STRUCTURAL ANALYSIS OF NUR PUR AREA, DISTRICT CHAKWAL, SALT RANGE, PUNJAB PAKISTAN

By

SYED DANIAL HAIDER SHAH

MUHAMMAD SOHAIL

TAIMOOR ZAFAR

Department of Earth and Environmental Sciences

Bahria University, Islamabad

2017

STRUCTURAL ANALYSIS OF NUR PUR AREA, DISTRICT CHAKWAL, SALT RANGE, PUNJAB PAKISTAN

A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of BS in Geology

SYED DANIAL HAIDER SHAH

MUHAMMAD SOHAIL

TAIMOOR ZAFAR

Department of Earth and Environmental Sciences

Bahria University, Islamabad

2017

ACKNOWLEDGEMENTS

All praise to **Allah Almighty**, Lord of all creations and His **Prophet Muhammad** ﷺ whose blessing enabled us to carry out this thesis project and who bestowed us with knowledge and courage to complete it successfully.

We wish to express our gratitude to the person who have given their heart whelming support in completion of our thesis and in our educational career. First of all, Mr. Ehtisham Javed for supervising us in this thesis we really appreciate his effort and care and honorable HOD for their continuous support and guidance and to all the teachers who taught us and enhanced our knowledge. Our teachers guidance and suggestions will always help us in every of our lives.

Special thanks goes to our families and friends for their support throughout the years, in times both good and bad to keep us focus on our goals. Also a big thanks to my class fellows for spending good four years together in a friendly atmosphere, we learned a lot from them. Finally we like to our parents who deserves regards and special thanks for their moral and financial support throughout our educational career, without their help we might not have been able achieve our goals. May Allah bless them and give us a chance to serve them better.

We like to thanks Bahria University for enabling us to carry out this thesis and forwarding us to practical life with full strength. To sum it up it was a total effort between all of the mentioned people that led us to our accomplishments.

ABSTRACT

This research is carried out in central to western Salt Range near vicinity of Nurpur village and Kallar Kahar. Surface and subsurface geological data is incorporated to construct two North South geological cross sections. The interpretation suggest that Salt Range Thrust emanates from basal detachment at crystalline evaporites, cuts up section as fault bend folds and terminate as blind thrust on Punjab plain. The strata above the Salt Range Thrust is evolved as multi bend fault bend fold with a series of anticlines and synclines, which are partially eroded and provide sediments to Punjab plain in the South. Tapering of layers is also interpolated to be present in foot wall in order to be in accordance with well data. However, in hanging wall a thrust fault is observed exactly above the foot wall ramp of the thrust system. In the basement rocks, a ramp resulting from pre-existing Normal fault is present which is also interpreted in previous work. The subsurface setting and the surface folds and faults are evolved in response to collapse of competent younger strata over weaker evaporites deposits of Salt Range Formation which manifest the idea of salt tectonics in the region.

CONTENTS

Page no

FIGURES

CHAPTER 1
INTRODUCTION

For well over a century the Salt Range Mountains of Pakistan have attracted the special attention of geologists. Starting in the foothills of the Himalayas in northeastern Pakistan, the Salt Range Mountains run about 141km in a westerly direction, roughly parallel to the Jhelum River until it joins the Indus. The Salt Range Mountains then extend some distance beyond the Indus. Salt Range is a major geological landscape of Potwar plateau which is the sub basin of the upper Indus basin. River Indus lies to its west and Jhelum River to its east, similarly Kala-Chita Margalla Hill ranges lies in the north and in south there is Salt Range (Kazmi and Jan, 1997).

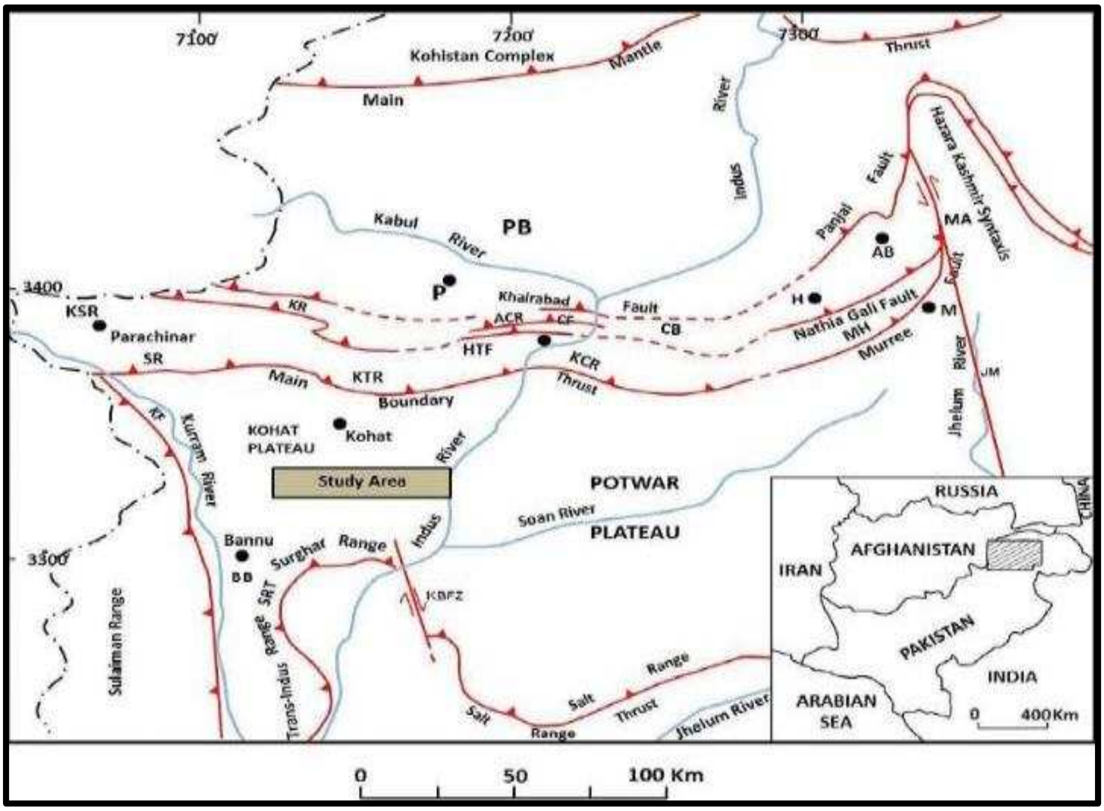

Figure.1.1. Tectonic map of Potwar Plateau (modified after Ghazanfar, 1993; Kazmi and Jan, 1997; Ahsan and Chaudhry, 2008).

Northern part of Potwar plateau is highly deformed which is known as North Potwar deformed zone (NPDZ). The southern part of the Himalayan collision zone in Pakistan is Salt Range. The front side of the Salt Range contain Eocambrian evaporites and overlying strata over ride syn-orogenic fan material and alluvium (Yeats et al., 1984).

Two narrow north east trending ridges lies in the eastward of the Salt Range. Salt Range western side has North West bend near Warchha, Where Kala-Bagh tear fault separates Salt Range from the Trans Indus ranges. Salt Range Thrust truncates the Salt Range in the south. Along the southern margin between the Jhelum and Indus River lies the Salt Range Thrust. Fault blocks are bounded by forward and backward verging thrust in the east side of the Salt Range (Johnson et al., 1986).

Stuart Elphiston, 1808 was the first British to use the name Salt Range. In Pakistan Salt Range is considered very important place for the study of the Geology. Its geology is complex and interesting and contains folds and faults. It is also called the Museum of the Geology because it contains a lot of fascinating geological features. Extensive fossiliferous strata of various formation are exposed in the area as well.

1.1 Location and accessibility

Study area is located in Kallar Kahar, district Chakwal, Punjab province. Motorway is the best way to access this area form the capital territory Islamabad throughout the year. This area of Punjab lies in arid to semiarid region. This area contains most of the formation from Precambrian to Quaternary alluvium. The location map is shown in Figure 1.2.

1.2 Previous work

Salt Range, being the museum of the geology had been the center for many controversies among geologists from the middle nineteenth century to the middle twentieth century. Many geologists have done their work on the Salt Range and gave their hypothesis. But evidence for advanced plant and insect remains in the Salt Range Formation is not easily dismissed (McDougall and Hussain, 1990). It would appear that there is still a contradiction between the geological and paleontological evidence, just as there was during the time of active controversy (Holland, 1990).

During the time of active controversy the conflict might be resolved by positing the existence of an advanced flora and fauna in the Cambrian (Gee, 1945). Salt Range thrust and associated salt diapirisim bring the strata to surface, Evaporites deposits of Precambrian age are present in the strata (Gee, 1989; Butler et al, 1987; Baker et al, 1988; Pennock and others, 1989). Under the Potwar plateau, ductile evaporites form a

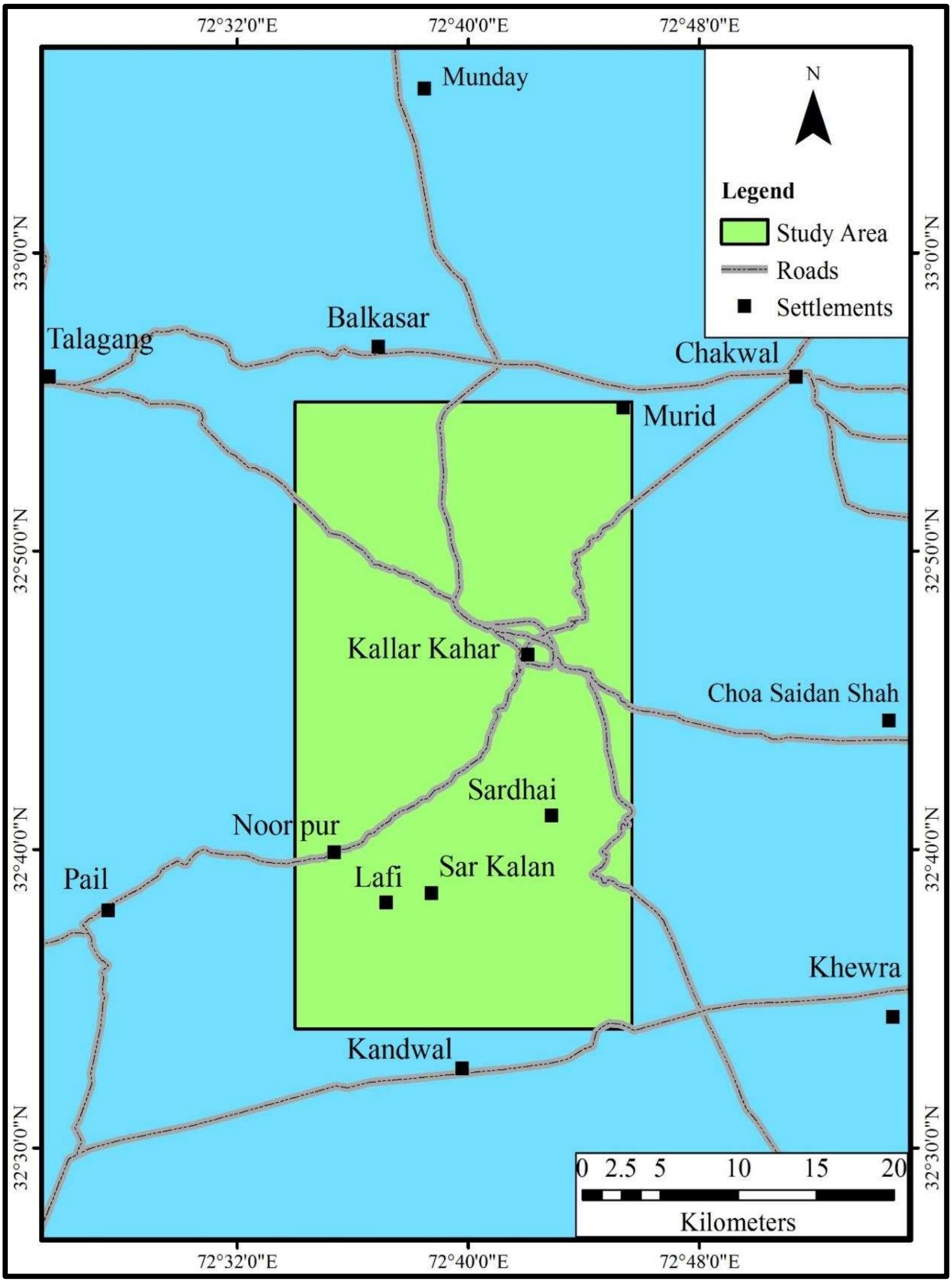

Figure 1.2. Green rectangle shows the location of study area (created using Google Imagery).

zone of decollement (Butler et al, 1987; Jaume and Lillie, 1988; Pennook, et al, 1989). For oil and gas exploration and production Potwar area is important. The wood fragments were also found in deeper part of salt mines in Khewra (Butler et al, 1987).

1.3 Aim and objectives

The research work was aimed to obtain the following objectives;

1) To carry out detailed lithological and structural mapping of the area.
2) To find out genetic relationship of surface features with sub-surface using geological cross sections.

1.4 Interpretation and its significance

The proposed study will help in;

1) Updating geological map of the area.
2) Defining nature of decollement and various structures, in structural evaluation of the area.

1.5 Methodology

1. Data had been acquired using existing geological maps, Google earth imagery and extensive field work.
2. Acquired data were interpreted into geological map via ESRI Arc GIS 10.2, using a variety of other software including Google earth, Global Mapper and Coral Draw X5.
3. Later, traverses were carefully marked to construct geological cross section.
4. Google Earth elevation profile of traverses, orientation data and geological maps aided in surface controls of cross sections. However, subsurface stratigraphic control was taken from formation tops data of two wells, Balakasar-01 in north and Lilla-01 well in south.
5. Kink method is adopted to construct the cross sections and understand subsurface structural trends.
6. Interpretation of cross sections was carefully appraised to understand the structural style and explain the structural evaluation.

CHAPTER 2
REGIONAL AND TECTONIC SETTING

2.1 Introduction

This chapter explains how the continental collision of Indian Plate and Eurasian Plate took place, along with the type of tectonic features and geodynamic settings. Over focus is on the features that developed during the collision of these two plates.

The world's youngest and highest mountain range Himalaya was crated due to collision of Eurasian Plate and Indian Plate. The Himalayan mountain range stretch over 2500 Km in the countries of Nepal, India and Pakistan, approx. width is about 16 to 400 Km. The complex geometry of these mountains have northwest-southeast trend in India. In Pakistan the orientation of mountain changes to east-west and along the western border of Pakistan it becomes more north-south. The highest peak in this range is mount Everest with the height of 8,854m above sea level, demonstrate one of the most visible and spectacular consequences of plate tectonics (Kazmi and Jan, 1997 ; Yeasts and Hussain, 1987, 1989; Hylland, 1990). This region is home to some of the greatest rivers and highest and largest glaciers outside of polar region.

The ongoing collision of Indian and Eurasian Plate is continuously increasing the height of these mountains. The height of these mountain is increasing 10mm per year, with the erosion rate of about 2 to 12mm per year. Himalayas are the product of geodynamic processes like collision tectonics, continental drift and sea floor spreading. The continuous thrusting of Indian Plate beneath the erosion and intervening of other micro plates which started about 50 or 60 million years ago is still active today (Le Fort, 1975).

2.2 Salt Range Thrust (SRT)

The Salt Range and Potwar Plateau are part of the active foreland fold-and-thrust belt of the Himalaya in northern Pakistan. In this region the distance from the Main Boundary Thrust (MBT) to the front of the fold-and-thrust belt is very wide (100–150 km) because a thick evaporites sequence forms the zone of decollement. The SRT run along the south side of Salt Range it is also known as Himalayan Frontal Thrust. This thrust lies between the two rivers Indus and Jhelum. Salt Range is roughly running in west direction about 250km, runs parallel to the Indus River until it joins the Salt Range. In east direction Jhelum River is present. Two narrow north-east trending ridges lies in the eastward direction of the Salt Range. Along the southern margin between the Jhelum and Indus River lies the Salt Range Thrust (Kazmi and Jan, 1997). Fault block area bounded by forward and backward verging thrust in the east side of the Salt Range (Johnson et al., 1986).

The overall trend of thrust from Main Boundary Thrust to Salt Range Thrust is shown in figure 2.3. This fault has pushed the Salt Range old rocks over Jhelum plain in less deformed Tertiary sequence. Fanglomerate and alluvium deposits are present in this thrust zone (Kazmi and Jan, 1997). Those areas where the thrust is exposed Paleozoic rocks are overlying the Neogene or Quaternary deposits of Jhelum plain (Gee, 1945, 1989; Yeats et al., 1984). With the help of different type geophysical techniques it is suggested that the Salt Range and Potwar Plateau is underlain by Eocambrian Evaporates. Decoupling of the sediments from the basement along the SRT has led southwards movement of Potwar Plateau and Salt Range over Jhelum plain (Kazmi and Jan, 1997).

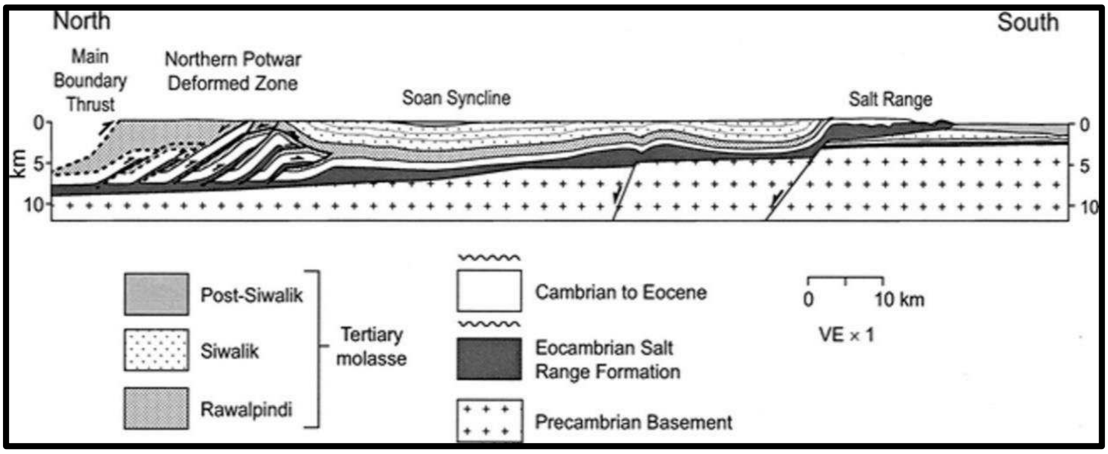

Figure 2.1. Generalized cross section across the western Potwar Plateau and West-Central Salt Range (after Jamue and Lillie, 1988; Gee, 1989).

2.3 Salt Range

Salt Range has upper Proterozoic to recent successions and it makes the southern frontal thrust of Himalayan mountain chain. Salt Range is a result of tectonic forces imposed during the later phase of Himalayan orogeny. The Salt Range Formation in the base of sedimentary sequence has contributed in the formation of many structures (Gee, 1989). The Himalayan Orogeny cause the extension southwards during the Quaternary time. Salt Range bridges the angle between the Suleiman Arc in the west and the outermost front of northwestern Himalaya (Gee, 1989).

Salt Range is rising abruptly out of the alluvial plain the approximate height is around 750 to 1000m. In some anticlines the average thickness of Salt Range Formation is 2000m. Salt anticlines has series of Salt Range anticlinorium of "salt pillow" type (Trusheim, 1960). The overall trend of Salt Range is shown in figure 2.2. The saline sequence has not penetrated the overlying sedimentary formations but in area like Kallar Kahar, Vasnal, Mari Indus, diapirisim is major factor in the uplifting of formation and penetrations. Vegetation cover is not great excellent out crop and rock exposure can be observed within the scraps and gorges. Older and younger formation are exposed in most of the part of Salt Range with complete succession with the dip angle in the north. In the Potwar Basin tertiary sequence is in continuity with Soan basin (Gee, 1989).

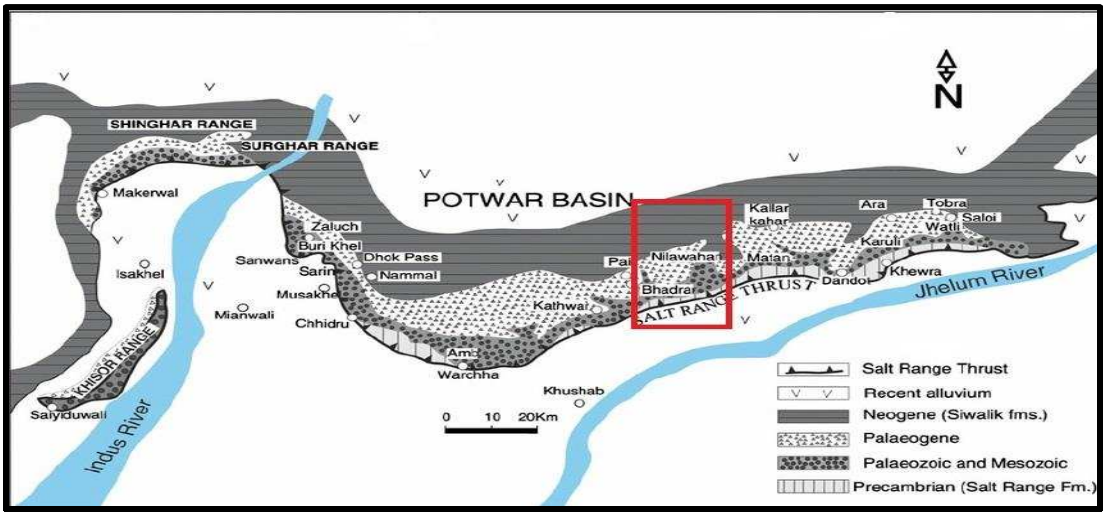

Figure 2.2. General Trend of Salt Range (after E.H. PASCOE, 1920).

2.4 Setting of Indian Plate

The Indo-Pak subcontinent was part of Gondwanaland in the south, it started to drift northwards about 130Ma. The northwards drifting of subcontinent cause the shrinking of neo-Tethys it was present in the south of Asian continent and in the north of Indo-Pak subcontinent (Johnson et al., 1976). Far below the equator the Indian plate is located in the southern hemisphere and thousand kilometers wide Neo-Tethys ocean was separating the subcontinent from the nearest land area in the north. With the help of magnetic anomalies it was suggested that the Indian Plate moved towards northwards between the times of 130 to 80Ma with the approx. rate of 3 to 5cm/year (Johnson et al., 1976). The Indian Plate start moving at average rate of 16cm/year relative to Australia and Antarctica about 80Ma years ago (Powell, 1979; Patriat and Achache, 1984). The continental drift was facilitating in the shrinking of Neo-Tethys in the north and opening of Indian Ocean in the south.

The Indian plate has transform motion along the Owen fracture zone, in the southeast and southwest of Indo-Pak subcontinent East Ridge is located. The extensive extrusion of Deccan Trap Basalt was the result of northwards movement of Indian plate around 60 to 65 Ma (Duncan and Pyle, 1988).

The shrinkage or closure of Neo-Tethys ocean interoceanic subduction took place which resulted in the formation of arcs most known among them is Kohistan-Ladakh, Nuristan and Kandhar during the age of Late Cretaceous (Searle, 1991; Treloar and lzatt, 1993). The movement and collision of Indian plate to Eurasian plate is shown in figure 2.1. When the series of arcs were formed the magmatism of arc lasted for 40 million years (Peterson and Windley, 1985), the back arc basin close with the Eurasian plate and when the Kohistan-Ladakh arc is under thrusted the Eurasian plate it forms the Andean type continental margin known as the MKT (Main Karakorum Thrust), in the time of Late Cretaceous around 102 to 75 Ma collision started (Coward, 1986; Powell, 1979; and Patriate and Achache, 1984).

The collision of the two plate cause the Neo-Tethys to subduct continuously beneath the Kohistan-Ladakh Arc and the leading edge of the Indian plate was completely sub ducted by the Eurasian plate. During the time period of 55 to 50 Ma the Indian plate collided with the remnant part of Kohistan-Ladakh Arc which slowed down the northwards movement of Indian plate from 18 or 19cm/year to 4.5cm/year. In the Eocene period the collision between the Indian plate and Kohistan-Ladakh Arc is marked by the MMT (Main Mantle Thrust) (Tahirkheli, 1979), which shows the end of marine sedimentation in the suture zone (Rowley, et al., 1996). In the area of Indus Tsangpo Suture Zone, Waziristan, Zhob valley and Lasbela the extensive emplacement of the Ophiolites makes the collisional zones (Gansser, 1964; Lefort, 1975).

In the southern margin of MMT the Himalayan deformation is represented by MBT (Main Boundary Thrust), the Northern Deformed Fold and Thrust belt is thrusted in Southwards direction and is present over the Kohat and Potwar Plateau molasses sediments (Ahmed, 2003).

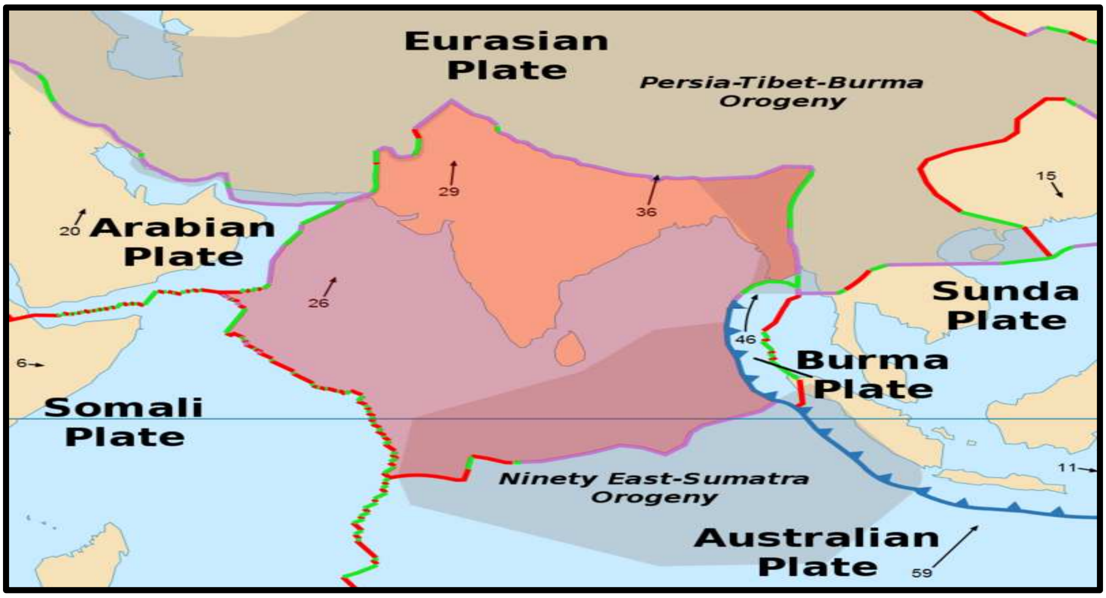

Figure 2.3. Movement of Indian plate towards Eurasian plate (Aitchison, Jonathan C, Jason R, Davis, 2007).

CHAPTER NO 3
STRATIGRAPHY OF THE AREA

Various lithological units ranging from the Proterozoic to recent are well exposed and extensively developed in Pakistan. Stratigraphic research in Pakistan is not too old, it traces back to the middle of the last century. Large and the impressive array of authors have contributed to the stratigraphy of the Pakistan. There are verities of stratigraphic nomenclature which are used in different literature for the same suite of the rocks. The national stratigraphic committee have reviewed and approved a set of lithostratigrahic names (Cheema at al. 1977, Fatmi, 1973, Shah, 1977).

Indian craton is covered by the Precambrian metasediments. In the Himalayan-Suleiman-Kirther fold belt, there is thick sequence of the precratonic shelf deposits of Mesozoic and Paleogene age. In the Chagai-Ras Koh region there is complex sedimentary sequence which is tectonically disturbed, are found and the age of this sequence is Cretaceous and Paleogene. The Cenozoic cover attains its maximum thickness in the fore deeps and the adjacent area of the fold belts in the Makran flysch zone. The quaternary sediments cover is present on the vast area of the intramountainous region, Indus plain and the Thar Desert. In valleys and the gorges of the Karakorum and the Himalaya, glacial and the fluvioglacial deposits are also present. (Kadri, 1995).

Pakistan is comprised of two large sedimentary basins, the Indus basin and the Makran basin. Indus basin covers the northwestern portion of the Indo-Pakistan crustal plate (area of the Indus platform and the Himalayan and Suleiman Kirther fold belts). The Makran basin covers the Tethyan zone west of the Indus basin (Raza et al. 1989).

Indus basin is divided in to two sub-basins, Potwar plateau and the Kohat plateau. The Indus basin is roughly defined by the Indus River in the west and the Jhelum River to the east. In the north Kala-Chitta ranges are present and in the south the boundary is Salt Rang. The plateau is covered by Siwaliks sequence on large scale, though at place upper Eocene shale and limestone crop out locally in folded inliers (Kadri, 1995). The northern part is highly deformed and intense, and known as North Potwar Deformed Zone (NPDZ), characterized by the east-west tight and complex folds, overturned to the south and sheared by steep-angle fault.

Second sub-basin is Kohat which lies in the west of Potwar. This is a tectonically restricted basin where Eocene and younger sedimentary rocks are deposited. In the southern part of the plateau, Eocene sequences which are evaporites (Bahadur khel salt and Jatta Gypsum) are also present (Kazmi and Jan, 1997).

Specifically, on account of study area, the Salt Range, it contains many possible sedimentary sequences. A diverse sedimentary sequence from Eocambrian to the recent is well exposed in the Salt Range and Kohat-Potwar Plateau. Figure 3.1 showing the stratigraphic sequence in the study area. The order of the stratigraphy is given from older to younger. As we have variation in thickness and exposure of various formation, which could lead to ambiguities in understanding structural style. To comprehend this scenario, stratigraphy is divided in to following major groups.

Group	Age	Members
Siwalik Group	Pliocene	Chinji
		Nagri
		Dhok Pathan
Rawalpindi Group	Miocene	Murree
		Kamlial
Cherat-Makarwal Group	Paleocene-Eocene	Patala
		Nammal
		Sakesar
		Chorgali
Nilawahan Group	Permian	Tobra
		Dandot
		Warchha
		Sardhai
Jhelum Group	Cambrian	Khewra Sandstone
		Kussak
		Juttana
		Baghnwala
Salt Range Formation	Precambrian	Sahwal Marl
		Bhander Kas
		Billianwalla Salt

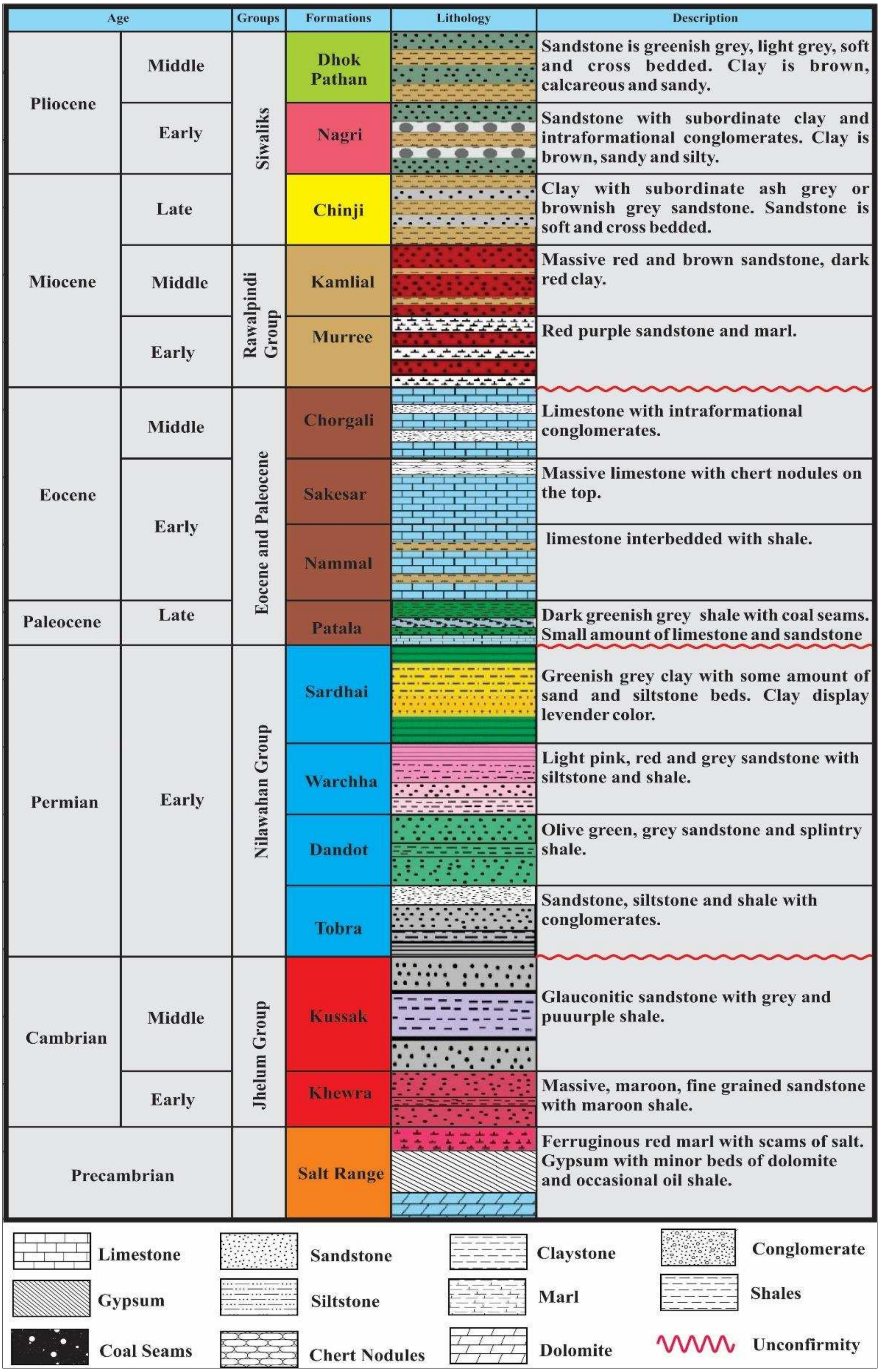

Figure 3.1. Generalized Stratigraphy of the area (Modified after E.R. Gee).

3.1 Salt Range Formation

Along the northwestern flank of the Indian shield, the basement rock are overlain by the non-metamorphic sediments of the Salt Range Formation (Asrarullah, 1967), formerly described as "Saline Series" by Gee, 1945. Wynne, 1878 named and described formation as 'Punjab Saline Series'. The present name of the Salt Range Formation is given by Asrarullah 1967 after the Salt Range Punjab.

The major part of the Formation is red, gypsiferous clay stone and their no apparent bedding is present. Red colored gypseous marl with thick seams of salt is present in the lower part of the Salt Range. In the upper part of the Salt Range Formation the beds of the gypsum, dolomite, greenish clay and low grade oil shale is existed. The age of the formation is Precambrian (Shah, 1977).

Asrarullah, 1967 done lot of work on the Salt Range Formation and he made a detailed study of the Salt Range Formation and divided the formation into groups according to their existence of the different sediments.

Figure 3.2. Marl of the Salt Range Formation is exposed in Sardhai village.

3.1.1 Sahwal Marl Member

This member consists the red marl bed with irregular gypsum and dolomite beds. Dull red marl with the seams of the salt and thickness of 10m gypsum beds are present on the upper part. Figure 3.2 shows the Marl of the Salt Range Formation.

3.1.2 Bhander Kas Gypsum

Massive gypsum is present in this member and also some minor beds of the dolomites and clay are present.

3.1.3 Billianwalla Salt Member

Thick seams of the salt is present in this and the red marl is also present in this member of the Salt Range Formation.

3.2 Jhelum Group

The Cambrian sequence is well exposed and developed in the Salt Range. In the Jhelum group there are four formations encountered. In some area full package is exposed and some area misses one formation from the group.

3.2.1 Khewra Sandstone

The name of the formation is originally proposed by the Noetling 1894 as a Khewra Group. The first name is given by the Wynne 1878 as the “purple sand stone series”. The present name “Khewra Sandstone” is given by the stratigraphic committee of Pakistan. Khewra Sandstone is present in the Khewra gorge near Khewra village Salt Range (Shah, 1977).

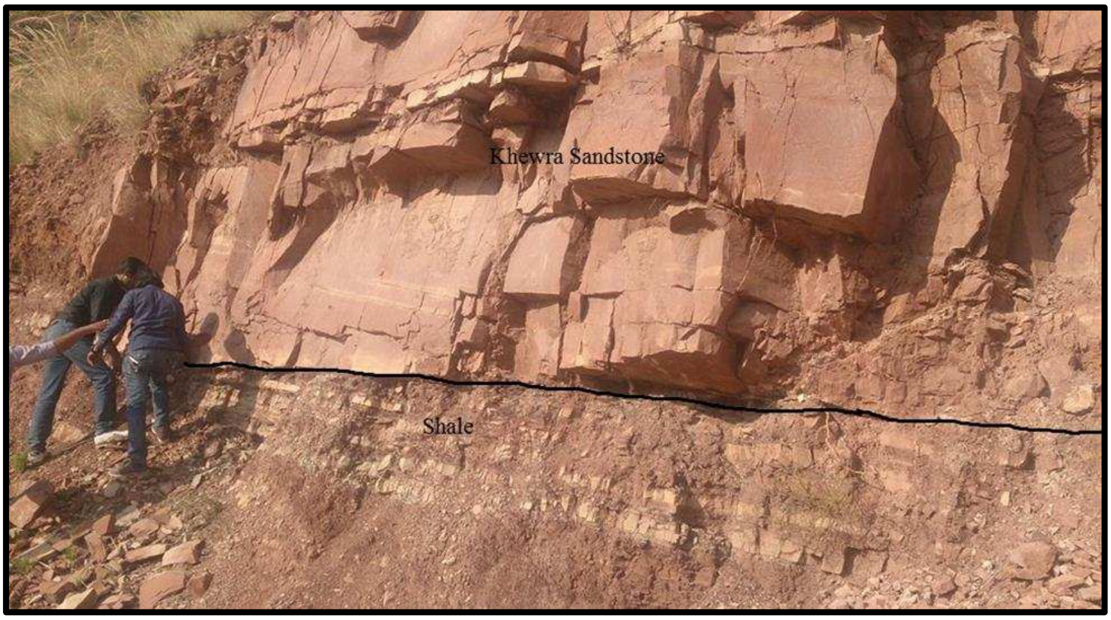

Figure 3.3. Sharp contact of Khewra Sandstone with Shale exposed in Sardhai Gorge.

The sandstone of this formation is purple to brown fine grained. In the lower part of the Khewra Sandstone there is red flaggy shale. Figure 3.3 shows the sharp contact between Khewra Sandstone and shale. The bedding of the formation is massive and the sedimentary structures are present i.e. ripple marks and mud crack (Shah, 1977). This formation is widely distributed in the Salt Range. Thickness in the type locality is 150 m and in the western Salt Range the thickness is about 200 m (Kadri, 1995).

3.2.2 Kussak Formation

First Wynne name the formation on the basis of his observation. “Obolus beds” or “siphonotreta beds” are the name used by Wynne 1878 for the greenish grey, glauconitic, micaceous sandstone and siltstone. Waagen 1895 used the “Neobolus beds” for the same unit. “Kussak group” is proposed by the Noetling 1894. At the last stratigraphic committee of Pakistan used the name Kussak Formation (Shah, 1977).

Formation contains greenish grey, glauconitic, micaceous sandstone and the silt stone is greenish grey. The interbeds of light grey dolomite is present in the formation. Intraformational conglomerates are present in many layers. Formation is widely distributed in the Salt Range but its best exposure is in the eastern Salt Range (Shah, 1977). Thickness is 70 m but it can be varies 6 to 53m in different places (Kadri, 1995).

3.2.3 Jutana Formation

“Magnesian sandstone” is the first name used by the Fleming 1853 for this rock unit. After this Noetling 1894 described this formation as “Jutana stage”. Jutana Formation is the final name given by the stratigraphic committee of Pakistan (Shah, 1977). The type locality lie near Jutana village in the eastern Salt Range.

Formation contain distinctively two types of dolomite. The lower part of the formation is light green, hard, massive and partly sandy dolomite. In the upper part of the formation brecciated dolomite is present with the matrix and fragment of the same rock. In the eastern Salt Range the lower contact of the formation is Kussak Formation and the upper contact is with Baghnwala Formation. In the most of western Salt Range it is not present. The thickness of the formation is 80m (Shah, 1977).

3.2.4 Baghanwala Formation

Wynne 1878 name this formation as “pseudomorph salt crystal zone”. Noetling 1894 name this formation as Baghnwala group and the Holland 1926 call these beds as salt pseudomorph beds. Pascoe 1959 name this formation as Baghnwala stage. The type section is located near Baghnwala village in the eastern Salt Range.

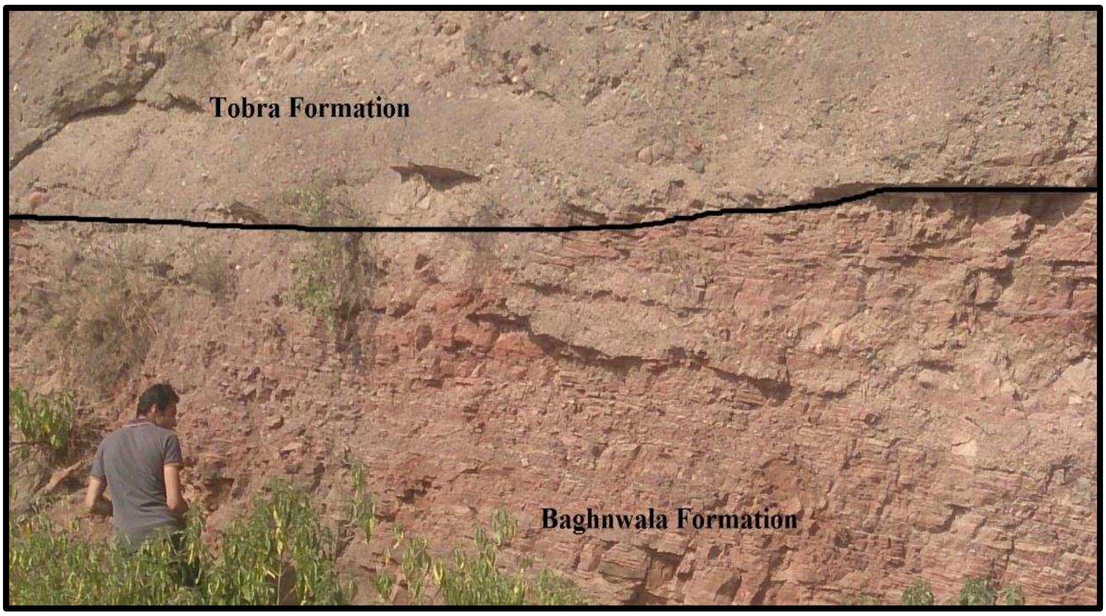

Figure 3.4. Contact of Baghnwala with Tobra Formation exposed in Tobra village.

In the formation different rock units are present. Red shale and clay with flaggy sandstone is present. Flaggy sandstone shows different colors in the lower half of the formation. Shale with clay and sandstone is shown in figure 3.4. In sedimentary structures the ripple marks and mud cracks are present in the formation (Shah, 1977). Numbers of pseduomorphic cast of the salt crystal is present in the formation. And it the main diagnostic criteria of the formation. The presence of the cast of the salt pseudomorph coupled with the lack of the fossils shows the lagoonal environment and arid climate condition for the time of the deposition (Kadri, 1995). The formation is extensively developed in eastern Salt Range. The thickness ranges from 100 to 116 m but in the Khewra gorge thickness is 40m because of the erosion (Shah, 1977).

3.3 Nilawahan Group

Gee (in Pascoe, 1959) proposed the name "Nilawahan series". The proposal of Gee has been formalized as Nilawahan group. Age of the formation is Permian. The following formations are present in the Nilawahan group

3.3.1 Tobra Formation

It is the lowest part of the Nilawahan group. First in literature Gee (in Pascoe, 1959) proposed its name as "Talchir Boulders beds" or "Talchir stages". Teichert, 1967

Figure 3.5. Conglomerates present in the Tobra Formation exposed in Tobra village.

Figure 3.6. Sandstone of Tobra Formation overlies on conglomerates exposed in Tobra village.

name this formation as “Salt Range boulder beds”. It is name due to the type locality near Tobra village in eastern Salt Range (Shah, 1977). Tobra formation is very mixed lithology containing three type of facies on different area with different depositional time span. First, in eastern Salt Range the tillitic facies are exposed. Secondly, in fresh water facies there are no boulders. It is alternating facies of silt and shale. Central Salt

Range have these facies. The last one is complex facie of diamictite, sandstone and boulder beds. The thickness is increased in western Salt Range.

Tobra Formation contains boulders of granite with fragment of quartz, feldspar, magnetite, garnet, clay stone, siltstone and bituminous shale. Conglomerates of Tobra Formation shown in figure 3.5. The matrix of the formation is clayey, sandy and calcareous in some places. The age of the formation is considered as early Permian (Shah, 1977).

3.3.2 Dandot Formation

Wynne 1878 proposed the different name of the formation. He use the name “olive series”, “eurydesma beds” and “conularia beds”. Waagen 1879 use the name “speckled sandstone” for the formation. Noetling 1901 proposed the name “Dandot Group” and the present name is formalized from this as Dandot Formation (Shah, 1977).

In the formation it contains light grey to olive yellowish sandstone with occasional thin pebbly beds and subordinate dark grey and greenish splintery shale. Cross bedding is also present in the formation. The cross bedding of the formation is shown in figure 3.7. In the eastern Salt Range the formation is well exposed (Shah, 1977).

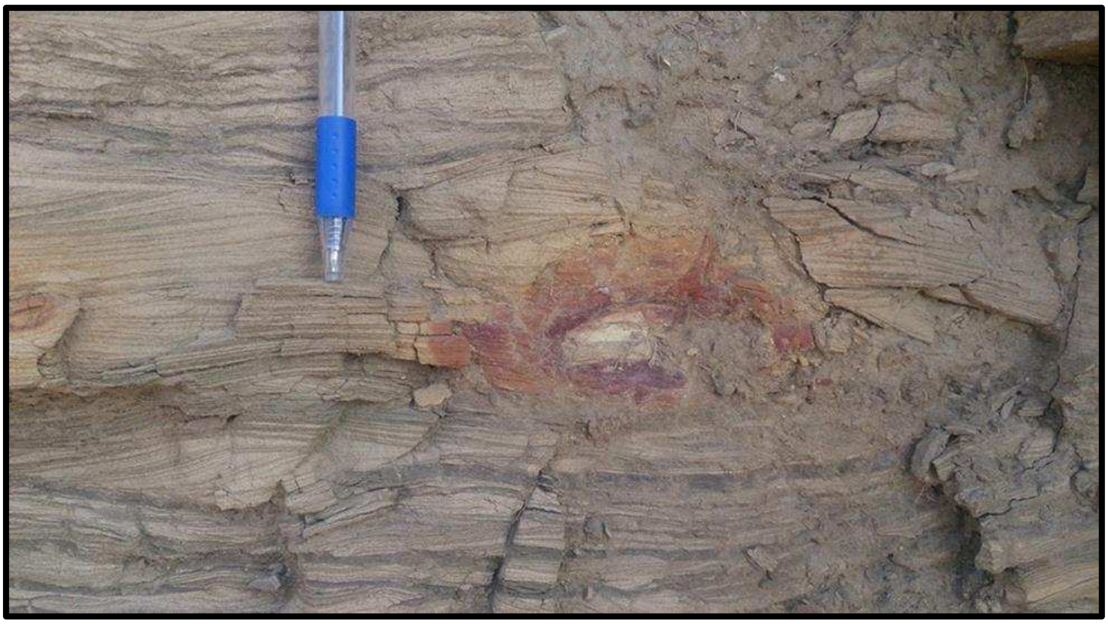

Figure 3.7. Trough cross bedding shown in Dandot Formation exposed in Dandot village.

3.3.3 Warchha Sandstone

Waagen 1889 use the name “middle speckled sandstone”. After this Gee 1945 name this formation as “speckled sandstone”. Noetling 1901 use the name “Warchha Group”. The name Warchha sandstone is coined by the Hussain 1967 which has been approved by the stratigraphic committee of Pakistan.

Medium to coarse grained sandstone, conglomeratic in place and interbeds of shale is present in the formation. The color of the sandstone is red, purple of shows the lighter shades of the pink. The cross bedding is present in the formation. Locally the formation is speckled because of which previous workers call it “Speckled sandstone”. The formation is widely distributed in the Salt Range. Thickness of the formation ranges from 26 to 180m. Variable thickness together with the strong cross bedding suggest that the formation was a fluviatile deposit and was laid down in a large alluvial flat (Shah, 1977).

Some plant remains have been reported from this formation. On the basis of its stratigraphic position with the overlying and underlying Early Permian formation, the same age may also assigned to it (Kadri, 1995).

3.3.4 Sardhai Formation

“Lavender clay” is the name use by the Wynne 1878. Noetling 1901 use the name “upper part of the Warchha group”. The name Sardhai formation is approved by the stratigraphic committee of Pakistan and the name is proposed by the Gee (written communication, 1964).

Formation contains the bluish and greenish-grey clay, with some minor sand and silt stone beds. Carbonaceous shale is also present. Clay shows the lavender color and contains some copper minerals including chalcopyrite. Lavender colors of the formation is shown in figure 3.8. The thickness of the formation is about 40m. The age of the formation is early Permian (Shah, 1977).

Different types of contacts are shown in the area, transitional, gradational and sharp contact. Nilawahan group of Permian age is overlies on the Jhelum group of Cambrian age. The contact between Nilawahan group and Jhelum group is shown in figure 3.9.

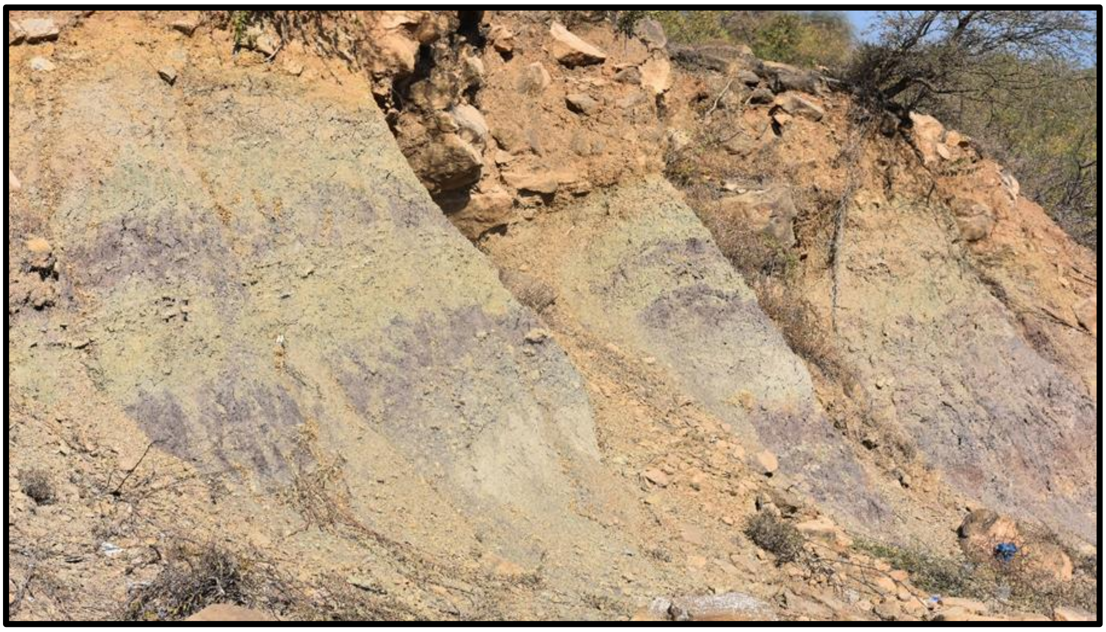

Figure 3.8. Sardhai Formation showing Lavender colors exposed in Sardhai village.

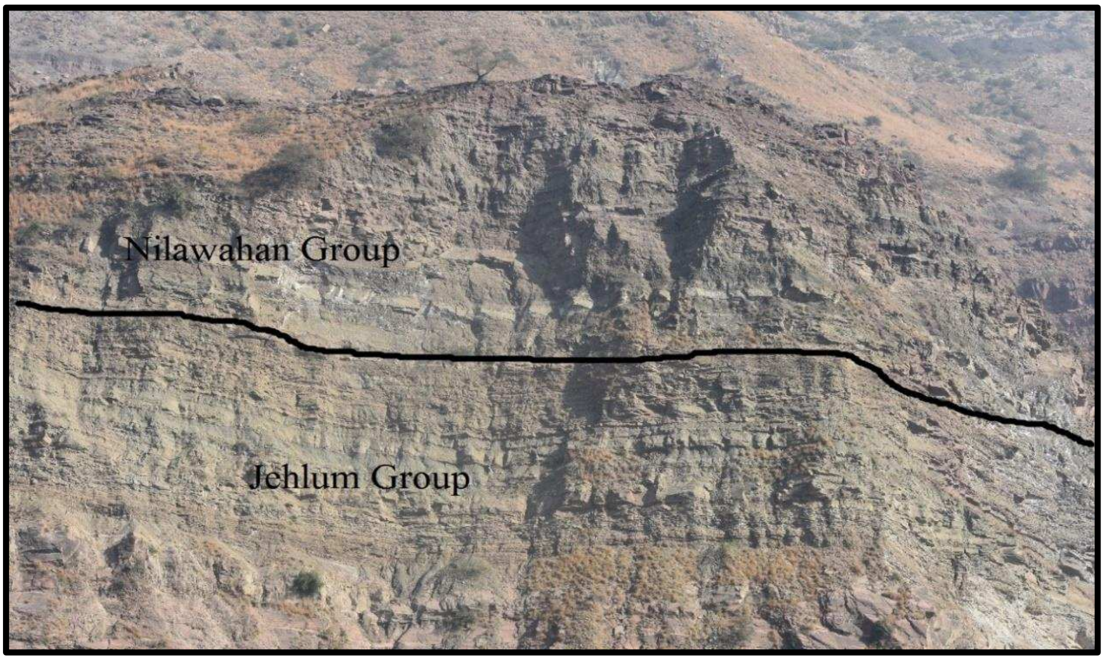

Figure 3.9. Contact of Jhelum and Nilawahan Group.

3.4 Cherat-Makarwal Group

3.4.1 Patala Formation

The name Patala Formation is name given by the stratigraphic committee of Pakistan. Davis and pinfold, 1937 gives the name "Patala shale" for this formation. The formation includes the "Tarkhobi Shales" of Eames, 1952, part of the "Hill Limestone" of Wynne, 1837 and Cotter, 1933, part of the "Nummulitic formation" of Waagen and

Wynne, 1872, part of the "Nummulitic Series" of Muddlemiss, 1896 and the "Kuzagali shale" of Latif, 1970.

Formation contains shale and marl with subordinate limestone and sandstone. The shale of the formation is dark greenish grey, selenite-bearing, in some places it also contains carbonaceous and calcareous and also some of marcasite nodules (Kadri, 1995). The limestone of the formation is light grey and nodular. It occur as interbeds. In the upper part of the formation subordinate interbeds of yellowish brown and calcareous sand stone are present. Formation contains economic value coal seams. The formation is conformably and transitionally overlain by Nammal formation in the Salt Range. The age of the formation is late Paleocene (Shah, 1977).

3.4.2 Nammal Formation

The term Nammal Formation is formally accepted by the stratigraphic committee of Pakistan after the "Nammal Limestone and Shale" of the Gee (in Fermor, 1935) and "Nammal Marl" of the "Danilchik and Shah 1967 occurring in the Salt and Trans-Indus Range.

Shale, marl and limestone is the part of the formation. In the Salt Range these formation occur as alternation. Grey to olive green color shows the shale of the formation, while the Limestone and marl is light grey to bluish grey (Shah, 1977). Argillaceous limestone is in some places. Nodular beds of the formation is shown in figure 3.10. The formation is well developed in the Salt Range. The upper contact of the formation is conformable with Sakesar Formation and the lower with the Patala Shale. The contacts are transitional. Early Eocene age is assigned to the formation (Kadri, 1995).

Figure 3.10. Nodular beds of Nammal Formation exposed in Sardhai gorge.

3.4.3 Sakesar Limestone

The name of the formation is introduced by the Gee (in Fermor, 1935) for the most prominent Eocene limestone unit in the Salt Range.

Dominantly formation contain the Limestone with subordinate of marl. The limestone, throughout its extent, is cream colored to light grey, nodular, usually massive, with considerable development of the chert in the upper part. Chert of the formation is shown in figure 3.11. Light grey marl is present. The formation is widely distributed in the Salt Range. Thickness in the Salt Range varies from 70 to 150m. Formation is highly fossiliferous. Early Eocene is the age of the formation (Shah, 1977).

Figure 3.11. Chert is present in Sakesar Limestone exposed in Simbal village.

3.4.4 Chorgali Formation

The formation shows the “Passage Beds” of Pinfold 1918 in the Attock area. “Badhrar beds” of Gee and Evans (in Davis and Pinfold 1937) in the Salt Range and the “Lora Formation” of Latif 1970 in the Hazara area. Pascoe 1920 suggest the name “Chorgali Beds” and the stratigraphic committee of Pakistan formalized the name Chorgali Formation.

Formation is divided into two parts. Limestone and shale is present in the lower part while mainly limestone is present in the upper part of the formation. In the lower part the shale is greenish grey or buff and calcareous, and the limestone is light grey and argillaceous. Limestone of the upper part is white or cream porcellaneous and well bedded.

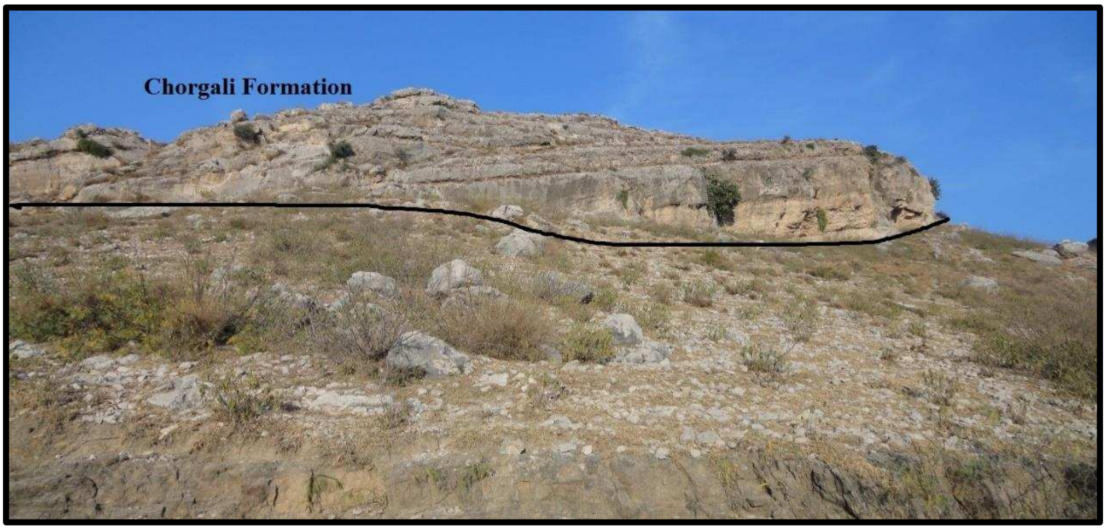

Figure 3.12. Gently dipping bed of Chorgali Formation exposed in Nilawahan village.

Figure 3.12 shows the angle of the dipping beds of formation. The formation is distributed in the eastern Salt Range. The age of the formation is early Eocene (Shah, 1977).

3.5 Rawalpindi Group

The stratigraphic committee of Pakistan approved the name Rawalpindi group after the Rawalpindi district, which is proposed by the Pinfold (written communication, 1964) for the formation comprising "Murree Formation" and the "Kamlial Formation" in the Kohat-Potwar Province. Formation of this group is widely distributed in the Kohat-Potwar Province. Age of the sequence is Miocene.

3.5.1 Murree Formation

Wynne 1874 gives the name "Mari Group" for the formation. "Murree Group" is proposed by the Lydekker 1878 and the "Murree Series" by the Pilgrim 1910. Stratigraphic committee of the Pakistan gives the name Murree Formation. The name is derived from the Murree hill in the Rawalpindi District.

The formation contains different lithology, it contains a monotonous sequence of dark red and purple clay and purple grey and greenish grey sandstone with some intraformational conglomerates (Shah, 1977). The lower part of the formation is greenish grey calcareous sandstone and conglomerates. The formation is widely developed in the region. The age of the formation is early Miocene.

3.5.2 Kamlial Formation

Pinfold 1918 use the name “Kamlial beds” for the formation. And the stratigraphic committee of Pakistan gives the name Kamlial Formation for the rock unit. The formation contains sandstone of purple-grey and dark brick-red sandstone which is medium to coarse grained, formation also contains interbeds of hard purple shale and yellow to purple intraformational conglomerates. The difference between Murree Formation and Kamlial Formation is its spheroidal weathering and heavy mineral content such as tourmaline dominates over epidote. The formation is widely distributed in Potwar region. The age of the formation is late Miocene (Shah, 1977).

3.6 Siwalik Group

For the upper part of the “Sub-Himalayan system” the term “Siwalik” is first used by the Medlicott 1864. After this Oldham 1893 and Holland et al. 1913 used the name “Siwalik series” and the “Siwalik system”. Cotter 1933, following Wynn’s 1878 classification, suggest that “Kamlial series” should be the grouped with “Murree Formation” because the boundary between them is quite arbitrary. The stratigraphic committee of Pakistan accepted the suggestion and grouped them into Rawalpindi group. Age of the sequence is Pliocene (Shah, 1977).

3.6.1 Chinji Formation

Pilgrim 1913 gives the name “Chinji Zone” for the upper faunal subdivision of the “Lower Siwalik”. Lewis 1937 named it as “Chinji Formation” which is accepted by the stratigraphic committee of Pakistan. Morris 1938 also give the name “Karghocha Formation”, the “Red Zone” of the Wynne 1878 and the “Chinji” and “Alternation Beds” of Eames 1952.

Chinji Formation contains red clay, sub ordinate brownish grey or ash grey sandstone. Size of sandstone is fine to medium grained. Sandstone is soft and friable. Sedimentary feature are present that is cross bedding. Throughout this formation thin lenses of intraformational conglomerates and pebbles of quartzite are present in different horizons (Shah, 1977). There is variation of clay and sandstone portion from place to place. Widely distributed in Kohat-Potwar province. Thickness of formation in type locality is 750m. Lower contact of the formation is with Kamlial Formation. Contact is sharp and conformable. The age of the formation is late Miocene (Kadri, 1995).

3.6.2 Nagri Formation

Lewis 1937 gives the name Nagri Formation. Stratigraphic committee of Pakistan accepted the name and gives to the formation. Pilgrim 1913 name the formation “Nagri zone” and in 1926 gives name “Nagri stage”. Wynne 1877 uses the name “Dandot sandstone”. “Marwat formation” of Morris 1938. “Uzhda Formation” of Kazmi et al. 1970.

Formation mainly consist of sandstone with conglomerate and sub ordinate clay. The color of sandstone is greenish grey and the size is medium to coarse grained. Cross bedding is noted in the formation and the beds are massive (Kadri, 1995). In some places bluish grey and dull red sandstone are present. The sandstone is moderately to poorly cemented and also calcareous. Poorly cemented or friable sandstone is shown in figure 3.13. High variation in thickness and composition in conglomerates beds. Widely distributed in Indus basin. Thickness ranges from 300m to 2000m. Lower conformable contact with Chinji Formation. Age is Pliocene in Kohat-Potwar region (Shah, 1977).

Figure 3.13. Friable sandstone of Nagri Formation exposed in Kallar Kahar area.

3.6.3 Dhok Pathan Formation

Dhok Pathan name is given by the Pilgrim 1913. The formation was redefined as “Dhok Pathan Formation” by Cotter 1913. Morris 1938 uses the name “Sheri Ghsaha Formation”. “Shin Matai Formation” by Kazmi 1970. Stratigraphic committee of Pakistan accepted the name Dhok Pathan Formation.

Formation contains cyclic alteration of sandstone and clay beds. Color of sandstone is grey, light grey, gleaming white or reddish brown. Sandstone is soft and contains cross bedding and formation is thick bedded. Grains are moderately cemented (Shah, 1977). Color of clay is orange brown and dull red. It is calcareous and sandy and contains minor intercalation of yellowish brown silt stone. Lens shape conglomerates are present. Thickness of one cycle of sandstone is varies from 6 to 16m. It has lower transitional contact with Nagri Formation and in Kohat-Potwar province it has dis-conformable upper contact with Soan Formation. The age of formation is Middle Pliocene (Kadri, 1995).

CHAPTER 4
STRUCTURAL GEOLOGY OF THE AREA

For lithological and structural interpretation of study area, detailed geological mapping is carried out and different structures like Faults, anticlines, synclines, dome has been identified. The area lies between 32°50' N, 72°35' E and 32°33' N, 72°45' E. The general trend of the structures is east west direction. The overall study area is 40km in length and 18km in width. A well-illustrated and revised map of study area at scale of 1:50,000 is prepared. The field data including dips / strike and geological boundaries are marked. Pre-existing Gee map is draped on Google Earth and field data is added onto it to confirm the information. With further modification in contacts and structural trends, all information is then exported in KMZ format to Global mapper for format conversion so that all the information could be interpreted into Coral Draw for map compilation. Location of two wells Balkasar-01 and Lilla-01 is also carefully identified on Google earth and then incorporated into geological map.

In North of study area, Siwaliks group are exposed dipping in north. These beds are less deformed, though, moving southward orientation trend as well as structural complexities increases. Figure 4.1 shows the revised geological map of the area. The Siwaliks group is dipping 20° to 40° in north making the western limb of Balkasar syncline which is explained in previous literature (Ghani et al, 2012). In central portion, major eastern beds are horizontal to sub-horizontal demarcating relatively stable zone. Near Kallar Kahar, a thrust fault is present which is confirmed by the formation tops of Balkasar-01 well. Further southward near Nur Pur area, mostly Eocene-Paleocene strata is exposed horizontally. However, in west of Nur Pur, near vicinity of Khandoyah village, dipping trend changes to north-east. In between Khandoyah and Nur Pur, the area is covered by alluvium. Near Makhial village a major normal fault is identified on the basis of variation of dipping trend of Paleocene-Eocene strata. Further southward deformation pattern are extensive exposing the older strata including Nilawahan, Jhelum and Precambrian sequence. Near Sardhai village an east-west dipping fold is present. The crest of anticline is eroded, exposing Salt Range Formation in the core and Paleocene-Eocene strata at the limbs. In the extreme south the formation of Jhelum group is in contact with Punjab plain deposits, conforming that Salt Range Thrust is acting as blind thrust in the region.

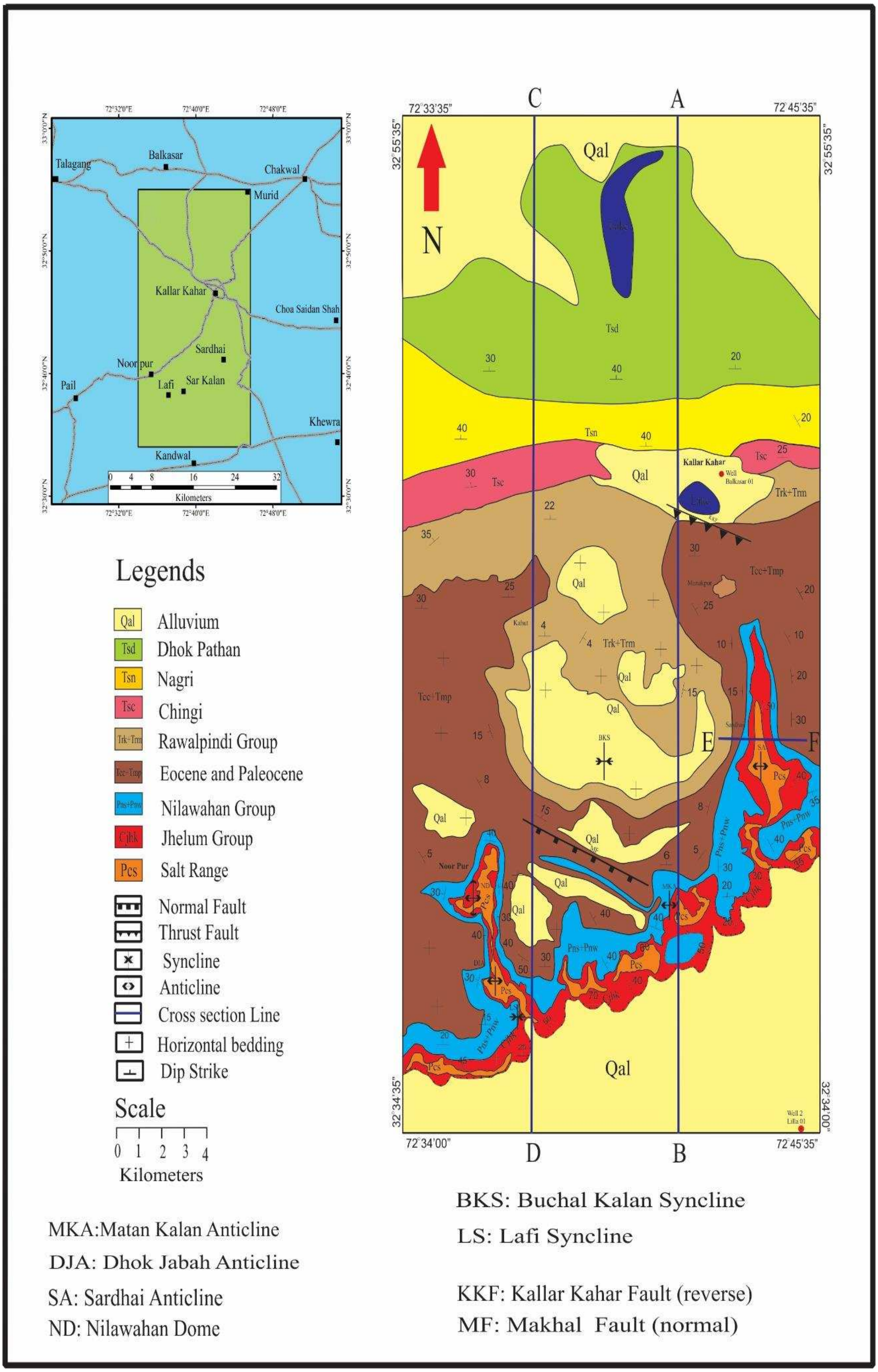

Figure 4.1. Revised geological map of the study area (modified after E.R. Gee)

Same situation is also valid for region in the south of Matan Kalan area. In western side, Nilawahan village, and Nilawahan dome is present exposing Salt Range Formation in core. Its northern limb is dipping 40° and eastern and western limb is dipping 35°. Further southward Dhok Jabah anticline is also exposed. In extreme south, the Salt Range Formation is directly in contact with Punjab plain deposit conforming that Salt Range Thrust is acting as emerging thrust in region. On Punjab plain deposits, the region is covered with alluvium which were thought to be provided by the hanging wall of thrust. Lillah-01 well is also present on Punjab plain in the eastern side, located 13 km off set of study area.

4.1 Folds

Folds are the indication of the compressional regime. The fold is stack of originally flat, level surfaces, such as sedimentary strata, are bent or curved as a result of pressure and high temperature (Kazmi and Jan, 1997). The Salt Range and Potwar Plateau are part of the active foreland fold-and-thrust belt of the Himalaya in northern Pakistan. In this region the distance from the Main Boundary Thrust (MBT) to the front of the fold-and-thrust belt is very wide (100–150 km) because a thick evaporites sequence forms the zone of decollement. Different structures are encountered along the road cuts as well (Figure 4.2, 4.3).

Figure 4.2. Anticline is present along the road cut in the vicinity of Khandoyah village.

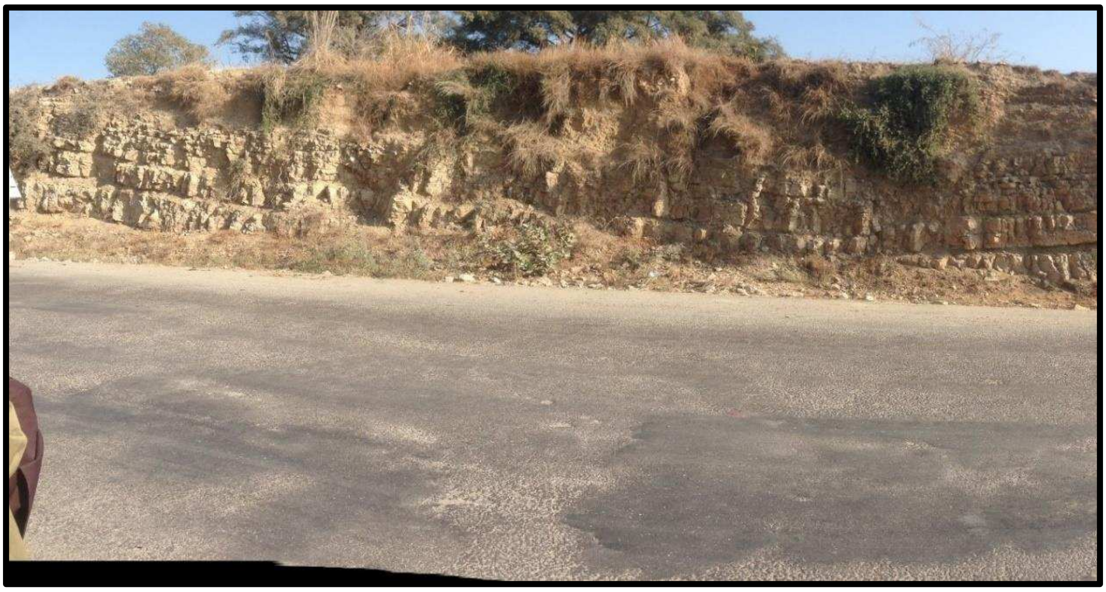

Figure 4.3. Syncline is present along the road side in the vicinity of Khandoyah village.

a) Kahut monocline

Kahut Monocline is present on the north of the Kahut village. The one limb of the monocline is dipping 15° north and the southern limb is almost horizontal. Paleocene and Eocene strata is exposed at the surface.

b) Buchal Kalan syncline

It is gentle syncline in the vicinity of the Buchal Kalan. In the core of the syncline the Rawalpindi group is exposed and on the limb of the syncline Paleocene-Eocene strata is exposed.

c) Lafi syncline

Lafi syncline is present in the southern side of the Salt Range near Lafi village. The dip data of Paleocene-Eocene strata shows the limb of the syncline is dipping 35° south and the other limb is also dipping 30° north.

d) Manakpur monocline

Monocline is present near the Manakpur village. The one limb of the monocline is dipping 40° north and the other limb is horizontal. As surface area is mainly cover by the alluvium, so subsurface control of the field data explains the presence of monocline.

e) Matankalan anticline

Matankalan anticline is exposed in the southern limb of the Salt Range. The northern limb of the anticline is dipping 30° north and the southern limb of the anticline is 35° south. In the core of the anticline the Salt Range Formation is exposed.

f) Dhok Jabah anticline

Anticline is present in the vicinity of Dhok Jabah village. The upper most formation of the anticline is Chorgali Limestone and in the core Salt Range Formation is exposed. Figure 4.4 showing the complete pattern of the formation from older to younger in the area.

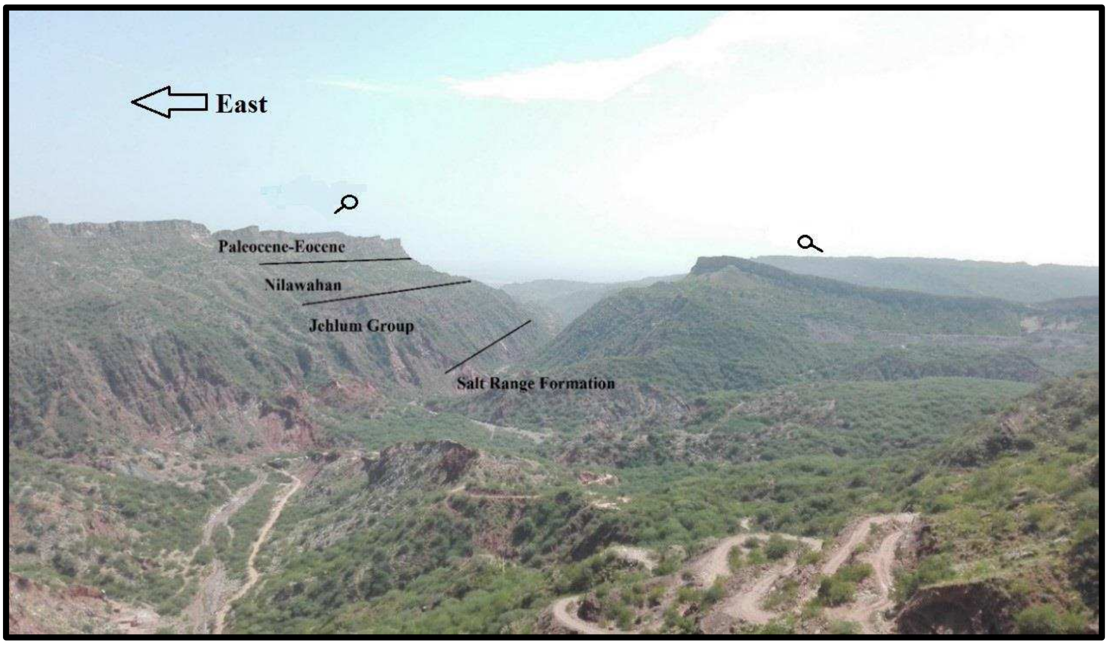

Figure 4.4. Dhok Jabah anticline with sequences present in the vicinity of Dhok Jabah.

g) Sardhai anticline

Sardhai anticline is present in the eastern side of the study area. This anticline is east west dipping. The eastern limb dips between 20°-30° whereas western limb dips between 25°-35°. Salt Range Formation is exposed in the core of the anticline. Salt diapirisim is considered as source of formation of the anticline. Figure 4.5 shows the eastern and western limbs of the Sardhai anticline.

Figure 4.5. Western and Eastern limbs of the Sardhai anticline is shown.

h) Nilawahan dome

Nilawahan dome is present in the vicinity of Nilawahan village. The orientation of the strata shows the shape of dome in that area. In the base of the dome Salt Range Formation is exposed and on the top youngest Chorgali Formation is exposed. The western limb of the dome is shown in the figure 4.3. Chorgali Formation is gently dipping in all direction with the some angle on the top of the dome.

Figure 4.6. Gently dipping the Western limb of the Nilawahan dome.

4.2 Faults

Makhal fault is present in the vicinity of the Makhal village. Makhal fault is the intraformational normal fault exposed with in Paleocene-Eocene Formation. From the field and the dip data of the strata this normal fault is interpreted. Normal fault in compressional area is due to salt activity.

The Kallar Kahar fault is present in the surrounding of the Kallar Kahar. The Kallar Kahar Reverse fault is present in the area. The Kallar Kahar fault is present in the subsurface in the southern limb. Revers fault is shown in which hanging wall is moves upward relative to foot wall, and the well data conforms the presence of fault because of the increment in thickness.

4.3 Cross sections

In order to describe the subsurface structural style, geological cross sections are constructed. Two N-S oriented cross sections are constructed along carefully selected traverses. Each cross section shows the major fault encountered in the study area. Both these geological cross sections are constructed by integrating Gee map, field data and well data (Balkasar-01 in the north and the Lilla-01 in the south). These are acquired from the Bahria University public domain database. Another cross section is constructed along E-W direction to understand the variation along the trend.

4.3.1 Methodology

Geological cross section are constructed using Kink method. The required data was the dip data, elevation and contact with various lithology. Elevation data is taken from the Google earth whereas dip data and contact data is acquired by field visit and were confirmed by existing geological map. The sub-surface control in the north is taken from the Balkasar-01, however in the south formation tops of Lillah-01 were used in the same regard. Because of internally less and homogeneous deformation of the strata same thickness were extended from North to South. These thickness were also confirmed by extending geological contacts along the Kink. However in the foot wall of the Salt Range Thrust pinching out of the formations was incorporated to justify the thickness encountered in Lillah-01 well.

4.3.2 Cross section AB

Geological section along the line AB is constructed to interpret the subsurface structural behavior of the strata present in the study area (Fig 4.7). The cross section is 40 km long and oriented in NS direction. The structures are also projected above the erosion surface to observe the complete geometry of Salt Range Thrust and related folds which are eroded now. No fault zone is present in the vicinity of MFT trace. The dip domain data of Pre-Cambrian to Miocene suggest the presence of ramp monocline, which can be molded as fault bend fold. The location of ramp and basal detachment is constrained from the dip data of ramp monocline and previous literature. The geometry of fault bend fold is comprised of numerous secondary syncline and anticlines along the hanging wall of thrust which shows it variance from typical fault bend fold model.

Moving from North to South, horizontal yet eroded strata of Dhok Pathan Formation is present which changes it dip above the ramp. The change in altitude of strata is also composed by the presence of Kallar Kahar fault and the thickness of the strata is explained by the utilization of formation top data of Balkasar-01 well. In this vicinity, the dip of strata encountered on the surface is also correlated with subsurface behavior to justify the hypothesis model. Further southward, thick sequence of strata is lying horizontally which further change its altitude near Matankalan. This is due to the presence of Matankalan anticline, which is an open anticline having Salt Range Formation in the core. Its northern limb has Paleocene-Eocene strata, whereas toward south Paleocene-Eocene is eroded and underlying sequence gently lying toward the Punjab plain deposits. The strata in footwall SRT is plotted in accordance with the formation data of Lillah-01. As most of sedimentary sequence is not reported in well so various layers are tapered to show pinch out. The space problem in footwall for Salt Range Formation is accommodated by placing a normal fault in bent which is acting as the activation zone for SRT (Suppee, 1983; Mukhopadhyay, 2004).

4.3.3 Cross section CD

Cross section CD is located in west of cross section AB with in on offset of 6.35km (Fig 4.8.). The cross section is 40 km long and oriented in N-S direction. Siwaliks group is horizontally exposed in the northern limb of the cross section. Moving toward south the strata is gently dipping in the north direction showing the presence of monocline near Kahut village. Monocline is named as Kahut monocline. After the monocline the strata is gently dipping in south and the other limb is dipping north showing the syncline structure. It is gentle syncline having Rawalpindi group in the core and limbs showing Paleocene-Eocene strata. Normal fault is present in south of Makhial village. The field data confirms the presence of normal fault in the area. The fault is named as Makhial fault. Near Lafi village the syncline is present and named as Lafi syncline. The dip data of Paleocene-Eocene strata shows the limb of the syncline is dipping 35° south and the other limb is also dipping 30° north. Salt Range Thrust is emerging thrust in this area because the Salt Range Formation is exposed in the southern limb.

4.3.4 Cross section EF

The EF is cross section of Sardhai anticline and it is the shallow depth. The cross section shows the general surface and structure trend in the area (Figure 4.9). The cross section is oriented in the east-west direction and is about 2.5 km long. The eastern limb dip 20°-30° whereas western limb dip 30°-35°. The surface of the anticline is eroded until the Pre-Cambrian Formation is exposed in the core.

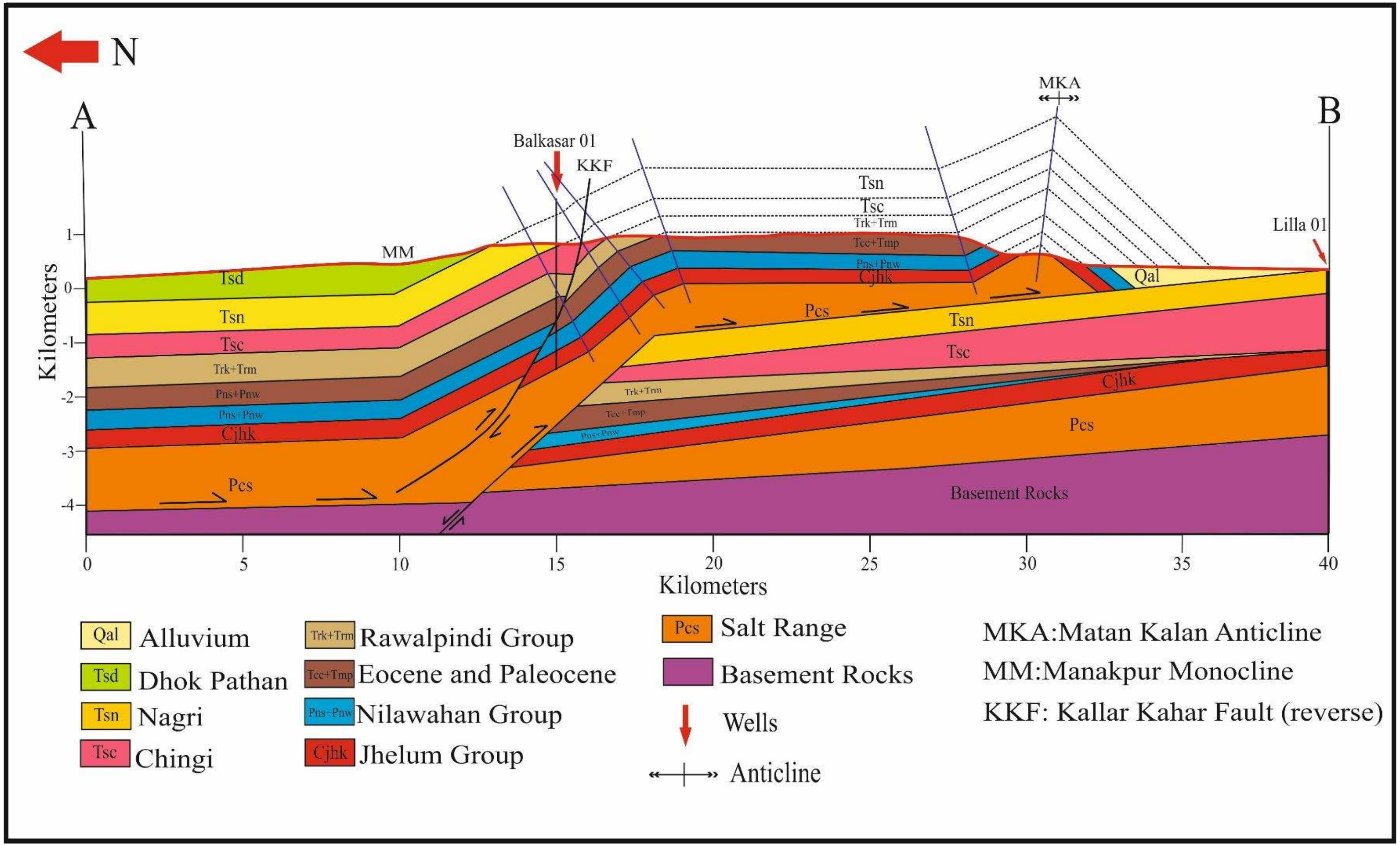

Figure 4.7. Geological cross section AB showing deformed subsurface architecture.

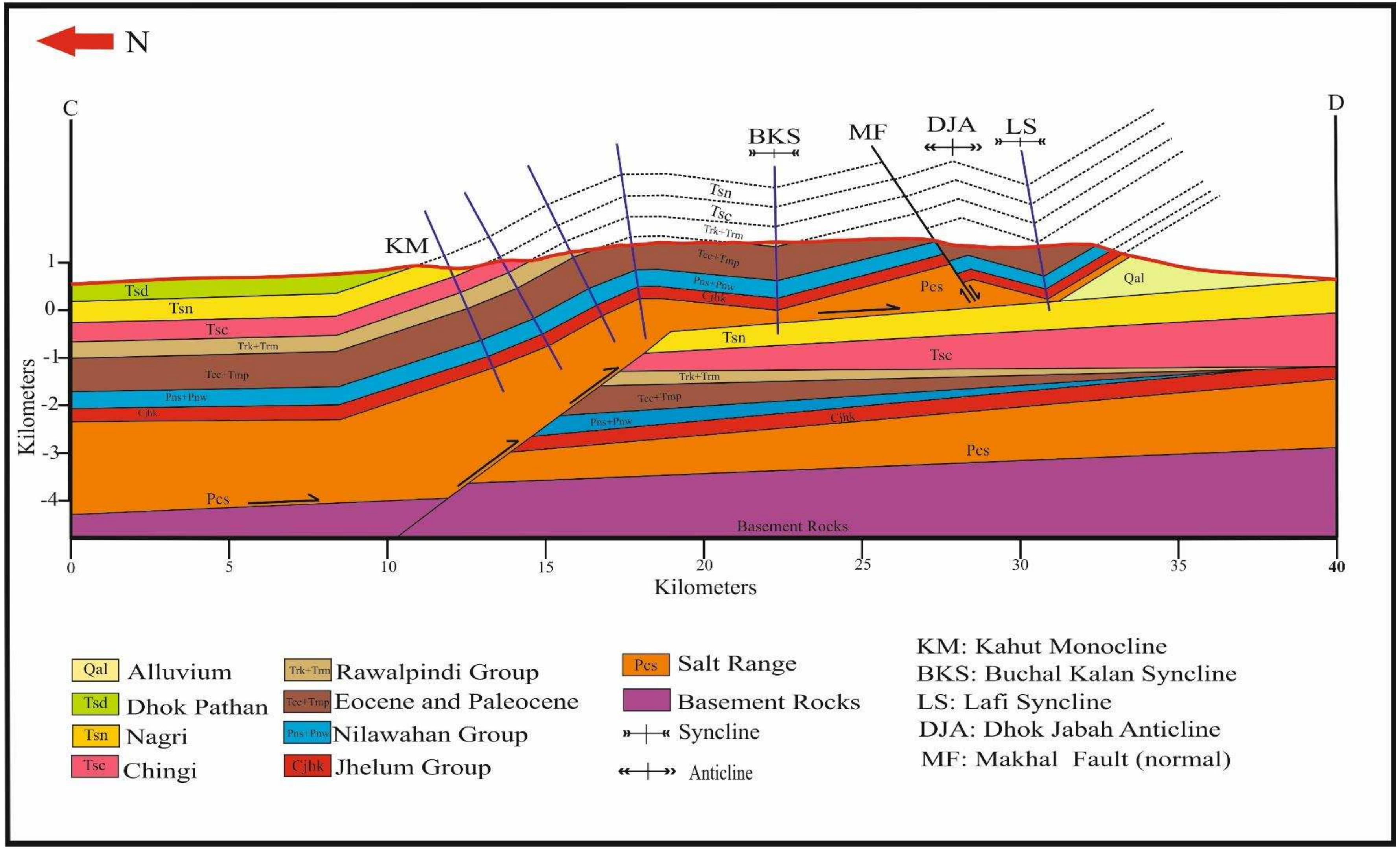

Figure 4.8. Geological cross section CD showing deformed subsurface architecture.

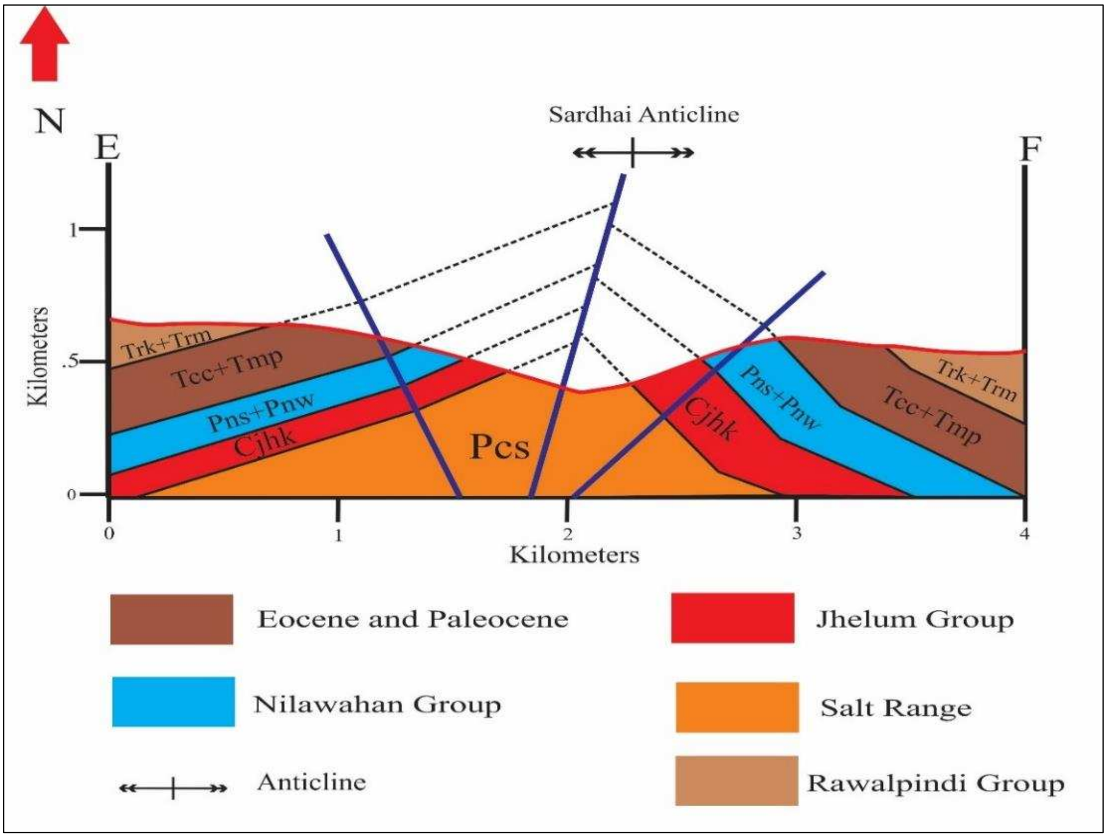

Figure 4.9. Shallow cross section EF of Sardhai anticline.

Conclusion

The Salt Range Thrust in Pakistan represents the southern boundary of Himalayan foreland fold and thrust belt. A revised geological map of the study area is compiled at 1:50,000 by using a variety of softwares. The structural interpretation of the area suggests that frontal part of the thrust sheet was folded passively as it overrode the sub thrust surface on a ductile layer of Eocambrian salt. Lack of internal deformation of the rear part of the thrust sheet is due to decoupling of sediments from the basement along the salt layer. The SRT plays a vital role for depositing Pre-Cambrian strata over the younger one. The previous presented model suggest that the SRT is controlled by thick skinned tectonic in which SRT ramps across pre-existing normal fault in the basement. The interpretation also suggest that Salt Range Thrust emanates from basal detachment at crystalline evaporites, cuts up section as fault bend folds and terminate as blind thrust on Punjab plain. The strata above the Salt Range Thrust is evolved as multi bend fault bend fold with a series of anticline and syncline, which are partially eroded and provide sediments to Punjab plain in South. SRT moves as decollement in Precambrian evaporites sequence which ramp upward through Cambrian to Siwaliks succession to the surface bring Precambrian Salt Range Formation over Punjab plain deposits.

The trend of the Salt range thrust is not coherent in study area. In most region, older strata which is in contact with Punjab plain deposits, is covered with eroded sediments of the thrusted regime confirming that it is a blind thrust. Contrary to this, in some parts of MFT trace, Salt Range Formation is directly in contact with Punjab plain deposits, showing that Salt Range Thrust is an emerging thrust. Another important aspect is the tapering of layers in foot wall of the thrust as confirmed by Lillah-01 well-tops. This leads to the idea of pinching out of strata in the southern direction. The whole structural architecture of the study area could only be modelled by active salt diapirism. Due to the presence of the salt in older strata, compressional forces had initiated halo-kinetics which resulted in various faults, folds and domes.

References

Asrarullah, 1967, geology of the Khewra Dome: Pakistan sci. conf., 18th/19th Jamshoro, proc., Part III, Abs., pp. F3-F4.

Ahsan, N., and M.N. Chaudhry, 2008. Geology of Hettangian to Middle Eocene Rocks of Hazara and Kashmir Basins, Northwest Lesser Himalayas, Pakistan. Geol. Bull. Punjab Univ., 43: 131-152

Baker, D. M., Lillie, R. J., Yeats, R. S., Johnson, G. D., Yousuf, M., Zamin, A. S. H. (1988) Development of the Himalayan frontal thrust zone: Salt Range, Pakistan. Geology, 16: 3-7.

Butler, R. W. H., Coward, M. P., Harwood, G. M., and Knipe, R. J. (1987) Salt control on thrust geometry, structural style and gravitational collapse along the Himalayan Mountain Front in the Salt Range of Northern Pakistan. In Lerche, I., and O'Brian, J. J., eds. Dynamical Geology of Salt and Related Structures. Orlando, Academic Press, pp. 339-418.

Cotter, G. de P., 1933, The Geology of the Part of the Attock District, west of Longitude 72° 45' E : India Geol. Surv., Mem., v,55, pp.63-161.

Coward, M. P., Widley, B.F., Broughton, R., Luff, I.W., Petreson, M., Pudscy, C.J., Rex, D., and Asif khan, M., (1986). Collision tectonics in the North West Himalayas. Special publication of the geological society, London, V.19, p. 203-219.

Danilchik, W., and Shah, S. M. I., 1967, Stratigraphic Nomenclature of Formations in Trans-Indus Mountains, Mianwali District, west Pakistan: U.S. Geol. Surv., Proj. Report (IR) PK-33, 45 p.

Davies, L. M., and Pinfold, E. S., 1937, Eocene beds of Punjab Salt Range: India Geol. Sur., Mem., Palaeont. Indica, New space series, v. 24, no. 1, 79 p.

Eames, F. E., 1952a, A Contribution to the Study of Eocene in western Pakistan and western India, part a., the Geology of standard sections in the western Punjab and in the Kohat district: Geolo. Soc. London, Quart. Jour., v. 107, pt. 2, pp. 159-172.

Fatmi, A. N., 1973, lithostratigrahic units of the Kohat-Potwar province, indus basin, Pakistan: Pakistan geol. Surv., mem., v. 10, 80 p.

Fermor, L. L., 1935, General Report of the Year 1934: India Geol. Surv., Recs., v. 69 , pt. 1, pp. 1-108.

Fleming, A., 1853, On the Salt Range in the Punjab: Geol. Soc. London, Quart. Jour., v. 9, pt. 1, pp. 189-200.

Gee, E. R., 1945, the age of the saline series of the Punjab and of Kohat: India Natl. Acad. Sci., Proc., Sec, P. v. 14, pt. 6, pp. 269-310.

Gee, E. R., 1989, "overview of Geology and structure of the Salt Range, with observation on related areas of northern Pakistan", In: Malinconico, L.L., and Lillie, R. J., (eds.) Tectonic of the western Himalayas. Geol. Soc. Am. spec. pp. 232: 95-112.

Ghani, H. T., Javed, E., Saeed, A. and Khan, I., 2013. A balanced cross section from Balkasar to Lillah, across Central Salt Range, Kallar Kahar, Punjab, Pakistan. G and G Student Papers, PAPG-SPE ATC-2013 Pakistan.

Ghazanfar, M. 1993. Petro tectonic elements and tectonic frame work of Northwest Himalaya. (Ph.D. thesis), University of the Punjab, pp. 1-380.

Holland, T. H., 1926, Indian Geological Terminology: Ibid., Mem., v. 51, pt. 1, pp. 1-84.

Holland, T. H., and Tipper, G. H., 1913, Indian Geological Terminology: Ibid., Mem., v. 43, pt. 1, pp. 1-27.

Hussain, B. R., 1967, Saiduwwali member, A new name for the lower part of the Permian Amb Formation, West Pakistan: Univ. Study (Karachi), Sci. and Technol., v.4, no. 3, p.88-95.

Hylland, M.D., 1990, geology of the southern Gandghar range and Kheirmar Hills, northern Pakistan: corallis Oregon state university, M.S, thesis, 77p.

Jaumé, S. C. and Lillie, R. J. (1988) Mechanics of the Salt Range-Potwar Plateau, Pakistan: a fold-and-thrust belt underlain by evaporites. Tectonics, 7: 57-71.

Johnson, G. D., Raynolds, R. G., and Burbank, D. W., 1986, "Late Cenozoic tectonic and sedimentation in the north western Himalayan fore deep", International Association of sedimentologist special publication 8, p. 273-291.

Kazmi, A. H., and Raza, S. Q., 1970, Water supply of Quetta Basin, Baluchistan, Pakistan: Ibid., Recs., v. 20, pt. 2, pp. 114-115.

Kazmi, A. H., and Jan, M.Q., 1997 "Geology and tectonic of Pakistan", Graphic publisher Karachi Pakistan.

Latif, M. A., 1970, Micropalaeontology of the Chanali Limestone, upper cretaceous of the Hazara, west Pakistan: Ibid., Sonderb. 15, pp. 25-61.

Le Fort, P. (1975). "Himalayas, the collided range: Present Knowledge of the continental arc". American Journal of Science. 275A: 1–44.

Lewis, G. E., 1937, a new Siwalik correlation (India): American Jour sci., Ser. 5, no. 195, v. 33, pp. 191-204.

Lydekker, R., 1878, Notes on the Geology of Kashmir, Kishtwwar and Pangi: India Geol. Surv., Recs., v.11, pp. 30-63.

Medlicott, H. B., 1864, on the geological structure and relation of southern portion of Himalayan ranges between the river Ganges and Ravee: India Geol. Surv., Mem., v.3, pt. 2, pp.1-212.

McDougall, J. W. and Khan, S. H. (1990) Strike-slip faulting in a foreland fold-thrust belt: the Kalabagh Fault and Western Salt Range, Pakistan. Tectonics, 9: 1061-1075.

Morris, T. O., 1938, The Bain Boulder Beds; A Glacial Episode in Siwalik Series of the Marwat Kundi Range and Sheikh Budin, North west frontier province, India: Geol. Soc. London, Quart. Jour., v. 94, pt. 3, pp. 385-421.

Noetling, F., 1894, On the Cambrian Formation of the Eastern Salt Range: India Geol. Surv., Recs., v.27, pt. 4, pp. 71-86.

Noetling, F., 1901, Beitrage zur Geologie der Salt Range, insbesondere der per-michen und triasuchen Ablagerungen: Ueues Jahrb. Mineral. Beilage-Band 14, pp. 369-471.

Mukhopadhyay, D,K., Mishra, P., (2005). A balanced cross section across the Himalaya frontal fold thrust belt, subathu area, and Himachal Pradesh, India: thrust sequence, structural evolution and shortening. Journal of Asian earth sciences. 25, p.735-746.

Oldham, R. D., 1893, a manual of the Geology of India: Govt. India press, 2nd Ed. Pakistan petroleum Ltd. (P.P.L.), 1975, progress, a monthly publication of P.P.L.: v. 20, nos. 1 and 2, Aug. and Sep., 1975.

Pascoe, E. H., 1959, A Manual of the Geology of the India and Berma, vol.II: India Govt. Press, Calcutta, pp. 484-1338.

Pascoe, E. H., 1920, Petroleum in the Punjab and northwest frontier province: India Geol. Surv., Mem., v. 40, pt. 3, pp. 330-489.

Patriat, P., and Archache, J., (1984). Indain-Eurasion collision chronology and its implication for crustal shorting and driving mechanism of plates. Nature, v.311 p.615-621.

Pennock, E. S., Lillie, R. J., Zaman, A. S. H., and Yousaf, M. (1989) Structural interpretation of seismic reflection data from Eastern Salt Range and Potwar Plateau, Pakistan. The American Association of Petroleum Geologists Bulletin, 73: 841-857.

Pilgrim, G. E., 1910, Preliminary notes on a revised classification of the Tertiary fresh water deposit of India: India Geol. Surv., Recs., v. 40, pt. 3, pp. 185-205.

Pilgrim, G. E., 1913, the correlation of the Siwaliks with Mammal Horizon of Europe: Ibid., Recs., v.43, pt. 4, pp. 264-326.

Pinfold, E. S., 1918, Notes on structure and stratigraphy in the northwest Punjab: India Geol. Surv., Recs., v. pt. 3, pp. 137-160.

Powell, C. McA., (1979) "A speculative tectonic history of Pakistan and surrounding: some constraints from the Indian Ocean", in: Farah, A., and Dejong K.A., (eds.) geodynamic of Pakistan.

Shah, S. M. I., 1977, Stratigraphy of Pakistan, Mem. Geol. Surv. Pakistan. V. 12., pp. 3-92.

Suppe, J. (1983). Geometry and kinematic of Fault bend folding, American journal of science., v. 283, p. 684-721.

Tahirkheli, R.A.K., (1979). Geology of Kohistan and adjoin Eurasian and Indo-Pakistan continent, Karakorum Himalaya, northern Pakistan. Special issue geol. Bull. Univ. Peshawar. Vol. 2. P. 1-30.

Teichert, C., 1967, Nature of the Permian glacial record, Salt Range and Khisor Range west Pakistan: Neues Jahrb, Geol. Palaeont., Abh., v.129, pt. 2, pp. 167-184.

Waagen, W., 1879, Salt Range fossils, Products Limestone Group: India Geol. Surv., Mem., Palaeont. Indica, ser. 13, v. 1, pp. IV and VI.

Waagen, W., 1895, Salt Range Fossils; fossils from the Ceratite Formation; Pisces-Ammonoidea: Ibid., Mem., Palaeont. Indica, ser. 13, v. 2, pt. 1, 324 p.

Wynne, A. B., 1874, Notes on the Geology of the neighborhood of Mari Hill station in the Punjab: Ibid., Recs., v.7, pt. 2, pp. 64-74.

Wynne, A. B., 1878, On the Geology of Salt Range in the Punjab: Ibid., Mem., v.14, 313 p.

Yeast, R. S. and Lawrence, R. D., 1984, "Tectonic of the Himalayan thrust belt in Northern Pakistan", In: Haq, B.U. and Milliman, J. D., editor, 1984, "Marine Geology and Oceanography of Arabian sea in costal Pakistan", Von no strand rein hold, New York, pp. 177-198.