Pakistan Journal of Hydrocarbon Research
Vol.15, (June 2005), p.1-8, 6 Figs.

# Structure and Stratigraphy of the Paleozoic and Mesozoic Sequence in the Vicinity of Zaluch Nala, Western Salt Range, Punjab Pakistan

**Sajjad Ahmad[1], Irshad Ahmad[2] and M. Irfan Khan[3]**

## ABSTRACT

**Paleozoic to Mesozoic age sedimentary rocks predominantly characterize the Zaluch area of the Western Salt Range. The Salt Range Formation is the oldest rock unit which represents the Paleozoic sequence. The Tobra Formation of the Nilawahan Group marks the base of the Permian sequence and grades upward into medium to coarse-grained Warchha 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 Sakessar formations. The structural fabric of the area is mainly attributed to a series of northwest trending parallel to en echelon 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 these structures have formed as a result of shortening associated with ramping from a regional basal decollement. All the structures clearly demonstrate that the Zaluch area has been subjected to compressional deformation/stresses oriented northeast southwest. The southwest vergence of folds and thrust faults suggest that the deformation is progressing southwestwards.**

## INTRODUCTION

The Himalayan collision zone extends over 5000 km in Burma, Nepal, India and Pakistan (Gansser, 1981). This extensive zone manifests variable tectonic, structural and morphological features in Pakistani Himalayas (Figure 1; Gansser, 1981; Yeats and Lawrence, 1984). The Kohat-Potwar province constitutes the western margin of Himalayan foreland fold and thrust belt and is marked by the Trans-Indus Ranges Thrust and Salt Range Thrust in the south along which the Eocambrian to Pleistocene continental shelf sequence of Salt Ranges and is thrust southward over the Indo Gangatic Foredeep. The narrow ~30 km Himalayan foreland fold-and-thrust belt in India broadens to more than 100 km along series of lobes in Pakistan (Figure 2; Lillie et al., 1987). The study area located between the latitudes 32° 48' 00" to 32° 50' 30" N and longitudes 71° 37' 30" to 71° 40 30" is a part of the Western Salt Range within the Potwar plateau, lying in the vicinity of Zaluch Nala. It is underlain by a thick succession of Precambrian to Eocene platform rocks that are highly deformed.

The initial geological research in the Salt Range has been mainly focused on describing its stratigraphic set up. Wynne (1878) measured the stratigraphic section for the first time in Salt Range and described the history of Permian and Triassic rocks. Wynne (1878-80) introduced the names Chhidru 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. Tschernyscliew (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.

Gee (1945, 1947) conducted extensive work in the Salt Range. He constructed a detailed and comprehensive geological map and established the stratigraphic section in Nammal Gorge in detail.

This paper elaborates all available surface data used to construct cross sections to understand the structural evolution of the study area. The structures are analyzed on macroscopic scale. However, structures on small scale were used to interpret the primary macroscopic structures.

## REGIONAL GEOLOGY

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 started northward drift (Johnson et al., 1976). Intra-oceanic island arcs (Kohistan-Laddakh, Noristan, 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 Karakoram mega suture which give 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 (Coward, 1985; Zeitler, 1985). Gravity data modeling indicates that the MMT and MKT dip

[1] Department of Geology University of Peshawar, Peshawar.
[2] NCE in Geology, University of Peshawar, Peshawar.
[3] MOL Oil & Gas Pakistan Co. Ltd., Islamabad.


Figure 1- Tectonomprphic map of Pakistan (Modified after Kazmi and Rana, 1982).

northward at 35° to 50° (Malinconico, 1989). Seismological data suggests that the arc underlies the Indian Crustal Plate (Seeber and Armbuster, 1979) and the thickness of the Kohistan terrain based on gravity modeling data is about 8 to 10 km (Malinconico, 1989).

The rocks of the lesser Himalayas are thrust southward over the sub-Himalayan sequence of Neogene Siwalik molasse along the Main Boundary Thrust zone (Figure 2). The Main Boundary Thrust zone is comprised of a series of parallel or en echelon thrust faults dividing the NW Himalayan sequence into a deformed southern zone or foreland, and a deformed and metamorphosed northern zone or the hinterland (Pivinik and wells, 1996). From NE to SW, the Main Boundary Thrust is located in the Hazara Kashmir Syntaxis, northern Potwar and Kohat plateau of Pakistani Himalayas.

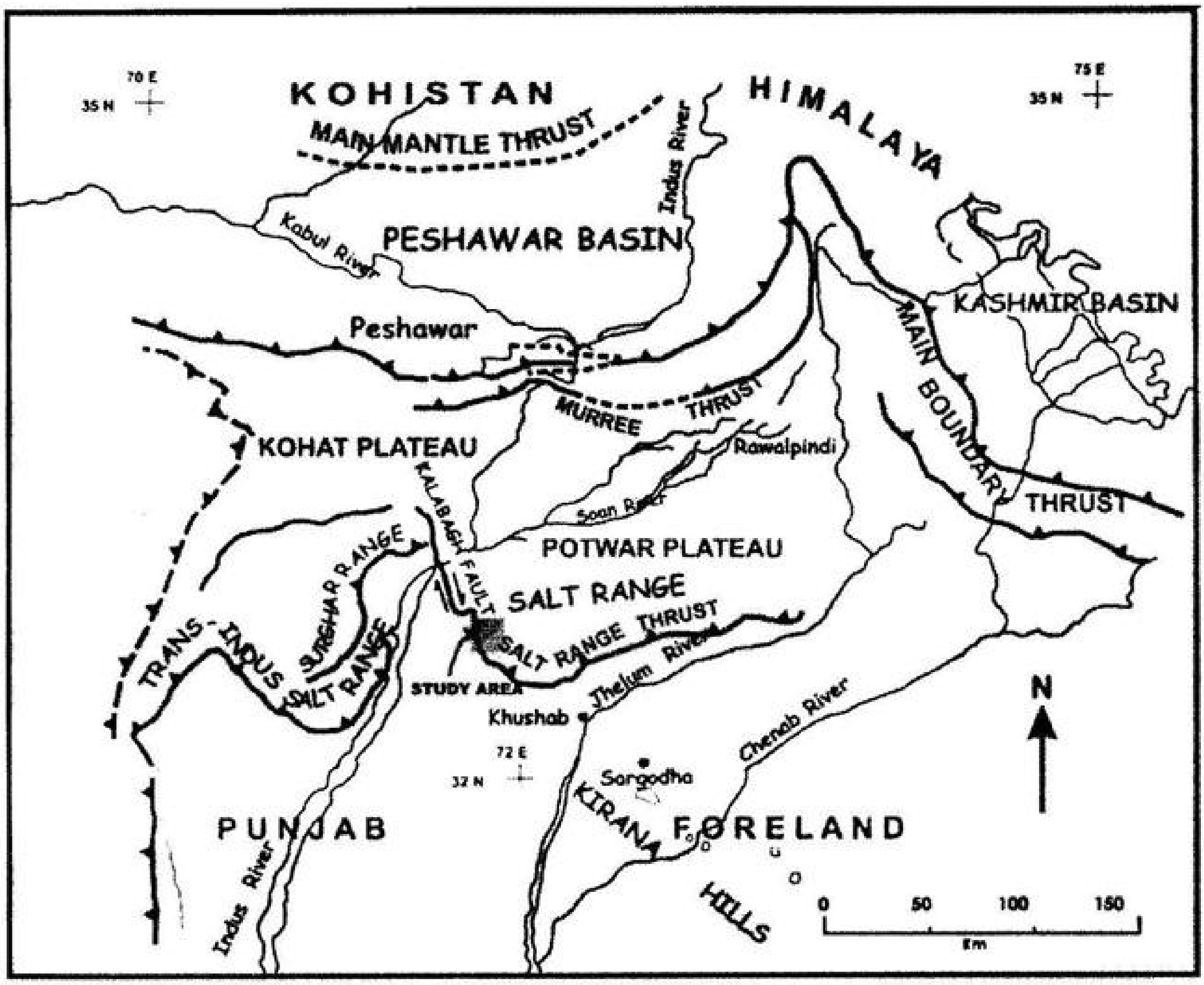


**Figure 2- Tectonic map of North Pakistan showing the location of study area (Modified after Kazmi and Raza, 1982).**

The Himalayan frontal fault or the Salt Range Thrust is the southern most thrust zone along the foothills of Salt Range and Trans-Indus Himalayan ranges (Gee, 1945; Yeats and Lawrence, 1984). This thrust is largely covered by alluvium and fanglomerates (Yeats and Lawrence 1984). However, at places the thrust is exposed and shows that the Paleozoic rocks overly the Neogene or Quaternary deposits of the Jhelum Plain (Gee, 1945, Yeats and Lawrencel., 1984). The Salt Range Thrust is considered as the surface expression of the leading edge of a regional decollement thrust (Lillie et al., 1987).

## STRATIGRAPHY

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 (Figure 3). 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 Warchha 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 Para conformably 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

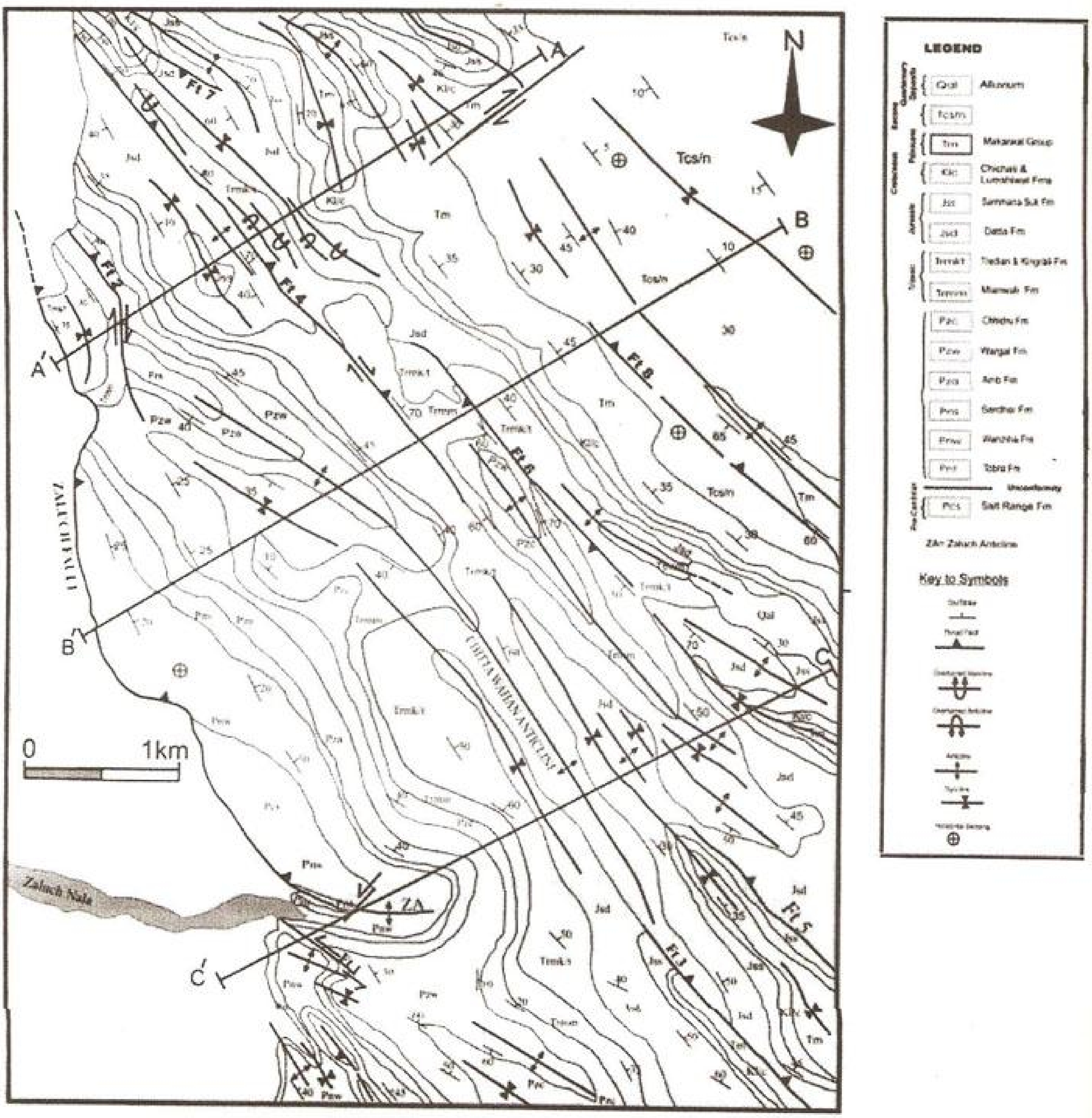


**Figure 3- Geological map of the Zaluch Nala, Western Salt Range, Mianwali District, Punjab, Pakistan.**

Formation with the Data Formation is disconformable. The Data Formation marks the base of the Jurassic sequence and contains red, grey 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, grey 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, Lockhart and Patala formations, whereas the youngest rock exposed in the area belongs to the Eocene age and is represented by Nammal and Sakessar formations.

## STRUCTURE

The structural geology of the Eastern and Central Salt ranges has been well documented and defined by previous workers (Gee, 1980; Yeats and Lawrencel., 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 it lacks detailed structural interpretation. The Geological mapping of the western Salt Range owes to the excellent work of Gee (1945) including the study area Zaluch Nala that represents the first ever geological map of the entire Salt Range on 1:50,000 scale. According to McDougall 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 3 clearly demonstrates that the study area occupies a part of the main Kalabagh Fault strand.

The Zaluch Nala area 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 the frontal ramping along the Salt Range Thrust.

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 3). Most of the kilometer scale folds observed in the mapped area have steeper forelimbs and gentle back limbs (Figure 3). The steep forelimbs generally dip 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. Most of these folds are found to be southwest facing (Figure 3).

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.

## NORTHEASTERN DOMAIN

The Northeastern domain lies northeast of the faults labeled as FT6 and FT8 on figure 3. The structural fabric of this domain is dominated by a series of macroscopic scale folds. The Triassic-Eocene rocks are open to gently fold into anticlinal and synclinal trends with a northwest axial trend (Figure 3). 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 3). 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, northwest oriented thrust fault labeled as F8 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.

## 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 3). 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 closely fold. In the extreme west the domain is marked by the Zaluch Fault.

## 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 (Figure 3) 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.

## SOUTHWESTERN DOMAIN

The Southwestern domain lays 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 3). A northwest trending, steeply southwest dipping thrust fault labeled as FT4, enters the area from northwestern corner of the map and is detached at the level of Datta Formation. It is steeply southwest dipping and emplaces the rocks of Datta Formation over the Cretaceous rocks in the footwall. This fault transfers its displacement in the southeast to a series of tight folds. Two prominent anticlines the Chitta Wahan and the Zaluch occur in the mapped area. 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 3). It brings the Permian-Precambrian rocks over the alluvial fans lying towards southwest (Figure 3). Along the southeastern end of Zaluch Fault a local scale splay fault (FT1) is mapped along which the Tobra Formation is thrust over the Warchha Sandstone in the footwall (Figure 3).

## STRUCTURAL MODEL

The structural geometry illustrated in Figure 3 can be best understood by considering geological cross-sections along line AA′, BB′ and CC′ (Figure 4, 5 & 6). 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 FT4 fault. The fold belt in the northeastern sector seems to have originated as simple buckles detaching directly from the Precambrian salt. The FT4 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 FT4 fault the out cropping rocks are tight to openly fold until FT2 fault breaks the surface. FT2 is gently northeast dipping and brings the Permian rocks in its hanging wall above the Triassic rocks in the footwall. Southeast of FT2 fault another fault splay named as Zaluch Fault is mapped. 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-section along BB/ and CC/ (Figure 5 & 6) 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 cross sections because they outcrop to the surface immediately southeast of the line BB′ (Figure 3). The fault FT1 occupies the forelimb of the Zaluch Anticline, which is the most prominent anticlinal structure of the region and appears to be an out of sequence fault. The fault FT1 is interpreted to be shallow level fault that does not relate to deeper level deformation. A small popup structure is also observed along both BB/ and CC/ lines.

## DISCUSSION AND CONCLUSIONS

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 (McDougall & Hussain, 1991). However the present investigation portrayed in figure 3, 4, 5 and 6 clearly demonstrates that the study area has been subjected to compressional deformation. The general structural trend of the folds and faults suggest that compressional stresses were largely oriented northeast 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 the fold are

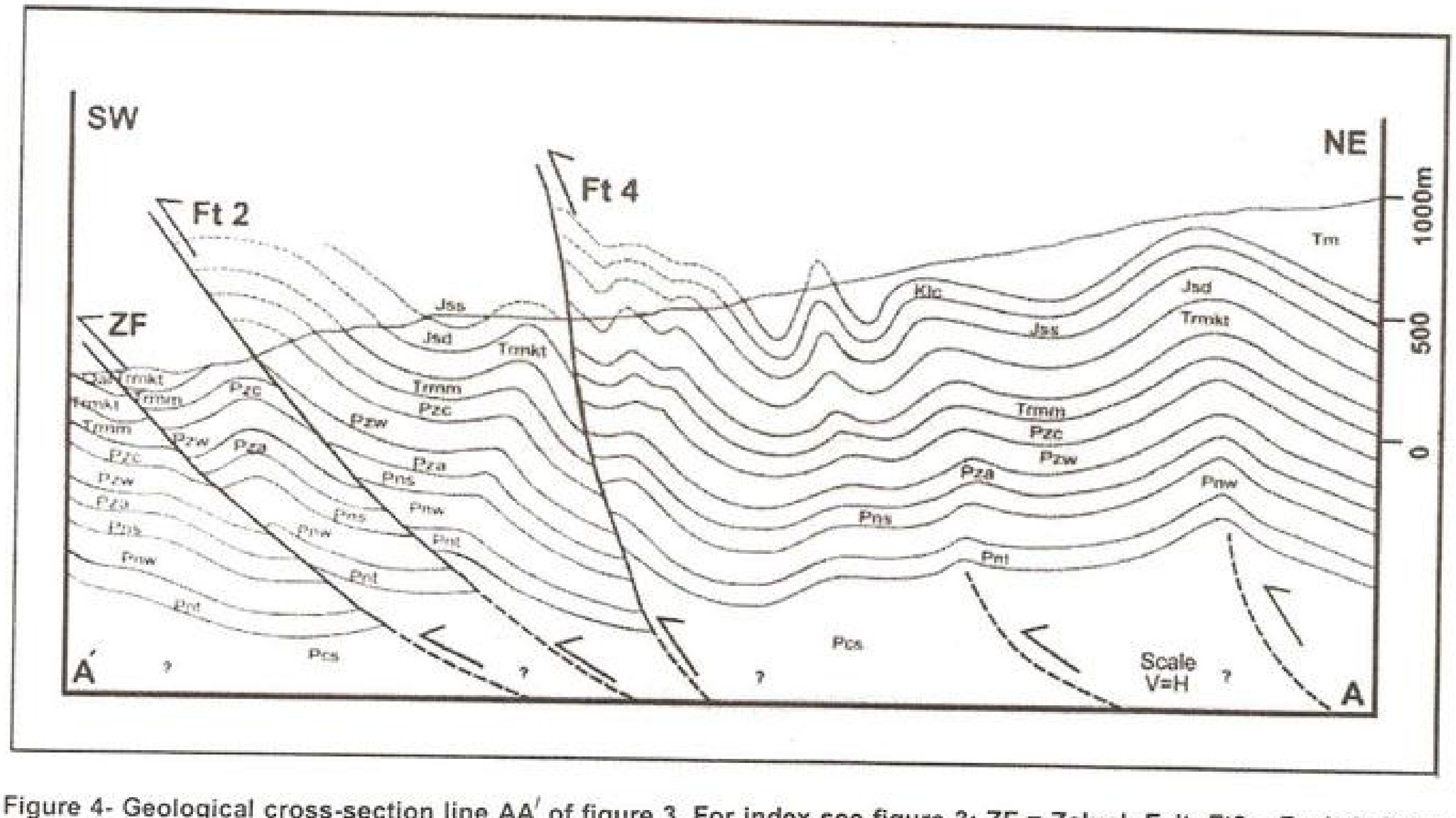


Figure 4- Geological cross-section line AA′ of figure 3. For index see figure 3; ZF = Zaluch Falt; Ft2 = Fault 2; Ft4 = Fault 4.

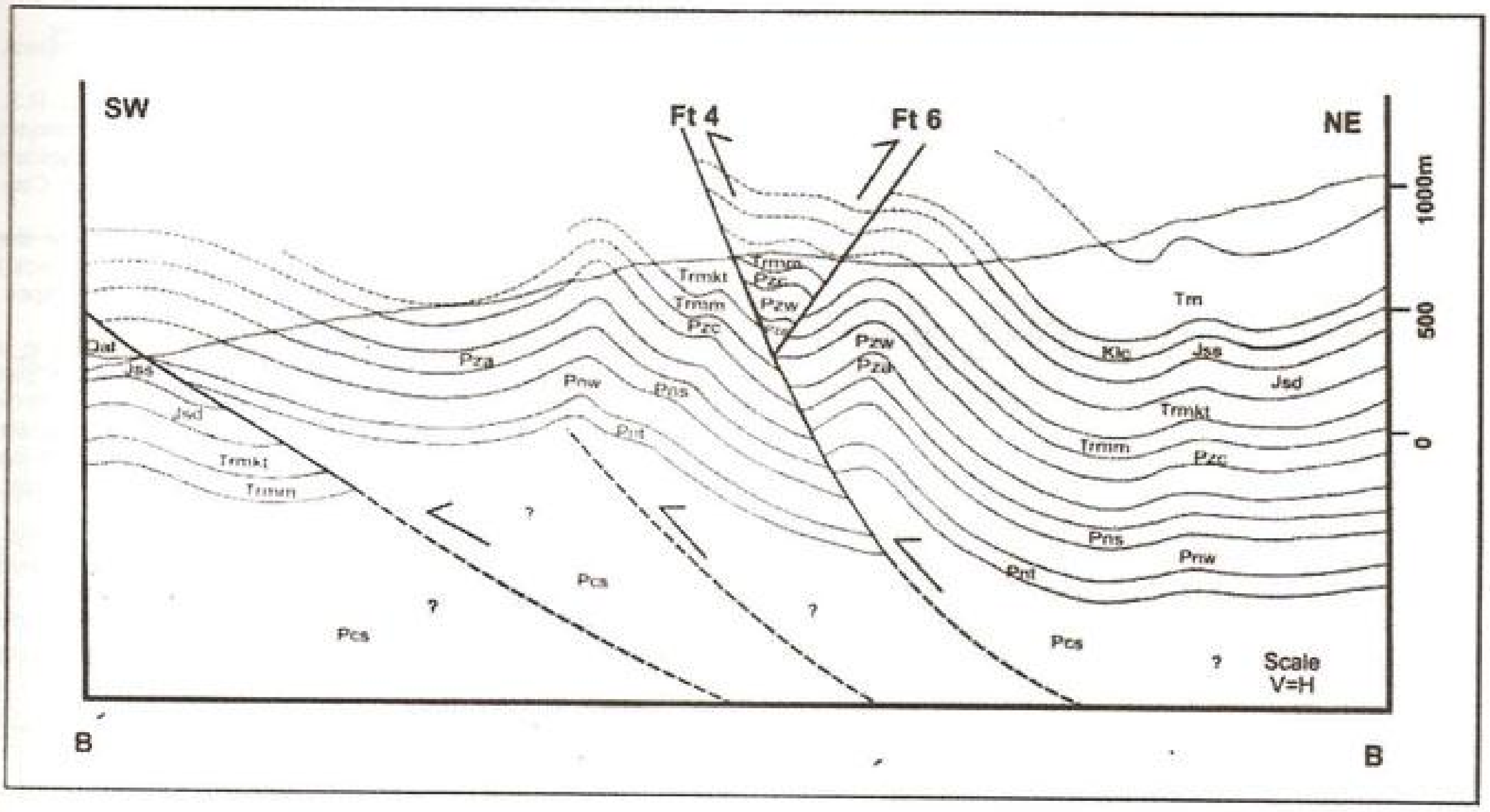


Figure 5- Geological cross-section line BB' of figure 3. For index see figure 3; ZF = Zaluch Falt; Ft4 = Fault 4; Ft6 = Fault 6.

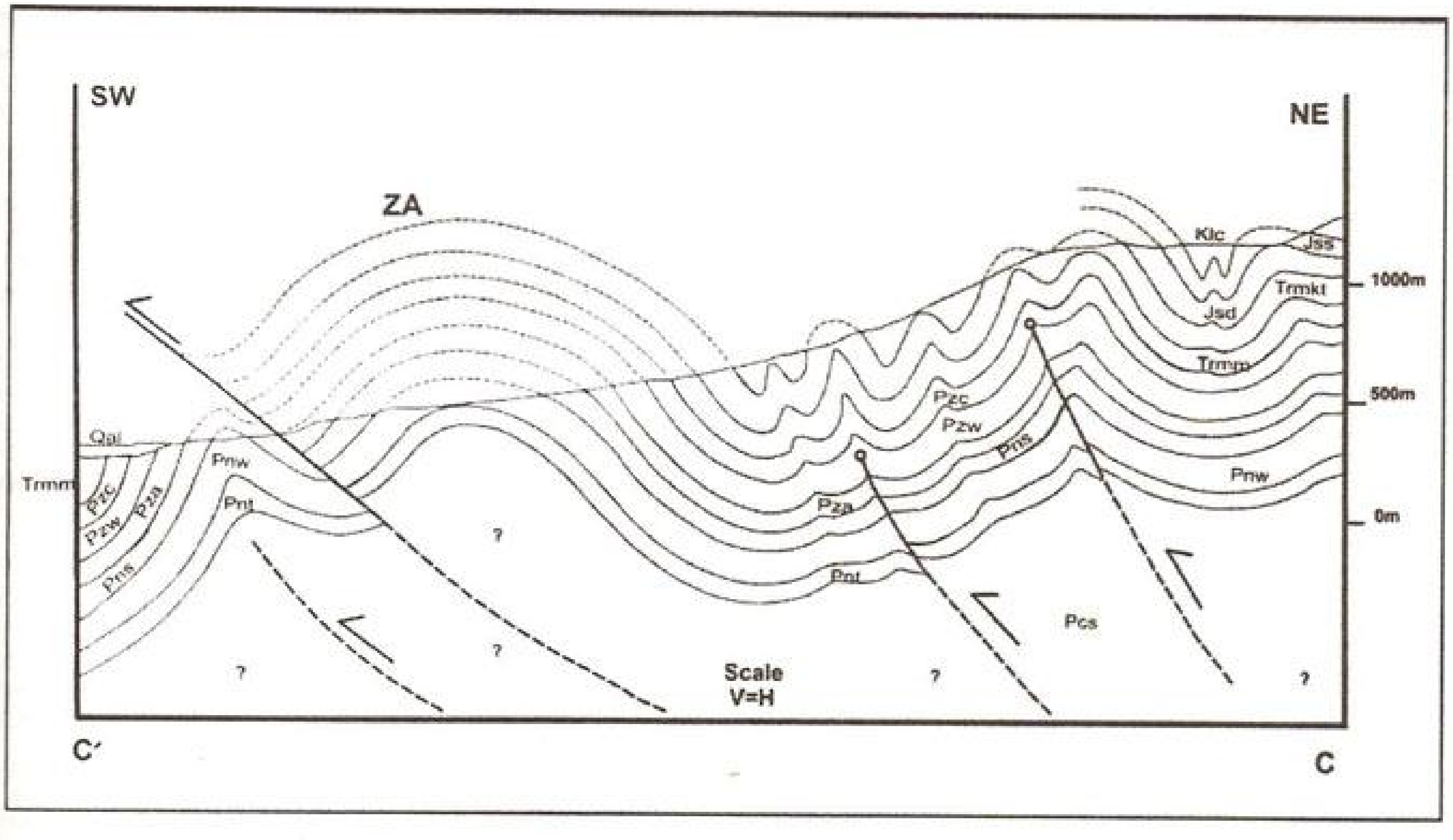


Figure 6- Geological cross-section line CC' of figure 3. For index see figure 3; ZA = Zaluch Anticline.

related to the subsurface fold projection suggests that the folds are related to shortening associated with translation above a regional basal decollement and the faults have developed as 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 from the base of the Salt Range Formation. 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 scale structures is from NW-SE suggesting 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, has been rotated due to lateral movement associated with Kalabagh Fault. The structural style studied in the area is of a typical thin-skinned fold and thrust belt.

## ACKNOWLEDGEMENT

The authors acknowledge the efforts of Dr. Ishtiaq A. Khan Jadoon, Geologist at Schlumberger, Islamabad for critical review of the manuscript and suggestion.

## REFERENCES


Coward, M. P., 1985, A Section through the Nanga Parbat Syntaxis Indus Valley. Kohistan. Geol. Bull. Univ. Peshawar, 18: p.147-152.

Gansser, A., 1981, The Geodynamics History of the Himalayas. In: Gupta, H. K. and Delany, F.M. (eds.) Zagros-Hindukush-Himalaya geodynamic evolution. Am. Geophys. Union, Geodyn. Ser. 3: p.111-121.

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

___, 1947, Further note on the age of saline series of the Punjab and Kohat: Proc., Sec. B. v.16 pt. 2-4, p.95-153.

Jaswal, T. M., R.J. Lillie and R.D. Lawrence, 1997, Structure and Evolution of the Northern Potwar Deform Zone, Pakistan: AAPG Bull., v.81, p.308-328.

Jaume, S. C. and R. J. Lillie, 1988, Mechanics of the Salt Range-Potwar Plateau, Pakistan: a fold and thrust belt underlain by evaporates: Tectonics, v.7, p.57-71.

Johnson, G. D., C.M.A. Powell and J.J. Veevers, 1976, Spreading history of the eastern Indian Ocean and Greater India's northward flight from Antarctica and Australia. Bull. Geol. Soc. Amer., 87: p.1560-1566.

Kazmi, A. H. and M.Q. Jan, 1997, Geology and Tectonics of Pakistan; Graphic Publishers, Karachi. Pakistan,

___ and R.A. Rana, 1982, Tectonic map of Pakistan, bf. Ed., Geol. Sum. Pakistan, Scale 1:2, 000,000, Quetta.

Lillie, R. J., G.H. Johnson, M. Yousaf, A.S.H. Zamin and R.S. Yeats, 1987, Structural development within the Himalayan foreland fold-thrust belt of Pakistan. *In*: Beaumont and Tankard (eds) Sedimentary Basins and Basin forming Mechanism. Can. Soc. Petro. Geol., Memoir 12, p.379-392.

Malinconico, L. L., 1989, Crustal thickness estimates for the western Himalaya, *In:* Malinconico, L. L. and R.J. Lillie (eds.) Tectonics of the Western Himalayas. Geol. Soc. Amer., Spec. Paper 232: p.237-242.

McDougall, J. W. and S.W. Khan, 1990, Strike slip faulting in a foreland fold-thrust belt: the Kalabagh fault and western Salt range, Pakistan. tectonics, 9, p.1061-1075.

___ and A. Hussain, 1991, Fold and Thrust Propagation in the Western Himalaya based on a balanced cross section of the Surghar Range and Kohat Plateau, Pakistan. Bull. Amer. Assoc. Petrol. Geol., 75, p.463- 478.

Noetling, F., 1901, BeritrageZur Geologieder Salt Range, Imesondere der Permichen and Triasuchen Albagerungen: Ucues Jahrb. Mineral., Beilageband, 14, p.369-471.

Patterson, M. G. and B.F. Windley, 1985, Rb- Sr dating of the Kohistan Arc Batholith in the Trans-Himalaya of North Pakistan and tectonic implications. Earth Planet. Sei. Lett., v.74, p.54-75.

Pivnik, D. A. and N.A. Wells, 1996, The transition from Tethys to the Himalayas as recorded in north west Pakistan. Bull. Geol. Soc. Amer., 108: p.1295-1313.

Searle, M. P., 1991, Geology and Tectonics of the Karakoram Mountains. J. Wiley and Sons, New York, 358p.

Seeber, L., and J. Armbruster, 1979, Seissmicity of the Hazara arc in northern Pakistan: decollementversus basement faulting. *In:* Farah, A. and K.A. DeJong, (eds.). Geodynamics of Pakistan. Geological Survey of Pakistan, Quetta, p.131-142.

Tschernyscliew, T., 1902, Die obercarbonischen Brachiopoden des Urlas ud des Timan. Comite geol. Russie, Mem. v.816, 116p.

Wynne, A. B., 1878, On the geology of the Salt Range in Punjab: India. Geol. Surv, Mem, Paleont. Indica, Ser. 13, v.4, Pt. 1 & 2, 242p.

___, 1879, Further notes on the geology of the upper Punjab: Ibid., Recs., v.12, pt. 2, p.114-133.

___, 1880, On the Trans-Indus Extension of the Punjab Salt Range. Geol. Surv.India, Mem. 17(2): p.163-169.

Yeats, R. S., and R.D. Lawrance, 1984, Tectonics of the Himalayan Thrust Belt in Northern Pakistan. *In:* Haq, B. U. and J.D. Milliman (eds.). Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan Van Nostrand Reinhold Co., New York, p.177-200.

Zeitler, P. K., 1985, Cooling History of the NW Himalaya, Pakistan. Tectonics, 4: p.127-15.