Structure and Stratigraphy of the Paleozoic and Mesozoic sequences in the vicinity of Zaluch Nala, Western Salt Range, Punjab Pakistan.

Submitted by:

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DEDICATION

DEDICATED TO MY BELOVED PARENTS WHO, WITH THEIR VERY LIMITED RESOURCES, PROVIDED ME EVERY THING AND MADE ME ABLE TO COMPLETE THIS MAMMOTH WORK.

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ABSTRACT

Paleozoic to Mesozoic age sedimentary rocks predominantly characterize the Zaluch area of the western Salt Range. The structural fabric of the area is mainly attributed to a series of northwest trending parallel to enechelon anticlines and synclines. Most of these folds are found to be asymmetric and are southwest facing. Several thrust faults verging both to the north and south have been mapped that generally dissect the forelimbs of the anticlinal structures. Subsurface projection of folds and faults along the structural transects of the area suggests that the folds have evolved as buckles over the underlining Pre-Cambrian Salt Range Formation and the associated faults are formed as accommodation structures in response to room problem created by the compressional stresses. All the structures clearly demonstrate that the Zaluch has been subjected to contractile deformation due to compressional stresses oriented northeast southwest. The southwest overturning on fold structures and the facing of thrust faults suggests that the deformation is progressing southwestwards.

In study area the Salt Range Formation is the oldest rock unit represents the Paleozoic sequence. The Tobra Formation of the Nilawahan Group marks the base of Permian sequence and grades upward into medium to coarse-grained Warcha Sandstone whereas Dandot Formation is missing. The Triassic sequence is represented by Mianwali, Tredian and Kingriali Formations. The Jurassic sequence comprises from top to bottom Datta, Shinawari, and Samana Suk Formations whereas the Cretaceous exposed are Chichali and Lumshiwal Formations. The Eocene sequence consists of Nammal and Sakesar Formations.

CHAPTER No.1

INTRODUCTION

1.1 GENERAL DESCRIPTION

The Himalayan collision zone extends over 5000 km in Burma, Nepal, India and Pakistan (Gansser, 1981). The Himalayas have been actively growing since 55 Ma (Powell, 1979) due to the collision between Indian and Eurasian plates. In the main Himalayas, continent/continent collision is in progress due to advanced stage of convergence (LeFort, 1975). This collision manifests variable tectonic, structural and morphological features in the main Himalaya (Figure 1.1; Gansser, 1981; Yeats and Lawrence, 1984; Farah et al., 1984; Searle, 1986). The narrow ~30 km Himalayan foreland fold-and-thrust belt in India broadens to more than 100 km along series of lobes in Pakistan (Lillie et al., 1987, Jaume and Lillie, 1988). The study area is a part of the Western Salt Range lying in the vicinity of Zaluch Nala. It is underlain by a thick succession of Precambrian to Eocene plateform rocks that are highly deformed. The Kohat-Potwar plateau constitutes the western margin of Himalayan foreland fold and thrust belt and is marked by the Trans-Indus Ranges (TIRT) and Salt Range Thrust (SRT) in the south along which the Eocambrian to Pleistocene continental shelf sequence of the Salt Ranges and Trans Indus Ranges is thrust southward over the Punjab Plain.

The structure of the Zaluch Nala which has low hills (Figure 1.2) is poorly understood. The initial geological research in the Salt Range was done in the beginning of the 18th century. **Elphinstone (1815),** for the first time discovered and named the Salt Range. **Fleming (1853),** studied and published his report about the Salt Range. **Wynne (1878),** measured the stratigraphic section for the first time and he described the history of Permian and Triassic rocks in the Salt Range. **Wynne (1879-80)** introduced the names Chhidru and Wargal Group for the upper and middle Productus limestone.

Theoblade (1854), published another important paper and introduced the name of "productus limestone" and also indicated the thickness of this formation, quite accurately, to be 335.28m (1100 feet). **Wynne (1878),** introduced the name of Productus limestone and used the term “Chiddru Group” and “Wargal Group” for the upper and middle Productus Limestone. **Noetling (1901),** described the contact relationship between Productus limestone and ceratite beds in the Chua Gorge near Wargal. **Tschnernysehew (1902),** discussed the age and correlation of the productus limestone. He believed that sharp faunal break between uppermost Paleozoic and lower most Triassic is due to stratigraphic hiatus.

Grabou (1931), made the “productus limestone” slightly younger than Tschernyschew had done, but did not share the view of the existence of longer hiatus between Permian and Triassic. **Gee (1945-47),** made an extensive work in the Salt Range. He constructed a detailed and comprehensive geological map. He also established the stratigraphic section in the Nammal Gorge in detail. Schindewolf (1954-55) produced first detailed stratigraphic section and measured Permo-Triassic beds on the west of Chhidru Nala. His work produced first detailed stratigraphic section of the critical passage beds. **Kummal and Tiechert (1964,1966),** described the lithology and distribution of a fauna of the beds above and below the Permo-Triassic Boundary. They concluded that Permo-Triassic Boundary is Para conformity of undetermined magnitude.

This study will concentrate on all available surface data stratigraphy and to construct cross sections to understand the structural evolution of the study area. The structures are analyzed on macroscopic scale. However, structures on *mesoscopic* scale were also vital to interpret the primary macroscopic structures.

1.2 LOCATIONS AND ACCESSIBILITY

The study area is located within the Survey of Pakistan topographic sheet # 38P/9 and is located between the latitudes 32° 48′ 00″ and 32° 50′ 30″ N and longitudes 71° 37′ 30″ to 71° 40′ 30″ E. It constitutes a part of Western Salt Range (Figure 1.2). The study area is easily accessible from the Mianwali-Kalabagh trunk road. From the village Paikhel that lies along Mianwali-Kalabagh road a 10 Km dirt track leads to the mouth of Zaluch Nala.

1.3 PURPOSE OF STUDY

The previous geological account of the proposed study area has been mainly focused on its stratigraphic understanding. Since the geological mapping of Gee (1980), no attempt has been made to revise the previous maps and to understand its structural framework.

The main purpose of the present study is as given bellow;

1) To construct the geological map of the area at the scale 1:50,000
2) To identify and map various structural features
3) To work out the style of deformation
4) To construct a structural model

1.4 METHODOLOGY

To get detailed geological data, three week fieldwork was conducted in September 2002, under the supervision of Dr. Irshad Ahmad and Dr. Sajjad Ahmad. This fieldwork was carried out with the help of toposheet # 38P/9 as base map and mapping was conducted by making traverses in the area. Brunton Compass was used for measuring attitudes and orientation of different small scale and large-scale structures in the outcrops. The bedding and fault attitude at different outcrops were measured and then transferred to map to prepare a comprehensive geological map. Both small and large-scale structures were plotted on the geological map.

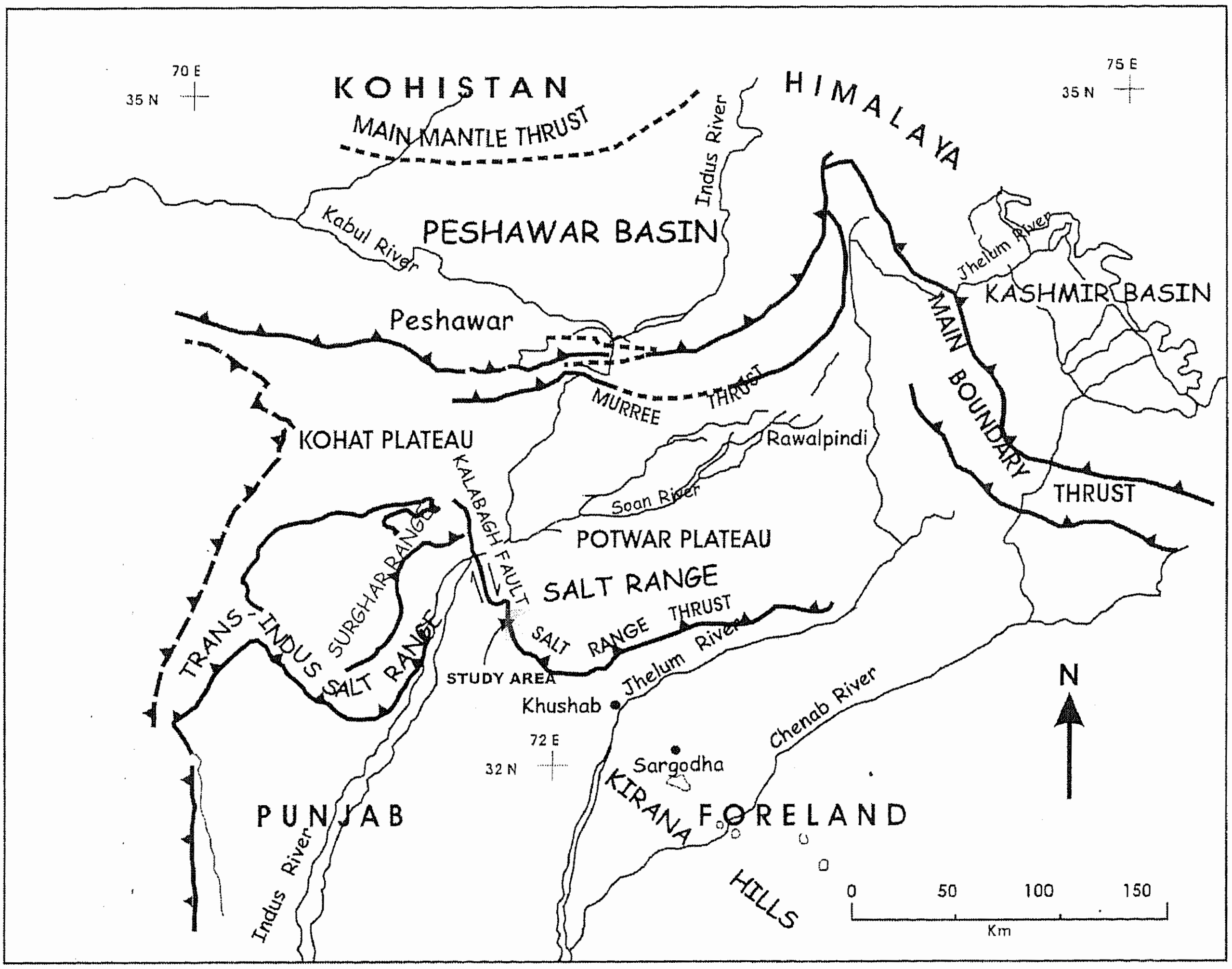


Figure. 1.1. Structural map showing tectonic location of Potwar and Kohat Plateaus (After McDoughal and Khan, 1990).

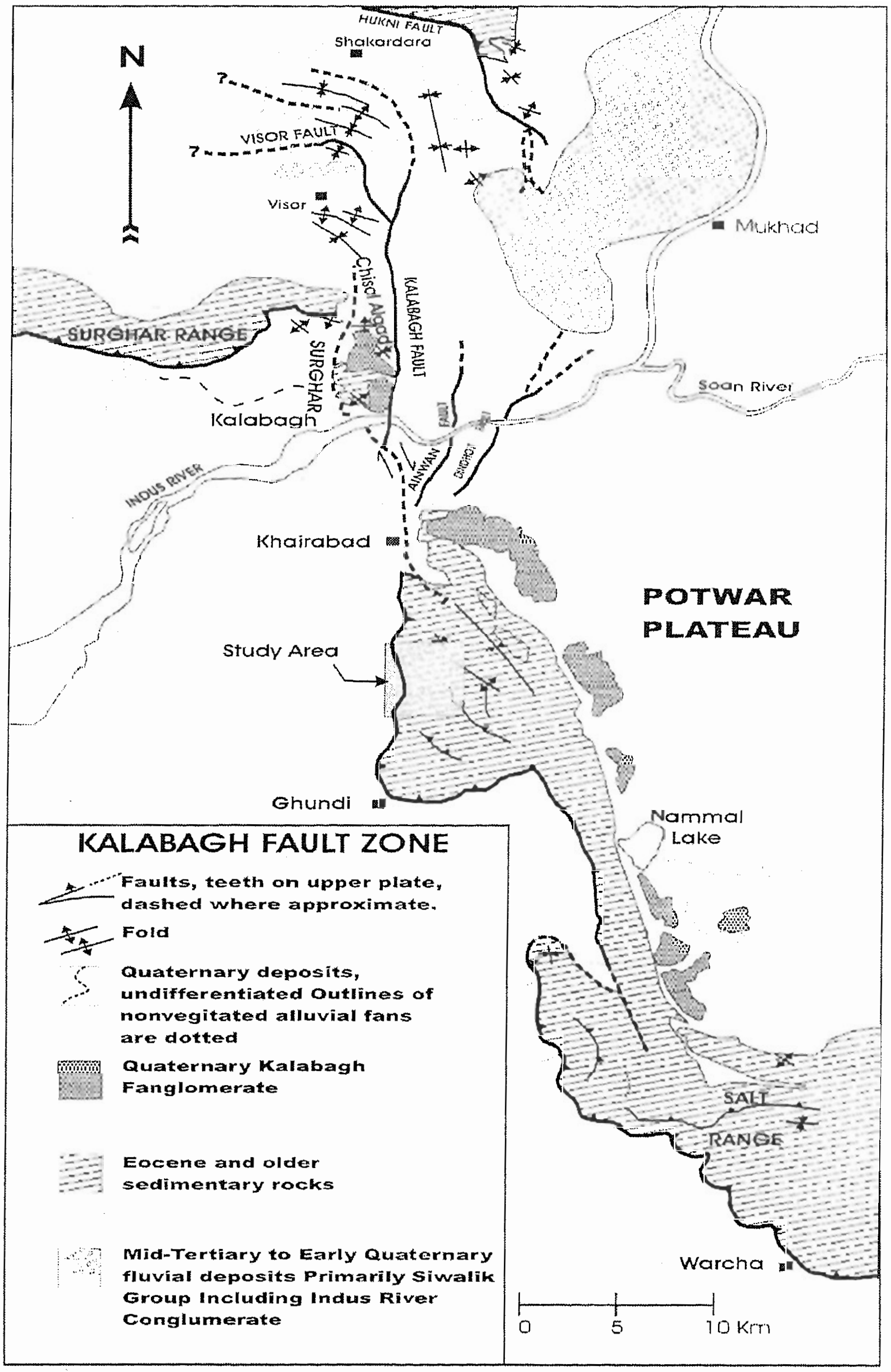


Figure 1.2. Geological and Structural map of Kalabagh Fault Zone. The box shows the location of the study area. (Reprodeuced after McDoughall and Khan, 1990)

CHAPTER No.2

REGIONAL GEOLOGICAL SETTING

2.1 General Statement

The geodynamic setting of the Indian plate has been presented in a chronological order dating back to 130 million years (m.y.). Himalayan Thrust Tectonics has been discussed briefly. Also structure setup of the Salt Range Thrust and its deformation pattern of the surrounding area have been elaborated in order to understand the structural intricacies in response to the Himalayan tectonics.

2.2 Geodynamics

The Indo-Pakistan sub-continent is bounded by the Indian Ocean in the south and the Himalayan fold belt to the north. Continued NNW drift of the Indian landmass and the consequent collision tectonics resulted in evolution of Himalayas and accretion of Indo-Pakistan sub-continent with Eurasia. The sub-continent was separated from Gondwanaland about 130 m.y. ago (Johnson et al., 1976). It is estimated, on the basis of magnetic anomalies that between 130-80 m.y. Indo Pak sub-continent moved northward at a rate of about 3 to 5 cm/year (Johnson et al., 1976). From 80 m.y. India moved at an average rate of 15-25 cm/year relative to Australia and Antarctica (Powell, 1979; Patriat and Achache, 1984). During this period the movement was facilitated by extensive sea-floor spreading along Mid Oceanic Ridges and Transform faulting in the Proto-Owen fracture zone (Kazmi and Jan, 1997). Between 60-65 m.y. the northward drift of India was accompanied by an extensive extrusion of Decan Trap Basalts (Duncan and Pyle, 1988).

The opening of Indian Ocean in the south and squeezing of the Tethys Ocean in the north started about 130 m.y. ago when India progressed its northward drift (Johnson et al., 1976). Intra-oceanic island arcs (Kohistan-Laddakh, Noristan, and Kandhar) were formed by the Intra-oceanic subduction within the Neotethys during the Cretaceous times and back-arc ocean at the southern margin of Eurasia (Searle, 1991). With the closure of the back-arc basins, the Kohistan-Ladakh island arc underthrusted the Eurasian plate margin along the Main Karakorum mega suture which gave rise to an accreted plate tectonics similar in nature to the Andean-type continental margin (Petterson and Windley, 1985). The youngest marine sediments deposited in the back-arc basin, between the Kohistan and Karakorum, are Early to Middle Cretaceous carbonate. The Indus Suture zone also bordered a structural conspicuous feature called as the Nanga Parbat Syntaxis interrupt the regional trend of the Himalayas (Coward, 1985; Zeitler, 1985). Gravity data modeling indicates that the MMT and MKT dip northward at 35° to 50° (Malinconico, 1989). Seismological data suggests that the arc underlies the Indian Crustal Plate (Seeber and Armbuster, 1979; Fineti et al., 1979) and the thickness of the Kohistan terrain based on gravity modeling data is about 8 to 10 km (Malinconico, 1989).

The India-Eurasia collision produced the spectacular Himalayas along some 2500 km long Indo-Pakistan plate margin. The collision zones are marked by the extensive emplacement of ophiolites along the Indus-Tsangbo Suture Zone, Waziristan, Zhob Valley and Lasbela area (Ganser, 1964; Le Fort, 1975). Along Suture Zones the youngest sediments are of Lower Eocene age. At places Indus molasse overlies Early Eocene limestone and contains debris of Indian and Eurasian terrains. Continental collision of India with Eurasia formed vast mountain range with a thick pile of intensely deformed and thrusted Phanerozoic and Proterozoic basement affected by various metamorphic events and intruded by a series of magmatic rocks. The present day Pakistani Himalayan Thrust System from north to south, (Figures 2.1) comprises of Main Karakoram Thrust (MKT) (Gansser, 1981; Coward and Butler, 1985; Coward et al., 1986; Searle, 1988), Main Mantle Thrust (MMT) (Tahirkheli and Jan, 1979; Kazmi et al., 1982), Main Central Thrust (MCT) (Heim and Dansser, 1939; Le Fort, 1975; Tahirkheli, 1989) Main Boundary Thrust (MBT) (Yeats and Lawrence, 1984; Treloar et al., 1989), and Salt Range Thrust (Gee, 1945,1989: Yeats et al., 1984; Lillie et al., 1987). The Salt Range Thrust is also known as Main Frontal Thrust (MFT) Nakata (1972). This Thrust System is the natural base for the subdivision of Himalayas in Pakistan from hinterland to the north and foreland to the south (Gansser, 1964). General features of each thrust and their respective blocks in Pakistan are briefly discussed here.

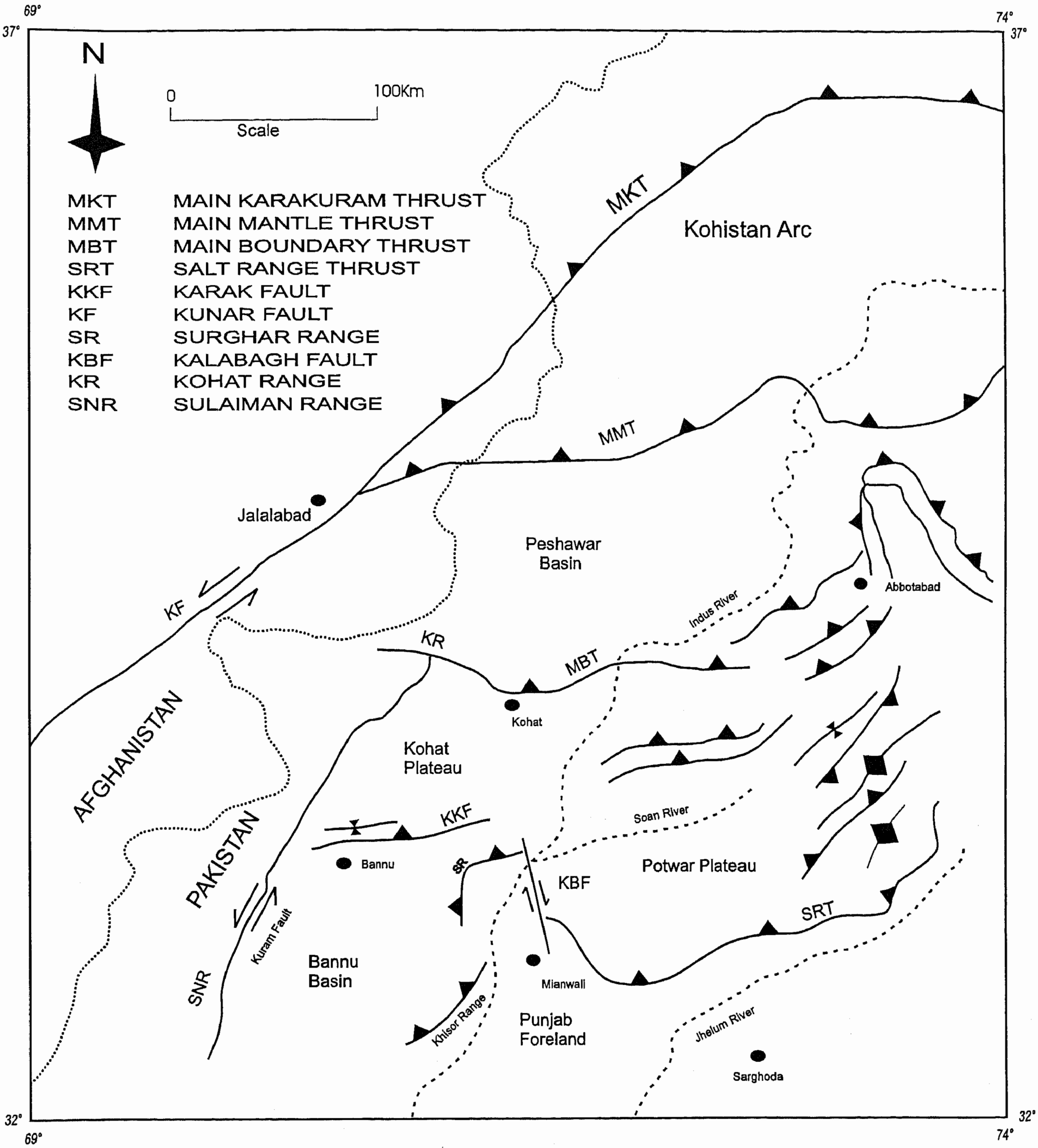


Figure 2.1. Outline Structural map of northern Pakistan (Modified after Kazmi & Rana, 1982).

The MKT or Shyoke Suture Zone was formed as result of collision between the Karakoram Plate and the Kohistan Island Arc (Tahirkheli, 1979, 1982) and was named as Northern Suture (Pudsey et al., 1985). It was formed during Late Cretaceous (Coward et al., 1986). The Shyoke Suture Zone is located to the south of Karakoram Batholith along the metasedimentary belt. The southern metasedimentary belt of the Karakoram terrane is thrust over the Kohistan-Ladakh sequence along this suture zone. The structural horizon is characterized by grey to green slates, interbeded clastic sediments and blocks and exoitic clasts of greenstone, limestone, red shale and minor ultramafics and is considered as olistostromal (Pudsey et al., 1985).

The MMT or Indus Suture Zone was formed as a result of collision and subduction of the Indian Plate underneath the Kohistan Island Arc during Eocene time (Tahirkheli, 1979, 1982; Gansser, 1981). To the southeast, in India and Tibet, the MMT and MKT join together as the Indus-Tsangpo Suture of the central Himalaya. To the southwest, in Northern Pakistan MKT and MMT join short of the right lateral Sarobi-Chaman Fault System and later merge into it. The Indus Suture terminates the Tethyan Himalayan on the north and marks the boundary between the Indian crustal plate and the Kohistan Island Arc (Tahirkheli and Jan, 1979). In Pakistan the Indus Suture is comprised of a complex sequence of imbricated melanges, which consist of tectonic blocks of ophiolites, Blue schists, green schist, meta-volcanics and metasediments in a matrix of shear-sediments and or serpentines (Tahirkheli and Jan, 1979,1982; Jan, 1980; Kazmi et al., 1982). The Indus Suture Zone and Shyoke Suture Zone bound the Kohistan-Lidakh Island Arc to its north and south respectively. The Indus Suture Zone also bordered a structural conspicuous features called as the Nanga Parbat Syntaxis Interrupt the regional trend of the Himalayas (Coward, 1985; Zeitler, 1985). Gravity data modeling indicates that the MMT and MKT dip northward at 35° to 50° (Malinconico, 1989). Seismological data suggests that the arc is underlain by the Indian Crustal Plate (Seeber and Armbuster, 1979) and based on gravity modeling data, the thickness of the Kohistan terrain is about 8 to 10 km (Malinconico, 1989).

The Main Central Thrust (MCT) is an intracontinental thrust that separates the Higher and Lesser Himalayas in India and Nepal. It was described by Heim and Gansser

(1939) as a tectonic contact between the Himalayans autochthonous sedimentary sequence and the overlying crystalline complex. It has been traced from Nepal upto Southern Kashmir (Gansser, 1964). Its westward extension across the Hazara-Kashmir Syntaxis into the Pakistani Part of the Himalaya has been controversial and in doubt largely because the region northwest of the last confirmed location of MCT has been only scantily mapped. Some of the earlier worker (Gansser, 1964; Yeats and Lawrence, 1984) extended MCT into the Panjal Thrust.

A hairpin-shaped system of faults truncates the Murree Formation on the east, north and west. It abuts the Mesozoic and earlier rocks against the Murree Formation west and north of this fault zone, within the short distance of 1 to 5 km there is a parallel thrust fault along which Precambrian sequence has been pushed over the Paleozoic and Mesozoic rocks. These two faults were named as Murree and Panjal thrusts respectively by Wadia (1931). Some recent workers call the Murree Thrust on both limbs of the Syntaxis as the Main Boundary Thrust (Treloar et al., 1989a, 1990). The rocks of Lesser Himalayas are thrust southward over the Sub-Himalayan sequence of Neogene Siwalik molasse along the Main Boundary Thrust Zone. The MBT Zone is comprised of a series of parallel or enechelon thrust faults dividing the NW Himalayan sequence into a deformed southern zone or foreland, and a deformed and metamorphosed northern zone or the hinterland (DiPetrio et al., 1996; Pivnik and Wells, 1996). From NE to SW, the MBT is located in the Hazara-Kashmir Syntaxis, Northern Potwar and Kohat Plateau of Pakistani Himalayas.

The Salt Range Thrust (SRT) or the Himalayan Frontal Thrust (MFT) runs along the southern margin of the Salt Range, Between Jhelum and Indus rivers, and it has pushed the older rocks of the Salt Range upon the less deformed Tertiary sequence of the south-lying Jhelum Plain. The thrust zone is largely covered by recent fanglomerates and alluvium (Kazmi and Jan, 1997). However at places, the thrust is exposed and shows the Paleozoic rocks overlying the Neogene or Quaternary deposits of the Jhelum Plain (Gee, 1945, 1989; Yeats et al., 1984). Seismic reflection profiles, gravity, and drill hole data indicates that the Salt Range and Potwar Plateau are underlain by a decollement zone within Eocambrian evaporites. Along the Salt Range Thrust, effective decoupling of sediments from the basement along the salt layer has led to southward transport of the

Salt Range and Potwar Plateau in the form of a large slab over the Jhelum Plain. Thus the Salt Range is the surface expression of the leading edge of a decollement thrust (Lillie et al., 1987).

2.3 Salt Range and Kohat-Potwar Fold Belt

The east-west trending fold-belt comprises the low altitude hills and valleys of the uplifted Kohat-Potwar Plateau, the Salt Range and the Trans Indus mountain ranges (Fig. 2.1). This sedimentary fold belt is bounded in the north by the Main Boundary Thrust (Sarwar and Dejong, 1979; Yeats et al., 1984; Coward et al., 1985). Southward the Salt Range Thrust and the Surghar Thrust collectively form the southern boundary of the Salt Range (Gee, 1989; Yeats and Lawrence, 1984). Towards west and eastward, it is terminated by the N-S oriented Kurram Thrust and Jhelum Fault respectively (Kazmi and Rana, 1982).

2.3.1 Salt Range

The Salt Range is a complex anticlinorium structure with a series of salt anticlines (Gee, 1945). The structure along its northern slope is comprised of broad, simple and shallow folds, followed by a gentle monocline (Gee, 1945, 1989). Along the southern scarp, the structures are more complicated and comprise east-west trending faults and tight overfolds (Gee, 1945, 1989). The Pre-Cambrian Salt Range Formation is exposed along these overfolded and faulted anticlines. The general trend of the folds is east-west in the Central Salt Range. A few NNE and NNW trending and northward plunging anticlines are forming "nose" type structures (Kazmi and Jan, 1997). Eastward, the Salt Range bifurcates into two narrow northeast trending ridges (the Diljabba and the Chambal-Jogi Tilla ridge) which are also folded. (Gee, 1989). Westward, the Kalabagh Fault separates the Salt Range from the Trans Indus Ranges (McDougall and Khan, 1990).

2.3.2 Salt Range Thrust

The Salt Range Thrust forms the southern margin of the Salt Range and apparently continues westward along the southeastern margins of the Surghar-Shinghar and Khisor Marwat Ranges (Gee, 1989). The Salt Range thrust is largely covered by recent fanglomerates (Gee, 1989). However, near Jalalpur and Kalabagh, the thrust is exposed and shows that the Paleozoic rocks are overlying the Neogene or Quaternary deposits of the Jhelum Plain (Gee, 1945, 1989; Yeats and Lawrence., 1984). Along the Salt Range Thrust, effective decoupling of sediments from the basement along the salt layer has led to southward transport of the Salt Range and Potwar Plateau in the form of a large slab over the Jhelum Plain (Lillie et al., 1987).

A few teleseismic events are located along the southern margin of the central and eastern Salt Range (Kazmi, 1979c). According to Allen (1976c) there is a good evidence for ongoing thrust faulting at the base of the Khisor Range. The teleseismic data from Tarbela-Chashma network shows that the Salt Range, particularly the Trans-Indus Range is an active structure (Seeber et al., 1980a).

2.3.3 Kohat Plateau

The Kohat plateau is located to the west of Potwar, and is comprised of east-west trending, gentle to steeply dipping, doubly plunging, overturned folds. Likewise the Potwar, the Kohat plateau is divided into northern and southern parts. Tight, commonly overturned folds, out of syncline faults and several thrust faults, characterize the northern region. Some of the low angle thrust faults have folded and form klippen. They constitute a distinct thrust belt, the Kir Khweli Sar thrust Belt (MKSTB).

In the southern part of the Kohat Plateau east-west trending folds and north- and south dipping reverse faults are common. Fault propagation folds are common in the southern part. The Bahadur Khel Salt is exposed in anitclinal cores, where Jatta Gypsum is commonly imbricated and folded with slivers of Ponoba Shale. In this region, the lower Eocene rocks have been thrust over the Miocene molasses at several places (Pivnik and Sercombe, 1993).

Based on field surveys and seismic profiles across the Kohat Plateau, Pivnik and Sercombe (1993) demonstrated the absence of duplexes, passive roof thrusts, antiformal stacks in this region. They invoked that the Kohat basement is traversed by high angle conjugate reverse faults which are indicating a significant degree of wrench faulting and positive flower structures.

The geometries of structures in the Kohat Plateau are the product of both compressional and transpressional tectonics (Pivinik and Sercombe, 1993).

2.3.4 Potwar Plateau

The Potwar Plateau to the north is bounded by the Kalachitta- Margalla Hill Ranges and to the south the Salt Range, Indus River to the west and the Jhelum River to the east (Fig. 2.1). Its northern part is known as the North Potwar Deformed Zone (NPDZ), which is more intensely deformed. It is characterized by east-west right folds, overturned to the south and sheared by steep-angle faults, pop-up and triangle zones (Kazmi and Rana, 1982, Bannert et al., 1992). The NPDZ is followed to the south by wide and broad asymmetrical Soan syncline, with a gentle northward dipping southern flank along the Salt Range and a steeply dipping northern limb along NPDZ (Khan et al., 1986 and Bannert et al., 1992). In its eastern part, the strike abruptly changes to the northeast where the structures comprise of tightly folded anticlines and broad synclines (Khan et al., 1986). There is less evidence of faulting of the anticlines (Pennock et al., 1989). In the western part this basin is occupied by several east-west, broad and gentle folds. This east to west difference in the structural style has been attributed to the reduced thickness of evaporites and lesser basement slope in the eastern part of the Potwar and Salt Range.

Geophysical data and surface geology of the area shows that Salt Range and Potwar are underlain by a gentle northward-dipping basement, with an upward convexity, and traversed by north-dipping normal faults (Lillie, 1987). Above the basement there is a decollement zone in the Pre-Cambrian evaporites, which have been an effective zone of decoupling, allowing thrusting without involving the basement (Lillie et al., 1987). The Salt Range is the topographic expression of this great thrust sheet. Beneath NPDZ the Phanerozoic sedimentary wedge thickens to 9 km and forms a north dipping stack of thrust faults, some of which reach the surface while other terminate at depth as blind thrusts (Lillie et al, 1987).

2.4 Trans Indus Ranges

This region is composed of the Surghar, Marwat, Khisor and Manzai Ranges that form an "S" shaped double re-entrant and surrounded the Bannu Depression (Figure 2.2). The Surghar Range is bounded by Indus River in the east and the Kurram on the southern side, while it merges into Shinghar Range towards northern and northeast sides. The Surghar Range is characterized by Pre-siwaliks sediments, escarpment ridges facing the Indus River towards the east (Danilchik and Shah, 1987). According to Gee (1989) the range forms asymmetrical, overfolded anticlines structure plunging to the south near the Kurram River (Akthar, 1983), with Permian strata exposed in the core, overlain by Mesozoic and Paleogene rocks. The western limb of the range is well exposed, while its eastern limb is steeply eroded exposing older formations (Gee, 1989). The Surghar Range corresponding to the Salt Range Thrust is expected to continue along the axis of the Surghar Anticline bringing Punjab foreland alluvium in contact with Permian and Mesozoic rocks in the north and Neogene in the south (Gee, 1989).

2.4.1. Kalabagh Fault

The Surghar-Shinghar Range is separated from the Salt Range by an active dextral strike slip lineament, which is known as the Kalabagh Fault (Yeats and Lawrence, 1984; Kazmi, 1979c). This NNW oriented fault has a long southward continuation as indicated by lineaments on Landsat images and buried dextral wrench fault inferred from seismic data (Seeber and Armbuster, 1979; Seeber et al., 1980; Kazmi, 1979c, Kazmi and Rana, 1982). Southward, the Kalabagh Fault apparently displaces the Salt Range Thrust and splays out into two additional sub parallel faults, the Dinghot and Ainwan faults (Mc Dougall and Khan, 1990). At its northern end the Kalabagh Fault bends westward and branches out into a number of smaller, north dipping thrust faults. According to McDougall and Khan (1990), the Kalabagh Fault system forms a lateral ramp extending to the base of Salt Range Potwar Plateau allochthon. They interpreted the residual gravity anomalies in this

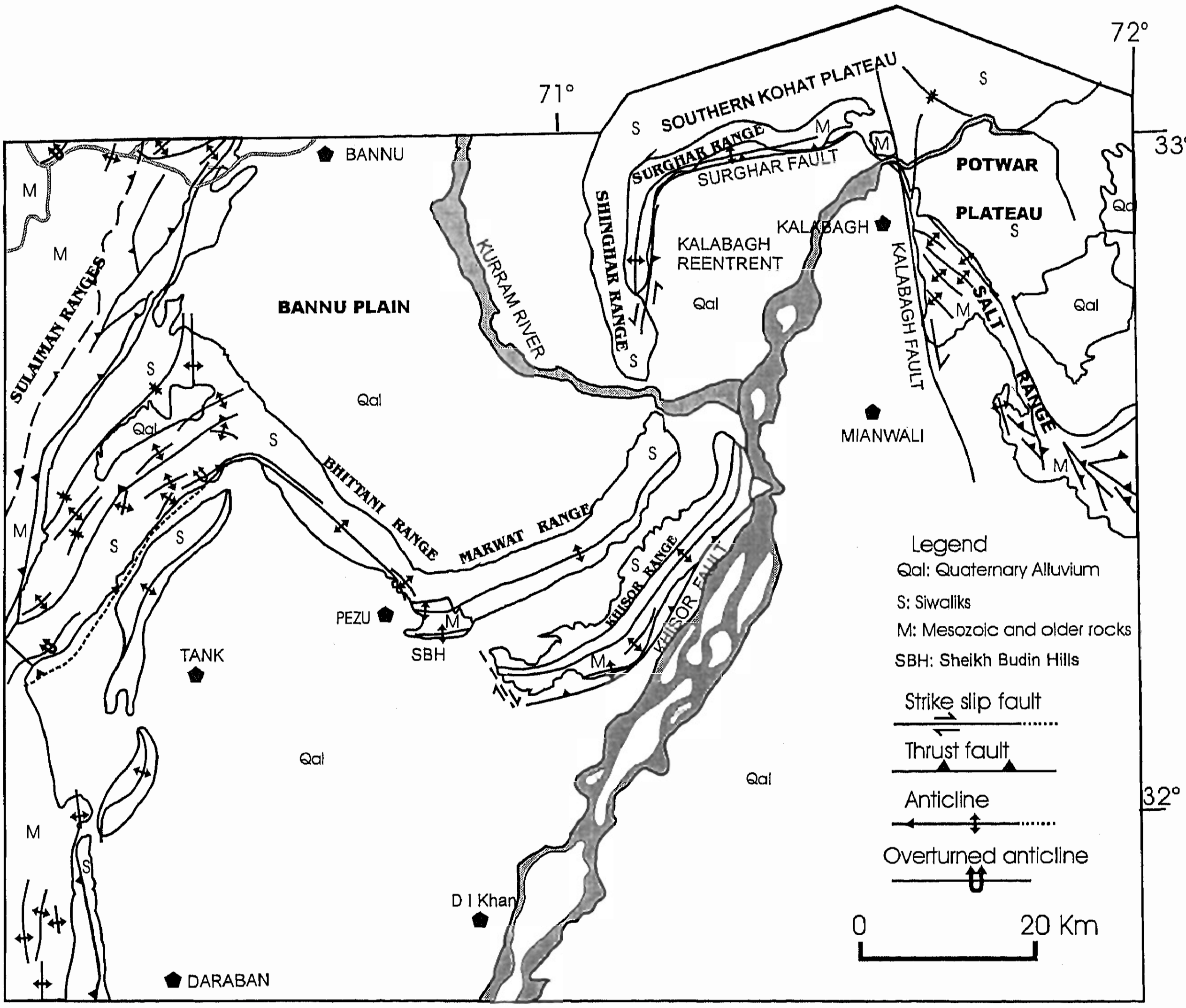


Figure. 2.2. Generalized Geological Map of the Western Salt Ranges and Trans Indus Ranges, showing the location of study area. (Modified after Hemphil and Kidwai, 1973)

region in terms of NNW trending discontinuous basement ridge. According to their model the Kalabagh Fault over rides this ridge.

2.4.2 Surghar-Shinghar Range

The Surghar and Shinghar are north-south oriented parallel ranges covering the southeastern margin of the Bannu Basin. The Surghar Range is mostly composed of Pre-Siwalik sediments with an escarpment ridges facing the Indus River towards the east and is facing the Bannu Basin towards west (Danilchik and Shah, 1987). According to Gee (1989) the range forms asymmetrical, overfolded anticlinal structure plunging to the south near the Kurram River, with Permian strata exposed in the core, overlain by Mesozoic and Paleogene rocks. The western limb of the range is well exposed, while its eastern limb is deeply eroded exposing older formations (Gee, 1989). The Surghar Thrust corresponding to the Salt Range Thrust is expected to continue along the axis of the Surghar Anticline brining Punjab foreland alluvium in contact with Permian and Mesozoic rocks in the north and Neogene rocks in the south (Gee, 1989).

The earliest tectonic phase of Surghar-Shinghar Range is characterized by the formation of north-south oriented Makarwal anticline and is followed by the normal and thrust faulting on the flank of Surghar Range (Danilchik and Shah, 1987). Compressive forces in the area also resulted in strike slip Miranwal fault (Danilchik and Shah, 1987). After an uplift of the topography of the Surghar-Shinghar Range, the material eroded from these mountains is being deposited on the adjacent Bannu and Indus Plains (Danilchik and Shah, 1987).

2.5 Study Area

Zaluch and Chitta wahan nalas are the parts of western Salt Range which have been greatly influenced by the activity of Salt Range Thrust and Kalabagh Fault. Activity on the Salt Range Thrust began at approximately 1.0 million years in the Trans Indus Region and perhaps at 5.0 million years in the Potwar portion of the Salt Range (Yeats et al., 1984).

Evidence of deformation as young as 0.4 Ma has been described by Yeats et al. (1984) for the southwestern part of the Pakistani Himalaya which is as up thrown block of low angle imbricate thrust faults (Seeber and Jacob, 1977) and is the lateral equivalent of the Main Frontal Thrust (MFT) of the Central Himalaya. In the Central Himalaya the foreland fold and thrust belt is internally cut by two north dipping thrust faults i.e. early to late Miocene Main Central Thrust (MCT) in the north and the late Miocene Main Boundary Thrust (MBT) in the south.

CHAPTER No. 3

STRATIGRAPHIC FRAMEWORK

3.1. BACKGROUND

Exposed stratigraphic sequence in the vicinity of Zaluch Nala consists of about one and half km thick succession of rocks of Eocambrian to Eocene age (Table 3.1). The Salt Range Formation that is the oldest rock sequence in the area represents the Eocambrian sequence. The Tobra Formation of the Nilawahan Group marks the base of the Permian sequence in the study area and grades upward into medium- to coarse-grained Warcha Sandstone, whereas Dandot Formation is missing in the area.

The Warcha Sandstone is overlain by the Sardhai Formation with a transitional contact and is placed at the top of the highest massive sandstone bed and grades upward into the Amb Formation, which is composed of sandy limestone, gray in color and medium- to thick-bedded.

The Amb Formation having a conformable contact grade upward into the Wargal Formation. It grades into the overlying Chhidru Formation which is Paraconformably overlain by the Mianwali Formation of early Triassic age. The upper contact of the Mianwali Formation is marked by the Tredian Formation, which consists of sandstone, shale and dolomite.

The Tredian Formation is conformably overlain by Kingriali Formation, which is composed of dolomite and dolomitic limestone. The upper contact of the Kingriali Formation with the Data Formation is disconformable. The Data Formation marks the base of the Jurassic sequence and contains red, gray and white sandstone with siltstone, shale and mudstone and fine clay horizons. It grades upward into medium-bedded limestone, marl and sandstone of the Shinawari Formation, which is disconformably overlain by medium-bedded, gray limestone of Samana Suk Formation. Towards top of the Jurassic sequence overlies Chichali, Lumshiwal formations of Cretaceous age. The Cretaceous sequence is in turn overlain by Paleocene age rocks of the Hangu, Lochart and Patala formations, whereas the youngest rock exposed in the area belongs to the Eocene age and is represented by Nammal and Sakesar formations. In the following section detailed stratigraphy of the area has been described.

3.2. PRECAMBRIAN SEQUENCE

3.2.1 Salt Range Formation

Wynne (1878) named and described the formation as 'Saline series'. Gee (1945) called the same unit as the 'Punjab saline series'. The present name, Salt Range Formation, has been given by Asrarullah (1967) after Salt Range, Punjab. Khewra Gorge in the Eastern Salt Range has been regarded as the type section.

The lower part of the Salt Range Formation is composed of red-coloured gypseous marl with thick seams of salt, while the beds of gypsum, dolomite, greenish clay and low-grade oil shale are the constituents of the upper part. A highly weathered igneous body "Khewra Trape" has been reported from the upper part of the formation. The "Khewra Trap", also known as "*khewraite*" proposed by Mosebach (1956) is six meters thick and is purple to green in colour. It consists of highly decomposed radiating needles of a light-coloured mineral, probably pyroxene.

The red coloured marl consists chiefly of clay, gypsum and dolomite with occasional grains and crystals of quartz of variable size. Thick-bedded salt shows various shades of pink colour and well-developed laminations and colour bandings up to a meter thick. Minor amounts of Potassium-Magnesium Sulphate are found in association with the shale beds. The gypsum is white to light grey in colour. It is about 45 m thick, massive and associated with bluish grey, clayey gypsum and earthy, friable gypseous clay. The dolomite is usually light grey in colour. It is flaggy and cherty and is associated with dolomitic shale, bituminous shale and low-grade oil shale. In the study area the contact between the Salt Range Formation and Warcha Formation is marked by a major *unconformity,* that means Tobra formation is missing here.

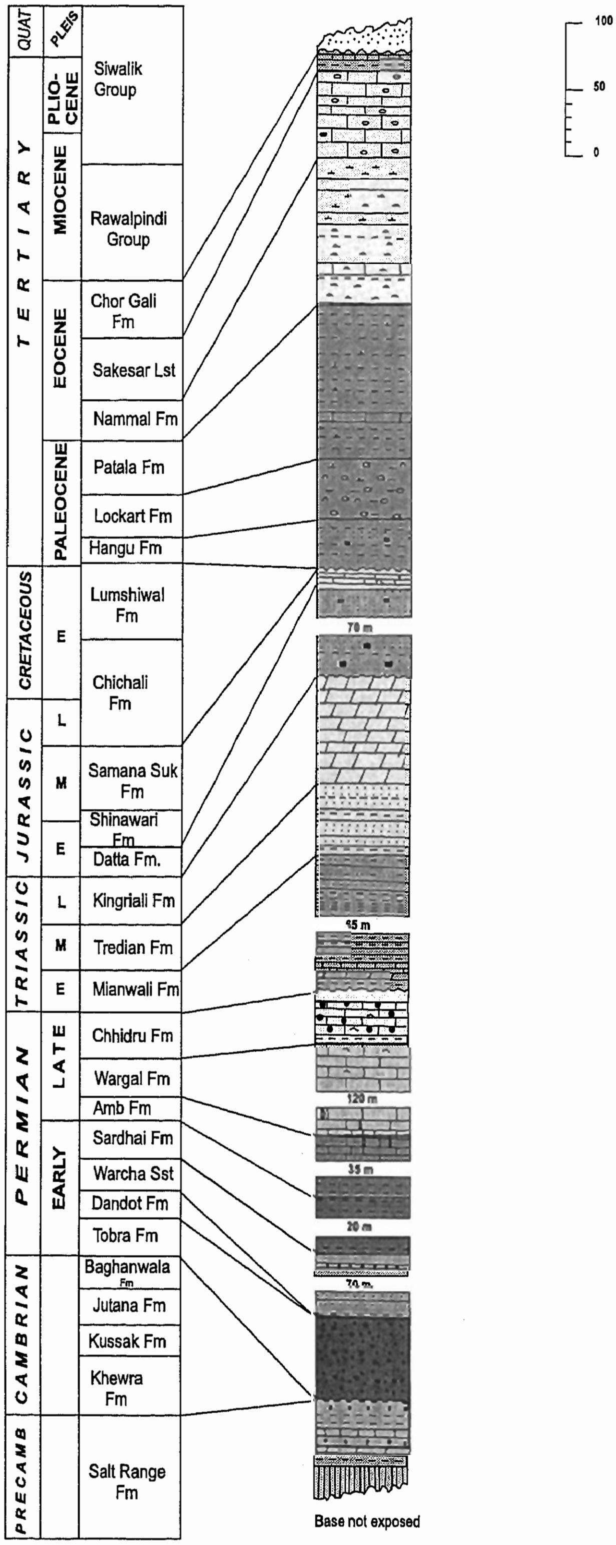


Table. 3.1. Columnar section of the sedimentary sequences in the western Salt Range.

3.3 PERMIAN SEQUENCE

The Permian sequence of the Zaluch Nala is divisible in to two parts that is Early and Late Permian.

EARLY PERMIAN

The Early Permian stratigraphy of the Zaluch Nala comprises Nilawahan Group. The Nilawahan Group includes the following Formations from bottom to top.

3. Sardhai Formation
2. Warcha Sandstone
1. Tobra Formation

3.3.1. Tobra Formation

The term Tobra Formation has been introduced by Gee (1934) for the lowest unit of the Nilawahan Group after the Tobra village of the eastern Salt Range.

In the Zaluch Nala section (western Salt Range), the unit exhibits a complex facies of diamictite, sandstone and boulders beds of probably marine origin. Here the formation is divisible into three units. The lower unit consists of massive unsorted detrital material of brown, green colors. Small pebbles of quartzite and other rocks are embedded in the above matrix (Figure. 3.1). Large pebbles and small boulders with faceted surfaces and striations are also found. The middle part comprises sandstone, which is dark to light grey, medium- to coarse-grained, thick-bedded with conglomerate beds at the base and in pockets near the top. The upper part of the formation resembles the lower one and comprises light gray to dark green clay and sandstone with pebbles and boulders and have yielded spores, pollen grains and microplanktons. The thickness of the formation in the Zaluch Nala is 400 feet, which is the maximum thickness of the formation exposed. The stratigraphic relationship of the Tobra Formation in the Zaluch Nala exhibit that its lower contact is not exposed and it conformably underlies Warcha Sandstone. The major fossils found in the Zaluch Nala are pollens, spores and microplanktons (unit 21C member of Teichert, 1967).

The age of the Tobra Formation is assigned Early Permian based on the fossils Striatopodocarpites, Protohahaploxypinus found in it. (Balme, *in* Teichert, 1967).

Figure 3.1. Outcrop of Tobra Formation showing light grey sandstone with granitic pebbles.

3.3.2. Warcha Sandstone

The term Warcha Sandstone was introduced by Hussain (1967), which has been approved by the Stratigraphic Committee of Pakistan. The Warcha Sandstone in Zaluch and Chitta Wahan Nala mainly consists of sandstone with alternation of carbonaceous shale and also some coal beds in the lower parts. The sandstone is dark red, purplish and light in color. The sandstone is cross-bedded (Figure 3.3). It is medium- to coarse-grained, occasionally pebbly, friable and is partly arkosic. The pebbles are mostly of pink granite and quartzite. The sandstone is locally speckled.

The formation is widely distributed in the Salt Range and attains maximum thickness at Zaluch Nala where it is about 184 m (550 feet) thick. The formation overlies the Tobra Formation of Early Permian age at Zaluch Nala, whereas the Dandot Formation is missing. It is conformably overlain by the Sardhai Formation with a transitional contact, which is placed at the top of the highest massive sandstone.

No diagnostic fossils are known from this formation except for worn-casts and petrified wood. The age of the Warcha Sandstone is considered to be Early Permian, because both the overlying and underlying formations are of that age (Shah, 1977).

3.3.3. Sardhai Formation

Gee (1934) introduced the name Sardhai Formation to the Lavender clays of Wynne (1878) after Sardhai Gorge in the Western Salt Range (Lat 32° 41′ N; Long 72° 43′ E), Mianwali district, Punjab province. Before the establishment of the name Sardhai Formation of Gee (1934), Noetling (1901) regarded it "the upper part of the Warcha Group". The formation consists of clay and subordinate carbonaceous shale (Figure 3.4) with chalcopyrite and gypsum and minor sandstone in the upper part. The clay is lavender, bluish and greenish grey in color. Occasional calcareous and chert bands are also present in the upper part.

The formation is 65 m (200 feet) thick at the Zaluch Nala. The contact relationship with the lower Warcha Sandstone and upper Amb Formation is conformable (Figure 3.4).

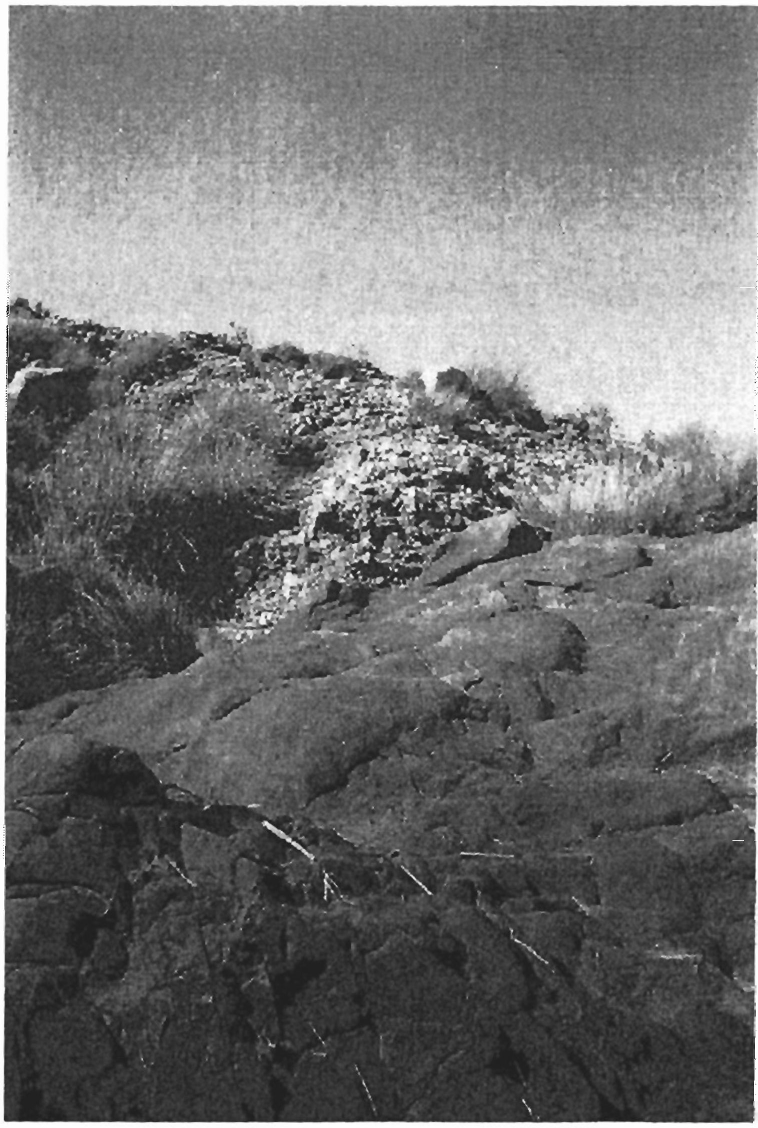


Figure 3.2. Thick bedded, pink colored sandstone of Warcha Sandstone.

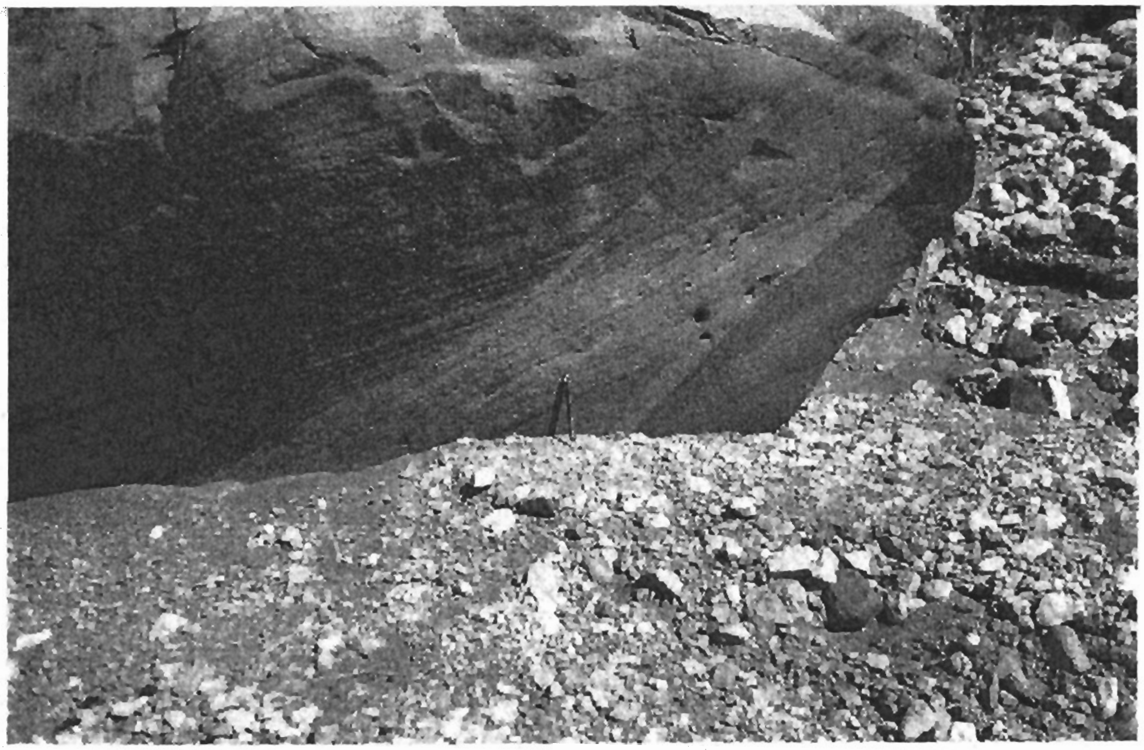


Figure 3.3. Massive, cross-bedded sand stone of Warcha sandstone, exposed along Zaluch Nala.

Figure 3.4. Outcrop of grey, brown and yellow colored clays within Sardhai Formation, conformably overlain toward top by the Amb Formation.

The Sardhai Formation is mostly unfossiliferous except for some fish scales and indeterminate shell fragments and some plant remains are also reported. Some bryozoans and brachiopods from the limestone beds has reported by (Hussain (1967). On the basis of these fossils the age of the formation is Early Permian.

LATE PERMIAN

The Late Permian fauna in the Western Salt Range is represented by Zaluch Group, which includes Amb, Wargal and Chiddru Formations from bottom to top.

3.3.4. Amb Formation

The Amb beds of Waagen (1891) are formalized as Amb Formation on the proposal of Teichert (1966) after the Amb Village where it is best exposed in the Central Salt Range, Punjab province. The name Amb Formation has been proposed from the village of Amb, 2 miles to the southeast in the Warcha Gorge (Lat 32° 27′ N, Long 71° 59′E), Central Salt Range, Punjab province, which is considered the type section for the formation.

The Amb Formation comprises sandstone, limestone and shale. The formation is predominantly sandy limestone or calcareous sandstone, which is grey in color and is medium- to thick-bedded (Figure 3.5). In the Amb Formation there are few sandstone beds of greenish grey and light brown color and are present in the lower part of the formation. The sandstone is fine- to medium-grained and is medium- to thick-bedded. The calcareous beds associated with the sandstone contain abundant fusulinid. Upward in the sequence(appears) limestone with (some) shale. The limestone is sandy, brownish grey, medium-bedded and richly fossiliferous, having productus such as *Dorloyia and Neospirifer*.

The shale is dark grey in color and is carbonaceous, consisting pyrite at places. Shale carrying.Glossopteris and Gangamopteris occurs as intercalation in the upper part. The formation is widely distributed in the Salt Range and in the Trans Indus Ranges. The thickness of the formation in the study area is about 80 m (150 feet). Stratigraphically the Amb Formation conformably overlies the Sardhai Formation and underlies the Wargal Limestone. The entire formation is highly fossiliferous (Pascoe, 1959). Pascoe described the presence of rich fauna from the formation, which consist of fusulinids, bryozoans, brachiopods, bivalves and gastropods. Kummel and Teichert (1970) have reported Ostracodes. The important index fossils reported from the formation indicates Artinskian (early permain) age for the Amb Formation (Dunbar, 1933, Teichert, 1966; Douglas, 1968). The age of the Amb Formation on the basis of fossils is considered early Permian.

Figure 3.5. Photograph showing light grey sandy limestone (in the lower part) the Amb Formation along its contact with the lower Sardhai Formation.

3.3.5. Wargal Limestone

The Wirgal Group of Noetling (1901) is formalized as Wargal Formation after the Village Wargal in the Salt Range, Punjab province. The type locality of the formation is Munta Nala, ½ to 1½ mile west of Wargal village (Lat 32° 28′ 30″N; Long 72° 03′ 30″E), Central Salt Range, Punjab province. Zaluch Nala (Lat 32° 47′ N; Long 71° 39′ E),Western Salt Range,(district) Mianwali, Punjab province has been designated as principle reference section.

The formation is essentially a carbonate unit consisting of limestone and dolomite (particularly in the lower part) with very subordinate sandstone and sandy limestone (Figure 3.6). The middle part of the formation has dolomitic limestone and chert nodules. The upper most part of the Wargal Formation is characteristically nodular and is crinoidal in places.The Wargal Formation is widely distributed in the Salt Range and extends into Trans Indus Ranges. The formation is about 183 m (507 feet) thick in the Zaluch Nala.

The contact of the Wargal Formation with the underlying Amb Formation is well defined and is placed above the uppermost shale unit of the Amb Formation. The upper contact of the formation with the Chhidru Formation is transitional.

There are abundant fossils present in the Wargal Formation such as brachiopods with sponges, bryozoans, corals, bivalves, gastropods, nautiloids, trilobites crinoids and other fossil groups such as ostracodes and fishes. Pascoe, (1959) and Ustritsky, (1962) placed the formation in the Late Permian on the basis of brachiopods found in the Wargal Limestone.

3.3.6. Chhidru Formation

The "Chhidru beds" of Waagan (1891) and "Chhidru Group" of Noetling (1901) was formalized by the Stratigraphic Committee of Pakistan as Chhidru Formation.The type locality of the formation(where it has best expousure) is Chhidru Nala (Lat 32° 31′ N; Long 71° 48′E), Western Salt Range, (district), Mianwali Punjab province.

The lithology is dominated by dark, soft, sandy and shale unit in the Chhidru Formation. The thickness of this unit ranges from 6 to 13 m (20 to 45 feet). The pale yellowish grey to medium grey shale is located towards the base containing ostracodes and brachiopods followed by fossiliferous, calcareous sandstone and sandy limestone. According to Teichert and Kummel (1970), the upper most richly fossiliferous unit is light grey, hard, sandy limestone or calcareous sandstone. The characteristic bed is a white sandstone unit present in most sections of this formation near the contact with the basal dolomite unit of Mianwali Formation of early Triassic age.

The Chhidru Formation is widely distributed in the Western Salt Range and in the Trans Indus Ranges. The thickness of the formation in the study area is 64 m (193 feet).The Chhidru Formation is conformably underlain by the Wargal Limestone and is marked by a paraconformity with the overlying Mianwali Formation of Early Triassic age (Figure. 3.7).

The fauna in the formation consists of brachiopods, bivalves, gastropods, crinoids, bryozoans, crinoids, nautiloids, ammonites and some conodonts. The age of the formation on the basis of the ammonoids is considered to be Late Permian (Shah, 1977).

Figure 3.6. An Outcrop of the limestone in the Wargal Formation.

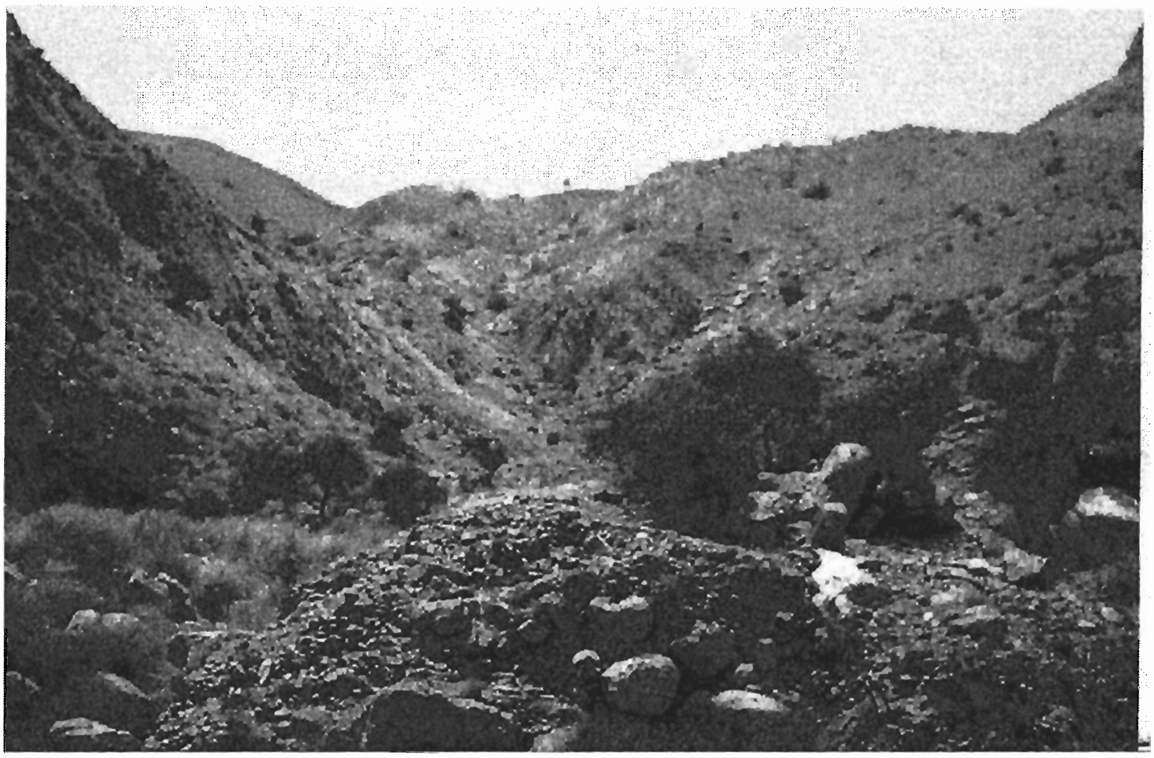


Figure. 3.7. Photograph showing the Paraconfermable contact between the Chhidru and Mianwali formations, view towards NNW direction.

3.4. TRIASSIC SEQUENCE

The Triassic system (in the Zaluch Nala, Western Salt Range, Punjab). is represented by Mianwali, Tredian and Kingriali formations.

3.4.1 Mianwali Formation

The term “Mianwali Formation” was approved by Stratigraphic Committee of Pakistan to represent the lower part of “Mianwali Series” of Gee (in Pascoe, 1959), after the district town of Mianwali in the Punjab province. The section exposed in Nammal Gorge (Lat 32° 40′N; Long 71° 48′E) Western Salt Range, Mianwali district, Punjab province has been designated as type section.

The Mianwali Formation in the Zaluch Nala, Western Salt Range includes varied facies consisting of marl, limestone, sandstone, siltstone and dolomite, which is thicker in the west and wedges out towards east. Three members namely Narmia, Mittiwali and Kathwai have been recognized by Kummel (1966), which corresponds to the three subdivisions recognized by Waagen (1879, 1895).

The Lower *Kathwai Member* consists of dolomite in the lower part and limestone in the upper part. The dolomite is finely crystalline and includes fossil fragments (mainly of Ammonites and Echinoderms) and quartz grains. The total thickness of Kathwai Member is 11½ feet in Zaluch Nala.

The Middle *Mittiwali Member* is the thickest unit (388 feet in Zaluch Nala) of the Mianwali Formation. The Mittiwali Member consists of limestone, marl and shale with subordinate sandstone (Figure 3.8). The limestone is grey, fine-grained with abundant Ammonites. The rest of the unit consists of greenish and greyish shale, silty shale with some sandstone and limestone interbeds. The unit is richly fossiliferous and most of the fossils are restricted in lenticular limestone beds.

The Upper *Narmia Member* is equivalent to “Bivalves Beds” and “Dolomite Unit” of Waagan (1895). The basal beds of the Narmia Member are approximately 10 feet thick and consist of limestone, which in Zaluch Nala are dark grey to brown and fragmental, in part containing Brachiopods, Bivalves and Ammonites. The rest of the members consist of shale, which is grey to brown in color with interbeds of sandstone, lenticular limestone or dolomite. The top most dolomite bed is (massive) and in colour grey to brown.

The thickness of the formation in the Zaluch Nala is 411 feet (about121 m). The lower contact of the formation with the Chhidru Formation of Late Permian age is marked by a Paraconformity while the upper contact with the Tredian Formation is sharp and well defined (Figure 3.9). Forams, Ostracods, crinoids and conodonts found in Mianwali Formation (Iqbal et al. 1980); it has been assigned an Early Triassic (Fatmi 1972).

3.4.2. Tredian Formation

The Name Tredian Formation was introduced by Gee (1945) to replace his earlier name "Kingriali Sandstone" (Gee, 1945) after the Tredian Hills in Mianwali district of Punjab province. The section exposed in the Tredian Hills (Lat 32° 43′ N; Long 71° 46′ E), (District) Mianwali, Punjab province has been designated as the type section.

The formation is divisible into two members, a Lower *Landa Member* and an *upper Khatkiara Member.* The name Landa Member was proposed by Kummel (1966) after Landa Nala (Lat 32° 57′N; Long 71° 12′ 30E) in the Surghar Range. It consists of sandstone and shale. The sandstone is micaceous and varies in color from black, pink, red and grey to greenish grey. It is thin- to thick-bedded with ripple marks and cross-beds (Figure 3.10).

The name Kathkiara member is after Khatiara Nala (Lat 32° 56′ N; Long 71° 11′E) in the Surghar Range Kummel (1966). It consists of massive, thick-bedded white sandstone that grade into the overlying Kingriali Formation with some dolomite beds in the upper part. The total thickness of the formation in the Zaluch Nala is 72 feet (36 m) in the Western Salt Range. The formation is conformably underlain by the Mianwali Formation and is conformably overlain by the Kingriali Formation (Figure 3.11).

No fossils have been found in this formation except some carbonaceous remains. On the basis of its stratigraphic position over the Mianwali Formation of Early Triassic age and its conformable contact with the overlying Kingriali Formation, the age is apprehensively assigned as Middle Triassic. Balme (1970) also supports the Middle Triassic age from the study of spores and pollens.

Figure 3.8. Green shale with interbedded flaggy limestone exposed along Zaluch Nala within the Mittiwali member of Mianwali Formation.

Figure. 3.9. Sharp, well define contact between the Mianwali and Tredian Formations along Zaluch Nala section, Western Salt Range.

Figure. 3.10. Cross-bedded, gray colored sandstone within the Tredian Formation along Zaluch Nala.

3.4.3. Kingriali Formation

The "Kingriali Dolomite" of Gee (1945) is formalized as Kingriali Formation after the Kingriali Peak in the Khisore Range, (district) D.I Khan, N.W.F.P. The section exposed along Kingriali Peak (Lat 32° 14′ E; Long 71° 02′ N), Khisore range has been designated as the type section.

The Kingriali Formation in the Zaluch Nala section dominantly consists of dolomite and dolomitic limestone. These rocks are light grey to brown in color; fine to coarse-textured and occurs in thin to thick-massive beds. The limestone is white to light grey with a very light greenish tint, at places dolomitic, very fine-grained, medium-bedded and breaks with concoidal fractures. There also are interbeds of greenish dolomitic shale and marl in the upper part of the formation. The thickness of the formation in the Zaluch Nala varies from 76 m to 106 m.

The formation conformably overlies the Tredian Formation in the Zaluch Nala, Western Salt Range. Transitional beds of sandstone and dolomite mark the lower contact with the Tredian Formation. The upper contact with the Datta Formation is disconformable as indicated by the development of ferruginous dolomite and the uneven surface at the base.

Fossils are rare and poorly preserved. Some bivalves, crinoidal remains and brachiopods have been reported.(Shah, 1977) Based on its transitional contact with the underlying Tredian Formation and disconformable contact with the overlying Datta Formation Early Jurassic or Late Triassic age has been assigned (Shah, 1977).

3.5. JURASSIC SEQUENCE

In the Zaluch Nala the Jurassic sequence comprises the following formations from bottom to top.

3. Samana Suk Formation
2. Shinawri Formation
1. Datta Formation

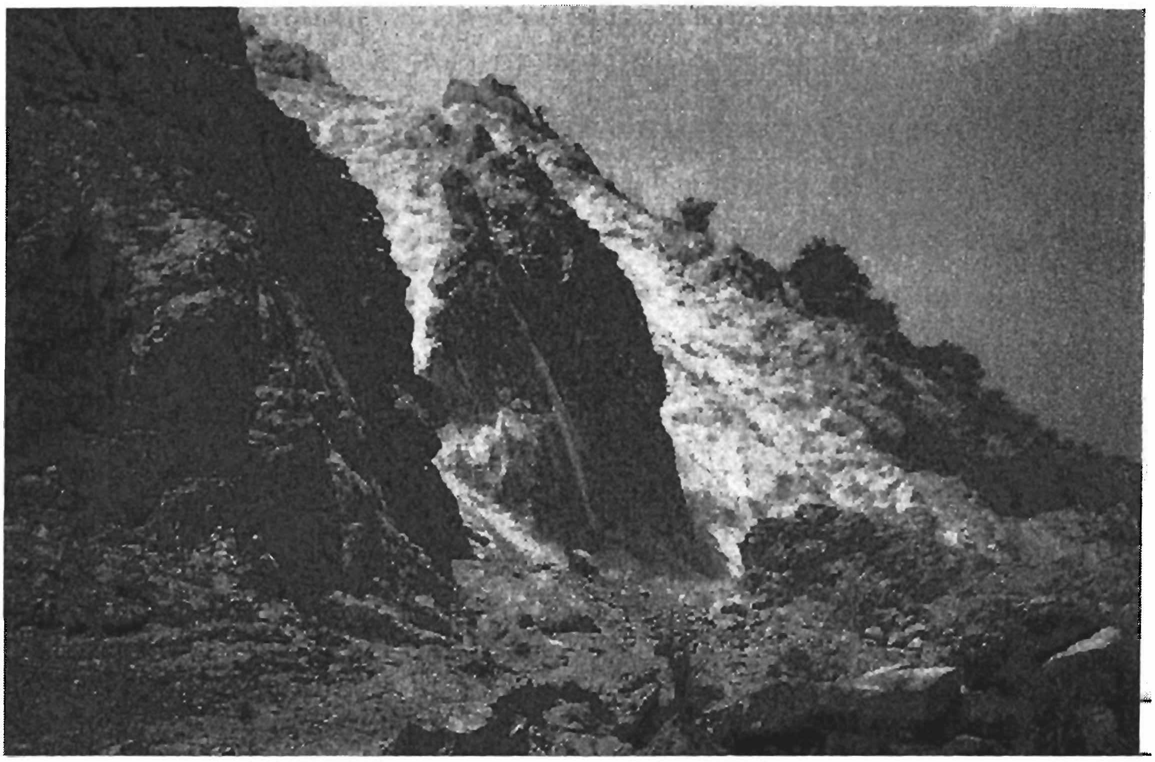


Figure. 3.11. Contact between Tredian and Kingriali formations exposed along Zaluch Nala, Western Salt Range.

3.5.1. Datta Formation

The name Datta Formation was introduced by Danilchik (1961) and Danilchik and Shah (1967) to replace the "Variegated stage" of Gee (1945) and earlier workers. The formation is named after Datta Nala, also locally referred to as Sadhri Nala, where the formation is best exposed and it follows along the road leading to Datta Coal Mines (Lat 33° 00'N; Long 71° 19'E).

The lithology of the formation in the study area is dominantly represented by alternating layers of varicolored sandstone, shales, siltstones and limestone (Figure. 3.12). The sandstone is varigated, fine- to medium-grained and is commonly medium-bedded in the lower part and become massive to thick-bedded to towards the top. Thin- to medium-bedded carbonaceous siltstone interbeds are commonly associated with sandstones. Thin- to medium-beds of bluish grey limestones are interbedded with varicolored shales and sandstones from base towards top. The beds of dusty yellowish brown limestone with a thick bed of maroon shale and sandstones are confined to the uppermost part of the formation. The formation contains thin coaly lenses at various places as well.

The formation has disconformable contact with the underlying Triassic rocks throughout its lateral extent in the Salt Range and Trans Indus Ranges.In the Zaluch Nala it unconformably overlies the Kingriali Formation where as its upper contact with the Shinawri Formation is gradational. The thickness of the formation in the study area is about 150 m and at the type section, it is 212 meters.No diagnostic fossils have been reported from the formation except some carbonaceous remains. As the formation underlies the Shinawri Formation, which in its lower part has yielded lower Toarcian ammonites, an Early Jurassic age has been assigned to it by the previous workers (Shah, 1977).

Figure. 3.12. An Outcrop of Datta Formation showing varicolored Sandstones.

3.5.2. Samana Suk Formation

The name "Samana Suk" has been introduced by Davies (1930) for the Jurassic limestone in Samana Range. The name Samana Suk is derived from the peak of this name in the Samana Range (Lat 33°50′ N; long 70°50′10″E). The name is extended to include similar limestone sequences in the Salt Range and Trans-Indus Ranges (Baroch Limestone of Gee, 1945) and Kala-Chitta Range (Upper part of Kirto Limestone of Cotter, 1933). Fatmi (1968) designated a section) of the Western part of the Samana Range north east of Shinawari (Lat 33° 31′ 13″ N; Long 70° 48′ 06″ E as the type locality.

The formation dominantly consists of limestone and sandstone with subordinate conglomerates and clay-stones. The formation consists of grey, medium to thick-bedded, limestone with subordinate marl and calcareous shale intercalations (Figure 3.13). The limestone is oolitic and has some shelly beds. The sandstone is pale, yellowish, and brown in color. It is dolomitic, sandy, and fossiliferous and makes beds up to 3 feet thick. The sandstone is light yellowish brown, calcareous and condensed bed of clay in the middle of the unit. The conglomerate is brownish gray, lenticular, fossiliferous and consists shells and fragments of limestone cemented together in arenaceous matrix. Thickness in the type locality is 186 m.

The lower contact is transitional with the Shinawari Formation and is placed at the top of the last sandstone unit of the Shinawari Formation. Its upper contact with the Chichali Formation is disconformable in the Chichali pass section. The Middle Callovaian fauna has been recorded in the Surghar Range (Fatmi, 1968, 1972).

The age of the Samana Suk Limestone was determined as late Jurassic (late Callorian), on the basis of Cephalopod fauna described by Spath (1939). However, Fatmi (1972) on the basis of Middle Callovian ammonites which he described from richly fossiliferous section in the Datta, Landa, Mallakhel and Makarwal area considered the formation to be lower to Middle Callovian (Middle Jurassic) age.

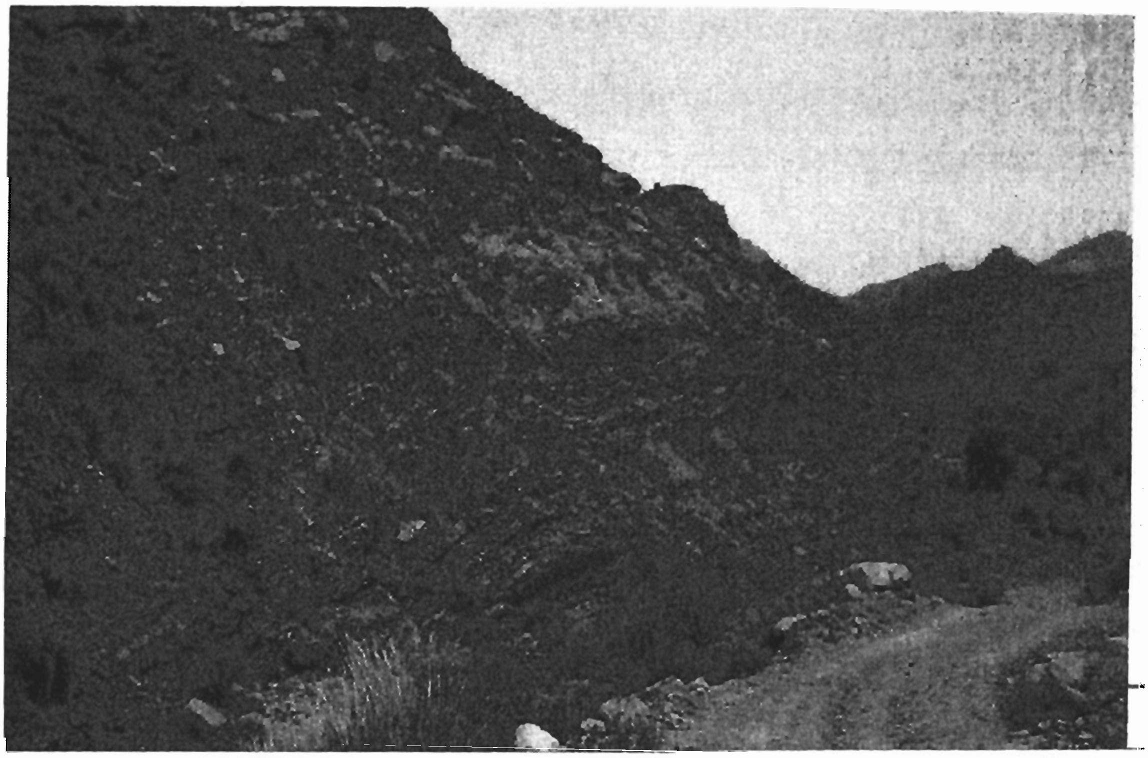


Figure. 3.13. Photograph showing medium to thin- beds of limestone interbedded with gray shale, along Zaluch Nala.

3.6. CRETACEOUS SEQUENCE

The Cretaceous Sequence comprises of the following formations from bottom to top.

2. Lumshiwal Formation
1. Chichali Formation

3.6.1. Chichali Formation

The "Belemnite beds" of Spath (1938), Gee (1945), Danilchick, and Shah (1967) after the Chichali Pass, in the Surghar Range where it is best exposed. The formation predominantly consists of dark, greenish grey glauconitic sandstone. The lower part of the formation is grey, calcareous claystone about 50 feet thick. The middle part of the formation is composed almost entirely of sand sized glauconite grains. The content of glauconite decreases upward. The glauconite sandstone and green sand are well cemented by calcium carbonate, although on outcrops both the green sand and glauconitic sandstones are friable and loosely coherent because of weathering. Beneath the weathered surfaces, the rock is firm and forms steep cliffs. Abundant belemnite, ammonite fossils are present in the formation. The grain size of the glauconitic sandstone of the Chichali Formation decreases upward, and the upper contact is placed at the base of relatively coarser grained and lighter colored sandstone of the Lumshiwal Formation. Its lower contact with Samana Suk Formation is disconformable where as its upper contact with Lumshiwal Formation though well defined, appears gradational. In the study area, the thickness is found to be 50 m.

The age of the formation, based on Cephalopods from Chichali Pass described by Spath (1939), is considered to be Early Cretaceous.

3.6.2. Lumshiwal Formation

The "Lumshiwal Sandstone" of Gee (1945), was later on referred to as the Lumshiwal Formation by Fatmi (1973). The type locality is one km north of Lumshiwai Nala in the Salt Range.

The lithology consists of light grey, locally iron stained, medium- and coarse-grained, thick-bedded sandstones containing beds of coaly shales and coal in the upper part. The sub rounded grains are coarse in the upper part of the formation. Pebbly bands are found locally near the top of the formation. The sandstone, which is commonly pyritic, decomposes to gypsiferous sandstone. The type locality of the section has been designated as the Patala Nala (Lat, 32°40′ N; Long, 71°49′ E) in the Central Salt Range. In the study area, the formation consists of shale and marl with subordinate limestone and sandstone. The shale is dark greenish grey, selenite bearing, in places carbonaceous and calcareous and also contains marcasite nodules. The limestone is white to light grey and nodular and occurs as interbeds. Subordinate interbeds of yellowish brown and calcareous sandstone are present in the upper part. Coal seems of economic value are present locally.

Throughout its extent, the Patala Formation conformably overlies the Lockhart Limestone. The Patala Formation is conformably and transitionally overlain by the Nammal Formation in the Salt Range. The formation is richly fossiliferous and contains abundant foraminifers, molluscs and ostracodes. From the Salt Range, Smout and Haque (1956) recorded larger foraminifera including Actinosiphon Tibetica, Assilina dondoticg etc. The smaller Foraminifera as reported by Haque (1956) include *Glandulina laevigata* etc.The formation has been assigned a Late Paleocene age throughout its extent, except for the Hazara area where it extends into the Early Eocene age (Shah, 1977).

3.7 PALEOCENE SEQUENCE

In the study area the Paleocene sequence is represented by Makarwal group and consist of the following formations.

3. Patala Formation.
2. Lockart Formation.
1. Hangu Formation.

3.7.1 Hangu Formation

(Davies 1930, Fatmi 1973) it unconformably overlies various formations of Paleozoic to Mesozoic age. The type locality is south of Fort Lockhart in Samana Ranges. It consist of grey to brown, fine to coarse-grained, silty and ferruginous sandstone which grades upward into fossiliferous shale and calcareous sandstone. At places, the formation is intercalated with grey argillaceous limestone and carbonaceous shale. Its thickness ranges from about 15m in Hazara to 150m at Kohat pass. The formation contains mollusk, corals, and foraminifera (Gregory 1930, Iqbal 1972). The Hangu Formation is Early Paleocene in age.

3.7.2 Lockart Limestone

(Davies 1930, Fatmi 1973): this unit conformably overlies the Hangu Formation. Its type section is exposed near Fort Lockhart. It consists of grey, medium to thick bedded and massive limestone, which is rubbly and brecciated at places. In Hazara and Kalachitta it contains subordinate intercalations of grey marl and shale. Its thickness ranges from about 30m to 240m. it contains foraminifera, corals, molluscs, echinoids and algae (Davies and Pinfold 1937, Davies 1943, Latif 1970c). Some of the important larger foraminifera comprise *Operculina Subsalsa, Lepidocyclina Punjabensis, Assilina Badotica*. The age of the Lockhart Limestone is Paleocene.

3.7.2 Patala Formation

(Davies and Pinfold 1937): It overlies the Lockhart Limestone conformably and its type section is in the Patala nala in the western Salt Range. It consists a largely of shale with subordinate marl, limestone and sandstone. Marcasite nodules are found in the shale. The sandstone is in the upper part. The formation also contains coal (Warwick et al. 1988a, 1990) and its thickness ranges from 27m to over 200m. it contains abundant foramnifira, molluscs and ostracodes (Davies and Pinfold 1937, Eames 1952, Latif 1970c). The larger foraminifera include Lockhartia conditi, Nummulites Globosa, Assilina dandotica. The age of the formation is late Paleocene.

3.8 EOCENE SEQUENCE

In the study area the Eocene sequence consists of the following two formations from top to bottom.

2. Sakesar Formation
1. Nammal Formation

3.8.1. Nammal Formation

The term Nammal Formation has been formally accepted by the Stratigraphic Committee of Pakistan for the 'Nammal Limestone" and "Shale" of Gee (in Fermor, 1935) and "Nammal Marl" of Danilchik and Shah (1987) occurring in the Salt Range and Trans Indus Ranges. The section exposed in the Nammal Gorge (Lat, 32°40′ N; Long, 71°07′ E) is the type locality.

The formation, throughout its extent, comprises shale, marl and limestone. In the Salt Range these rocks occur as alternations. The shale is grey to olive green, while the limestone and marl are light grey to bluish grey. The limestone is argillaceous in places. The formation is well-developed in the Salt and Surghar Ranges. It is 100 m thick in the Nammal Gorge and thins out westward to 60m at Khairabad. The lower contact with the Patala Formation and upper contact with the Sakesar Limestone are transitional.

Abundant fossils, mainly foraminiferas and molluscs, have been reported by khan, M.H (personal Communication, 1969). The larger foraminifers reported are *Nummulities atacicus, N. Laharii, N. irregularis, Assilina granulosa.*(Haque 1956) recorded abundant smaller foraminifers from the type section which includes *Alabamina wilcoxensis, Dentalina* *plummerae, Globigerina linaperta* and others. On the basis of these faunas, an Early Eocene age has been assigned to the formation.

3.8.2. Sakesar Limestone

The term Sakesar Limestone was introduced by Gee (*in* Fermor, 1935) for the most prominent Eocene limestone unit in the Salt and Trans-Indus Ranges. The Sakesar Peak (Lat 32°31′ N; Long, 71°56′ E) in the Salt Range has been designated as the type locality.

In the study area, the formation dominantly consists of limestone with subordinate marl. The limestone throughout its extent is cream colored to light grey, nodular usually massive with considerable development of chert in the upper part. The marl is cream colored to light grey and forms a persistent horizon near the top. The formation is widely distributed in the Salt Range and Surghar Range. In the Salt Range its thickness varies between 70 m and 150 m. The lower contact with the Nammal Formation is conformable and in the study area its upper contact is not exposed.

The formation has yielded a rich assemblage of *foraminifera, molluscs and echinoids*. Some of the important foraminifers are *Assilina leymeriei, A. laminosea, Fasciolites oblonga, Flosculina globosa, Sakesaria cotteri* and others. On the basis of these fossils an Early Eocene age has been given to the formation (Shah, 1977).

CHAPTER NO. 4

STRUCTURAL GEOLOGY

4.1. INTRODUCTION

The structural geology of the Eastern and Central Salt Ranges has been well documented and defined by previous workers (Gee, 1980; Yeats et al., 1984; Johnson et al., 1979; Lillie et al., 1987), but little attention has been given to the structural geology of the western part of the Salt Range. The western part of the Salt Range though is well documented stratigraphically but is lacking detailed structural interpretation. The Geological mapping of the western Salt Range owes to the excellent work of Gee (1945) including the study area Zaluch-Chitta-Wahan Nala that represents the first ever geological map of the entire Salt Range on 1:50,000 scale. According to Mc Doughall and Khan (1990), the Kalabagh Fault Zone extends 120 km from the southwestern corner of the Salt Range near Khushab to the southern Kohat Plateau and is characterized by right lateral transpressional deformation, (Figure. 1.2) clearly demonstrates that the proposed study area occupies a part of the main Kalabagh Fault strand.

The area Zaluch-Chitta wahan Nala of the Western Salt Range has been studied for detailed structural analysis to rework the geological map of the area and to understand that whether it has deformed by strike-slip faulting associated with the Kalabagh Fault Zone or it has evolved as an oblique ramp of the frontal Salt Range Thrust and has been deformed as a compressional regime.

4.2. STRUCTURAL GEOMETRY

The present detailed geological mapping conducted in the area describes the structural geology of the region for the first time. It has been found that the structural geology of the Western Salt Range in the vicinity of Zaluch Nala is dominated by the presence of northwest trending, parallel to enechelon folds (Figure 4.1). Most of the kilometer scale folds observed in the mapped area have steeper forelimbs and gentle back limbs (Figure 4.2). The steep forelimbs generally dip between 50°-70° although dips as low as 20° have been recorded locally along the forelimbs. Folds mapped within the region are generally asymmetrical and the fold limbs are faulted out at places (Figure 4.1). Most of these folds are found to be southwest facing (Figure 4.3).

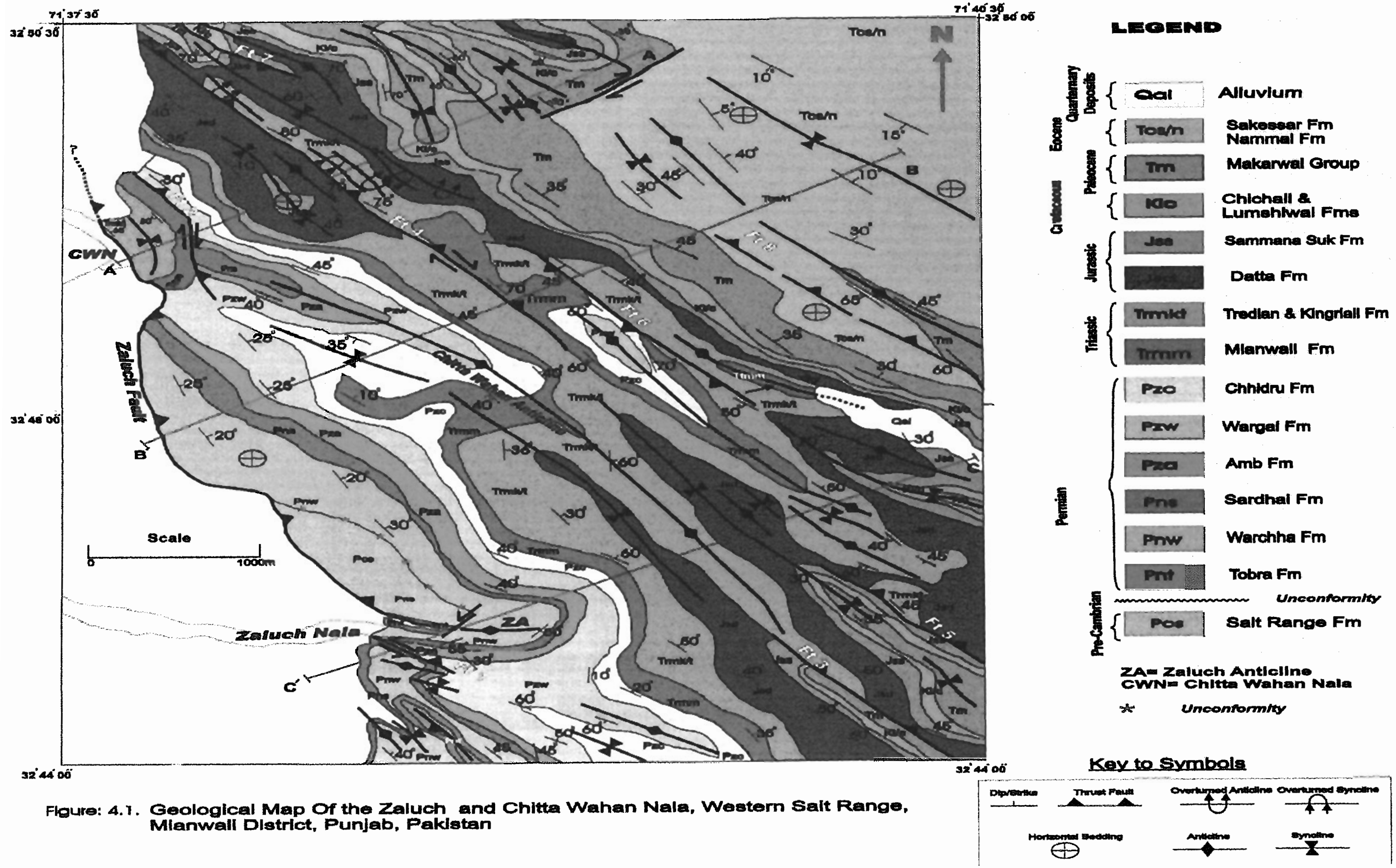


Figure: 4.1. Geological Map Of the Zaluch and Chitta Wahan Nala, Western Salt Range, Mianwali District, Punjab, Pakistan

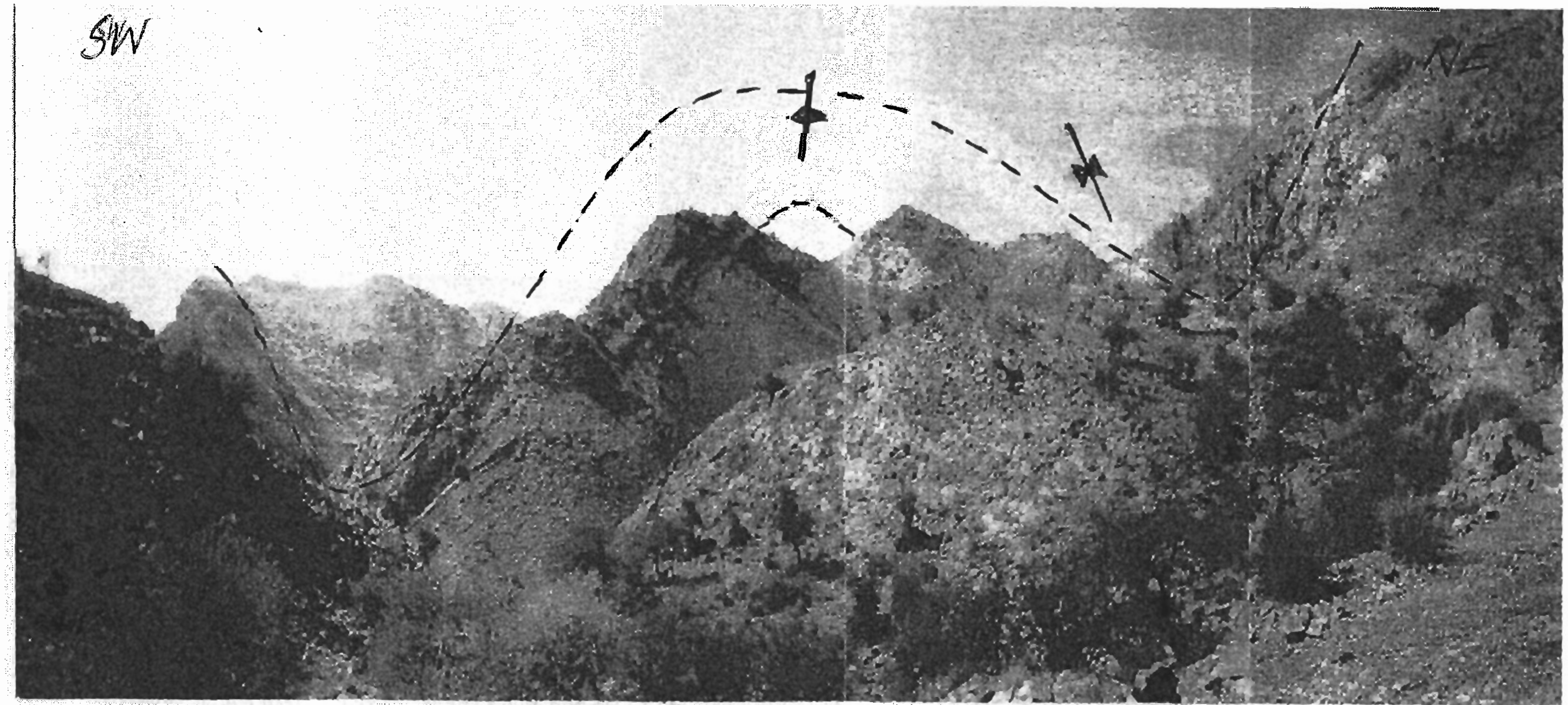
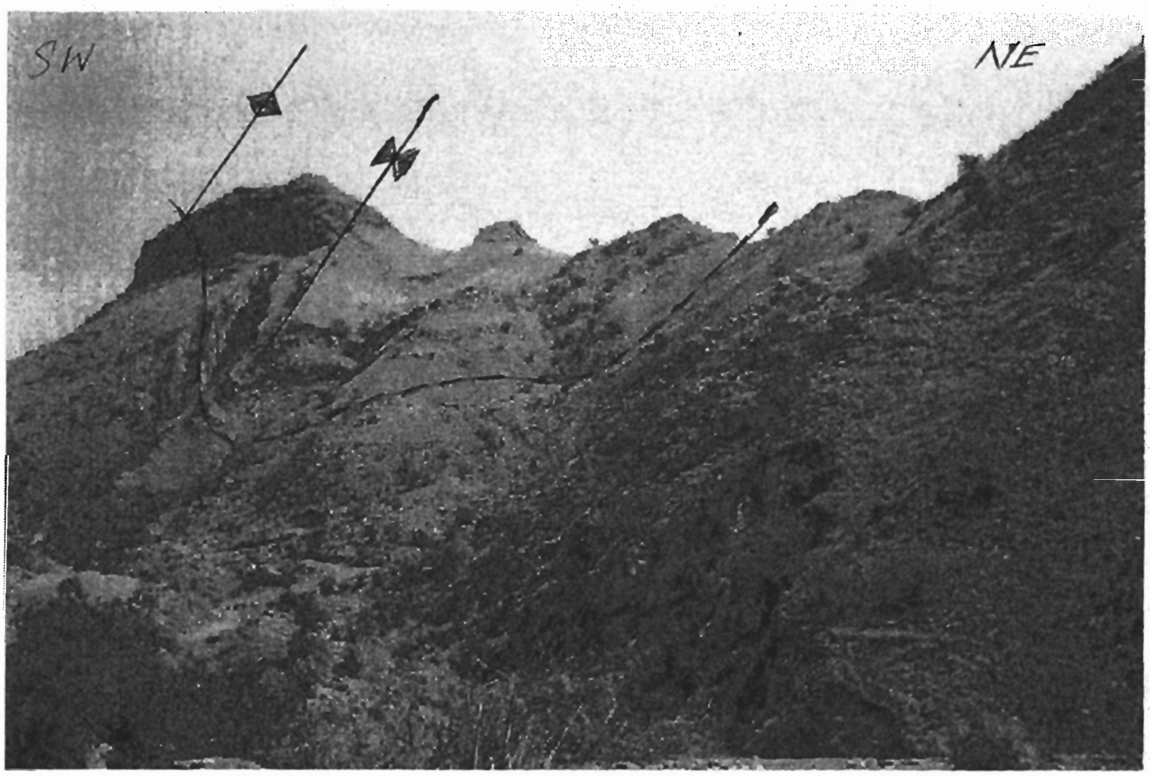


Figure 4.2. A Northwest looking view of asymmetrical fold within Jurassic rocks. Note the steep fore limbs of anticlines and gentle to moderate dipping back limbs.



4.3. Photograph Showing southeast facing folds in the Samana Suk Formation.

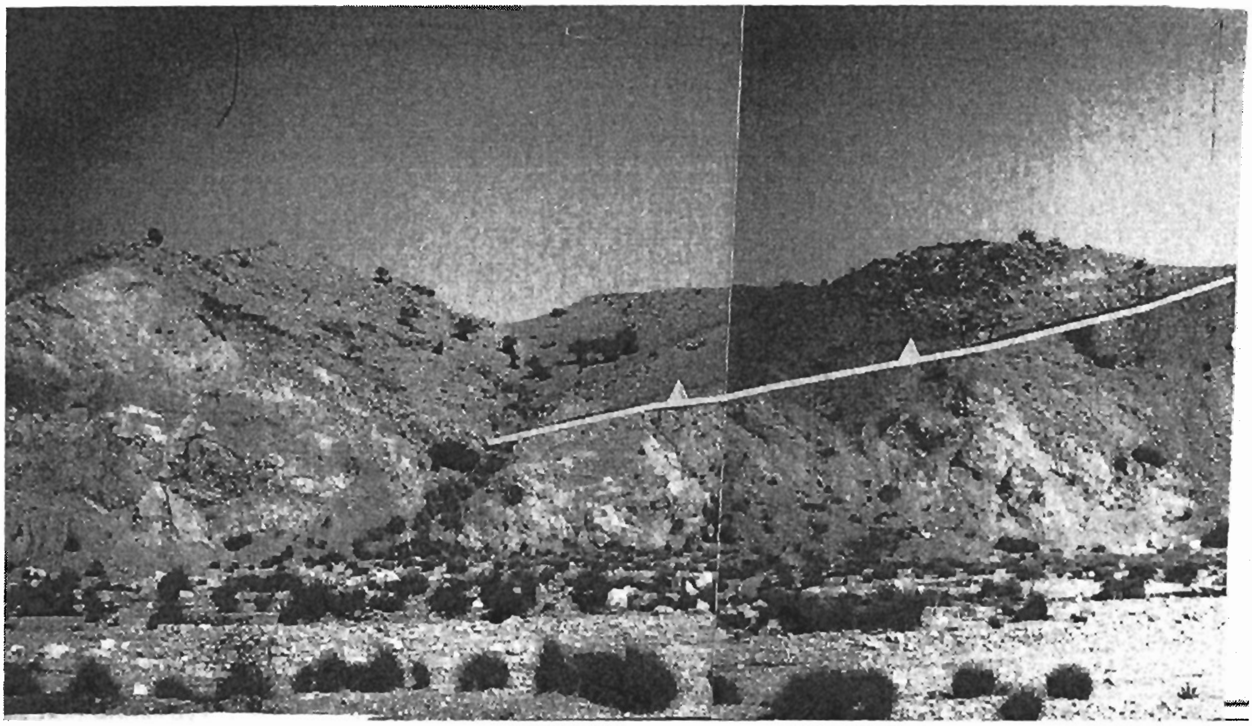


Figure 4.4. Northward looking view of fault Ft 7 along which Datta Formation is thrust over Jurassic rocks.

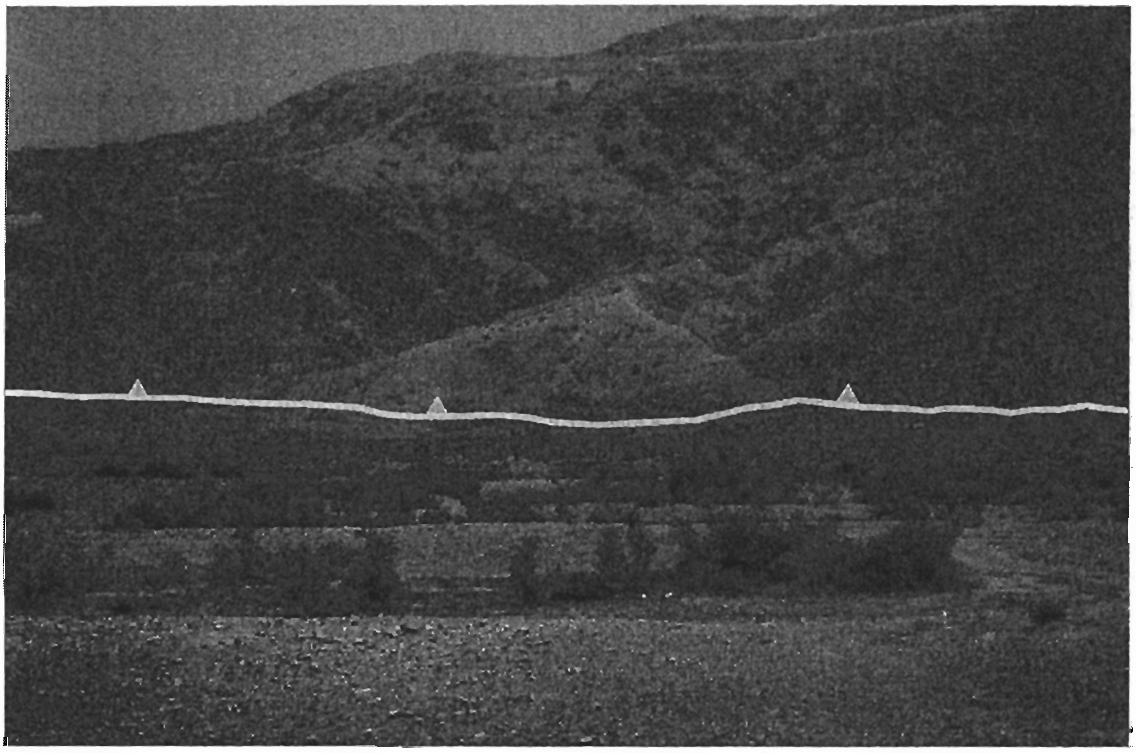


Figure 4.5. North ward looking view of the western front of the southwestern fold and thrust belt showing the Zaluch Fault. Along Zaluch Fault the Pre-Cambrian-Cambrian rocks are thrust westward over the Quaternary alluvial sediments.

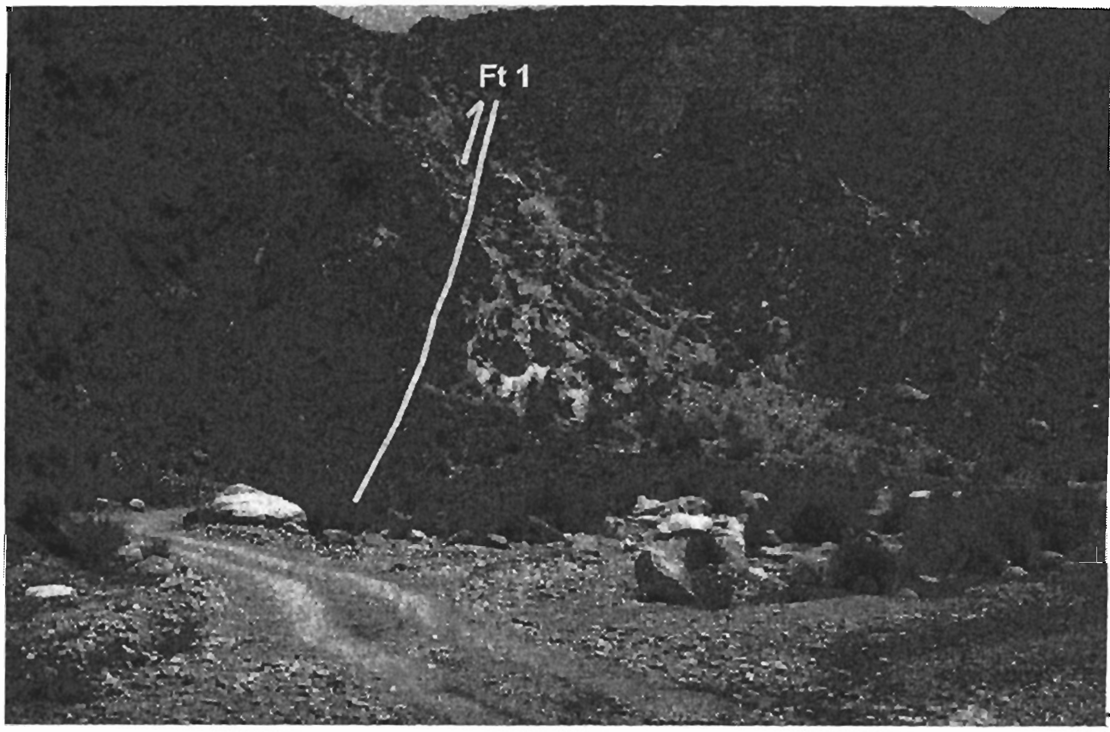


Figure 4.6. Southeast looking view of Ft1 Fault along which the Tobra Formation is emplaced over Warcha sandstone in the Footwall.

Based on the distribution of structural suites and variation in the structural style, the study area is divided into northeastern, northwestern, southeastern and southwestern domains.

4.3 NORTHEASTERN DOMAIN

The Northeastern domain lies northeast of the faults labeled as Ft6 and Ft8 on Figure 4.1. The structural fabric of this domain is dominated by a series of macroscopic scale folds. The Triassic-Eocene rocks are open to gently folded into anticlinal and synclinal trends with a northwest axial trend (Figure 4.1). The attitude data on the fold limbs suggest that in this sector of the map, the folds are gentle in the east and northeast and gradually become open as we proceed southwestward. A northeast oriented tear fault separates the northeastern domain into two sections. The section that lies north of the tear fault includes folds that trend north-northwest and are characterized by tight, upright limbs resulting in tight folds. The folds present in this section are generally developed at the level of Triassic to Jurassic succession (Figure 4.2). Whereas the folds mapped south of the tear fault are open to gentle over most of their exposures and becomes tight in the extreme south eastern corner of the map. The folds in this section are developed at the level of Triassic to Eocene rocks.

One, north west oriented thrust fault labeled as Ft8 enters the north eastern domain from the south eastern corner of the map and runs within Eocene succession without significant vertical uplift as suggested by its hanging wall and foot wall cutoffs.

4.4 NORTHWESTERN DOMAIN

The Northwestern domain lies west of the Ft6. The area is dominated by structures, which include folds, thrusts faults and strike slip faults. The folds in this domain are developed at the Permian to Paleocene age rocks and are mostly tight. Dips at the limbs vary from 40° to 70°. A major thrust (Ft4) occurs bringing the Tredian and Kingriali formation (Triassic) over the Datta formation (Jurassic) and has resulted in overturned anticline and synclines, which show strong deformation. A small tear fault (Ft2) running NS is also observed (Figure 4.1). A small back thrust (Ft7) in the northwestern corner trending

NW brings the Datta Formation over the Samana Suk Formation. The folds are oriented in NW direction. The attitude data on the folds limb indicate that these are tight to closed folds. In the extreme west the domain is marked by the Zaluch fault.

4.5 SOUTHEASTERN DOMAIN

This domain lies in the Southeastern part of the map and marked by the presence of two major thrust faults Ft3 and Ft5 and part of Chitta-Wahan anticline. Major rock units are Permian to Cretaceous in age. Rocks are mostly openly folded. The attitude data on the limbs is averaging 40-45°. Ft3 thrusts the rocks of Triassic (Datta Formation) and Tredian and Kingriali Formation over Makarwal group and also the Samana Suk Formation of Jurassic age. Ft3 also shows a lateral displacement. Ft5 thrusts Tredian and Datta Formations over Samana Suk formation.

4.6 SOUTHWESTERN DOMAIN

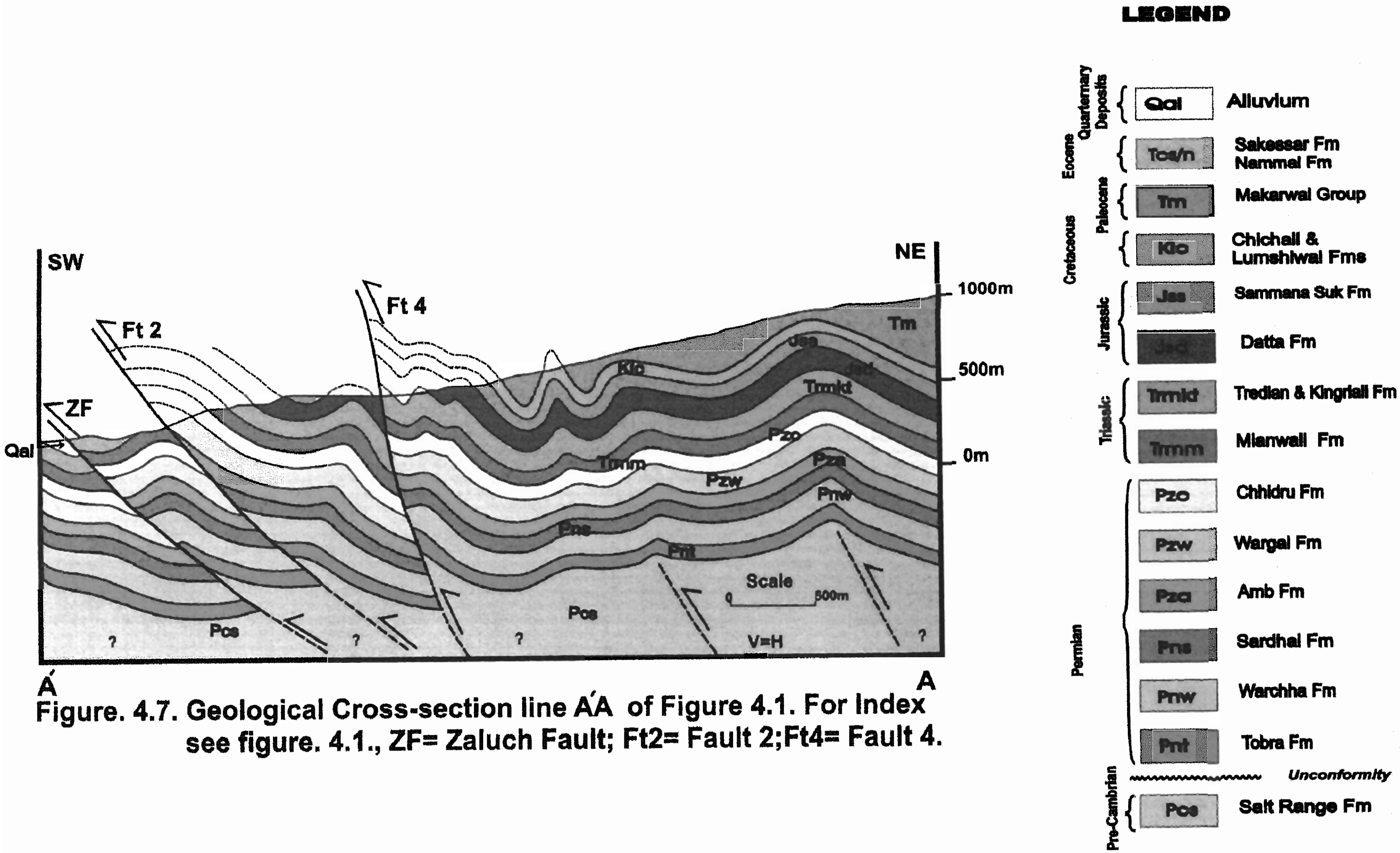
The Southwestern domain lies south west of the faults Ft3 and Ft4. In this sector of the map most of the folds are tight and asymmetric and are cored by Permian to Precambrian age rocks (Figure 4.1). A northwest trending, steeply northeast dipping thrust fault labeled as Ft4, enters the area from northwestern corner of the map and is detached at the level of Datta Formation. This fault transfers its displacement in the southeast to a series of tight folds. Two prominent anticlines the Chitta Wahan and the Zaluch occur. The Chitta Wahan anticline is cored by Permian rocks of Sardhai Formation. The attitude data on the limbs indicate that the southeastern limb is steeply dipping than the southwestern limb. This may be because of the close proximity of the Ft3 and Ft4 thrust faults. The Zaluch anticline is cored by Precambrian rocks of the Salt range Formation. The Zaluch anticline seems to be recumbent or an open upright fold.

The Zaluch Fault is the most prominent and western most of the mapped faults and constitutes the front of the southwestern fold and thrust belt in the west. The map trace of Zaluch Fault is undulating and is gently northeast dipping along its map trace (Figure 4.1). It brings the Permian and Precambrian rocks over the alluvial fans lying towards southwest (Figure 4.5). Along the southeastern end of Zaluch Fault a local scale splay fault (F1) is mapped along which the Tobra Formation is thrust over the Warcha Sandstone in the footwall (Figure 4.6).

4.7 STRUCTURAL MODEL

The structural geometry illustrated in Figure 4.2 can be best understood by considering a geological cross-sections along line $A'A$, $B'B$ and $C'C$ (Figure 4.7, 4.8 and 4.9). Cross-section AA' demonstrates that the northeastern sector is characterized by a fold chain that incorporates upright to southeast overturning structures, developed within the non-outcropping Precambrian to outcropping Triassic-Eocene rocks. The fold train comprises open upright folds in the extreme northeast that becomes tight and asymmetric gradually towards southeast until it encounters a major structural break along Ft5 fault. The fold belt in the northeastern sector seems to have originated as simple buckles detaching directly from the Precambrian salt. The Ft5 fault appears as vertical to steeply northeast dipping in the cross section and emplace Triassic rocks over the Jurassic rocks in the footwall. South of the Ft5 fault the out cropping rocks are tight to openly folded. The Zaluch Fault is the western most frontal fault of the study area, along which the Triassic rocks are thrust southwards over the Quaternary sediments of Punjab foreland in the south.

The geological cross-sections along lines $B'B$ and $C'C$ (Figure 4.8 and 4.9) depicts that on a traverse from northeast to southwest, the structure of the area is dominantly controlled by a series of folds that are open-tight and asymmetric and shows a dominant southwest facing as indicated by the forelimbs of the anticlines. The prominent anticlinal forelimbs are occupied by a couple of blind and one emergent thrust fault. The blind thrusts are indicated on the map (Figure 4.1) because they outcrop to the surface immediately southeast of the line $B'B$. The fault Ft8 occupies the forelimbs of the Zaluch Anticlines, which is the most prominent anticlinal structure of the region. The fault Ft8 appears as an out of sequence fault that has been developed in response to the room problem created by tight folding. The fault Ft8 is interpreted to be shallow level fault that does not relate to deeper level deformation. A small popup structure is also observed along both $B^{/}B$ and $C^{/}C$ lines.



Á A

Figure. 4.7. Geological Cross-section line ÁA of Figure 4.1. For Index see figure. 4.1., ZF= Zaluch Fault; Ft2= Fault 2;Ft4= Fault 4.

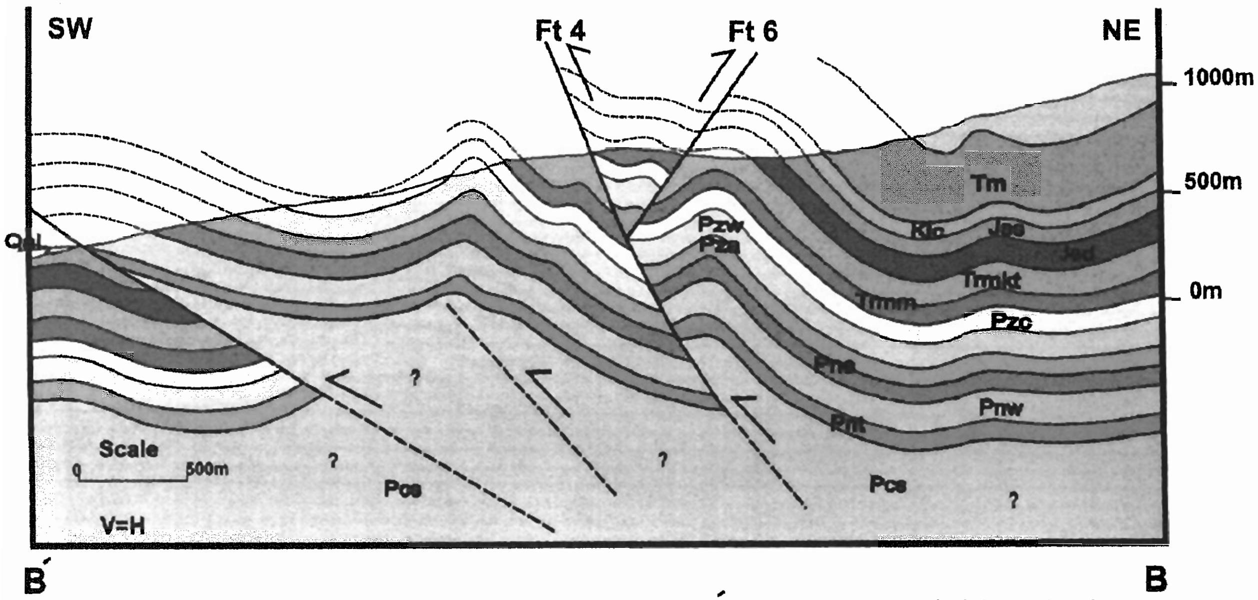
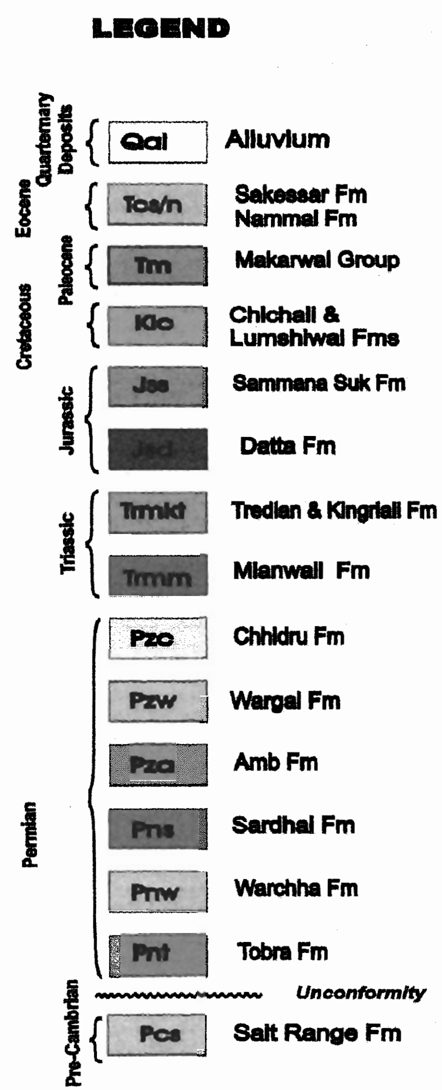


Figure.4.8. Geological Cross-section line B́B of Figure 4.1.For Index see figure. 4.1., ZF=Zaluch Fault.Ft4=Fault 4., Ft6= Fault6.



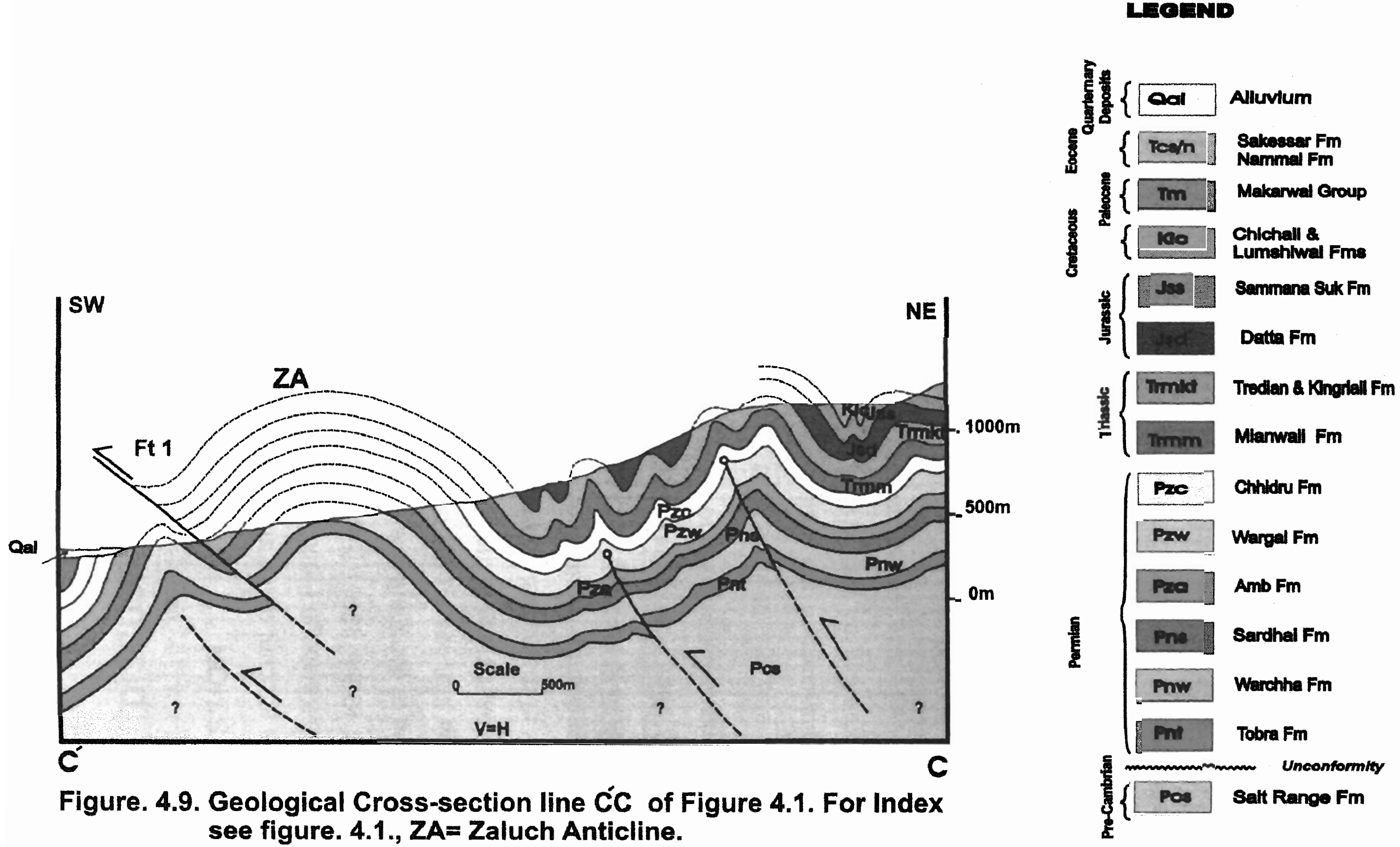


Figure. 4.9. Geological Cross-section line ĆC of Figure 4.1. For Index see figure. 4.1., ZA= Zaluch Anticline.

CHAPTER No. 5

DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

Previous account of the structural geology of the western Salt Range suggests that it is a part of the Kalabagh Fault Zone and has dominantly exhibited strike-slip deformation (McDoughall & Khan, 1991) (Figure 1.2). However, the present investigation does not support the idea of dominant role of a strike-slip faulting in the region. If it is assumed that the Zaluch area that lies on the eastern side of the Kalabagh Fault Zone and has been displaced southwards due to the right lateral motion along the Kalabagh Fault then it must preserve some of the typical geometries like enechelon array of thrust faults and folds to support the dominancy of strike slip deformation. In contrast, the structural geometries portrayed in Figure 4.1, Figure 4.7, Figure 4.8 and Figure 4.9 clearly demonstrates that the study area has been mainly subjected to contractile deformation along with some of the wrench deformation accompanying as well.

The general structural trend of the folds and faults suggests that compressional stresses that prevailed in the region were largely oriented northeast to southwest. The southwest overturning on fold structures and the facing of thrust faults suggest that the major transport direction was southwest. The subsurface fold projection suggests that all the folds were buckled above the evaporite horizon and the faults have developed as an accommodation response of the rocks in order to achieve the shortening that is beyond the capacity of the fold structures. The thrust fault seems to have emerged as sole splays from the base of the Salt Range Formation. Beside the fact that the study area is characterized by a deeper level salt detachment the fold structures are very tight and the faults are very steep, whereas in such kind of rheological environments the most probable suite of structures will be open folds and the faults will be of thrust slip and low angle nature. The steep nature of faults and folds can be attributed to strike-slip deformation in addition to a major thrust slip deformation. It can be assumed that initially the thrust faults evolved as low angle imbricates along with open folds that later on became steep with the progressive onset of strike-slip deformation due to the movements associated with the Kalabagh fault.

The direction of tectonic transport worked out on the basis of the current study is also not in agreement with the previous interpretation. The general trend of tectonic transport direction has been calculated as southwards for the structural evolution of the Central Salt Range (Jaswal et al., 1997; Jaume and Lillie, 1988; Lillie et al., 1987). Whereas, in the study area the orientation of both large and small structures suggests that the tectonic transport is southwestward. One logical explanation for this may be that the Zaluch area, which is a part of the Western Salt Range, may have been deformed as an oblique ramp of the thrust system in the Central Salt Range that is regarded as a frontal ramp. The structural style studied in the area suggests that it is a typical fold and thrust belt deformed in thin-skinned manner.

5.2 CONCLUSION

1) The Zaluch nala area exposes typical fold and Thrust belt structures including fore and back thrusts, pop-up and tight to open asymmetrical anticlines and synclines that are dominantly oriented northwest.
2) The structural style clearly demonstrates that it has been mainly subjected to contractile deformation accompanied by strike-slip adjustments related to motion along Kalabagh Fault as well.
3) The compressional stresses producing the contractile features were oriented northeast to southwest.
4) The projection of the fold structures suggests that these were buckled above a basal evaporite horizon whereas all the mapped faults splays from this basal decollement as well.
5) The structural style suggests that the study area is dominantly a southwest structural system, impinging upon Punjab Foreland in the Southwest.
6) The tight nature of folding and steeply dipping faults is attributed to wrench faulting that post date these structures.

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