STRUCTURAL MODEL FOR THE EVALUTION OF A PART OF THE EASTERN KALACHITTA RANGE: HASSANABDAL-FATEH JHANG TRANSECT.

A thesis submitted to the National Centre of Excellence in Geology, University of Peshawar in partial fulfillmint of the degree of Master of Philosophy in Geology.

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ABSTRACT

The eastern part of the Kalachitta Range occupying the southern periphery of the hill ranges exposes a suite of shelf platform rocks of Mesozoic-Cenozoic age. Stratigraphic column comprises the Samana Suk(Jurassic), the Lumshiwal(Cretaceous),the Lockhart and Patala(Paleocene), the Margala, Chorgali, Kuldana and Kohat (Eocene)and the Murree (Miocene)Formations.

The structure of the area is characterized by two distinct styles of deformation controlled by two detachment levels. The lower detachment is at the base of the Samana Suk Formation and the upper one is within the Patala Formation. The deformation between the two detachment levels is controlled by thrusting in the form of a duplex structure, in which the lower detachment is acting as sole or floor thrust and the upper one as roof thrust. This duplex is best exposed at Katha colony, where the Jurassic-Paleocene strata is repeated four times in the form of south verging horses. No folding except for that related with thrusts (open hanging wall anticlines) has been observed in the sequence between the two detachment levels. In contrast the structural style in the Cenozoic strata overlying the upper detachment is fold dominated, with both hinterland and foreland vergence. The structural model of the area is of a forward verging duplex separated from the roof sequence by a passive back thrust in Patala shale. This structure is expressed at the surface by fault related folds with north-south vergence.

The mountain front shows no regional emergent thrust analogous to MBT of India, perhaps due to back thrust at upper level detachment accommodating the forward propagation of duplex. At the mountain front the south dipping Patala Formation and Margala Hill limestone tectonically overly the Overturned Jurassic Samana Suk Formation, showing a north verging back thrust. This emergent back thrust at the mountain front, shows that the passive back thrust is dissected by overstep back thrust.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 GENERAL DESCRIPTION

The part of the eastern Kalachitta Range constituting the area of investigation, lies in the survey of Pakistan topographic sheet no 43 C/10 (Fig. 1.1) and is located approximately 12 km north of the Fatehjhang town. The area is restricted between the longitude 72°, 34', E - 72°, 44', E and Latitude 33°, 36', N - 33°, 40',18" N. The range is a barrier between the alluvium of Campbellpore basin to the north and the Potwar plateau to the south (Fig. 1.2), having an elevation difference of about 183 meters from it's northern and southern surroundings. Geographically the Kalachitta Range falls in the hill ranges, which in addition include Margala, Gandghar, Attock-Cherat, Kohat and Samana Ranges as other members. The hill ranges are, however, divisible into two tectonic blocks. The northern block comprises Gandghar, Attock-Cherat and Khyber ranges (Fig 1.2), predominantly consisting of Precambrian slates. The southern block comprising Margala, Kalachitta, Kohat and Samana ranges at the northern margin of Potwar and Kohat Plateau (Fig 1.2), consists exclusively of un-metamorphosed sedimentary rocks of platform affinity. Rocks of hill ranges are brought to the surface along the major ramps branching from a single detachment surface (Yeats and Lawrence, 1984). The rocks exposed in the area range from Jurassic to Miocene in age.

The structure of the area is controlled by folds and faults. The folds display east-west trend and are asymmetric in nature lacking consistency in vergence, whereas the faults are mostly south vergent, showing south directed horizontal compression.

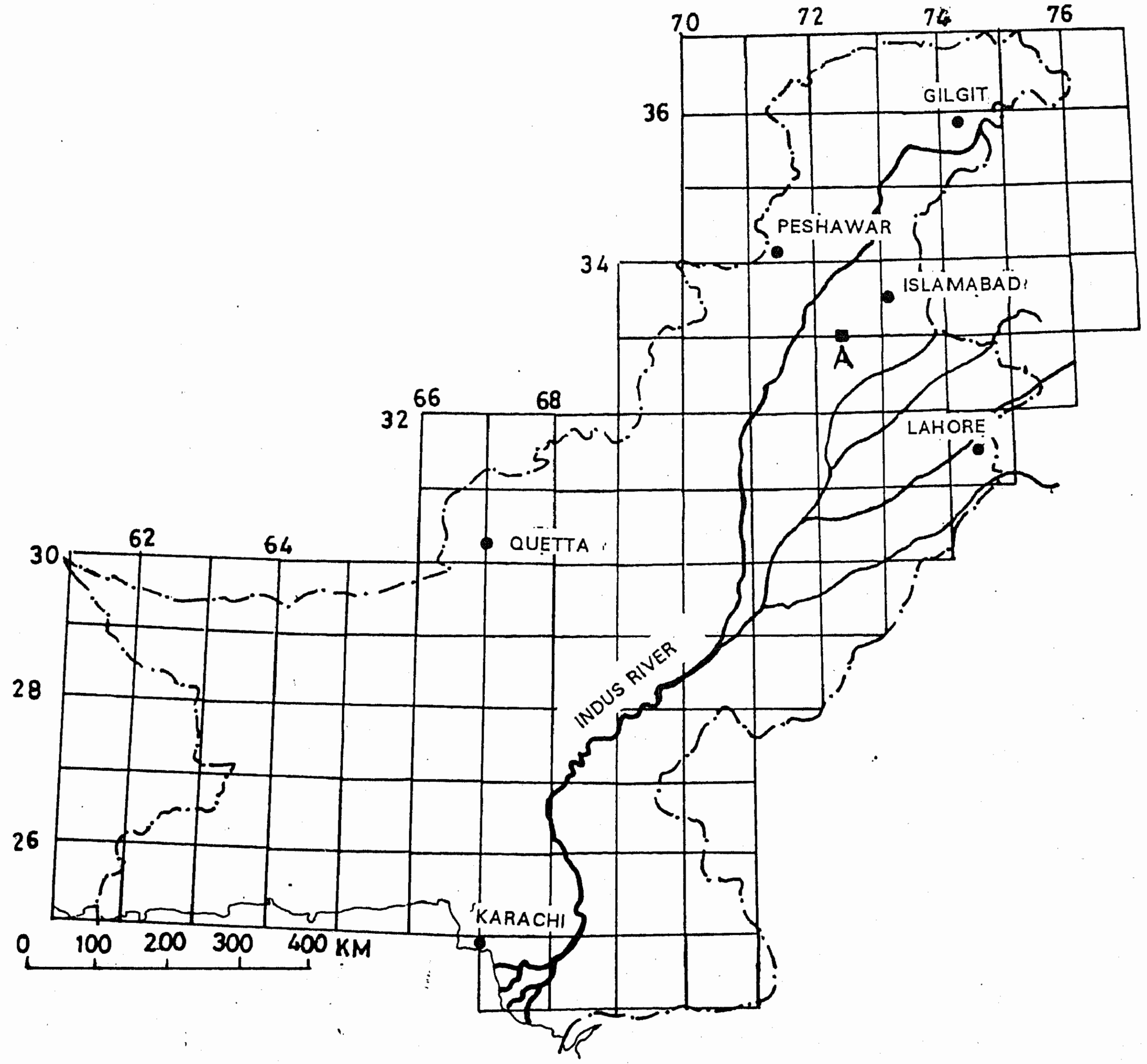
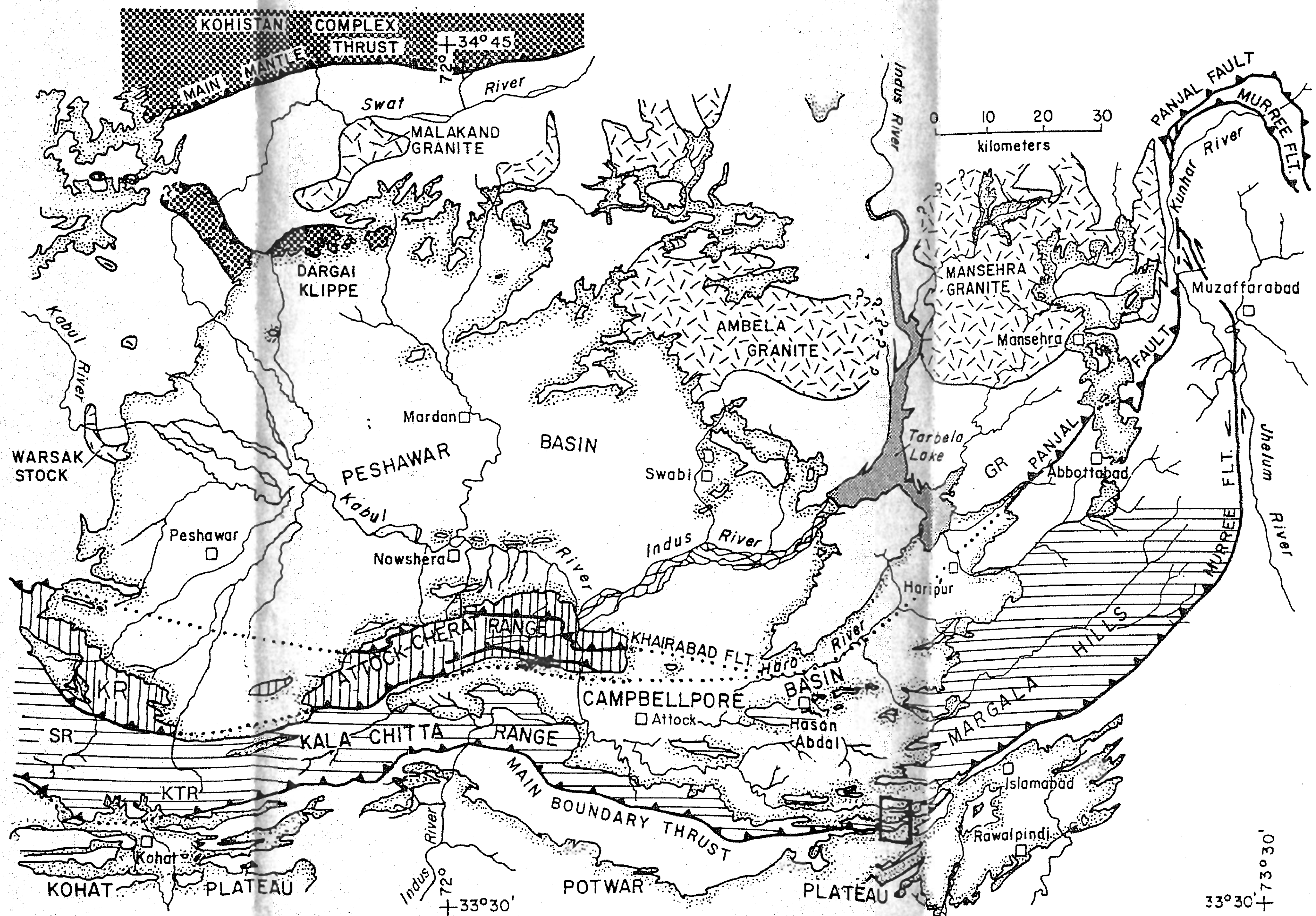


Fig. 1.1. Index map of Pakistan showing the location (A) of the study area.

Fig. 1.2. Geological map of Peshawar basin and adjacent areas, GR: Gandghar Range, KR: Khyber Range, KTR: Kohat Range, SR: Samana Range.Box shows location of the studied area.(adapted from Burbank and Tahirkheli (1985).

3a


KOHISTAN COMPLEX
MAIN MANTLE THRUST
34°45
72°
Swat River
MALAKAND GRANITE
DARGAI KLIPPE
Indus River
0 10 20 30
kilometers
PANJAL FAULT
MURREE FLT.
Kunhar River
MANSEHRA GRANITE
Muzaffarabad
Mansehra
AMBELA GRANITE
Kabul River
WARSAK STOCK
Mardan
PESHAWAR
BASIN
Swabi
Tarbela Lake
GR
PANJAL
FAULT
Abbottabad
Jhelum River
FLT.
MURREE
Peshawar
Kabul
Nowshera
River
Indus River
Haripur
ATTOCK-CHERAT RANGE
KHAIRABAD FLT.
Haro River
HILLS
KR
CAMPBELLPORE
BASIN
Attock
Hasan Abdal
MARGALA
SR
KALA CHITTA RANGE
KTR
MAIN BOUNDARY THRUST
Islamabad
Rawalpindi
Kohat
KOHAT PLATEAU
Indus River
72°
33°30'
POTWAR
PLATEAU
33°30'
73°30'

3b

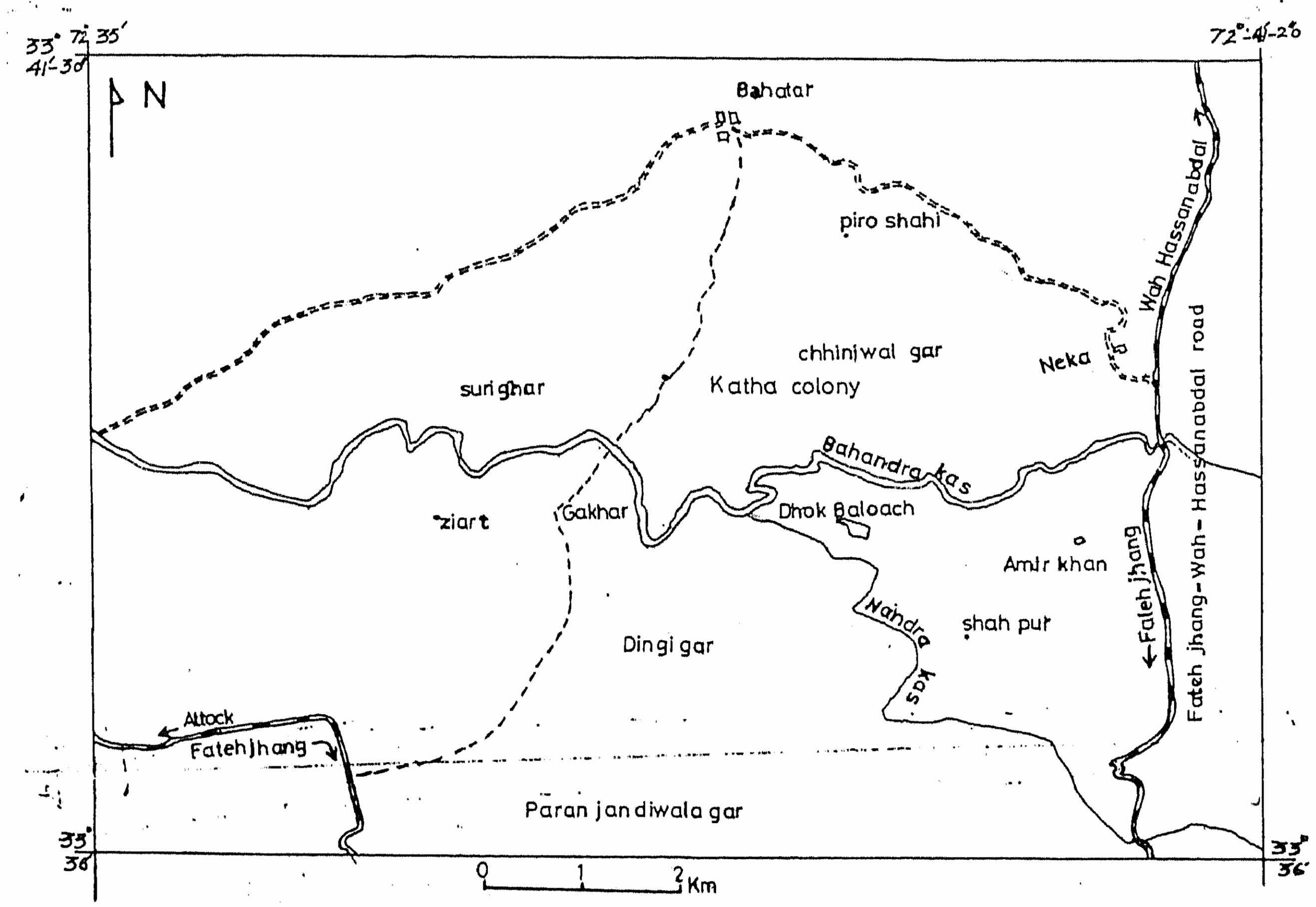
1.2 PREVIOUS WORK

Being a part of the settled area with an easy accessibility, the Kalachitta Range has been the focus of attention of since long time. In addition to it's stratigraphic significance (as being the potential source for hydrocarbon), it was also the focus of attention of the structural geologists working in the Potwar trough. Cotter (1933) was one of the pioneers who described the geology of the Kalachitta Range. As against the isoclinal folding of Cotter (1933), Pinfold (1954), Sokolov and shah (1966), Gardezi (1974), is of the view that the cross-folding is the result of differential right lateral transverse movement of the basement effecting the overlying sedimentary veneer. Later Yeats and Hussain (1987), while working on the western part of the range described the structural setup as south verging imbrication resulting in response to south directed horizontal compression. Recent mapping of Akhtar et al. (1985) provides a good frame work for detailed structural and tectonic studies of the eastern part of Kalachitta Range.

1.3 ACCESSIBILITY

The eastern Kalachitta Range is traversed by two metaled roads linking the Fateh Jhang town with Attock and Hassanabdal cities (Fig. 1.3), providing easy accessibility and opportunity to look into the geology of the area. A local jeepable track linking the Bahtar and Gakhar villages offers a good access for the study of excellent exposures near the Katha colony.

Fig. 1.3. Accessibility map of the studied area in the eastern Kalachitta Range.



1.4 PURPOSE OF INVESTIGATION

The Himalayan foreland fold and thrust belt is best exposed in northern Pakistan exhibiting a wide variety of structures. Most of the previous work was confined to the western and central parts of the Kalachitta range. Recent mapping of Akhtar et al. (1985) provides a good framework for detailed structural studies in the eastern part of Kalachitta Range. A major objective of this study is to describe the style of deformation and examine the relationship between the structures. The present work was carried out with the following objectives in mind.

1) Stratigraphic analysis of the area and comparison with other parts of the range.

2) Investigation of the Kalachitta mountain front and it's relationship with the Main Boundry Thrust .

3) Determination of the style of deformation.

4) Modeling the tectonic evolution of the eastern Kalachitta range.

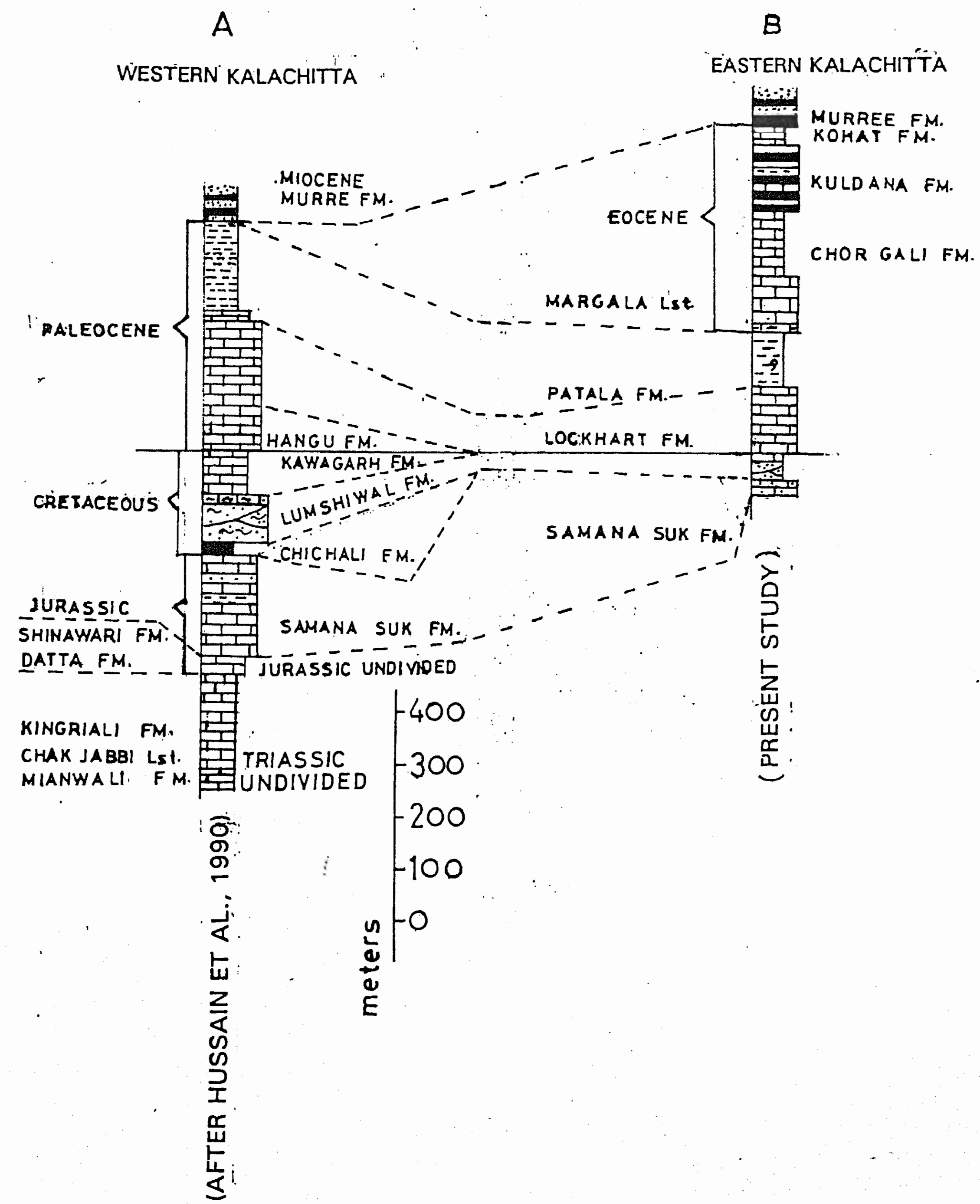
CHAPTER 2

STRATIGRAPHY

2.1 GENERAL DESCRIPTION

The Kalachitta Range occupying the southern periphery of the Hill Ranges consists of un-metamorphosed shelf platform sequence of Mesozoic and Cenozoic age. Lithologies are dominated by carbonates but shale and sandstone are also common. The Kalachitta Range is divisible into eastern and western blocks, lying to the east and to the west of river Indus respectively (Fig,2.1). The western block shows a stratigraphic sequence from Triassic upto Paleocene, having Miocene Murree Formation lying unconformably over Paleocene Patala Formation (Hussain et al., 1990). The whole Eocene package in between the Patala and Murree Formation is missing. The absence of Eocene package in the western block may be attributed to the ongoing tectonic activity during that period. In the study area Cretaceous Chichali and Kawagarh and Paleocene Hangu Formation are missing (Fig.2.1 b). The absence of the Chichali Formation may be related with the Mesozoic rift related tectonics in the Indian plate (Jadoon and Baig, 1991). Eastern part of the range was probably more exposed as compared to the other parts of the range, as a result whole of the Chichali Formation and part of the Samana Suk Formation got eroded. This continued till the partial transgression of sea resulting in the deposition of the Lumshiwal Formation. The absence of the Kawagarh and the Hangu Formations in the study area is probably related with the Late Cretaceous tectonic event (Tahirkheli, 1882), resulting in the uplift and erosion of the eastern part of the Kalachitta Range.

Fig. 2.1. Summary correlation log of Kalachitta Range.



Study area is confined to the eastern block, occupying it's eastern part. Oldest stratigraphic unit exposed is the Jurassic Samana Suk Formation whereas the youngest one is Miocene Murree Formation (Fig.2.1 b). The paleocene - Eocene strata crops out as a single lithotectonic unit . This package is separated from Mesozoic by a regional unconformity and the younger sediments by a regional para-conformity.

As a result of present study the Chichali Formation of Akhtar et, al (1985) is included in the Lumshiwal Formation on the basis of same lithofacies in different parts of the range.

2.2 REVISED STRATIGRAPHY OF THE STUDY AREA

	Akhtar at al(1985)	Present study (1992)	
	Formations	Formations	
	Murree	Murree	
Unconformity	Kohat	Kohat	Unconformity
	Kuldana	Kuldana	
	Chorgali	Chorgali	
	Margala	Margala	
	Patala	Patala	
	Lockhart	Lockhart	
Unconformity	Chichali	Lumshiwal	Unconformity
Unconformity	Samana Suk	Samana Suk	Unconformity

FORMATIONS DESCRIPTION

2.2.1 SAMANA SUK FORMATION

Davis (1930) introduced the name " Samana Suk" which later on applied to similar limestone sequenceses by Gee (1945), Cotter (1933), Middlemiss (1896), Latif (1970), exposed in Salt Range, Trans Indus Ranges, Kalachitta Range and Hazara.

Type section is located in the western part of Samana Range north east of Shinwari village.

The Samana Suk Formation is mainly exposed in the northern part of the mapped area. It consists of limestone having light pinkish gray, and yellow to yellowish brown colour. The limestone is medium to thick bedded with some marl and ferrogenious sandy beds. In the mapped area the lower contact is not exposed and it's upper contact is disconformable with Lumshiwal Formation. It is about 37 meters thick in the studied area.

A rich fauna has been reported which includes Ammonite, Corals and Gastropode (Akhtar et al.,1985). On the fauna basis Early to middle Jurassic age has been assigned to it.

Samana Suk Formation is correlated to Chilton Limestone and Mazar Drick Formation of lower Indus Basin and axial belt by stratigraphic committee of Pakistan.

2.2.2 LUMSHIWAL FORMATION

Stratigraphic committee of Pakistan revised the name as "Lumshiwal Formation" to "Lumshiwal sandstone" of Gee (1945) in Salt Range, " Giumal sandstone" of Middlemiss (1896), Cotter (1933) in Hazara and Kalachitta .

Type locality is one kilometer north of Lumshiwal Nala Salt Range. Due to varying lithofacies and thicknesses three reference sections have been designated.

1) Fort Lockhart section in Samana Range.

2) Wach Khawar section in Nizampur area, Kalachitta Range.

3) Jamiri village on Haripur Jabrian road in Hazara.

Lumshiwal Formation is well exposed in the northern part of the mapped area. It comprises sandstone and limestone from bottom to top. The sandstone is yellowish brown to greenish gray, fine to coarse grained, medium to thick bedded, feldspethic silty, calcareous and at places ferrogenious. Limestone is dark gray, brownish gray and greenish orange to pink, medium to thick bedded shelly and contains broken shells of Bivalves and Oysters. Calcite veins are abundant at places. Basal part of the formation is glacunitic. Thickness in the eastern Kalachitta Range is not more than 50 meters .

The lower contact with the Samana Suk Formation is disconformable as shown by glacunitic sandstone while the upper contact with Lockhart Limestone is unconformable as suggested by the presence of ferrogenious sandstone. The formation is fossiliferous and contains Brachiopodes, Ammonides and Gastropodes (Akhtar et al., 1985). On the basis of fauna Early Cretaceous age (Neocomian) to late early Cretaceous (Albanian) age has been assigned to this formation.

The formation is correlated with the Goru Formation of the axial belt and the lower Indus basin by stratigraphic committee of Pakistan.

2.2.3 LOCKHART LIMESTONE

Davis (1930) introduced the name "Lockhart limestone" to the Paleocene limestone unit in Kohat area. Stratigraphic committee of Pakistan generalized the term for "Nummulitic series" of Middldemiss (1896), lower part of "Hill limestone" of Wynne (1873) and Cotter (1933), the "Tarkhobi limestone" of Emaes (1952) and "Mari limestone"of Latif (1970).

Type locality is near Fort Lockhart in the Samana Range.

Lockhart Limestone outcrops in the northern part of the mapped area. The limestone is dark gray to grayish black, medium grained, medium to thick bedded and nodular. The nodules are 3 to 20 mm in diameter. Freshly broken limestone gives feted smell .

Marl is intercalated along the nodules interspaces.

The basal 1 to 5 meters has ferrogenious and laterritic clays. Maximum thickness of the formation in the Kalachitta Range is 165 meters. In the study area it is about 140 meters thick.

Lockhart limestone overlies the Lumshiwal Formation with an unconformable contact, whereas it's upper contact with the Patala Formation is transitional. The formation is richly fossiliferous preserving Foraminifers, Molluscus and Echinoids. On the faunal basis Paleocene age is assigned to the formation (Akhtar and Khan,1983).

Stratigraphic committee of Pakistan has correlated Lockhart limestone with the Bara Formation, the lower part of the Dungan and Rakhshai Formations of lower Indus basin , axial belt and Baluchistan basin respectively.

2.2.4 PATALA FORMATION

Davis and Pinfold (1937) introduced the name " Patala shale " for the shale of Patala Nalah. Stratigraphic committee of Paki-stan amended it as "Patala Formation" and generalized it to "Tarkhobi shale" of Eames (1952), Part of "Hill limestone" of Wynne (1873) and Cotter (1933), part of " Nummulitic Formation" of Waagan and Wynne (1872), part of "Nummulitic series" of Middlemiss (1896) and the "Kuzagah shale" of Latif (1970).

Type section is in Patala Nala .

In the mapped area Patala Formation is exposed in the northern and southern parts. It consists of shale, marl and intercalated limestone. The shale are light brownish gray and dusty yellowish green , laminated to thin bedded, fissile and splintery. The marl is light gray , thin bedded and richly fossiliferous. The limestone is light gray , medium bedded, medium grained, fossiliferous and nodular at places. It has transitional contacts with the overlying Margala Hill Limestone and underlying Lockhart Limestone. Maximum reported thickness is 225 meters. In the studied area it is about 113 meters thick. The formation contains Foraminifers , Molluscs and Ostrocods as a fossil record. In Kalachitta Range it has been assigned late Paleocene age on faunal basis (Akhtar and Khan, 1983).

It is correlated with the Lakhra Formation, the upper part of Dunghan and Rakshani Formations, lower part of Ghazij and Lahi Formations of lower Indus basin , Axial belt and Baluchistan basin by stratigraphic committee of Pakistan.

2.2.5 MARGALA HILL LIMESTONE

Latif (1970) introduced the name "Margala Hill limestone", which later on formalized to " Nummulitic Formation " of Waagan and Wynne (1872), upper part of the "Hill limestone" of Wynne and Cotter (1933) and part of "Nummulitic series" of Middlemiss (1896), by stratigraphic committee of Pakistan.

Type section is Shahdara in south-eastern Hazara. It is well exposed in the study area.

It has limestone with subordinate marl. The limestone is light to dark gray,in colour weathers to dull to brownish gray, fine to medium grained. Upper part is massive nodular, and jointed. Lower part is argillaceous and well bedded, light ash gray to greenish gray in colour and grades into greenish gray shale. Calcite veins are common in the limestone beds. Marl has flowage along the nodules interspaces as well as intercalated with limestone. In the mapped area it is about 110 meters thick. The contacts with overlying Chorgali Formation and underlying Patala Formation are conformable. Preserved fossil record includes Foraminifera, Molluscus and Echinoids (Akhtar and Khan, 1983). Early Eocene age has been assigned to Margala Hill Limestone.

2.2.6 CHORGALI FORMATION

The term "Chorgali Formation" was introduced to "Chorgali beds" of Passcoe (1920) by stratigraphic committee of Pakistan and formalized for " Passage beds" of Pinfold (1918) , "Badhrar beds" of Gee and Evan (in Davis and Pinfold, 1937) and " Lora Formation" of Latif (1970).

Type section is Chorgali pass in Khair-e-Murat Range. The Chorgali Formation is well developed in Kalachitta Range.

In the study area the formation is exposed in the central and southern parts. It comprises limestone and marl with subordinate shale. The limestone is light to dark gray and yellowish gray, weathers brownish gray, fine to medium grained, medium bedded, argillaceous at places. Chert is interbedded with limestone. The marl is gray, shale is greenish green, thin bedded ,fissile and splintery. In the study area it has conformable lower and upper contacts with the Margala Hill Limestone and the Kuldana Formation respectively. It is about 125 meters thick in the study area. The fauna record shows Foraminifers, Molluscs, Ostrocods, suggesting it Early Eocene age. (Akhtar et al., 1985)

It is correlated with the Jatta Gypsum of Kohat Province "Baska shale" and Alabaster member of Ghazij Formation of lower Indus basin and Axial belt by stratigraphic committee of Pakistan.

2.2.7 KULDANA FORMATION

Latif (1970) introduced the name "Kuldana Formation" for "Kuldana beds" of Wynne (1874), "Kuldana series" of Middlemiss (1896), "variegated shale" of Pinfold(1918), "Lower Cherat series" of Eames (1952), and "Mami khel clay" of Meissner et al. 1968.

Type section is located near "Kuldana village" north of Murree hill station.

The formation is well developed in southern Hazara, Kalachitta, northern Potwar and Kohat areas. Formation is exposed in the southern part of the mapped area. It is comprised of varicoloured shale and limestone. The shale is gray, green and purplish red, thin bedded, fissile and at places gypsiferous. Limestone is gray, fine grained medium bedded, argillaceous, fossiliferous and intercalated with marl. The formation has conformable lower and upper contacts with the Chorgali and the Kohat Formations respectively. It is about 124 meters thick in the study area. Bivalves , Foraminifers and Gastropodes have been reported by Akhtar et al (1985), assigning it Early to Middle Eocene age.

2.2.8 KOHAT FORMATION

" Nummulitic shale" of Pinfold (1918) and "Kohat shale" of Davis (1926) was subdivided into three subdivisions i.e., "Nummulitic shale", "Kohat limestone" and "Sirki shales" by Eames (1952), and Meissner et al. (1968), naming it as "Kohat Formation".

The Kohat Formation is confined to Kohat, Northern Potwar, and Kalachitta Range. Type section is exposed on Kohat-Khusahlgarh road.

It is exposed to the south-eastern side of the mapped area. It comprises mainly limestone and shale. The limestone is gray to olive gray, medium bedded, constituted by Foraminiferal shells and fossils, exclusively Nummulites. The interbedded shale is greenish gray thin bedded and fossiliferous. It is about 33 meters thick in the study area. The formation has conformable lower contact with Kuldana Formation whereas the upper contact with the Murree Formation is unconformable. Foraminifers and Bivalves have been reported by earlier workers. Middle Eocene age has been assigned to it in the study area by Akhtar et al. (1985).

2.2.9 MURREE FORMATION

Stratigraphic committee of Pakistan introduced the term "Murree Formation" to the "Mari group" of Wynne (1874), "Murree beds" of Lydekker (1876) and "Murree series" of Pilgrim (1910).

Type section is referred to the north of Dhok Maiki in the Attock district.

The formation is widely distributed in Kohat - Potwar province and also is reported from Kashmir. In the mapped area it is exposed to the south of main boundary front. It comprises sandstone and clay . The sandstone is brown and buff, fresh broken surface gives gray, greenish gray to reddish gray colour. Sandstone is medium to fine grained, hard, medium to thin bedded, calcareous and cross-stratified. Clay is purple and pink. Gray calcareous sandstone and conglomerate with abundant derived fossils is present as basal bed. Maximum reported thickness in the adjacent areas is 600 meters (Akhtar et al., 1985). The formation is lying unconformably over Kohat Formation. Vertebrate fauna has been reported . Early Miocene age has been assigned to the formation.

Wells (1984) has correlated it with the Subathu Formation near Simla, India.

CHAPTER 3

REGIONAL SETTING AND STRUCTURE OF KALACHITTA RANGE

3.1 REGIONAL SETTING

The Himalayan-Karakoram-Hindukush Ranges in northern Pakistan are considered to be a broad collision zone between the Eurasian plate in the north and the Indian plate in the south (Fig. 3.1). Several micro-continents mostly of Gondwana affinity (Searle, 1991) and more than one island-arcs (Dietrich et al., 1983) are involved in this collision zone. The micro-continents such as the Karakorum plate, Afghanistan block and the Kohistan island arc, which occurred to the north of the Indian continent in Mesozoic, converged and collided with the southern margin of the Eurasian plate in that order (Le Fort, 1975; Windley, 1983).

In northern Pakistan the collision between the Karakoram plate in the north and Kohistan island-arc in the south resulted in a major tectonic feature named as Main Karakoram Trust (MKT), (Tahirkheli, 1979a, 1979b, 1982, 1983,) or northern suture (Pudsey et al., 1985; Pudsey, 1986). North of MKT or northern suture lie the Karakorum and the Hindukush terrains of Gondwana affinity (Kennette, 1982), (Fig. 3.1).

The Karakorum plate to the north of MKT consists of high grade metamorphic rocks with granitic intrusions (Searle,1991). To the south of the MKT lies the metamorphosed basic and ultra-

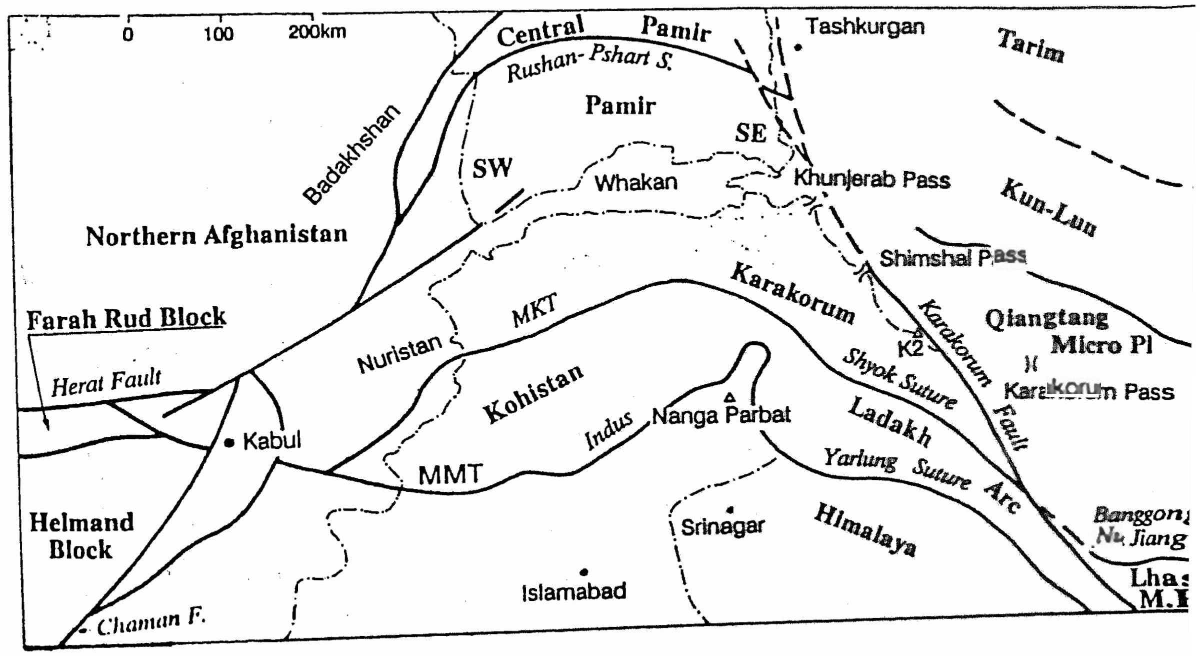


Fig. 3.1. Geotectonic setting of Central Asia around Karakorum. MKT: Main karakorum Thrust; MMT: Main Mantle Thrust. (after Gaetani et al., 1990).

basic rocks of the Kohistan Island-arc (Bard et al., 1980; Bard, 1983).

The ocean between the Karakoram plate and the Kohistan Island arc closed in late Cretaceous (between 102 and 75 Ma.) at the site of MKT (Coward et al., 1986). Continued subduction between the Kohistan island arc and the Indian plate produced an extensive batholith called Kohistan batholith, intrusive in the ultrabasic and basic Kohistan island arc. The ocean between the Indian plate and the Kohistan island arc was closed in Eocene at the site of Indus suture zone or Main Mantle Thrust (MMT) (Tahirkheli, 1979a,1979b,1982; Gansser, 1981) (Fig. 3.1).

The convergence which resulted in continent-arc-continent collision (Karakoram-Kohistan-India), however, did not cease with the formation of MMT, but rather continued since Eocene at a rate of 5mm/year (Patriat and Achache, 1984). This convergence resulted in the internal deformation of the Indian crust, resulting in the development of major thrust-fold belt to the south of MMT.

The Indian continental crust on the basis of "Himalayan age" deformation and metamorphism can be divided into internal (metamorphosed) and external (non-metamorphosed) zones (Coward et al., 1988), (Fig. 3.2).

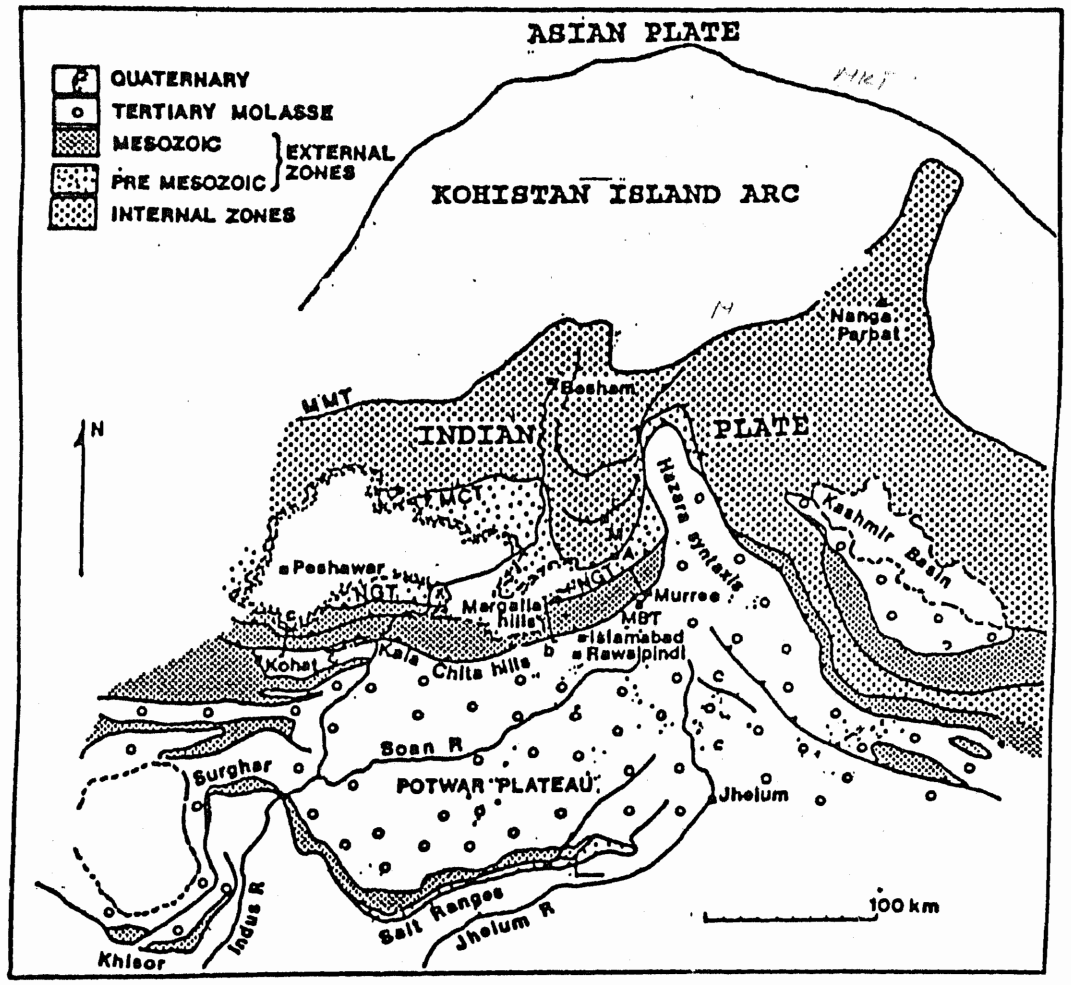


Fig. 3.2. Location map of northern Pakistan, showing the distribution of main thrusts (MMT, Main Mantle Thrust; MCT, Main Central Thrust; MBT, Main Boundary Thrust; NGT, Nathia Gali Thrust;), the Kohistan island arc and the internal and external zones: (after Coward et al., 1988).

3.1.1 INTERNAL ZONE

As a result of leading-edge subduction of the Indian plate beneath island-arc a large scale metamorphism and ductile deformation has occurred in the northern marginal parts of the Indian plate (Coward and Buttler, 1985). The characteristics of the internal zone of the Indian plate include, a) regional metamorphism and b) presence of intrusive and extrusive igneous rocks. In north Pakistan the southern limit of the internal zone is marked by the Nathiagali thrust (Coward et al., 1988), which brings Hazara slates over thrusted on Mesozoic-Cenozoic shelf sequence of Kalachitta -Margala Ranges (Fig. 3.2). The internal zone is divided into six nappes which are separated from each other by ductile-brittle thrusts (Treloar, 1989) (Fig. 3.3). These nappes include west to east Swat, Besham, Hazara, Banna, lower Kaghan and upper Kaghan.

3.1.2 EXTERNAL ZONE

The external zone can be classified from north to south into three tectonic units,

a) Hill Ranges (Kalachitta, Margalla, Kohat and Samana Ranges)

b) Potwar and Kohat Plateau

c) Salt Range and Punjab plain.

3.1.2.1 HILL RANGES

Margalla, Kalachitta, Kohat and Samana Ranges represent the southern most boundary of hill ranges. Stratigraphy of these

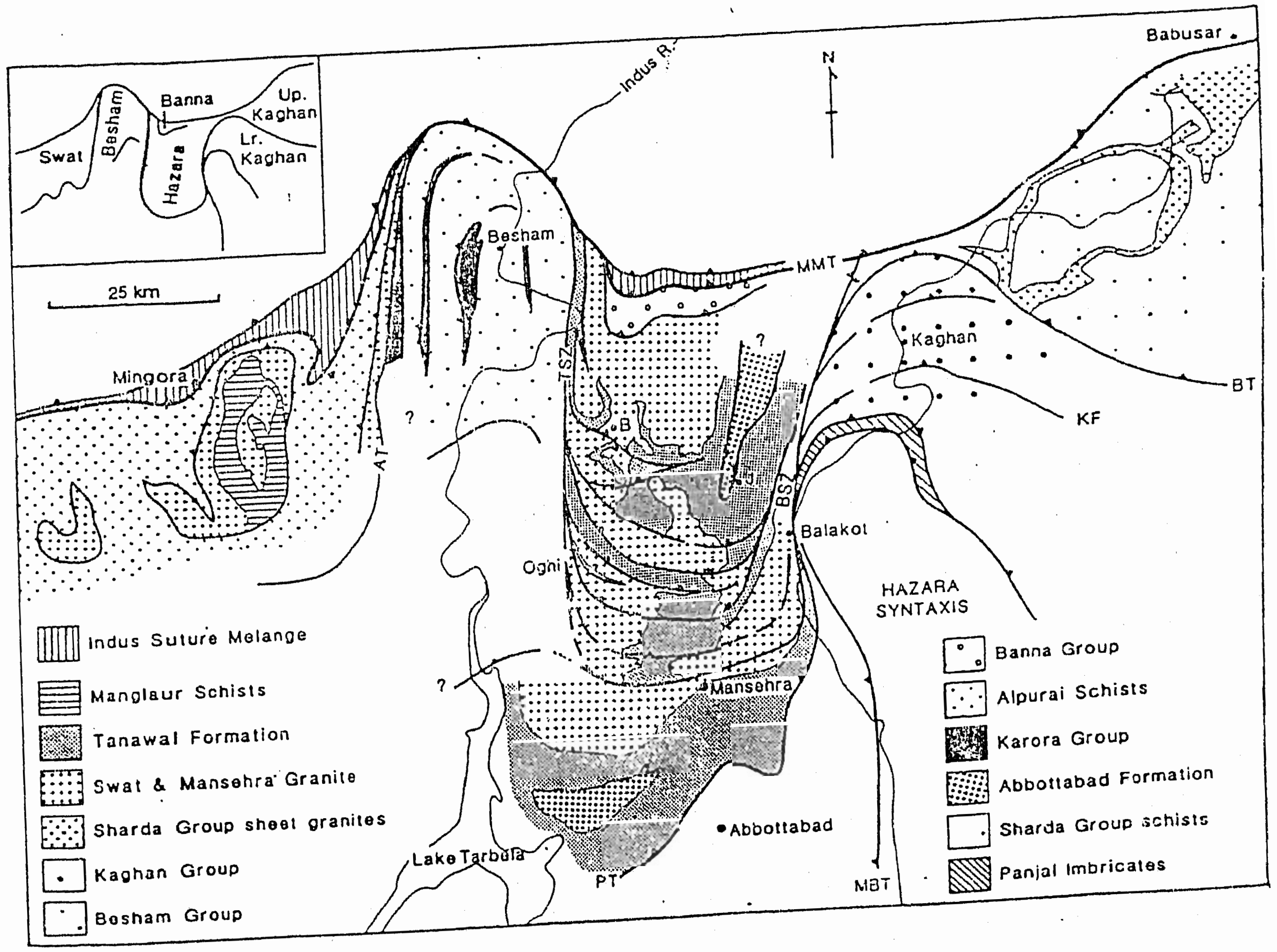


Fig. 3.3. Geological map of the Swat to Kaghan section of the Indian plate within North Pakistan to show (inset) the location of the major crustal nappes. B: Batgram; J: Jabori; BT: Batal Thrust; KF: Khannian Fault; AT: Alpuri Thrust; MBT: Main Boundary Thrust; PT; Panjal Thrust; BSZ and TSZ: Balakot and Thakot Shear Zones. (after Treloar, 1989)

ranges is comprised of shelf platformrocks of the Mesozoic-Cenozoic age. These ranges are characterized by various folds and faults. Most of the faults are south vergent while few are north vergent.

In Nizampur basin northern boundary of the Kalachitta Range is marked by Hisartang Thrust, where Precambrian to Silurian-Devonian rocks of the Attock-Cherat Range are over thrusted on the Mesozoic-Cenozoic rocks of the Kalachitta Range (Yeats and Hussain, 1987) (Fig. 3.4).

The hill ranges are separated from the Kohat-Potwar plateau by a regional fault called Main Boundary Thrust (MBT). This fault has general E-W trend. It extends eastward to become Murree fault and changes it's trend N-S around Muzaffarabad to become a strike slip fault. To the further north it curls around the Hazara Kashmir syntaxis and passes into the Indian part of Himalaya (Fig. 3.4). This fault is acknowledge as the western continuation of MBT as it separates the pre-Himalayan orogenic rocks from post-Himalayan orogenic rocks.

3.1.2.2 POTWAR KOHAT PLATEAU

Potwar plateau to the north and south is bounded by Kala-chitta and Salt Ranges respectively (Fig. 3.4), having approximately 150 Km N-S width (Kazmi and Rana, 1982). The eastern Potwar plateau is deformed by both hinterland and foreland directed thrusts (Pennock, 1989). Most of the deformation is concentrated in the northern parts of the plateau which is called North Potwar deformed zone (NPDZ) (Leather, 1987; Baker et al.,1988). In the NPDZ imbricate thrusting resulted in shorte-

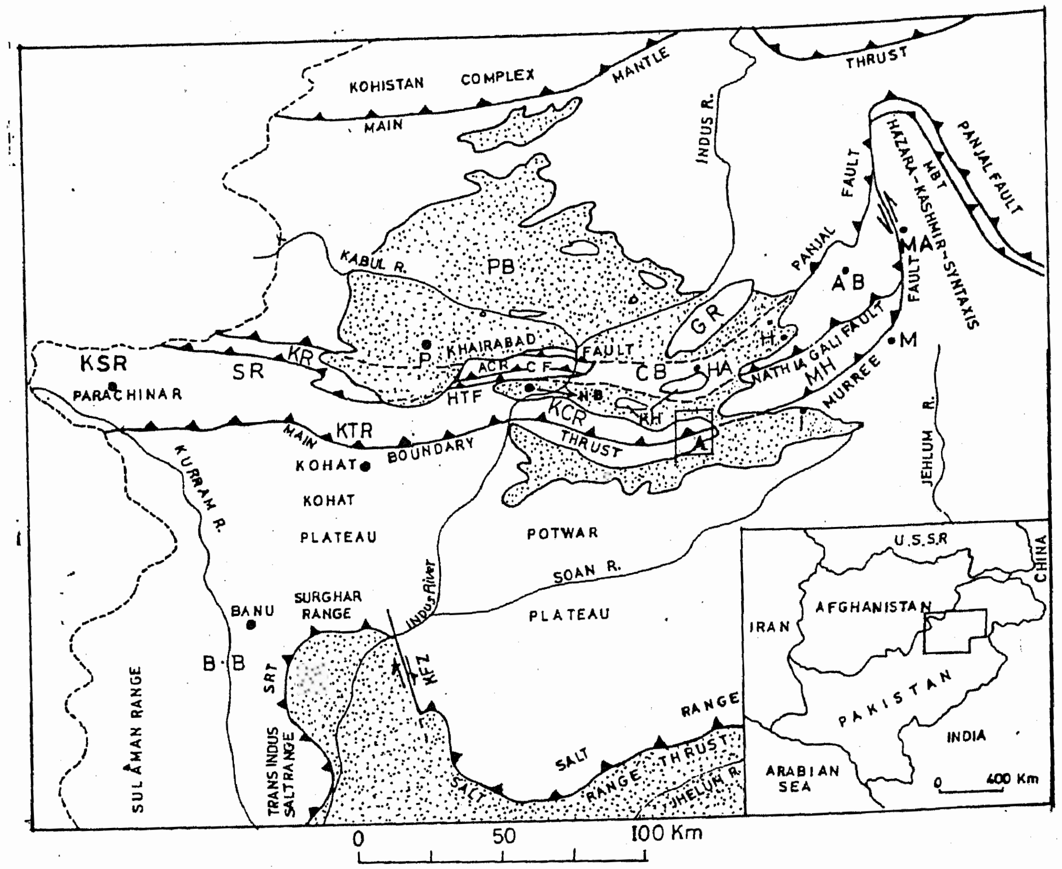


Fig. 3.4. Tectonic map of northern Pakistan showing maj structural boundaries. GR: Gandhar Range: KH: Kherimar Hills; ACR: Attock-Cherat Range; KR Khyber Ranges; MH: Margala Range; KCR: Kalac hitta Range; KTR: Kohat Range; SR: Saman Range; KSR: Koh-e-Sofaid Range; MBT: Mai Boundary Thrust; CF: Cherat Fault; HTF: Hisar tang Fault; KFZ: Kalabagh Fault Zone; SRT Surghar Range Thrust; PB: Peshawar Basin; CB Campbellpore Basin; NB: Nizampur Basin; BB Bannu Basin; MA: Muzaffarabad; AB: Abbottabad; M: Murree; H: Hassanabdal; P: Peshawar. (afte Hylland et al, 1988). Box show the location o the study area.

et al., 1989). n the NPDZ imbricate thrusting resulted in shortening of about 45 Km (Leather, 1987). To the south of NPDZ and north of Salt Range lies about 80 Km wide nearly undeformed allocthon in the form of Soan syncline, preserving a thick pile of molasse sediments (Leather 1987; Baker et al., 1988).

The Kohat plateau which is western feature of Himalayan fold thrust belt (Fig. 3.4) is about 70 Km wide. The Kohat plateau to the north is bounded by Main Boundary Thrust and to the south by Surghar Range Thrust (Kazmi and Rana, 1982) (Fig. 3.4). Structural trend of the Kohat plateau is generally E-W, but in the south-eastern part changes to N-S along the Kalabagh fault zone (Fig. 3.4).

3.1.2.3 SALT RANGE AND PUNJAB PLAIN

Salt Range is the southern boundary of the Himalayan active foreland fold and thrust belt. In general the range represents a fault bend fold (Baker et al., 1988). The general trend of Salt Range as traced from east changes from NE-SW to almost E-W in the middle to NW-SE to the west (Fig. 3.4). To the west the range is truncated from the Surghar Range by Kalabagh fault zone (Macdougal and Khan, 1990), (Fig. 3.4). The Kalabagh fault zone is a prominant N-S structural feature formed after the uplift of Surghar Range along the emergent thrust (Macdougall and Hussain, 1991). The structural style in the west and in the central Salt Range is dominated by south verging thrust, whereas the eastern portion is dominated by folding (Pennock, 1989). This difference of structural style and frequency of structures between eastern and central Salt Range is due to change in basement dip and change in salt thickness (Davis and Engelder, 1985).

At the Salt Range front Precambrian strata overrides synorogenic fan material and alluvium of Punjab plain (Yeats and Lawrence,1984). In the Punjab plain of Pakistan, the Indian shield slops gently northward interrupted by pre-Cambrian exposures in Sargodha high, a basement ridge (Farrah et al., 1977) (Fig.3.5). Trend of this ridge is compatible to the overall Himalayan trend. This is perhaps an "outer swell" related to the downflexing of the under-thrusting Indian plate (Seeber et al., 1981; Duroy, 1986).

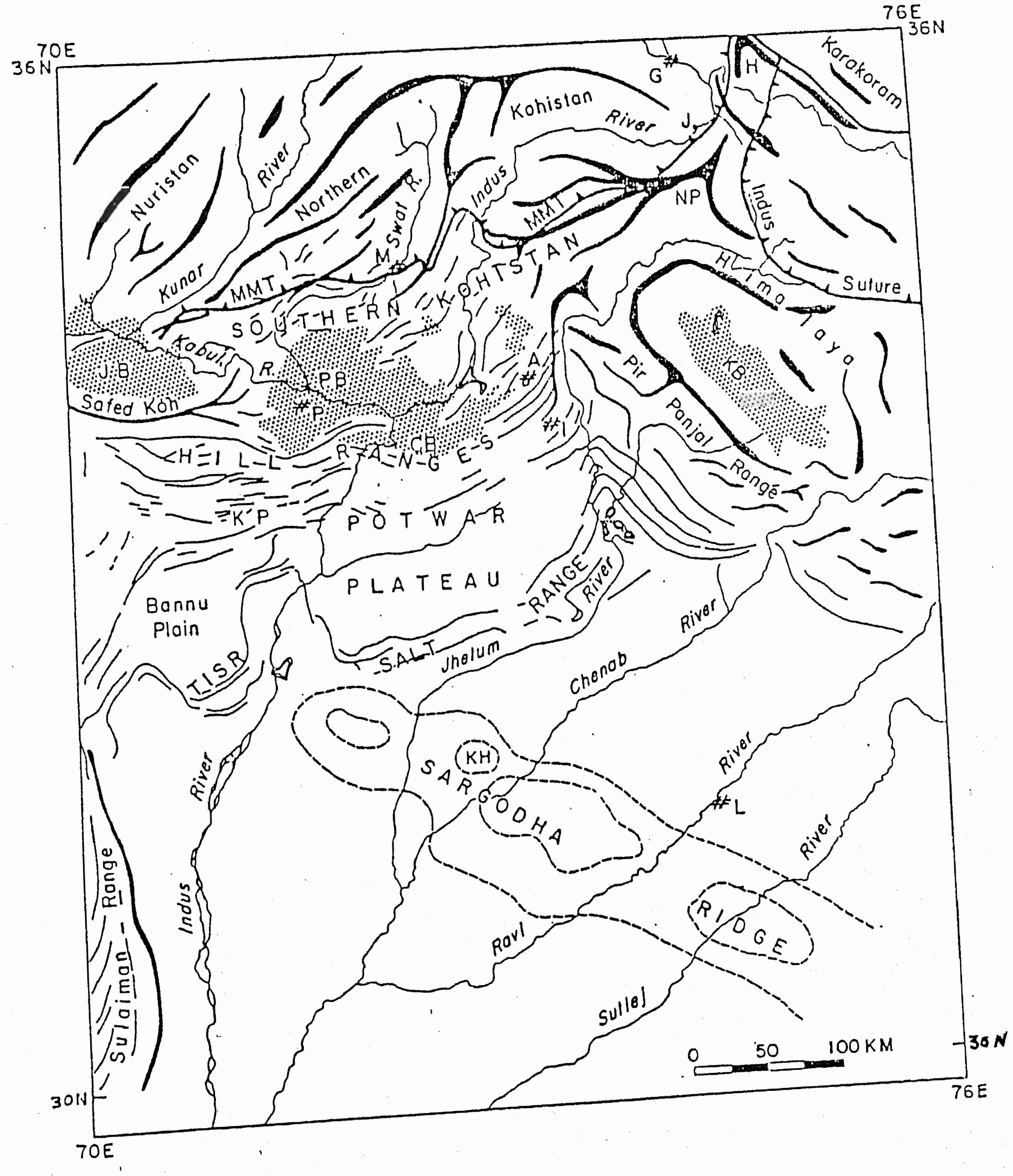


Fig. 3.5. Tectonic map of northern Pakistan.

TISR: Trans-Indus Salt Range, a continuation of Range thrust belt across Indus-Surghar Range reentrant. KH: Kirana Hills, exposure of Pre-cambrian basement along Sargodha Ridge. PB: Peshawar Basin; JB: Jalalabad Basin; CB: Camp-bellpore Basin; KB: Kashmir Basin. KP: Kohat plateau. Hill Ranges mark nearly continuous exposures of pre-molasse rocks along westward continuation of Main Boundary Thrust from India. MMT: Main Mantle Thrust, juxtaposing rocks of Indian plate with Kohistan island arc to north. (after Yeats and Lawrence, 1984)

3.2 STRUCTURE OF THE HASSANABDAL-FATEH JHANG TRANSECT OF THE EASTERN KALA-CHITTA RANGE

3.2.1 GENERAL DESCRIPTION

Geographically the study area is divided into northern and southern blocks by an almost east-west running Bahadra Kas stream (Fig. 3.6). As a result of present investigation it has been found that the structure of the area is controlled by folding and faulting. In the northern block faults seem to be the dominant structural features, whereas the southern block is dominated by folding.

3.2.2 NORTHERN BLOCK

South of village Bahtar (Fig. 3.6) surface outcrop shows a doubbly plunging anticline having a 1/2 wavelength of about 4 Km (Akhtar et al., 1985). The eastern closure of the anticline is observed just to the west of Wah - Fateh Jhang road near village Neka (Fig. 3.6), where the Eocene Margala Hill Limestone is observed in the outer limbs conformably overlying the Paleocene Patala Formation. However the best exposures of the core of anticline are observed on the un-metaled road providing linkage between the Jhang Bahtar, Katha colony and Gakhar villages (Fig. 3.6). Tracing from north to south along the line of section A-A', across the core of the anticline, the Jurassic Samana Suk Formation has been repeated four time over a distance of about than 1 Km. At least three times it comes in tectonic contact with the limestone of Paleocene Lockhart Formation and once with the shale of Paleocene Patala Formation.

From north to south these faults have been assigned names A,B,C,D. The general observed characteristics of these faults are:

1) They have general east-west trend but they are not laterally extensive.

2) They do not meet each other at any point.

3) Tracing from south to north they become progressively steeper.

4) Tracing eastward the fault B at a higher relief (at point E)is visibly back folded.

The Margala Hill Limestone is mainly exposed to the northern limb of the anticline and displays folds of asymmetric nature. A NW verging recumbent fold is exhibited by the Margalla Hill Limestone in the hanging wall of fault A (Fig. 3.6).

3.2.2.1 STRUCTURAL ANALYSIS

The stratigraphic sequence bounded between the faults is from Jurassic Samana Suk Formation to Paleocene Lockhart Formation, except the fault D (Fig.3.6) having the Paleocene Patala Formation in it's hanging wall. The Margalla Hill Limestone is exposed only in the limbs of the Katha colony anticline and no part of it is found bounded between the thrusts A to D. This clearly suggests that the Margala Hill limestone is not involved in thrusting. Furthermore the asymmetric folds exhibited by the Eocene strata in the hanging wall of the fault A are not compatible with the steeply dipping thrust imbrication. This demonstrates an existence of some detachment within the Patala shale where all the thrusts merge along a detachment immediately below the Margala Hill limestone.

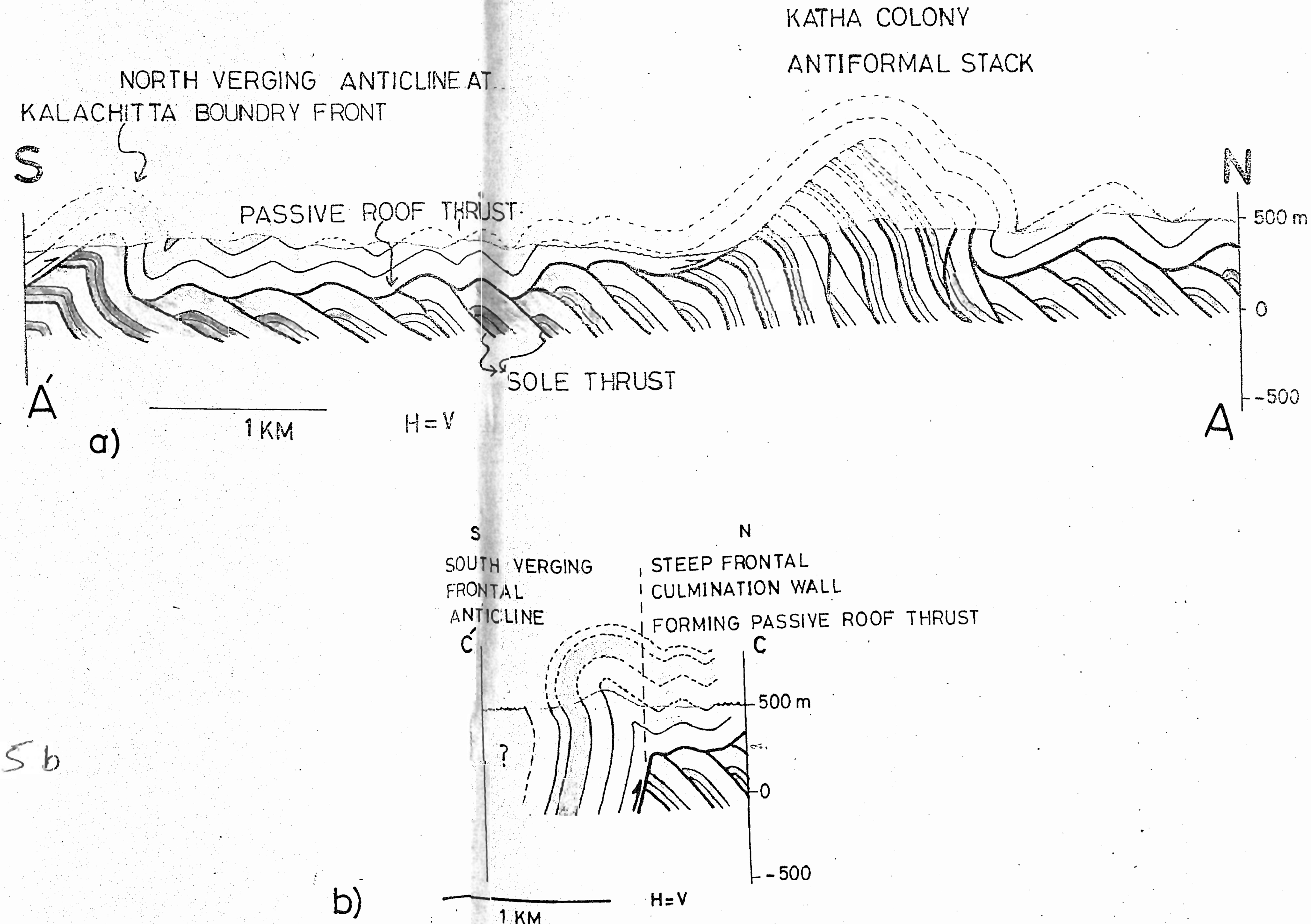
The oldest stratigraphic unit repeatedly exposed by thrust slices is the Jurassic Samana Suk Formation. This shows presence of a decollement at the base of the Samana Suk Formation. Here the detachment within the Patala Formation is roof thrust and one at the base of the Samana Suk is a sole thrust. The sole thrust joins the roof thrust forming a duplex system (Fig. 3.7a), as described by Boyer and Elliot (1982) (Fig. 3.8). The progressive steepening of thrust faults from foreland to hinterland suggests piggy back style of thrusting, and foreland direction of propagation (Dahlstrom, 1970; Eillot and Jhonson, 1980; Butler, 1984).

The fault B on tracing to the east shows that at a higher relief (at point E) it is visibly overturned, dipping to the south. This may be attributed to back steepening due to younger, southern thrusts in the footwall of fault B. However the presence of north-west verging recumbent fold in the hanging wall of the fault A suggests that either the roof thrust is a passive back thrust,or there are splays given out from the roof thrust which have back thrust (north verging) nature.

Fig. 3.7. Cross-sectional view of the eastern Kalachitta Range.

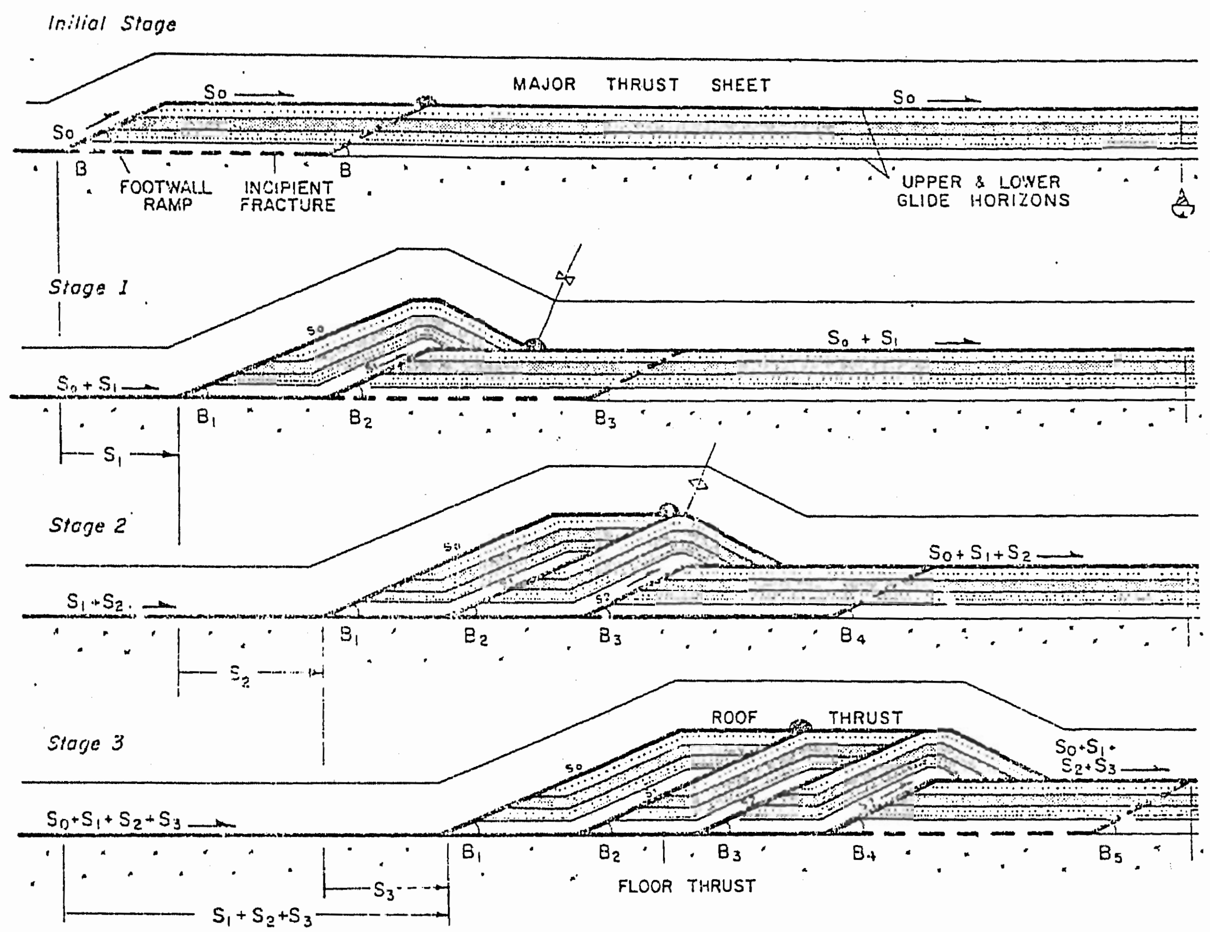
a) Cross-section along line AA'

b) Cross-section along line CC'


KATHA COLONY
ANTIFORMAL STACK
NORTH VERGING ANTICLINE AT
KALACHITTA BOUNDRY FRONT
S
N
PASSIVE ROOF THRUST
500 m
0
-500
SOLE THRUST
A′
A
1 KM
H=V
a)
S
N
SOUTH VERGING
FRONTAL
ANTICLINE
STEEP FRONTAL
CULMINATION WALL
FORMING PASSIVE ROOF THRUST
C′
C
500 m
?
0
-500
1 KM
H=V
b)

35b

Fig. 3.8. Progressive collapse of footwall ramp builds up duplex. (after Boyer and Eillot 1982).

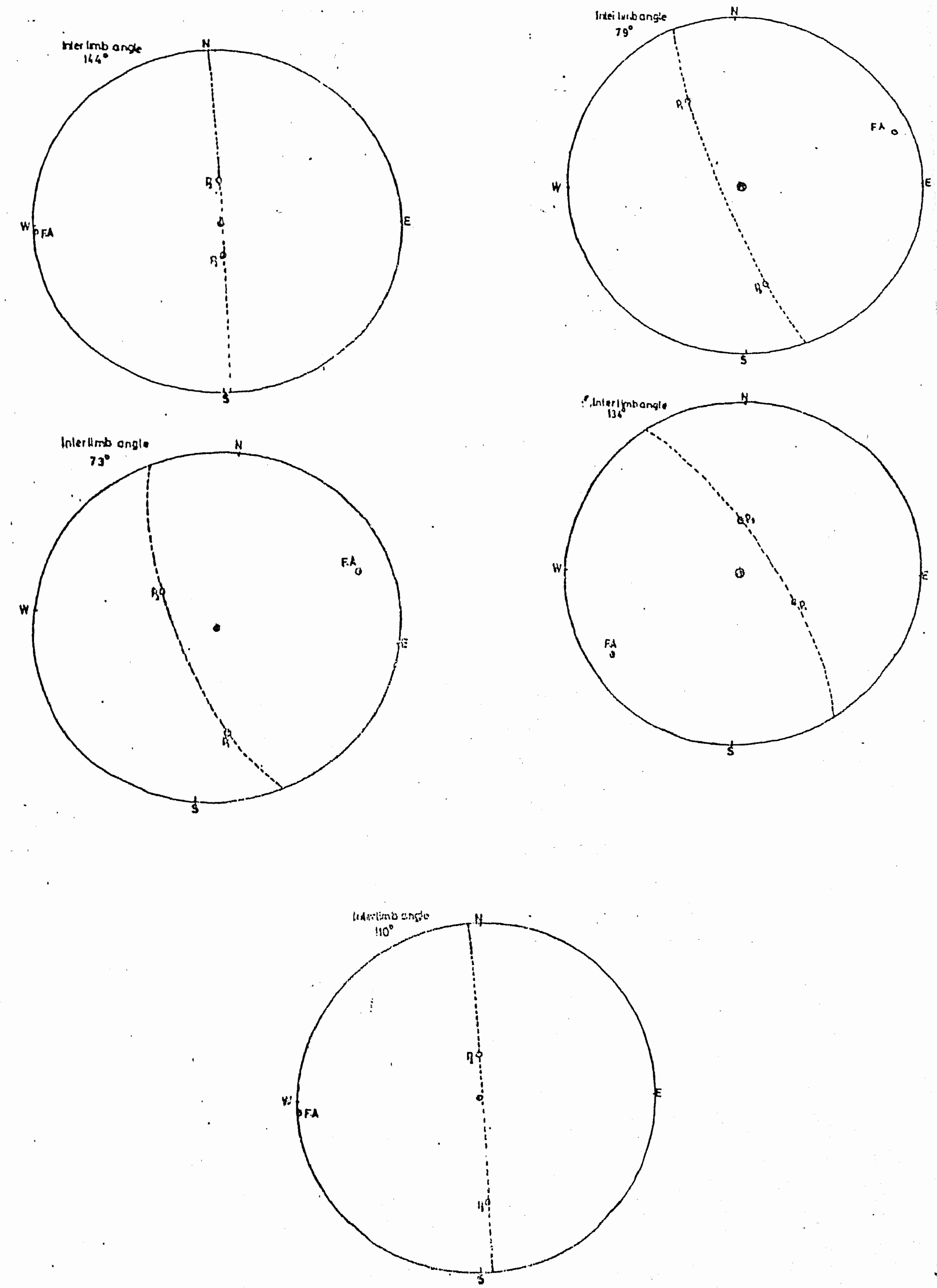


3.2.3 SOUTHERN BLOCK

The southern block or the frontal portion of the Kalachitta Range is a fold dominated foreland structure (Fig. 3.6). Tracing from east to west, south of Shahpur village, the range exhibits two broader folds. The eastern fold, an anticline can be best observed walking along the Wah-Fateh Jangh road traversing the south-eastern part of the range. The stratigraphy involved is from Eocene to Miocene in a conformable fashion. The fore and back limbs of the anticline are north dipping, of which the forelimb is overturned (Fig. 3.7). The forelimb, back-limb dip ratio is approximately about 60:30. The trend of the fold axis is almost in harmony with the trend of the range. The trend of the joints observed in Margala Hill Limestone near the fold axis of the anticline are also in harmony with the trend of the range. The back limb of the anticline shows a series of upright open folds of small wavelength and magnitude (Fig.3.9). Proceeding to the west the fold axis of the monocline goes under alluvium.

To the further west, tracing south to north along the line of section AA' (Fig. 3.6), Lockhart limestone is exposed in the core of an overturned anticline flanked by Paleocene Patala Formation, dipping southward. The gently dipping southern limb and steeply dipping northern overturned limb show a north verging anticlinal structure. Further to the north along the line of section Eocene strata is exposed in a conformable manner, exhibiting asymmetric folds of small wavelengths and tightness.

Fig. 3.9. Stereographic projection of open folds showing the interlimb angle and trend of fold axis.



3.2.3.1 STRUCTURAL ANALYSIS

Tracing along cross-section line CC', the frontal anticlinal structure at the eastern most side of the range has such surface expression that the forelimb is steeply dipping and overturned, showing south vergence of the structure (Fig 3.7b). The surface geometry of the upright open folds in the back limb of the anticline shows that they are folds of small wavelength resulting from small scale shortening during folding. From the thickness of Eocene and Miocene it is clear that the Eocene Margalla Hill Limestone has been uplifted about 992 metres from is regional level. The rate of uplift of Eocene Margalla Limestone and the amount of shortening within Margalla Hill Limestone due to folding are not matchable, showing that these folds are detachment folds and the level of detachment is just below Eocene as exhibited in the nortern block.The Margalla Hill Limestone is uplifted 992 metres from it's regional level probably due to blind thrusting which merge to the detachment level below Eocene (Roof thrust)forming a duplex system (Fig,3.7b), as exhibited in the northern block.The Eocene strata above the roof thrust is folded passively in response to the stacking of blind duplex (Fig.3.7b), e.g. folds formed by shortening of spacing between the adjacent faults in the blind duplex (Mitra, 1986) or drape over reactivated horsts (Vann et al., 1986). The steepened fore limb of the eastern anticline may be the result of sticking up of the sole thrust making a steep culmination wall to the foreland side, as described by Buttler (1982) and Banks and Warburton (1986). Other anticlinal structure to the south west of village Shapur is such that the both limbs of the anticline are dipping to the south (Fig.3.6). From the surface expression and the geometry of adjacent folds it looks that the structure probably first developed by the shortening of space between the adjacent faults in the blind duplex. In the second phase the hindward activation within the upper detachment in Patala Formation due to the sticking of the sole thrust is responsible for it's north vergence (Fig. 3.7a). Though on surface the western extension of the eastern anticline is covered by alluvium but the western anticline is supposed to be the western extension of same structure. To the west of the western anticline at point (F)a north verging back thrust is emergent. The opposite vergence of the eastern and western anticlinal structures is probably due to the degree of activation of back thrust from west to east.

In the southern block the Eocene strata exhibits a series of low amplitude folds of various tightness (Fig. 3.6). The area lacks indicators of faults, such as exposed fault traces, juxtaposed stratigraphy or apparently thickened stratigraphy. Features such as fold hinges and normal stratigrapy thickness are present, which are consistent with the fold dominated style of deformation. All these structures suggest that the lithotectonic unit above the roof thrust involving the rocks from late Paleocene to Eocene have observed the layer parallel shortening in the form of up right folds, due to the foreland propagation of strata bounded between the upper and lower detachments in the form of duplex (Fig. 3.7a,b), as described by Ferril and Dunne (1989).

The south verging eastern anticlinal structure on the Kalachitta mountain front shows a steep overturned forelimb, which has been interpreted as steep culmination wall, which bounds and involves the molasse sediments of Potwar trough (Fig. 3.7b). This zone with steep dip is similar to the culmination wall of Banks and Warburtan (1986). A higher elevation of range and relatively undeformed stratigraphic succession to the foreland side of the culmination wall suggests a blind back thrust on the foreland side of culmination wall. According to Banks and Warburton (1986), there must be a blind hindward directed thrust to the foreland side of the culmination wall to compensate the shortening.

On the Kalachitta mountain front tracining from east to west a north verging anticlinal structure suggests the presence of back thrust. According to Banks and Warburton (1986) a foreland dipping mountain front monocline is a key feature of back thrust.

CHAPTER 4

DISCUSSION

4.1 STYLE OF DEFORMATION

The Kalachitta Range represents the deformation front of the Hill Ranges.In the northern block lying to the north of stream Bahandra Kas (Fig. 3.6), the emergent thrusts repeats the stratigraphic succession from the Jurassic Samana Suk Formation to Paleocene Lockhart Formation except the fault C (Fig.3.6) which brings Jurrasic Samana Suk Formation in contact with Paleocene Patala Formation. Since no strata older than the Samana Suk Formation is involved in thrusting, there is a possibility that a detachment runs at the base of the Samana Suk Formation. Eocene rocks are not involved in thrusting and display open upright detachment folds suggesting, a second level of detachment within or at the base of Patala Formation. As described by Boyer and Eilliot (1982), in the area of double detachment where the sole or the floor thrust do not cut up the whole stratigraphic sequence rather it joins the upper detachment, the thrust geometry is termed as duplex (Fig. 3.8). The major displacement occurs along the sole thrust and it's splays while, the strata above the roof thrust behave passively. In the area of study this seems to be the case. The detachment at the base of the Samana Suk Formation serves as sole thrust and the one within the Patala Formation occupying the position of the roof thrust. The surface expression of the emergent faults is such that they get steeper on tracing from south to the north (Fig. 3.6).

This suggests

a) Piggy back style of thrusting (Jones, 1982).

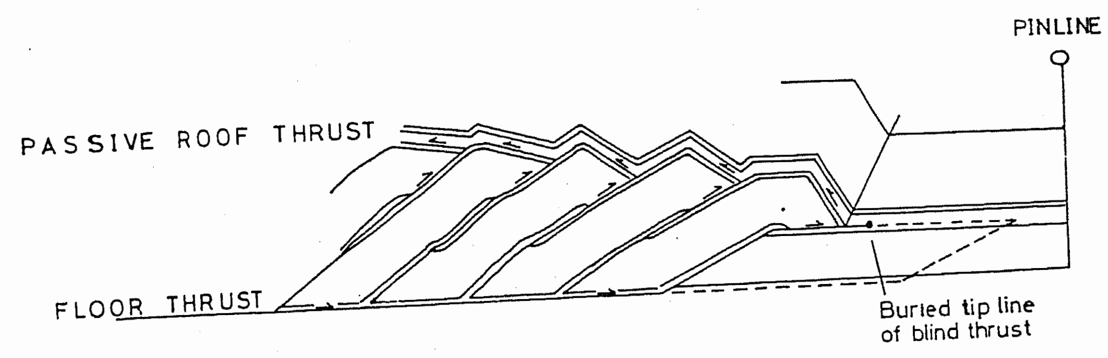
b) Progradation of thrusting towards foreland (Buttler, 1982).

As the structures within the Eocene strata (open upright folds, Fig. 3.9) are not compatible with the steeper thrusts suggesting the passive behaviour of the Eocene package. The style of deformation is concidered to be of a passive-roof duplex. (terminology used by Banks and Warburton 1986) (Fig.4.1).

According to Morely (1986), the passive-roof duplex appears to develop because of the mechanical problems inherent in trying to shorten a thick competent unit that lies above a less competent unit. In the study area a thick massive Margalla and Chorgalli limestone overlies the less competent Patala shale, supporting the development of a passive-roof duplex.

Similar style of deformation has been reported in Suliman Kirthar Thrust belt (Banks and Warburton, 1986; Jadoon, 1991), suggesting that the style of deformation of the trough bounded mountain fronts in most parts of the Pakistan is similar.

Fig. 4.1. Passive -roof duplex model: the roof sequence has backthrust sense relative to forelandward propagating duplex (after Banks and Warburton , 1986).



4.2 PASSIVE - ROOF SEQUENCE AND BACK THRUST

A normal stratigraphic sequence above the roof thrust is termed as the passive-roof sequence, which remains stationary above the landward propagating thrust sheet (Banks and Warburton 1986). Shortening of the duplex sequence to a small extent is accomodated in roof-sequence by uplift, folding and erosion. Many examples of long single back thrust have been cited by various workers like Suppe (1980), Price (1981), Jadoon (1991). Banks and Warburton (1986) suggest that a roof-sequence, instead of extending over a large number of horses, may be imbricated (Fig. 4.2). In the study area this seems to be the case. In the hanging wall of the fault A (Fig. 3.6), a NW verging recumbent fold is exhibited by Margala Hill limestone. Beside that we also observe a visibly back folded fault plane of fault B at a higher relief (at point E). Both these structures suggest that the area has experienced a north directed sense of compression.

On the mountain front of the Kalachitta Range to the SW of village Shahpur we have a bigger structure in the form of north verging anticline (Fig.3.7a), having axial plane dipping to the south. This too show hindward sense of compression at the Kalachitta mountain front. Comparing the recumbent fold in the hanging wall of the fault A with the north verging monocline at the mountain front (Fig.4.3), it appears that the recumbent fold having almost horizontal axial plane (4.3a), has experienced more compression as compared to the north verging anticline at the Kalachitta mountain front (4.3b). This denies the presence of

Fig. 4.2. Development of an overstep sequence of foreland dipping passive backthrust in the duplex. 1-2 represent successive stages in the development of the duplex. Thrusts are numbered in order of development (after Banks and Warburtan, 1986).

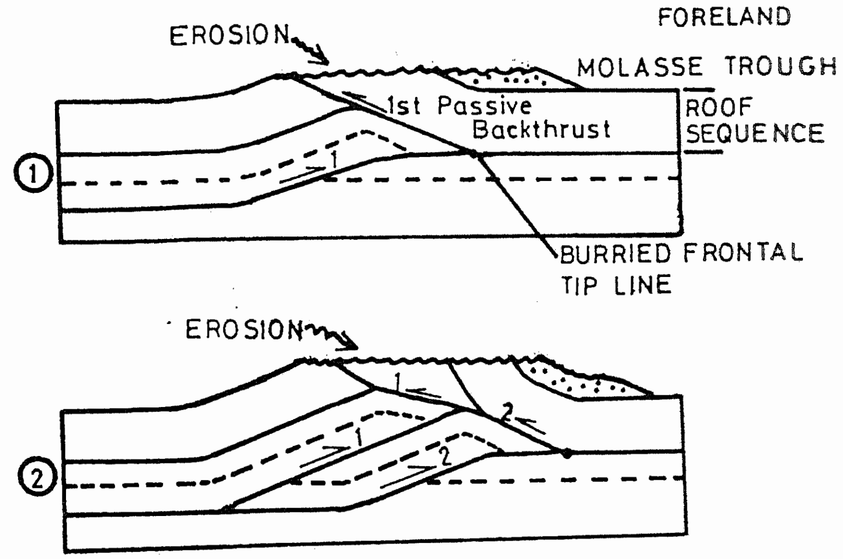
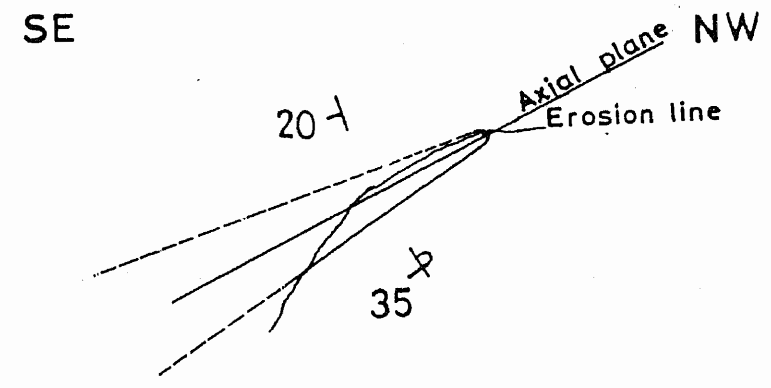


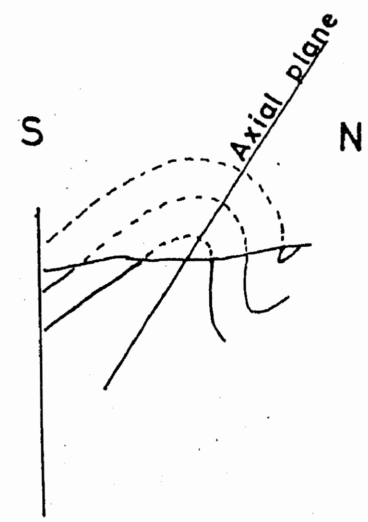
Fig. 4.3. Axial plane comparison of the two north verging structures.

a) Axial plane position of NW verging recumbent fold in the hanging wall of fault A.

b) Axial plane position of north verging anticline on the main boundary front.



a)



b)

a long single back thrust strating from the Kalachitta mountain front and covering the whole width of the range. Probably the back thrust first initiated at the foreland side of the antiformal stack at Katha colony (Fig.3.6), due to the sticking of basal thrust or locking of the antiformal stack. Reactivation of the basal decollement again started the duplex configuration. Sticking of the sole thrust at the Kalachitta mountain front again resulted in the hindward activation of passive-roof sequence in the form of north-verging anticline (Fig,3.6).

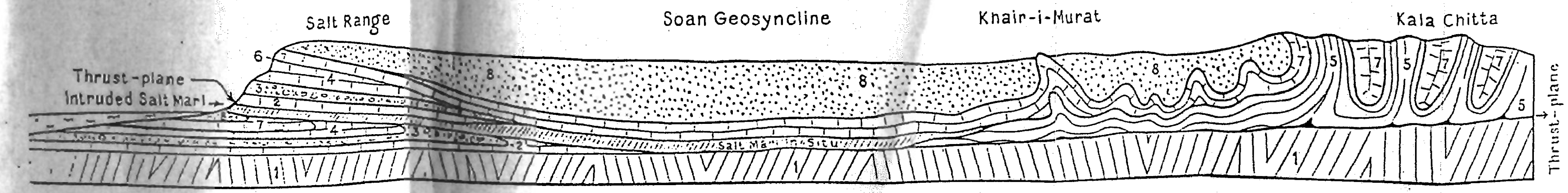
The mountain front of the eastern Kalachitta Range is variable in it's style of deformation from west to east. Just west of Attock - Fateh jhang road right on the Kalachitta mountain front (at point F) stratigraphic succession is such that the rocks of the Patala Formation and Margalla Hill limestone are tectonically overlying the overturned Samana Suk Formation and the whole strata is dipping to south showing an emergent back thrust. Tracing along it to the east this back thrust is in the form of north-verging monocline and to the further east as a culmination wall.

Cotter (1933), described the Kalachitta Range as anticlinorium, having fan shaped geometry, characterized by north-south verging folds (Fig. 4.4). According to him these structures resulted in response to swelling of Kalachitta mass due to lateral compression in which Precambrian slate has acted as lubricant.

It is important to note that all the north verging structures are exhibited by the rocks of Paleocene and Eocene in age.

Fig. 4.4. Diagrammatic section from the Kalachitta Range to Salt Range, showing the de'collement of the Kalachitta rocks and the sliding of the salt Range rocks on a thrust plane, in which the salt Marl has been partly injected, and partly in situ (after Cotter 1933).

49a



1. Autochthon of pre-Cambrian slates, etc.
2. Purple Sandstone and Cambrian rocks.
3. Speckled Sandstone and Boulder Bed.
4. Productus and Ceratite Limestone.
5. Kioto limestone and Giumal Spiti shale unit.
6. Ferruginous Pisolite (red line) and Salt Marl (stippled red bed).
7. Laki or Hill limestone.
8. Chharats, Murrees, Siwaliks.

Fig. 19. Diagrammatic Section from the Kala Chitta to the Salt Range, showing the *décollement* of the Kala Chitta rocks, and the sliding of the Salt Range rocks on a thrust-plane, in which the Salt Marl has been partly injected, and is partly *in situ*.

49b

therefore the author is of the view that the north vergence of the structures are due to the passive back thrust at the roof level detachment.

Mapping of the western and central parts of the Kalachitta Range by Hussain et al. (1990), shows that at more than one places the rocks of Eocene age are involved in imbrication (Fig.4.5). This involvement of Eocene strata in the thrust imbrication may be due to the variation in the style of deformation of thrust sheet.

The general observation of the strike of the Kalachitta Range show a lateral swing in it's trend (Fig. 4.6). In the east, north of Fateh jhang it is 090° - 080°, whereas to the west it becomes 130°. A change of 33° - 40°. This swing in the trend of the rocks is probably due to the differential movement in the lower and upper detachments, which can be developed in two ways:

a) As against the central part the western part of the range may have experienced the hindward sence of motion in the from of backthrust at upper detachment level (Fig. 4.7a). As a result the east has rotated counterclock wise while the west has experienced a clock wise rotation.

b) Alternately, the basal detachment in the eastern and western parts of the range may have encountered difficulties to south ward propagation due to change in lithology as compare to the central part. Thinning of salt to the east is already mentioned (Jaume and Lille, 1988). Resulting in counterclockwise rotation of the eastern Kalachitta range and clockwise rotation of the western Kalachitta Range (Fig.4.7b).

Fig. 4.5. Geological map of the western and central Kalachitta Range. (after Hussain et al., 1990).

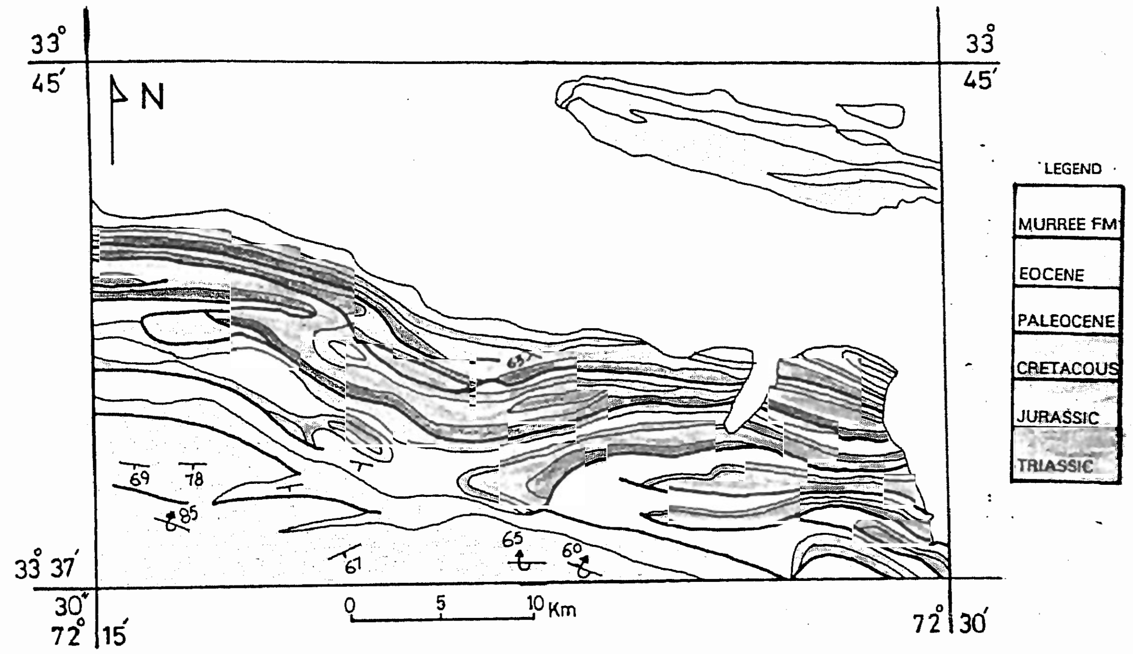
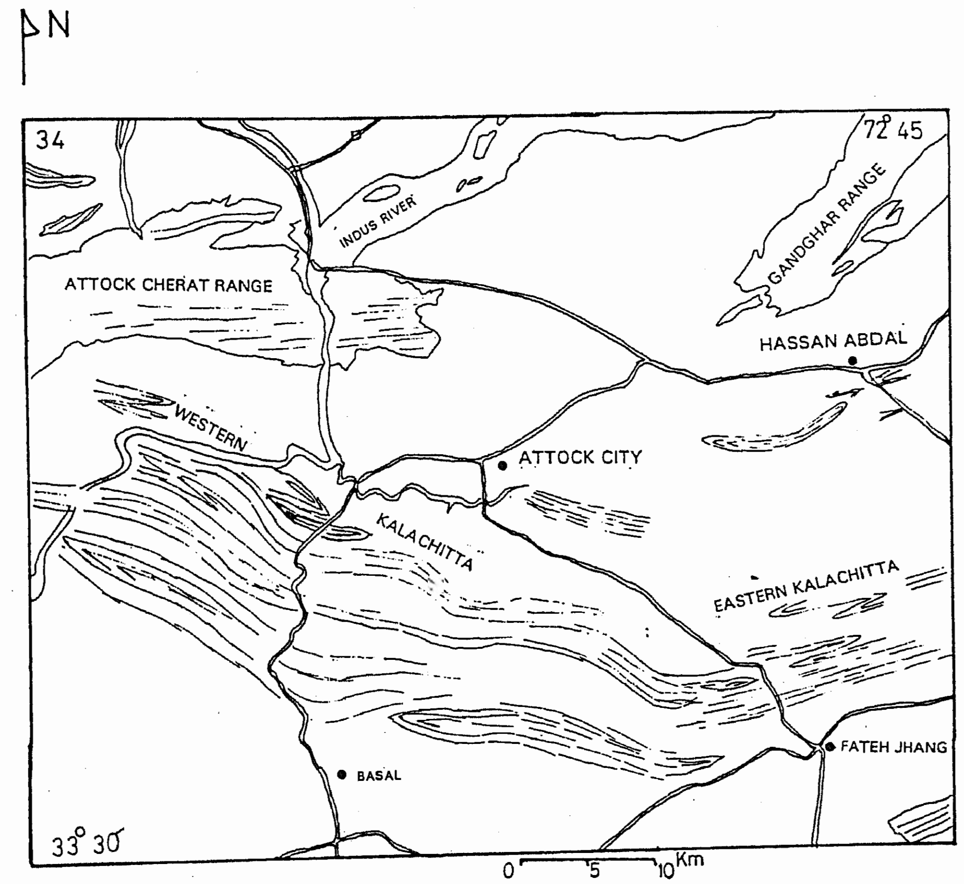


Fig. 4.6. Sketch map of Kalachitta range showing the lateral swing in the general trend.



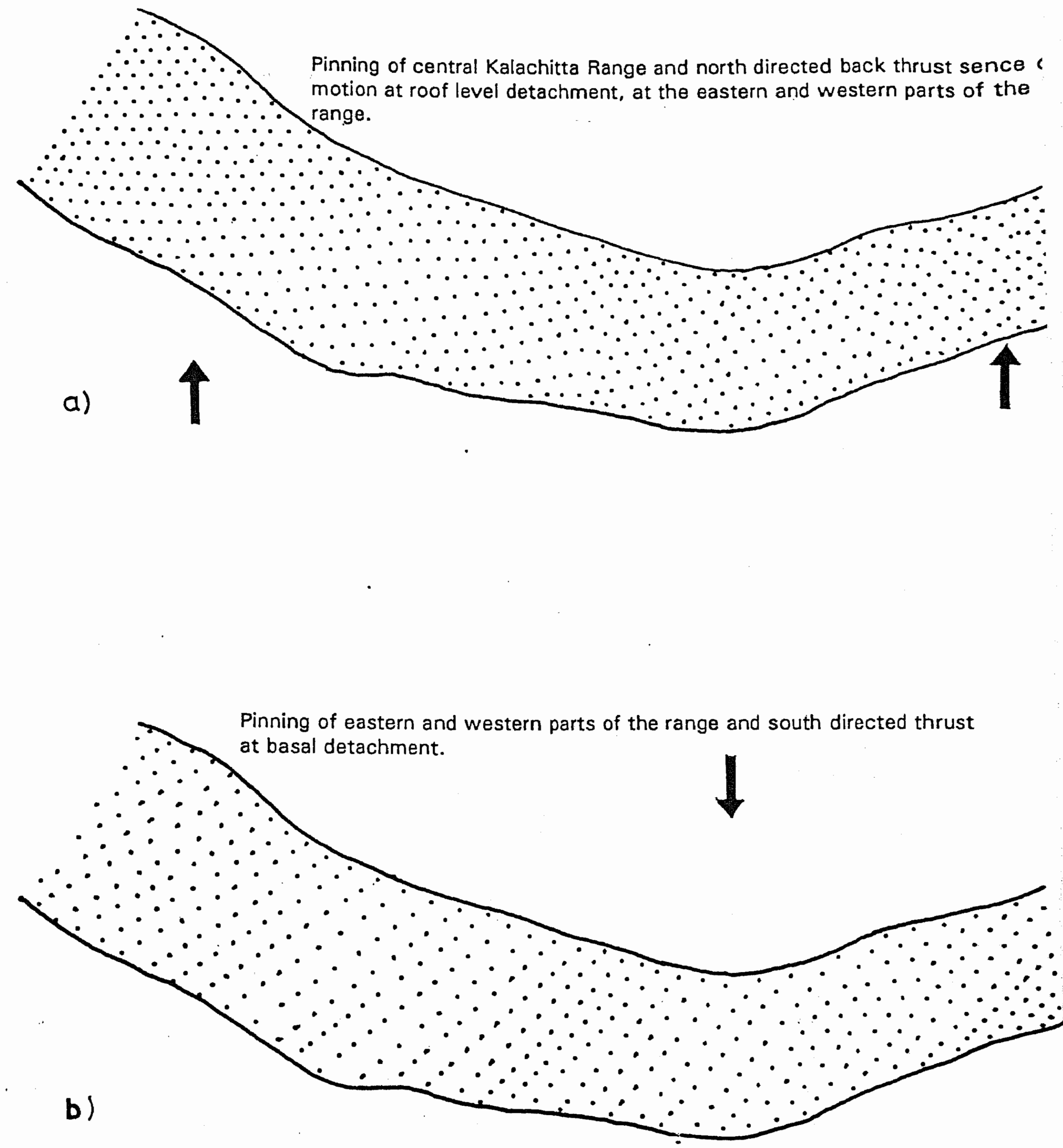


Fig. 4.7. Pinning model shwowing the possible cause of the lateral swing in the general trend of Kalachitta Range.

4.3 IMPLICATIONS FOR MBT

It is commonly believed that the Kalachitta Range is separated from the Potwar trough by a regional thrust analogous to MBT in India. Detailed mapping of the thesis area has shown that the molasse of the Potwar Plateau at the mountain front is in normal stratigraphic contact with the shelf platform rock sequence of Kalachitta Range. Since none of the early southward verging structure in the Kalachitta Range cut the molasse section, therefore they must end as blind thrust " fault bend folds" or connect to a common roof thrust. The absence of regional thrust may be attributed to the roof back thrust in the Paleocene Patala shale which has accommodated the forward movement of the duplex sequence (Fig.3.7a,b). Consequently we do not have a thrust fault at the surface in the tectonically thickened wedge from the frontal part of the eastern Kalachitta Range. As the style of deformation of the thrust sheet changes to the west, the possibility of thrust bounded mountain front with the molasse is there, which is documented by Yeats and Hussain (1987), Coward et al. (1988), Khan et al. (in press).

4.4 CONCLUSIONS

Surface data have been integrated to determine the structural evolution of the Himalayan fold belt along the eastern margin of the Kalachitta Range. The important conclusions are summarized as fallows:

1) The style of deformation of the eastern part of Kalachitta Range is of a passive roof duplex, having floor or sole thrust at the base of Jurassic Samana Suk Formation and roof thrust in Paleocene Patala Formation.

2) The surface expression of deformation is of detachment as well as fault related folds.

3) Progressive structural development includes:

a) The development of hinterland dipping duplex showing a progressive steepening of thrust faults from south to north, demonstrating a piggy back style of deformation having southward progradation.

b) Forward propagation of duplex to produce structural features of different geometrical configuration, including broad monoclinal structures at the tip of mountain front and detachment folds in cover sequence.

4) The roof thrust is breached , demonstrating no single passive back thrust as shown in the other mountain fronts of Pakistan.

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