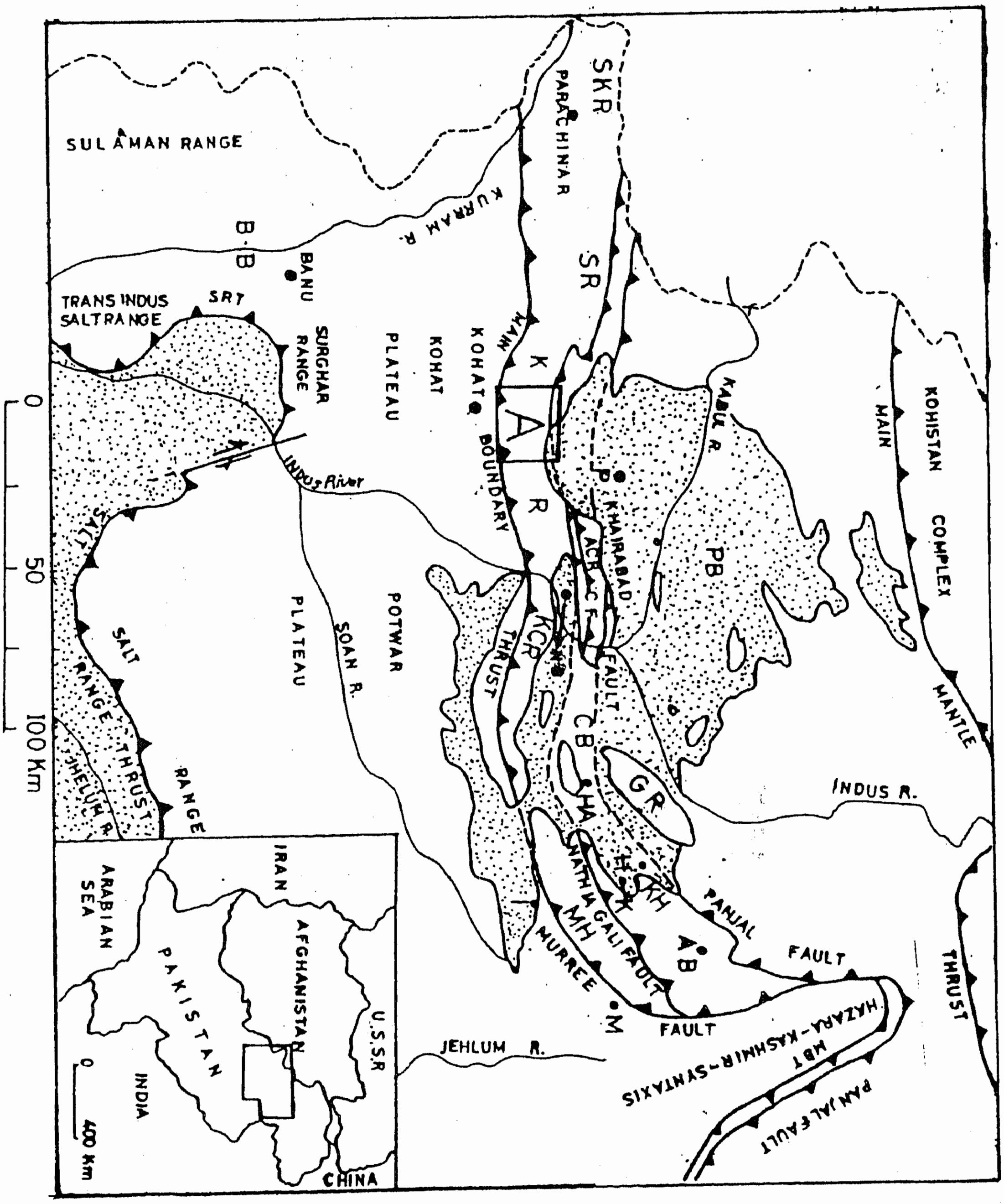

SULAIMAN RANGE
KURRAM R.
B·B
BANU
TRANS INDUS SALTRANGE
SRT
SURGHAR RANGE
KOHAT PLATEAU
KOHAT
MAIN BOUNDARY THRUST
PARACHINAR
SKR
SR
K
A
R
INDUS River
POTWAR PLATEAU
SOAN R.
SALT RANGE THRUST
SALT RANGE
JHELUM R.
KCR
KHAIRABAD FAULT
P
PB
KABUL R.
CB
HA
GR
NATHIA GALI FAULT
MURREE FAULT
MH
AB
PANJAL FAULT
M
INDUS R.
JEHLUM R.
HAZARA-KASHMIR-SYNTAXIS
MBT
PANJAL FAULT
MAIN MANTLE THRUST
KOHISTAN COMPLEX
0
50
100 Km
IRAN
AFGHANISTAN
U.S.S.R
PAKISTAN
INDIA
CHINA
ARABIAN SEA
0
400 Km

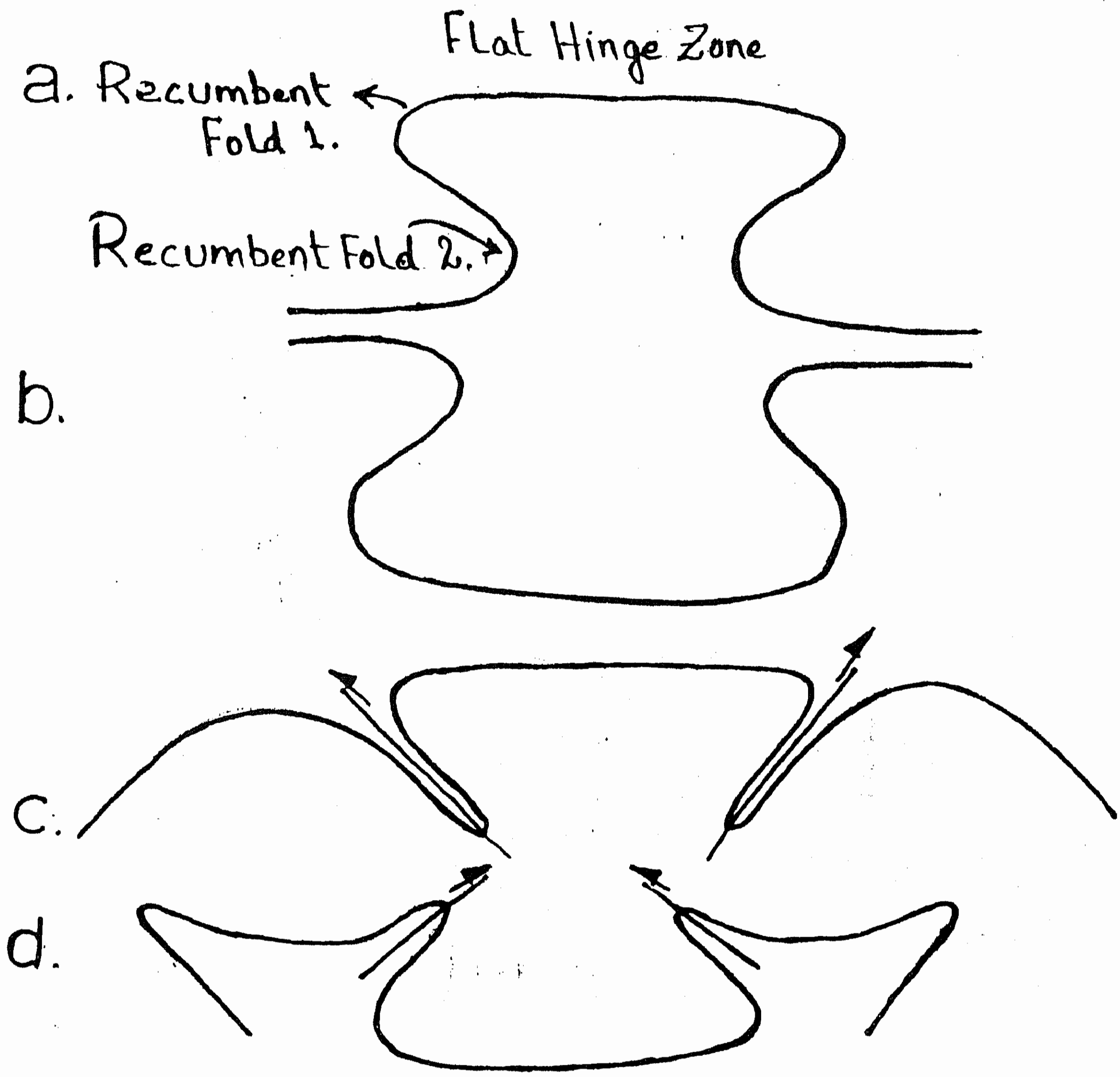
Fig 3.4b Geological cross-section of the Figure 3.4a from the studied area are schematically shown in figure (3.5). Paired anticlines and synclines through a pair of recumbent folds in the intervening limb (Fig. 3.5 a,b). This style of folding is exhibited by the structures from Qasim Khel to MBT (Fig. 3.4 b). Locally the limbs of the principal fan folds are attenuated to form tight anticlines and synclines. Sometimes these tight anticlines and synclines at the opposite limbs of the proncipal folds are so much attenuated that they are breached by oppositely verging reverse faults (Fig. 3.5 c,d). Tight sunclines associated with Akhurwall anticlines are and example of this style of folding.

The most important of the fan folds is a broad, box-shaped syncline, which has both of its southern and northern limbs tightly overturned, named as Wahabion valley syncline (Fig. 3.4b). Its southern overturned limb lies in the Kotal pass area near the southern flank of the study area. A traverse along a foot track at the eastern side of the valley leading to Kohat plain from the Kotal pass, gives an excellent view of the southern overturned limb of this syncline (Fig. 3.6). Toward the southeast of the Kotal check post the entire stratigraphic pile of the Kohat Hill Range is overturned; southwards dipping beds of the Patala Formation are successively overlain by older formations to the south, i.e., the Lockhart, Kawagarh, Lumshiwal, Chichali and Samana Suk Formations (Fig. 3.4b, 3.6). The northern overturned limb of the Wahabion valley syncline lies at the Shahida Talab, just at the southern side of the Qasim Khel anticline (Fig. 3.4b). This limb, however, does not expose formations older than Palaeocene. This large fold structure (with a 7 Km half wave length) involves the entire stratigraphy exposed in the Kohat Hill Range from the Samana Suk to the palaeocene Patala Formations.

The second important fan fold is another broad box-shaped syncline which has only its northern limb tightly overturned (Fig. 3.4b, 3.7). It lies in the immediate hanging wall of the MBT at the southern flank of the study area. It involves the Samana Suk Formation only. The southern limb of this large fold structure (with a 2.5 km half wave length) is overridden on the Miocene Murree and Kohat Formations along the MBT (Fig. 3.8).

In between the above mentioned synclines, there is an intervening large fan shaped

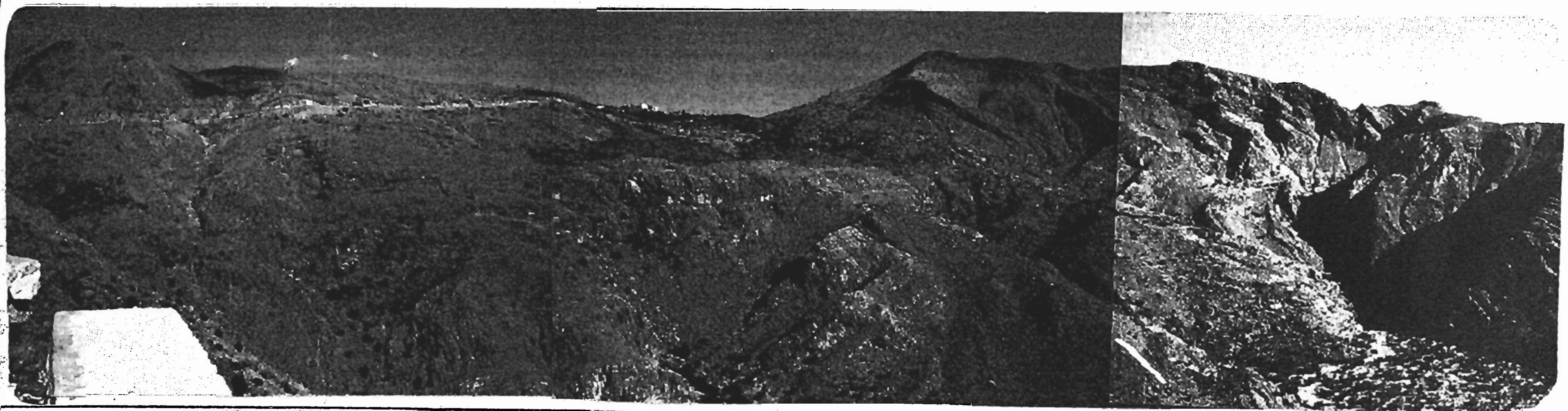
Fig. 3.5 A schomatic representation of various shapes characterictic of fan folds from the studied area. Paired anticlines and synclines with flat hinge zones may be mutally associated through a pair of recumbent folds in the tervening limb (a, b). Locally the limbs of the principal fan folds are attenuated to form tight anticlines and synclines and sometimes these are breached by oppositely verging reverse faults (c,d).

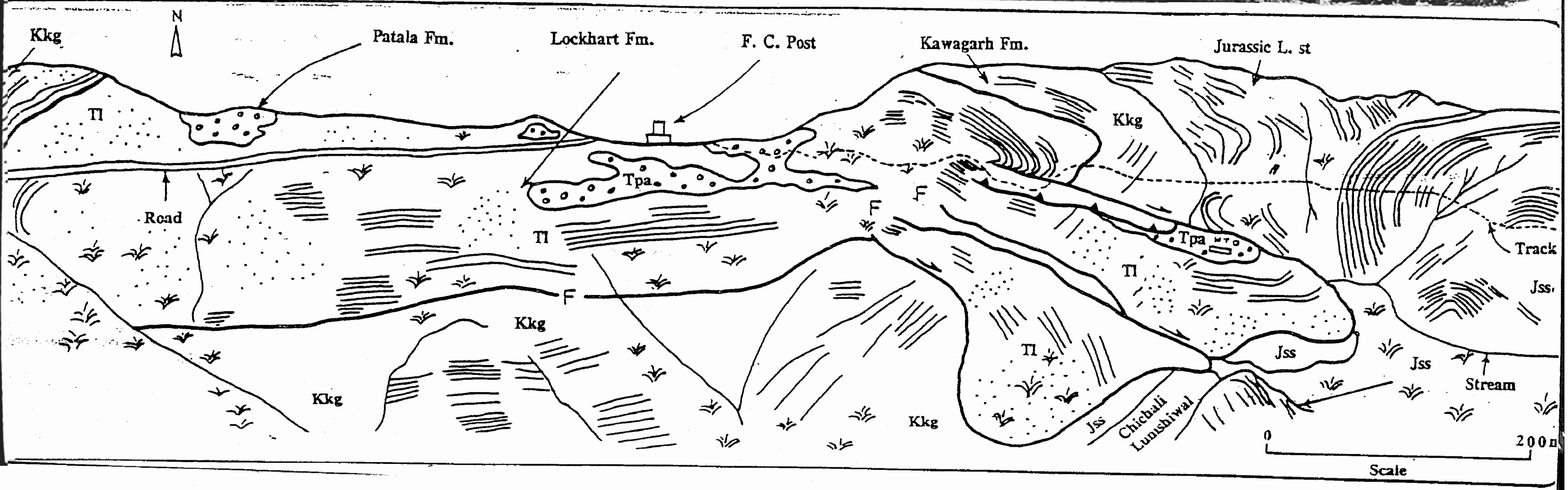


Flat Hinge Zone
a. Recumbent Fold 1.
Recumbent Fold 2.
b.
c.
d.

Fig 3.6 A panoramic view of the Kotal pass area, (Kohat Hill Range), looking from south. Note the major box shaped syncline, with its southern overturned limb. The contact between the Palaeocene Lockhart and Patala Formations and underlying Cretaceous Kawagarh Formation is an out-of-the-syncline fault. Two allock thonous blocks, comprising Palaeocene Lockhart and Patala Formation tectonically overlying the near vertical Mesozoic succession (right lower parts of the photograph) along shallowly south dipping late normal faults.

Fig 3.6 A panoramic view of the Kotal pass area, (Kohat Hill Range), looking from south. Note the major box shaped syncline, with its southern overturned limb. The contact between the Palaeocene Lockhart and Patala Formations and underlying Cretaceous Kawagarh Formation is an out-of-the-syncline fault. Two allock thonous blocks, comprising Palaeocene Lockhart and Patala Formation tectonically overlying the near vertical Mesozoic succession (right lower parts of the photograph) along shallowly south dipping late normal faults.





Kkg
N
Patala Fm.
Lockhart Fm.
F. C. Post
Kawagarh Fm.
Jurassic L. st
Tl
Tpa
Road
F
Kkg
Track
Jss
Jss
Stream
Chichali
Lunshiwal
0
200m
Scale

Fig 3.7 Another excellent view of the Kotal pass area, looking from west. Note the southern and northern overturned limbs of the Wahabion valley and Kotal pass synclines,respectively. In between the two synclines the Kotal anticline exists, formed by pop-up geometry.

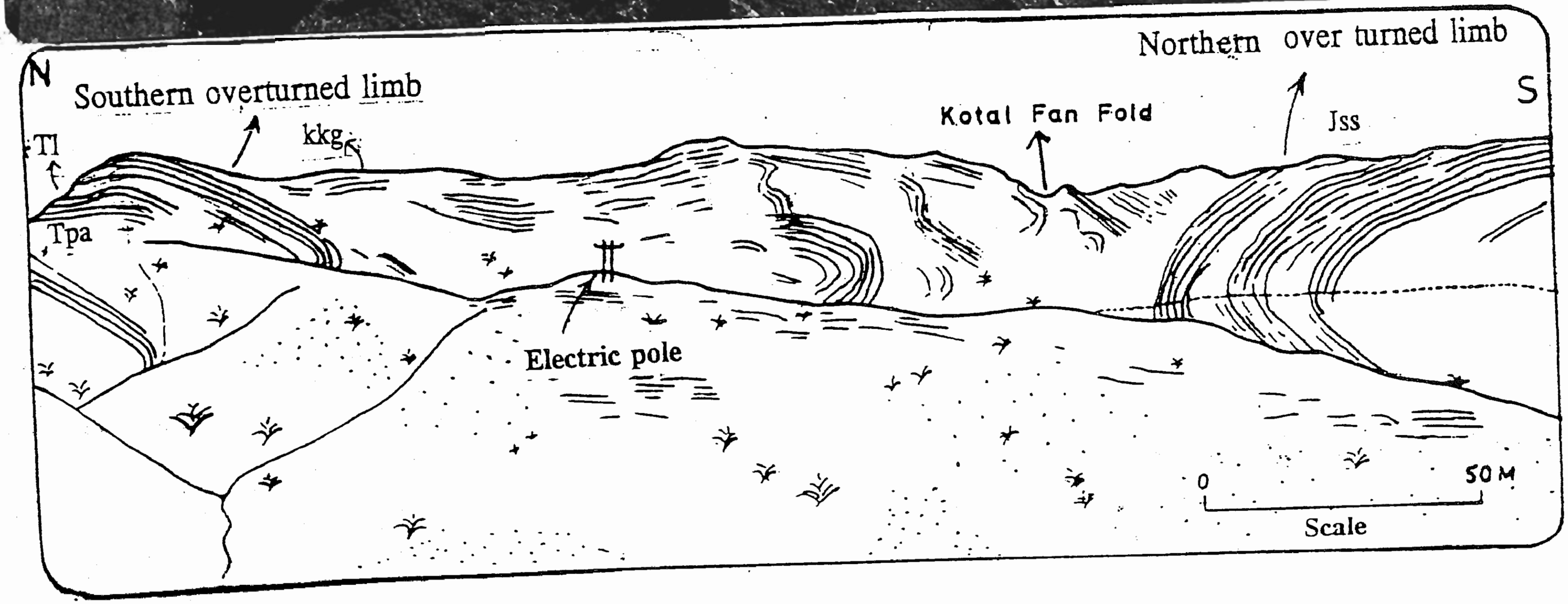
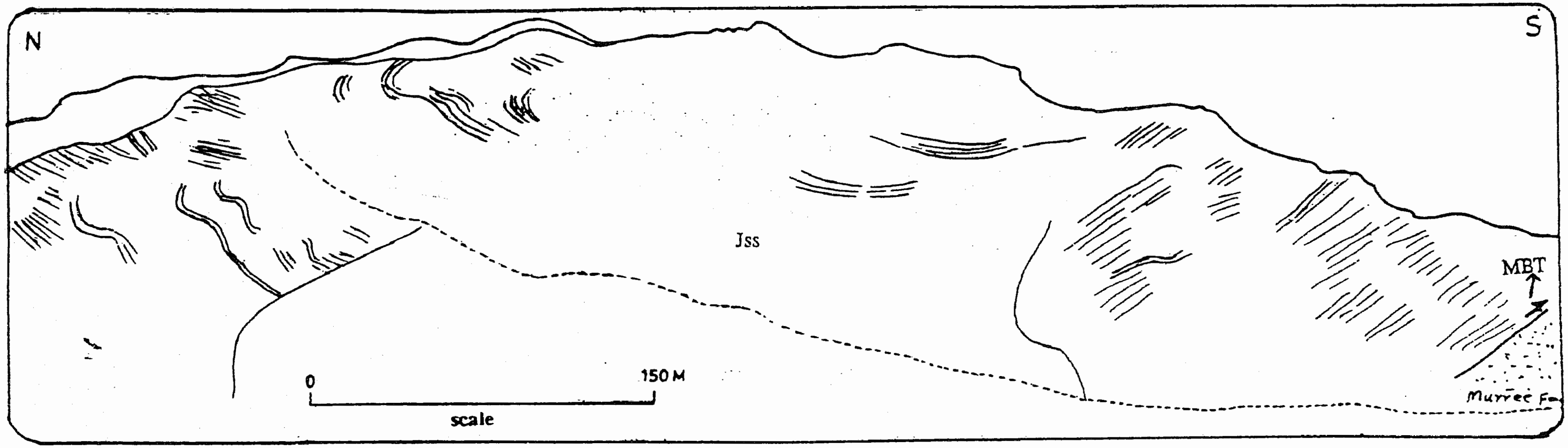

N
S
Southern overturned limb
Northern over turned limb
Kotal Fan Fold
Tl
Tpa
kkg
Jss
Electric pole
0
50 M
Scale

Fig 3.8 A view of the Kotal pass syncline. Note its southern limb which has been overridden on the Kohat and Murree Formations.


N
S
Jss
MBT
Murree F.
0
150 M
scale

anticline (with a 1.75 Km half wave length), the Kotal anticline (Fig. 3.4b, 3.7). The southern and northern overturned limbs of the Wahabion and Kotal synclines, respectively, turn back to form this anticline in a pop-up style (Fig. 3.4, 3.7). It involves entire stratigraphy from the Samana suk to the Patala Formations. From the metaled road on the southern slope of the Kotal pass, it can be excellently viewed, while looking east.

The Qasim Khel anticline is another large fan shaped, overturned north verging fold, which has been developed in the Samana Suk Formation of the Jurassic age (Fig. 3.4b). Infact it is a very large anticlinorium structure (with a 3 km half wave length), the core of which is represented by a large number of small scale anticlines and synclines.

The Akhur Wal fan shaped anticline (with a 0.75 Km half wave length) lies between the Barami anticline and Bazi Khel Dome, on the northern and southern sides, respectively. Both of its limbs are strongly attenuated and sheared (Fig. 3.4b, 3.9). Its core exhibits excellent horizontal beds with two hinge zones.

b) DOMAL FOLDS

The Bazi khel dome is a very large domal structure which has been named after the village Bazi khel. It is bounded by a tight syncline on its southern side, while its northern side is strongly sheared (Fig. 3.4b, 3.9). The north, south and west ward dipping beds of the dome are clearly visible. The domal shape of the structure is due to superimposition of a second phase of folding with a north-south trend, more or less at right angle to the east-west trending folds at southern and northern limbs of the structure.

c) OPEN FOLDS

Several open folds can be observed in the study area, which are named after their respective villages, e. g, the Sunny khel anticline, (Fig. 3.4b), (which is coaxial with its host syncline, i. e, Wahabion valley syncline), the Barami valley anticline (Fig. 3.10) and the Kot Mela syncline (Fig. 3.11).

The cores of both anticlines have been cut by streams and unmetaled roads run towards

Fig 3.9 View of the Akhur wal fan fold and Bazi Khel domal structure, looking from west. Note the horizontal beds in the core of the fan fold and the north south and west ward dipping beds of the dome.

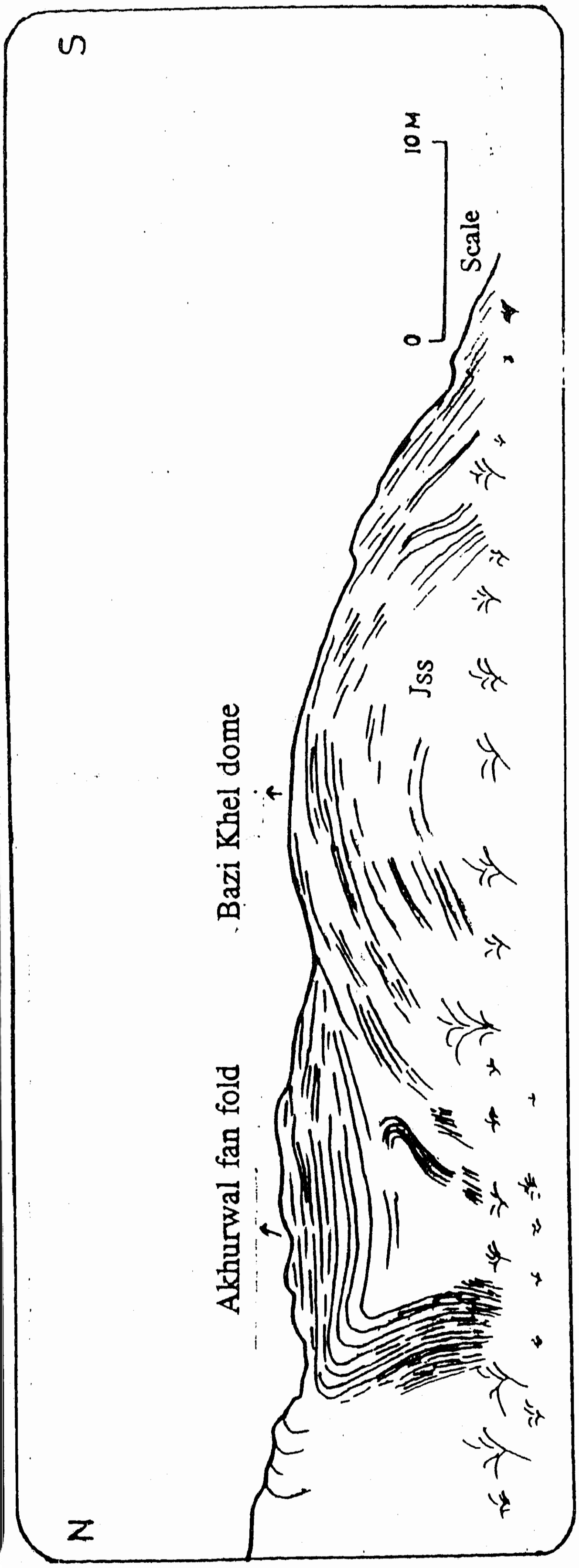

S
N
Scale
0
10 M
Jss
Bazi Khel dome
Akhurwal fan fold

Fig 3.10 Excellent south (left side) and north (right side) dipping beds of the Barami valley anticline. A stream follows the core of the nticline.

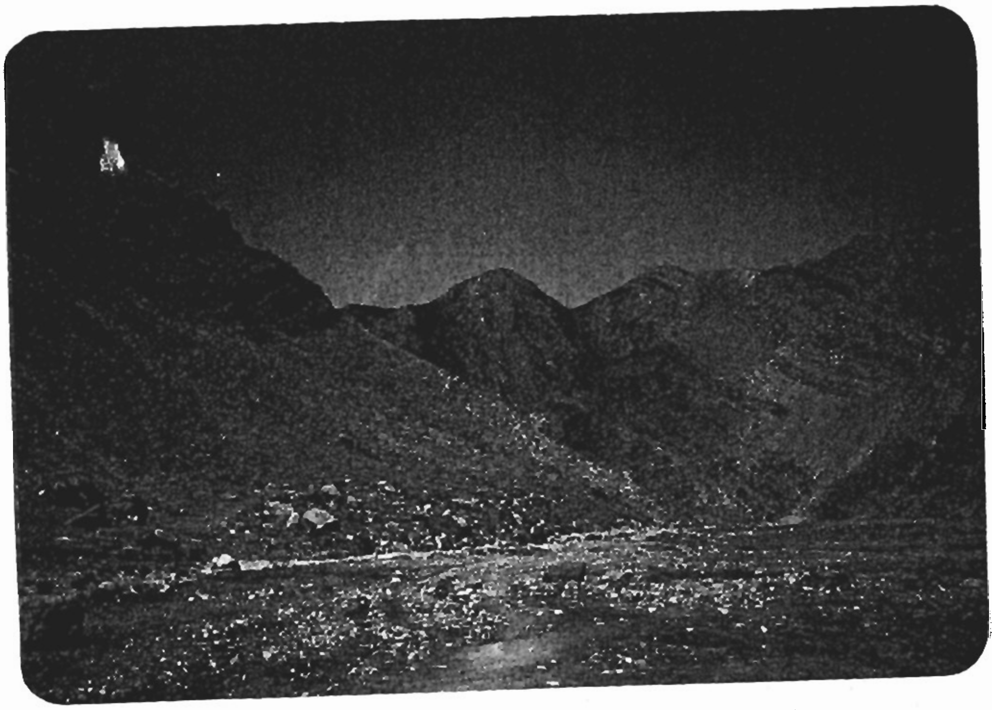
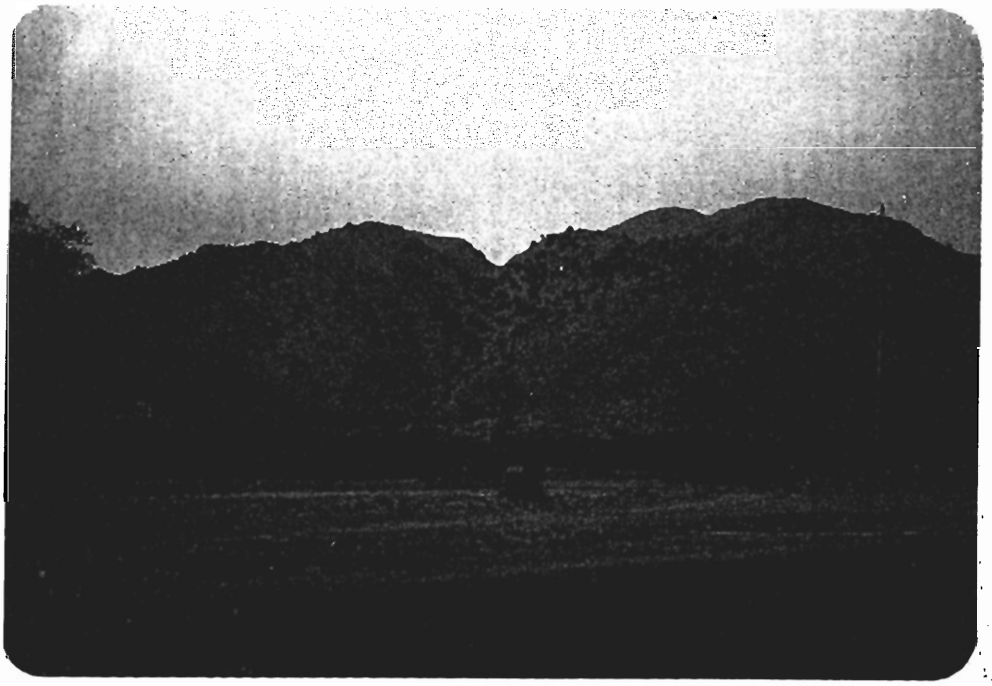
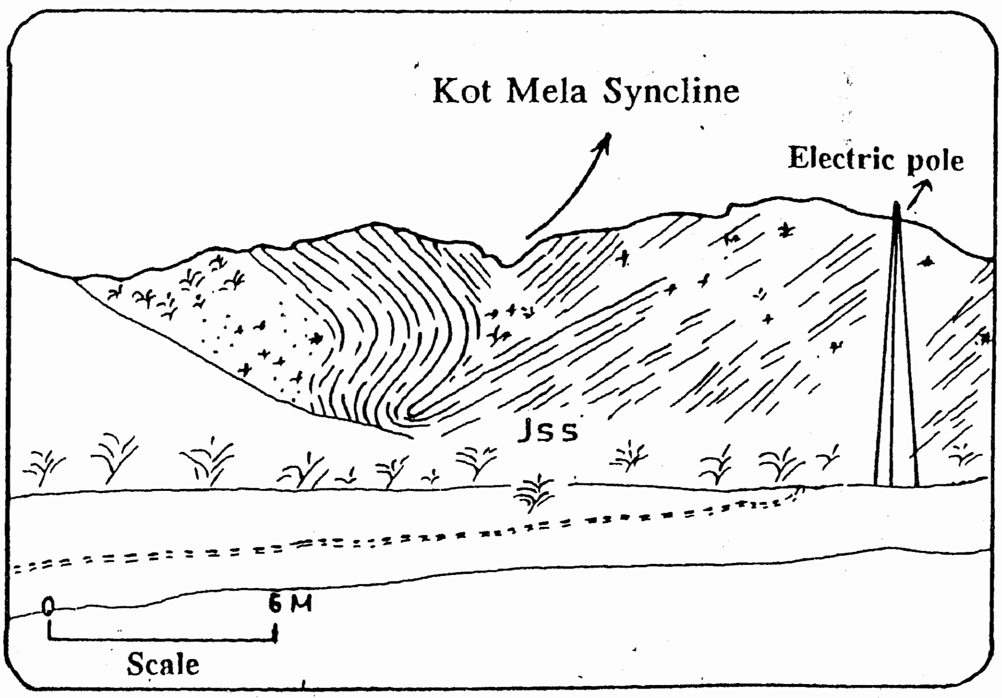


Fig 3.11 A view of the Kot mela syncline, looking west from the metaled road. at higher altitude the folds is an open one, while at the surface level, its hinge becomes sharp and overturned.




Kot Mela Syncline
Electric pole
Jss
0
6M
Scale

the western extreme of the study area through these streams.

The Kot Mela syncline looks an open symmetric fold at the higher altitude, but at the lower level, i.e., near the valley surface, its hinge becomes sharp and tightly overturned, verging south (Fig. 3.11).

d) TIGHT CYLINDRICAL FOLDS

The repetition of the Lockhart and Patala Formations in the core of the Wahabion valley syncline is due to tight, cylindrical folding, some of which are cut by local thrust faults (Fig. 3.4b, 3.12). Several overturned north and south verging tight synclines are observed on the limbs of the large Fan folds. The cores of some of these synclines are taken by the Lockhart Formation (Fig. 3.4b).

The Murree, Patala and the Kohat Formations have experienced severe tight, isoclinal and overturned folding in the broad shear zones which have developed in the footwalls of the fore and back thrusts (Fig. 3.13). Due to these folding the Samana Suk Formation of the fore thrust, therefore, is in direct contact with the Kohat Formation also at some places.

e) S and Z SHAPED FOLDS

In the study area, numerous minor folds are observed in the steeply dipping beds of different formations, which are asymmetrical, S and Z shaped. These folds range in size from ten to thirty centimeter in extent. It appears that the movements along the bedding have been compensated by these minor folds. Apart from the above mentioned folds, a second phase of folding with south and southwest plunging fold axes are observed in the Samana Suk Formation. This phase of folding is the result of east-west compression.

FAULTS

Besides the folding, the Kohat Hill Range has been deformed by imbricate thrusts and normal faulting. At least four sets of faults, i. e., F1, F2, F3,and F4 can be recognized in the study area. All of the faults strike east- west and verging north and south.

Fig 3.12 A view of the southern overturned limb of the wahabion valley syncline (looking east) in the core of which the Lockhart and Patala Formations are repeated due to tight, cylindrical folding.

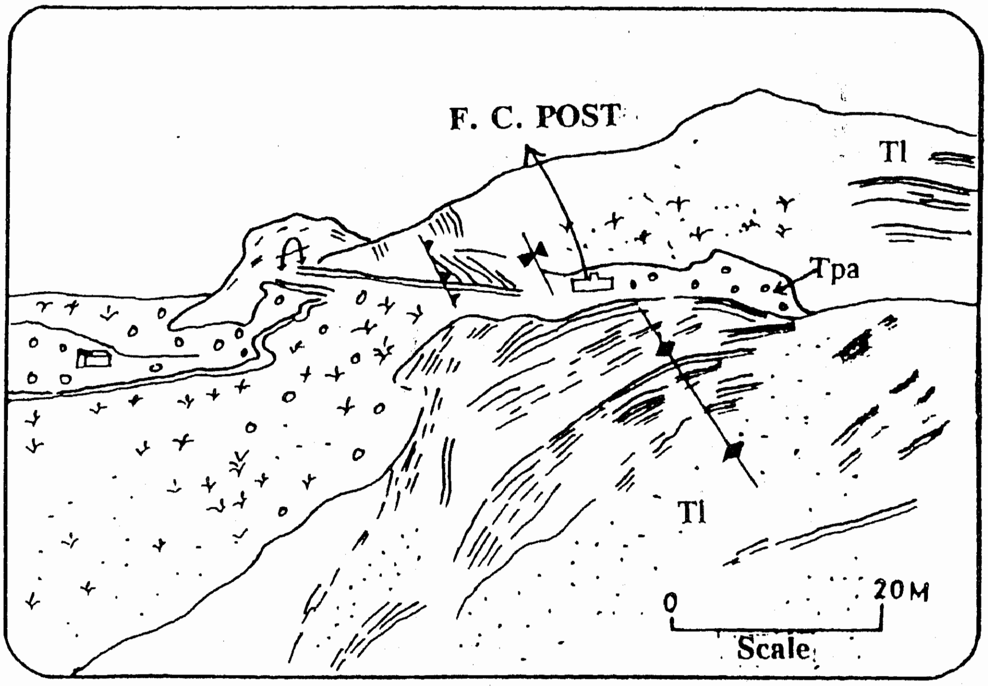

F. C. POST
Tl
Tpa
Tl
0
20M
Scale

Fig 3.13 Tight isoclinal overturned folding with south west plunging folds axes developed in the shear zone of the Patala Formation, between the back thrust on the northern flank of the study area.

a) FAULTS F1.

These faults represent the repetition in the Samana Suk Formation of the Jurassic age and the Chichali-Lumshiwal and Kawagarh Formations of the Cretaceous age in the southern flank of the study area. This repetition, is probably due to imbrication below a roof thrust which was apparently located in the Kawagarh Formation. Probably due to back turning these thrusts dip towards south, while in fact these are north dipping and indicate a duplex structure (Fig. 3.4b, 3.14, 3.15). The strata (from bottom to top), the Samana Suk, Chichali, Lumshiwal and kawagarh Formations, in this duplex zone is repeated, at one place , more than two times in the form of south-verging horses. Some parts of the duplex system are exposed in the eastern valley (Fig. 3.14) and along the western wall of the western valley of the Kotal Pass area, near water tank on the road. But mostly it is covered.

b) FAULTS F2

Faults F2, are , north and south verging blind thrusts, ramped from the main detachment surface (3.16) as well as the faults at the limbs of the fan shaped folds (Fig. 3.4b). One of the south verging and some of the north verging blind thrusts become emergent as fore and back thrusts. The fore thrust (MBT) is the most prominent regional structural feature in the study area which delimits the southern flank of the studied area (Fig. 3.4b). The MBT is a regional fault in the external zone of the Himalayan thrust fold belt in north Pakistan. It brings the Samana Suk Formation of Jurassic age of the Kohat Hill Range to lie tectonically over the Eocene Kohat and the Miocene Murree Formations. My structural interpretation suggests that it ramps from the main decollement which runs below the Mesozoic strata.

The back thrust is another most prominant regional structural feature in the Kohat Hill Range. It delimits the northern flank of the study area. It has got the Samana Suk Formation of Jurassic age to lie tectonically over the Patala Formation of the Palaeocene age. A broad shear zone in the Patala Formation can be clearly seen (Fig. 3.17). The competent beds in the Patala formation have developed into rounded boulders of different sizes, indicating a strong shearing

Fig 3.14 A view of the western lobe-shaped tectonic block of Palaeocene strata, resting on top of steeply dipping Mesozoic succession along a normal fault. Note that there is a repetition of the Samana Suk-Chichali-Lumshiwal and Kawagarh sequence more than once due to imbrication, forming a local duplex structure.

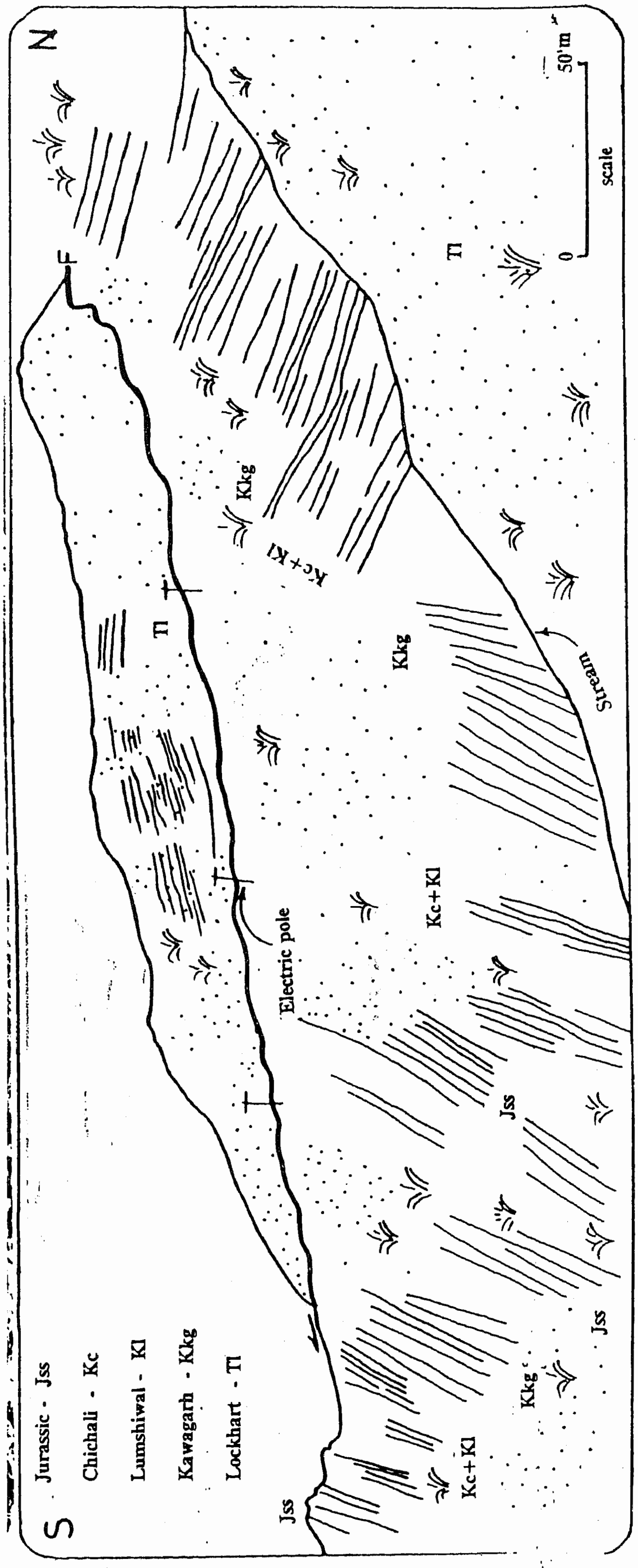

S
N
Jurassic - Jss
Chichali - Kc
Lumshiwal - Kl
Kawagarh - Kkg
Lockhart - Tl
Jss
Kc+Kl
Kkg
Jss
Jss
Electric pole
Kc+Kl
Kkg
Tl
Kc+Kl
Kkg
F
Stream
Tl
0
scale
50 m

Fig 3.15 A model for the development of local duplex structures during the deformation phase D1. Thrust horses involve stratigraphy comprising (from bottom to top) the Samana Suk, Chichali, Lumshiwal and Kawagarh Formations. At least three thrust slices are recognized in this area. D2 phase of deformation has overturned these thrust slices, which now occur in a large fan-shaped fold along the southern slope of the Kotal Pass ridge.

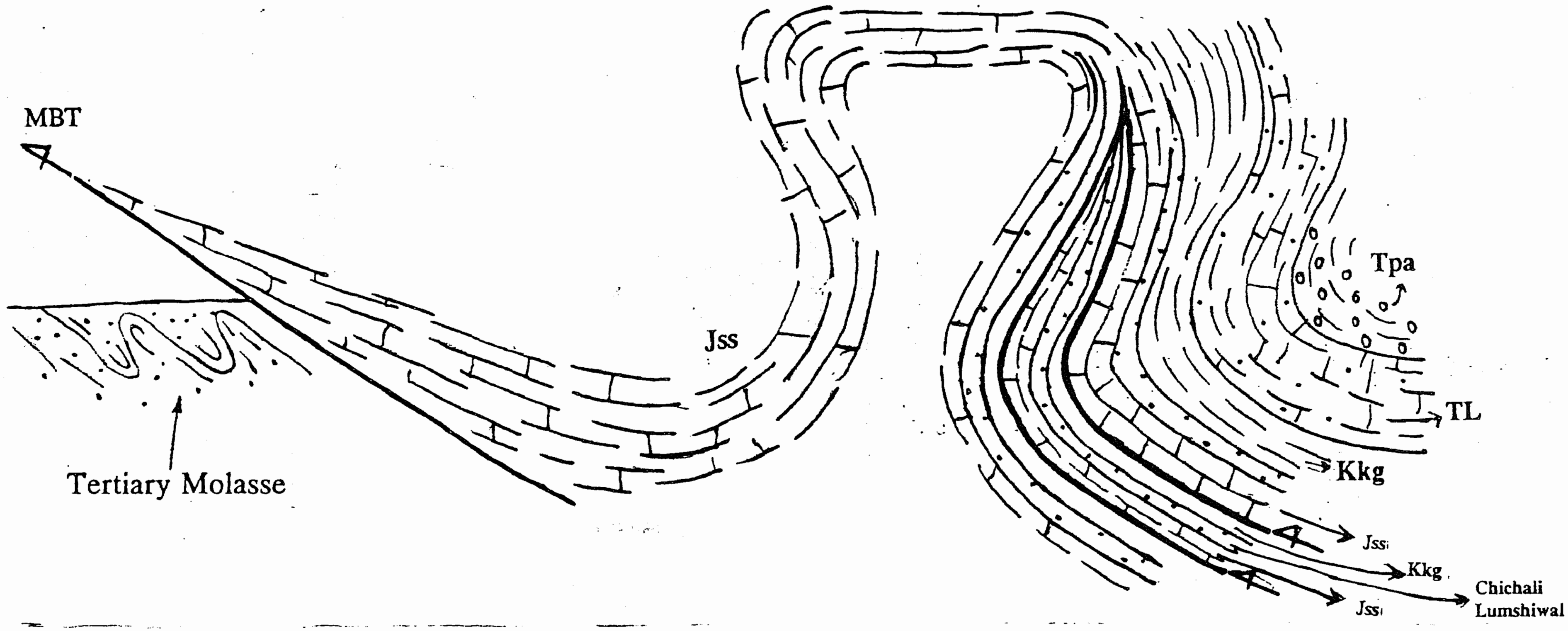

MBT
Jss
Tertiary Molasse
Tpa
TL
Kkg
Jss
Kkg
Chichali
Lumshiwal
Jss

Fig 3.16 A schematic model showing the development of the D2 pop-up fold and thrust (including MBT) structures in the Kohat Hill Range thrust sheet. a) simplified stratigraphic succession prior to deformation. b) development of south-verging detachment anticlines and blind and emergent thrust structures due to displacement along the basal detachment at the base of the Jurassic strata. c) inhibition of displacement along MBT, results in the development of north-verging ractures. Further compression in the transport irection results in the northward folding of the upper limbs of D2a anticlines along north-verging blind fractures,resulting in the displacement of pop-up fan-shaped anticlines. Some of the north-verging fractures become emergent back thrusts, displacing the Mesozoic strata on top of the Tertiary molasse in the hinterland.

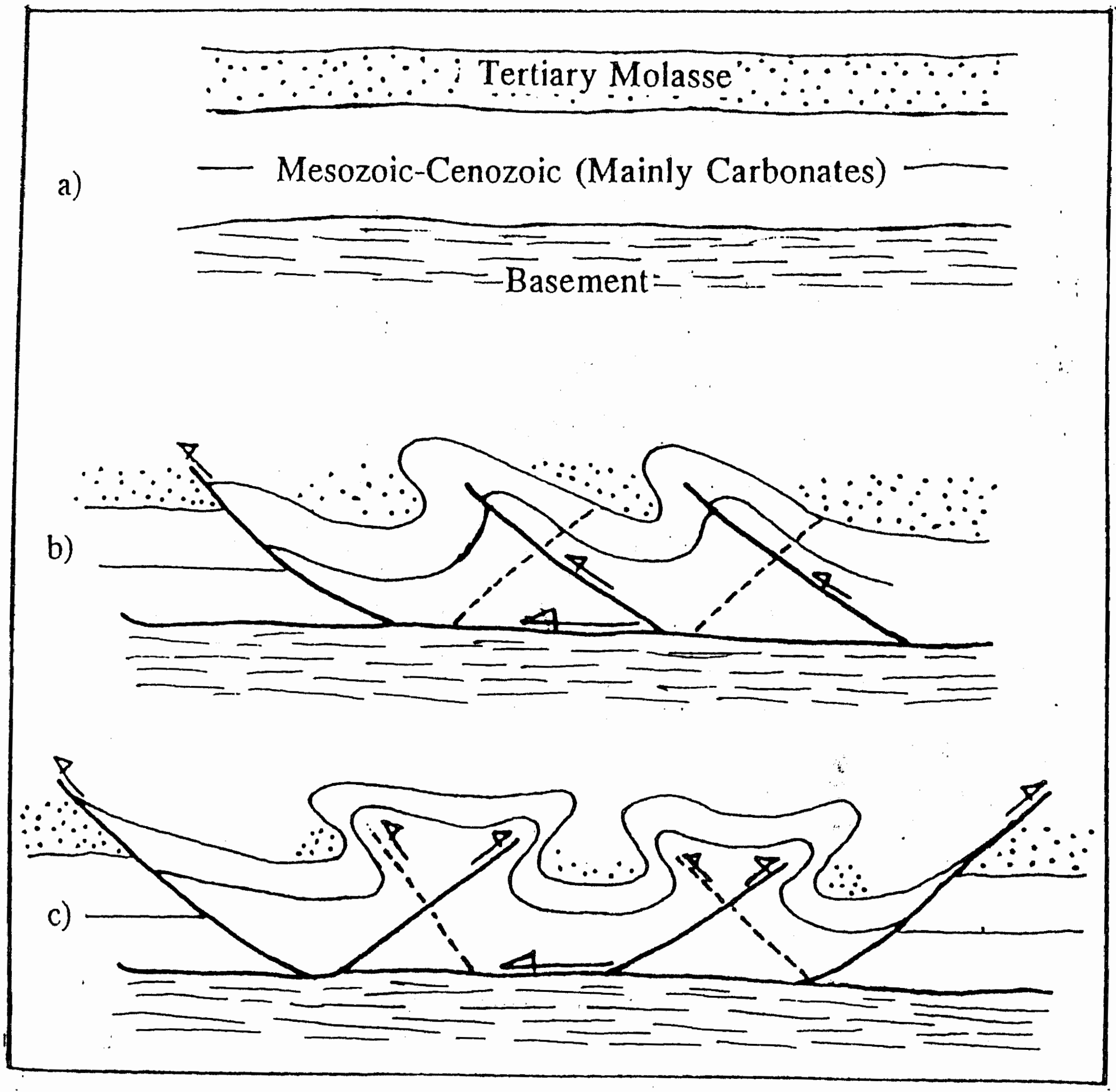

Tertiary Molasse
a)
Mesozoic-Cenozoic (Mainly Carbonates)
Basement
b)
c)

Fig 3.17 Shear zone with rounded boulders, developed in the Patala Formation in the footwall of back thrust, looking towards south. The length of the hammer is 22 cm.

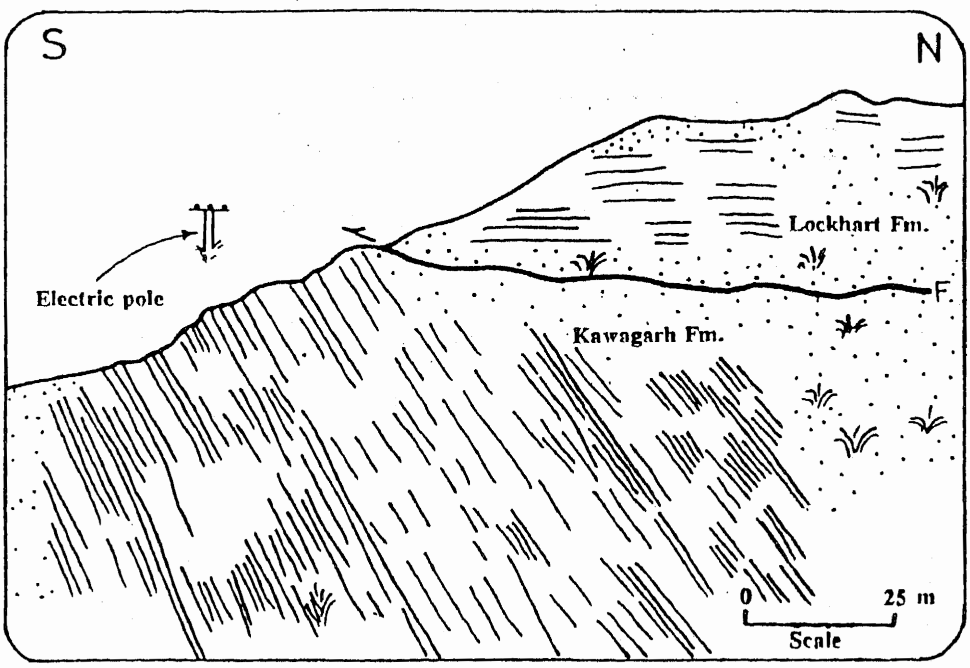
effect (Fig. 3.17). Numerous minor folds have also been developed in the Patala Formation. Another splay of the backthrust (northern most) brings the Patala Formation to lie over the Murree Formation (Fig. 3.4b).

c) FAULTS F3

The faults F3 represent local out-of-the-syncline thrusts which are post folding. Towards the southeast of the Kotal checkpost, there are southward dippig beds of the Patala Formation exposed in the southern overturned limb of the major box shaped syncline, which are successively overlain by older formations to the south (fig. 3.6). Generally there is a close correspondence in the attitudes of the various rock units involved in this overturned limb, but there is a strong discrepancy found at the contact between the Lockhart and Kawagarh Formations. Although, there is no tectonic missing of the stratigraphy at this contact, the attitudes of the bedding in the two formations is clearly out of correspondence (Fig. 3.18), suggesting presence of a fault structure at this contact.

A follow up in the ridges to the west (fig. 3.6) shows that the contact between the Lockhart and the Kawagarh formations is faulted for almost its entire length of exposure. The beds in the Lockhart and overlying Patala Formations are either horizontal or only shallowly dipping to the north, but they dip steeply (~ 70°) towards north in the underlying Kawagarh Formation (Fig. 3.18). The author considers the fault to be a south verging out-of-the-syncline thrust fault, which brings near horizontal strata of the Lockhart Formation from the core of the flat-hinged syncline displaced on top of the steep beds of the Kawagarh Formation in the southern overturned limb of the Wahabian valley syncline. A further evidence of south verging thrust faulting is met in the imbrication of the Palaeocene sequence on the lobe shaped ridge to the south of the Kotal Pass. Here a tectonic slice of the Lockhart Formation occurs on top of the Palaeocene Patala Formation, which is a part of a normal Lockhart-Patala succession (fig. 3.19, 3.20, 3.21). This fault which brings the Lockhart Formation on top of the Patala Formation has the southward sense of vergence and tectonic position in the southern

Fig 3.18 A shallowly north dipping strata of the Lockhart Formation resting tectonically on steep beds of the Kawagarh Formation. The intervening fault (F) is an out-of-the-syncline thrust (D3), which displaces shallow younger strata in the core of the syncline southward on top of the steeply dipping older strata in the limb.


S
N
Lockhart Fm.
Electric pole
F
Kawagarh Fm.
0
25 m
Scale

overturned limb of the wahabian valley syncline, which is almost identical to the fault described above.

d) FAULTS F4

These faults represent the normal faults in the study area. An indirect consequence of the south verging out-of-the-syncline thrusting in the southern overturned limb of the Wahabian valley syncline has been an allocthonous displacement of near horizontal Palaeocene strata on top of near vertical Mesozoic succession. Ghauri et al. (1983) mapped just to the south of Kotal pass, two lobe-shaped southward directed projections of the Palaeocene Lockhart and Patala Formations discordantly overlying the rest of the stratigraphy in this part of the Kohat Range (fig. 3.14, 3.19, 3.20). There is a marked difference in the attitude of bedding in these tectonic lobate projections of the Palaeocene strata and the underlying Mesozoic Succession. In the former, the bedding is either horizontal or dips only shallowly towards north (rarely exceeding 35°), while in the underlying Mesozoic succession, the dips are rarely less steeper than 60°. This type of relationship, in the author opinion, is nowhere near to the normal stratigraphic type as shown by Ghauri et al. (1983).

The tectonic relationship of the fault-bounded allocthonous blocks of the Palaeocene strata on top of the Mesozoic succession is illustrated in Figures (3.14, 3.19, 3.20). Commonly they are located over a shallowly south dipping fault plane at the base of the Palaeocene succession. The strata in the hangingwall of these faults is either horizontal or dips shallowly towards north, suggesting that the basal fault cuts downward in the stratigraphy as it propagated southward. There appears to be little effect of this fault structure on the attitude of the underlying Mesozoic succession, which is vertical to steep, and is remarkably continuous in its east-west strike.

An aspect which is probably worth mentioning is the existence of "window" type structure in between and on the either side of the southward projections of the tectonic blocks of the Palaeocene strata(Fig. 3.19). Apparently this "window" is a result of topographic effect, as they coincide and are roughly parallel to the north-south running valleys on the sides of the two ridges which are occupied by the tectonic blocks of the Palaeocene strata (Fig. 3.19).

Fig 3.19 Geological map of the southern slope of the ridge near Kotal F.C. check post. Late normal faults displace lobe-shaped tectonic blocks of the Palaeocen strata (Tl) southward on top of the steeply dipping Mesozoic succession (Samana Suk, Kawagarh), modified after Ghauri, et al. (1983).

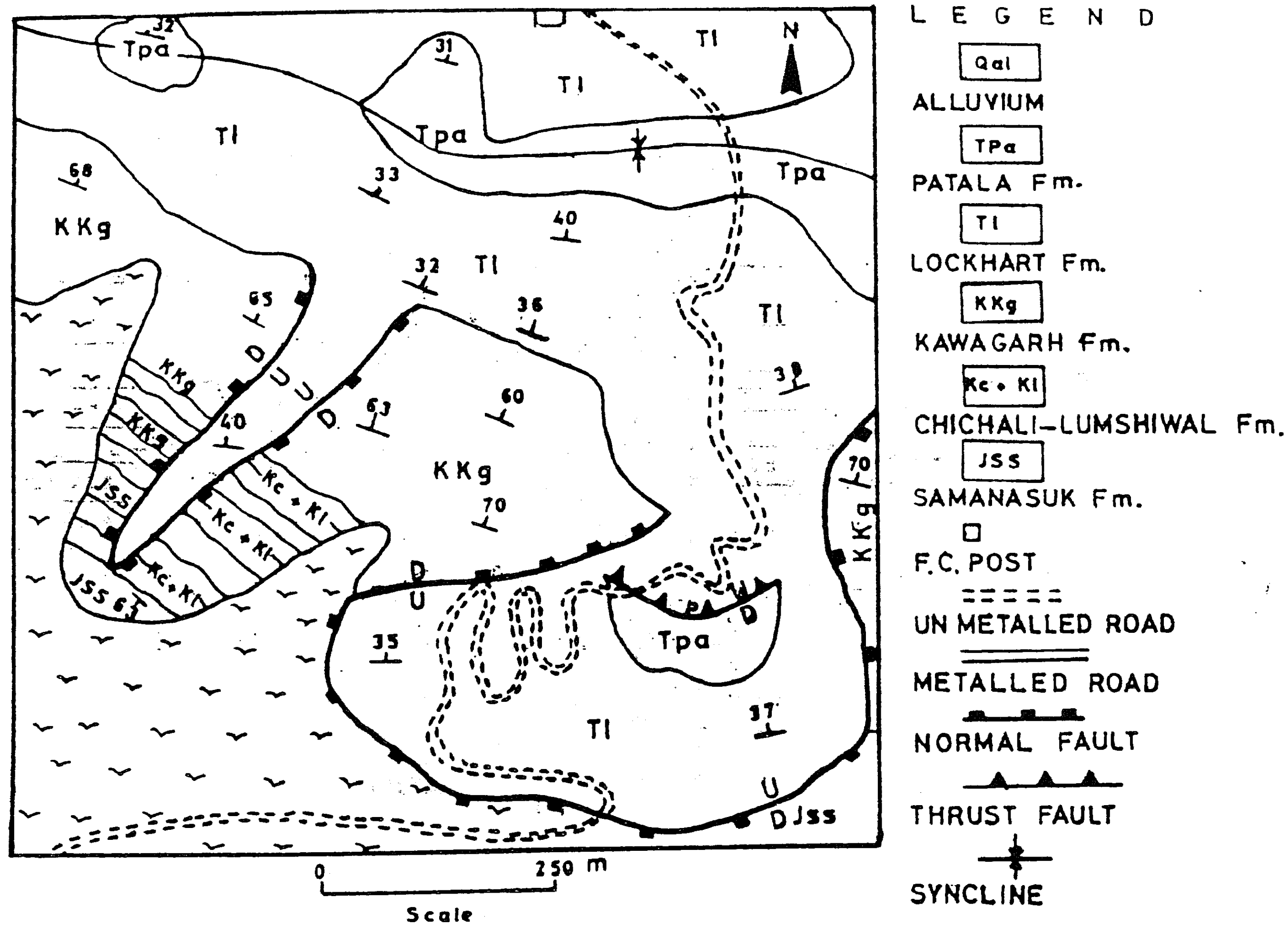
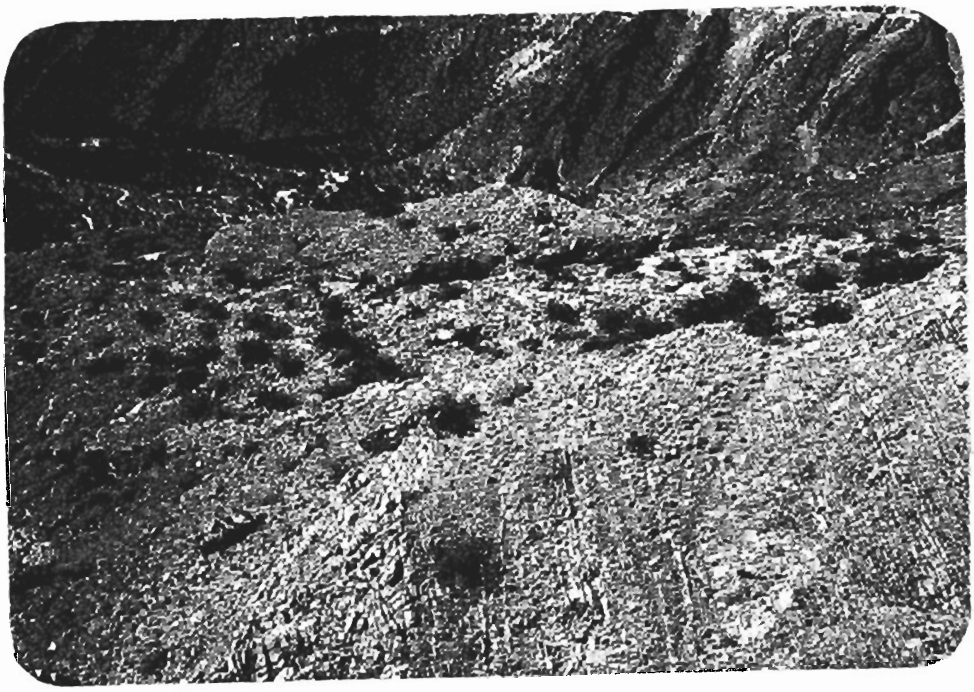

N
Tl
Tpa
KKg
Kc + Kl
Jss
D
U
0
250 m
Scale
LEGEND
Qal
ALLUVIUM
TPa
PATALA Fm.
Tl
LOCKHART Fm.
KKg
KAWAGARH Fm.
Kc + Kl
CHICHALI–LUMSHIWAL Fm.
JSS
SAMANASUK Fm.
F.C. POST
UN METALLED ROAD
METALLED ROAD
NORMAL FAULT
THRUST FAULT
SYNCLINE

Fig 3.20 An allocthonous block of Palaeocene strata resting tectonically on top of steeply dipping Mesozoic succession along normal fault. Within the tectonic block there is an imbricate thrust (Fig.3.18), which brings the Lockhart Formation to lie on top of a normal Lockhart-Patala succession.



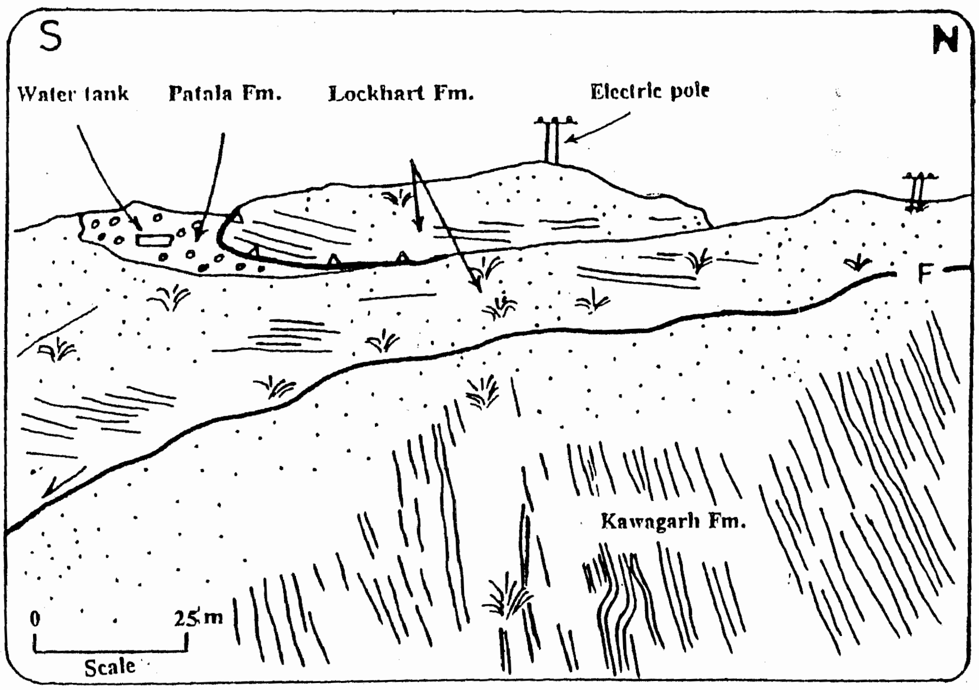
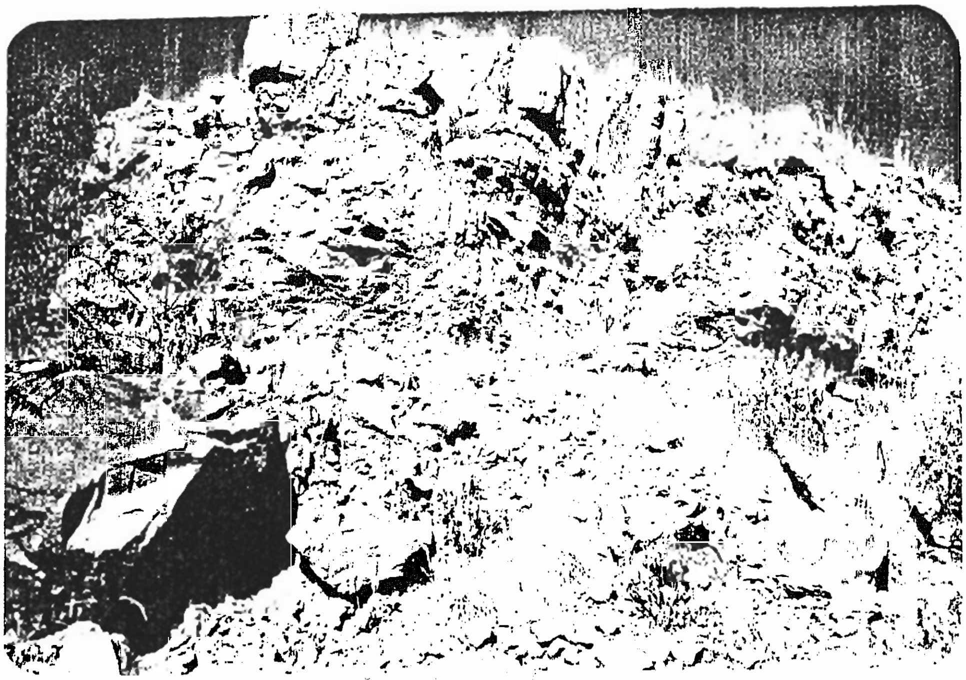
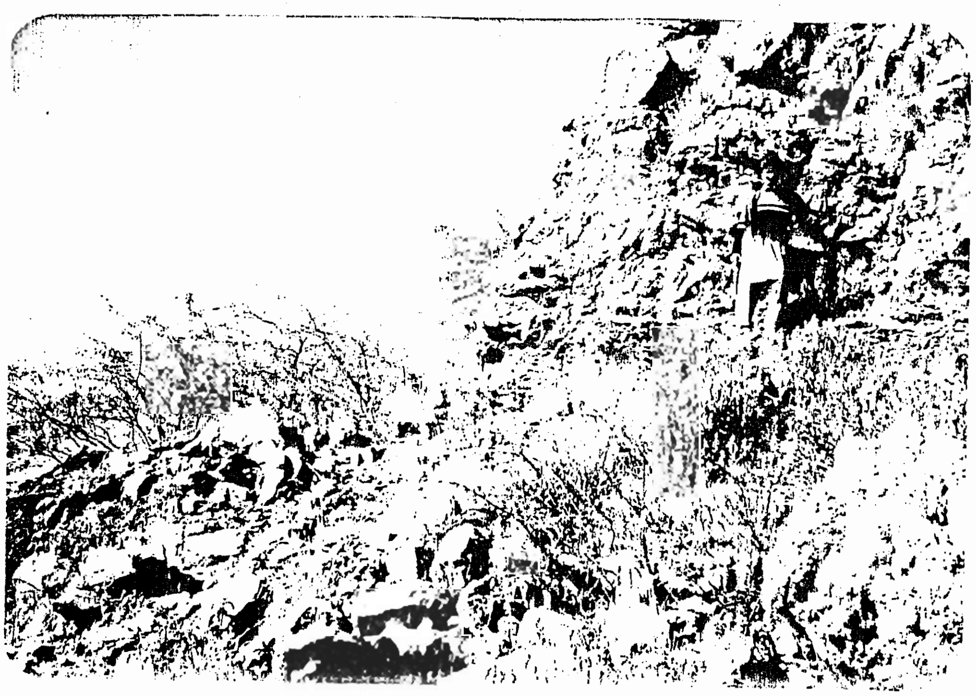

S
N
Water tank
Patala Fm.
Lockhart Fm.
Electric pole
F
Kawagarh Fm.
0
25 m
Scale

Fig 3.21 A close view (A & B) of the imbricate thrust (Fig. 3.19), which brings the Lockhart Formation over a normal Lockhart-Patala succession. The length of the hammer is 22 cm.





There is a considerable difference in the altitude of the two tectonic blocks, the eastern one lies almost near to the valley floor, while the western one being approximately 200- 300 meters high near to the top of the ridge. Since the two tectonic blocks occupying the adjacent ridges, are similar in all respects, e.g, stratigraphy, attitude of their basal fault planes and that of the bedding planes within these blocks, it is probable that originally the two blocks were continuous and were displaced along a common basal fault plane. The present difference in the altitude of the fault planes at the base of the two tectonic blocks may be due to an originally curvilinear nature of the basal fault plane, with an eastward tilt which resulted in the much lower position of the eastern block relative to the western one.

CHAPTER 4

4.1 Synthesis of structural geometry.

The study area is located in the foreland fold and thrust belt of southwestern Himalaya (Fig. 1.2). The data gathered from the present work and the data from the previous literature is all put together to model the systematic development of the structure in the Kohat Hill Range.

The general strike in the study area is northwest-southeast with a few deviations. The forward and hindward verging thrusts bounding the range in the south and north, trend northwest-southeast and dip towards north and south respectively. The orientation of fold axes of the major folds are parallel to the regional strike of the study area.

As the deformation proceeded south of the Main Mantle Thrust, a basal shear plane developed along a crystalline basement (Seeber et al., 1981; Lilli et al., 1987). The major fore and back thrusts probably sole onto this basal detachment below the Mesozoic strata. The southwest directed tectonic transport along the MBT and northeast directed transport along the back thrusts suggest a pop-up style of deformation. The fan shaped folding style closely matches the pop-up style displayed by the thrust faults. It is interpreted that they may be cored by blined thrusts at their diverging limbs (Fig. 3.16).

The repetition in the Palaeocene strata, i. e., the Lockhart and Patala Formations is due to tight cylindrical folding, locally cut by thrust faults (Fig.3.4b, 3.12)

A later strong phase of folding has developed complex interference patterns, which has further contributed to the uplift of the range. The structures, which post dates all these structures, include, 1) out-of-the-syncline thrust faults which record the culmination of shorting and uplift the Kohat range and 2) a set of normal faults which mark the ravitational adjustments following abnormal uplift associated with the MBT and its associated structures.

Although the recognition of faults in the study area has been a relatively simple matter of observation, owing mainly to dramatically good exposures and well established stratigraphy (Gardezi et al., 1976; Ghauri et al., 1983), the assessment about their nature is not that straightforward. The shallowly north- dipping fault (Fig. 3.18) at the contact between the Lockhart and the Kawagarh formations was apparently reverse in its sense of movement, as it brought near-horizontal strata of the Lockhart Formation probably from the core of the box-shaped syncline to lie on top of the steeply northward dipping strata of the Kawagarh Formation in the southern overturned limb of the Wahabian valley syncline. This fault owes its initiation probably to the tight folding in the area which resulted in south-verging out-of- the syncline thrusting. Late stage movement along this fault transported the Palaeocene strata southward to lie over the Mesozoic succession in the form of tectonic blocks. My interpretation about the initiation and subsequent movement on these south-verging fault structures have been portrayed in (Fig. 4.1 a,b) , together with their relationship to their host fold structures.

The author, however, does not believe that the fault planes at the bases of the southward projecting tectonic blocks comprising Palaeocene strata are entirely reverse in their sense of movement. The shallow, southward dip of these faults, together with a considerable displacement (approximately 1 km) of the younger strata on top of the steeply dipping Mesozoic succession would favor a normal sense of movement on these fault structures. As shown in the (Fig. 4.1, c), the author interprets that southward, up-dip movement of the Palaeocene strata out from the core of the synclinal fold structure resulted in an abnormal uplift of the Kotal Pass area. This led to initiation of southward dipping normal faults, along which there was a gravitational collapse of the uplifted Palaeocene strata. An abundance of fault breccia (Fig. 4.2), associated with the fault planes suggests a near- surface level of these late stage normal faults.

4.2 Deformational history

At least four phases of deformation, i.e, D1, D2, D3and D4 are recognized in the Kohat Hill Range strata.

a) Step 1;

The D1 phase of deformation is documented by the presence of local duplex structures

Fig 4.1 A schematic representation of the successive stages involved in the development of post-folding fault structures (D3,D4) in the Kotal Pass area of the Kohat Hill Range (not to scale): a) development of the southern overturned limb of the Wahabion valley syncline, with positions of, to be, out-of-the-syncline thrust (D3), showing by F3, b) southward displacement of the shallow dipping strata from the core of the syncline on top of the steep limb of the syncline. Also shown is the position of the fault (F4) which, in the next stage, marked the gravity collapse (D4) of the abnormally uplifted terrain in the Kotal Pass area, c) development of south-verging normal fault, which displaced abnormally uplifted Palaeocene strata (out-of-the-syncline thrust in stage b), downward on the southern steep limb of the syncline. Jss=Jurassic Samana Suk Formation, Kc = Cretaceous Chichali, Fm, Kl=Cretaceous Lumshiwal Fm, Kkg=Cretaceous Kawagarh Fm, Tl=Tertiary Lockhart Fm, Tpa=Tertiary Patala Fm.

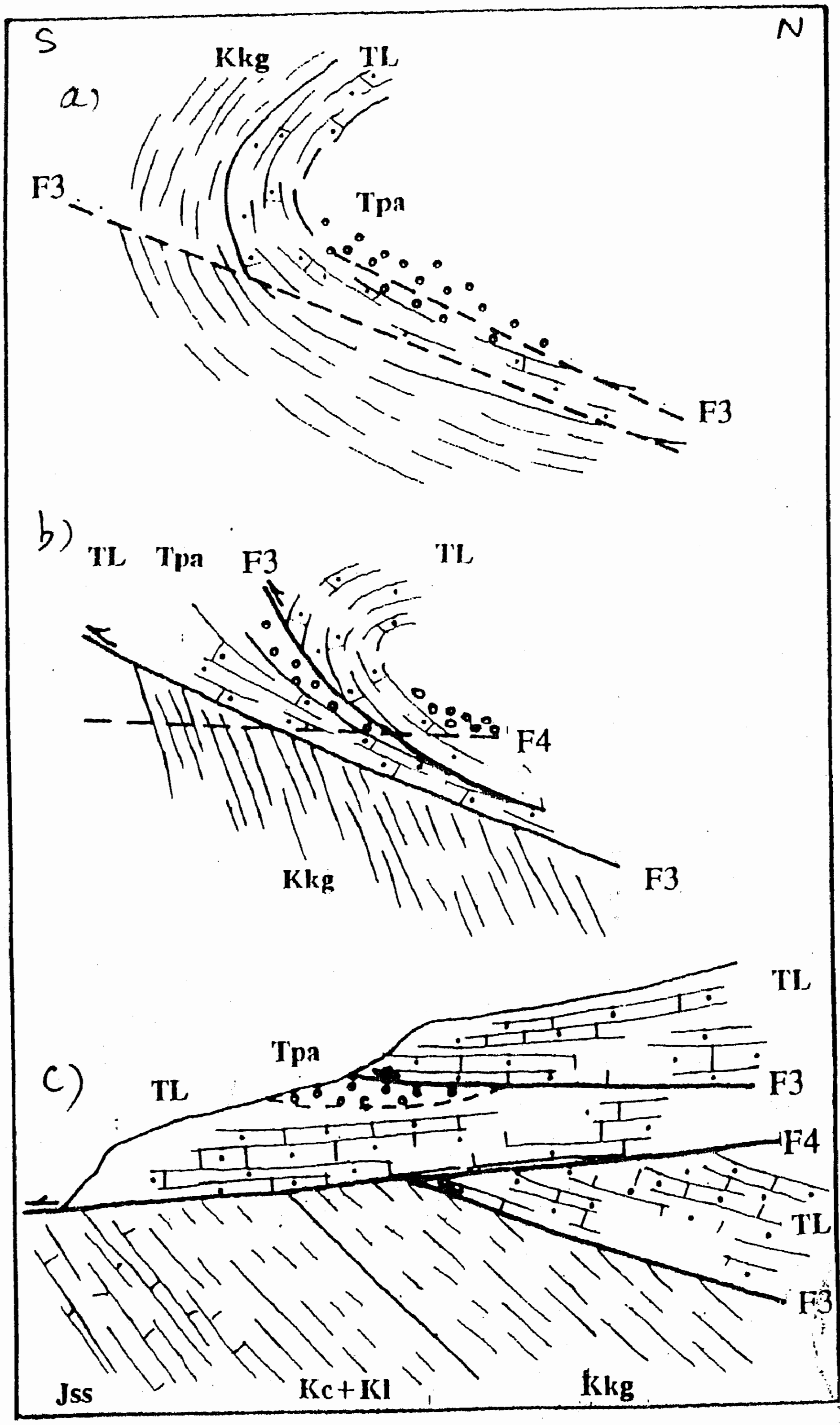

S
N
a)
Kkg
TL
F3
Tpa
F3
b)
TL
Tpa
F3
TL
F4
Kkg
F3
TL
Tpa
c)
TL
F3
F4
TL
F3
Jss
Kc+Kl
Kkg

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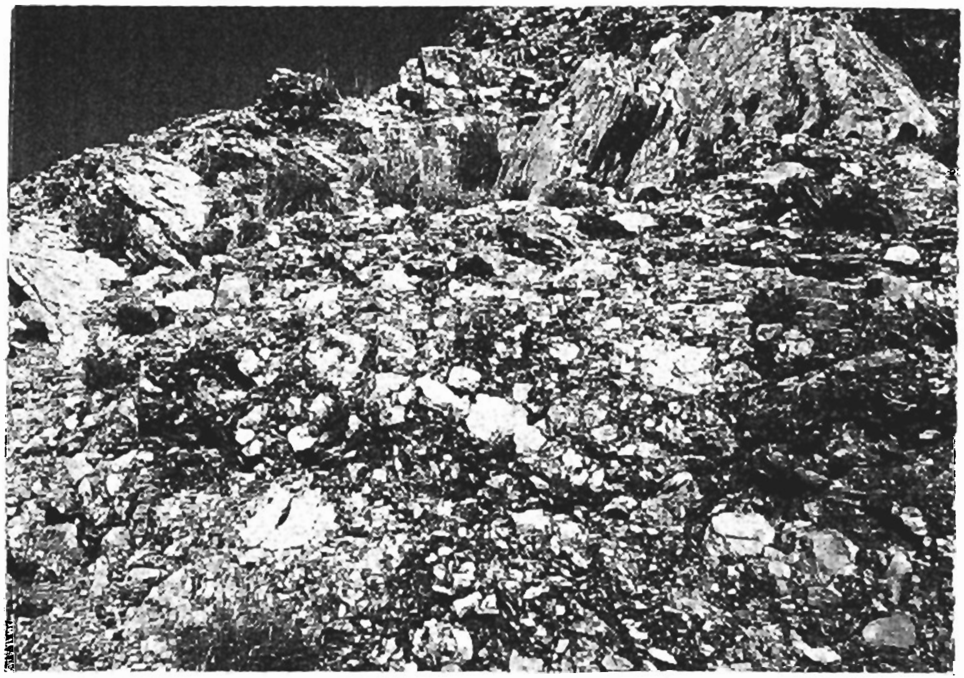
Fig 4.2 A view (A & B) of the fault breccia on the southern slope of the Kotal pass area, associated with the normal fault planes. This suggest a near surface origion of the late stage normal faults.



in the Mesozoic sequence (Fig. 3.4b, 3.14, 3.15). The thrust horses involve stratigraphy, comprising (from bottom to top) the Samana Suk, Chichali, Lumshiwal and Kawagarh Formations. The duplex occurs between a basal detachment at the base of the samana Suk Formation and a roof thrust at the base of the Palaeocene Lockhart Formation. The faults involved in this duplex structure are referred to as F1

b) Step 2;

The D2 is the principal phase of deformation in the Kohat Hill Range. At least two stages of fault and fold development are recognized in this phase of deformation.

Step 2a;

D2a In this phase of deformation a displacement occurred along a detachment at the base of the Samana Suk Formation which results in south-verging detachment folds, probably cored by blind thrusts (e.g, Kotal fan shaped anticline, Akhur wal fan shaped anticline). One of the these blind thrusts , i. e., the Kotal member of the MBT becomes emergent and displaces the thrust south wards on top of the Murree Formation (3.4b, Fig. 3.18).

Step 2b;

D2b In this phase of deformation the displacement on the MBT is inhibited for some reason. The ongoing compression along the basal decollement from north. This results in the initiation of north verging fractures. Further movement along the basal detachment causes displacement along these fractures rather than those verging to the south, resulting in refolding of the upper limbs of the d2a anticlines and development of large "pop-up" fan shaped folds (Fig. 3.4b, 3.16). Some of the north verging fractures in the northern part of the thrust sheet became emergent as back thrusts and displaced Mesozoic- Cenozoic shelf carbonates northward on the Tertiary molasse (Fig. 3.16).

c) Step 3;

The D3 phase of deformation is post folding. Ongoing compression in the thrust sheet results in local out-of-the-syncline thrust faults (Khan et al, 1990), (Fig. 3.6, 3.18, 4.1). Some of these structures in southern slopes of the Kotal Pass are studied and considered responsible for further uplift of the mountain front.

d) Step 4

The D4 which is the last phase of deformation in the Kohat Hill Range and is marked by gravity collapse of the tectonic blocks anomalously uplifted during D2 and D3 phases of deformation. Figures (3.14, 3.19. 3.20) show two such normal faults recognized at the southern slopes of the Kotal Pass ridge, which displace the Palaeocene strata down south ward on top of the steeply north dipping Mesozoic strata in the southern overturned limb of the Wahabion valley syncline. An abundance of fault breccia (Fig. 4.2), associated with the fault planes suggest a near surface origin of these late-stage normal faults.

CHAPTER 5

CONCLUSIONS

As a result of the present work, the following conclusions are drawn regarding the geology and structural setting of Darra Adam Khel-Kotal pass trasect, Kohat Hill Range.

1) Eight distinct lithostratigraphic units are recognized in the study area (Table. 2.1), Zurghun Khel Jurassic and Hangu Formation (Palaeocene) previously mapped by Gardezi et al. (1976) are not present.

2) The Samana Suk Formation thrusts over the Kohat Formation also in some places, because the footwall sequences below MBT are tightly folded and includes both the Kohat and the Murree Formation.

3) The study area is deformed by pop-up style both by large fan shaped folds and fore and back thrusts.

4) The repetition of the Samana Suk-Chichali-Lumshiwal and Kawagarh Formations is due to imbricate thrust faults, ramped from main decollement, while thr roof thrust is located some where in the Kawagarh Formation to form a local duplex zone.

5) The repetition of the Lockhart and Patala Formations is due to tight, cylindrical folding.

6) An out-of-the-syncline thrust is recognised at the contact of the Lockhart and Kawagarh Formations in the Kotal pass area for the first time.

7) Two normal faults are recognized in the Kotal pass area, which were previously unmapped.

8) Six major thrusts, four of which are fore thrusts and two back thrusts are mapped in the study area.

9) The major structures of the study area suggest that the rocks have undergone four

phases of deformation, i.e., D1, D2, D3 and D4. The D1 phase of deformation represents the development of local duplex structure. The principal phase of deformation D2 is responsible for the development of MBT, the back thrusts and the large scale fan shaped folding. The phase of deformation D3 is post folding which gives rise to out-of-the-syncline thrust faults. D4 is marked by low angle normal faults and is the latest stage of deformation.

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