

Range front structural style: An example from Surghar Range, North Pakistan

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Abstract

The Surghar Range is the easternmost extension of the Trans-Indus Salt ranges of North Pakistan that appears as an arcuate mountain belt. The range follows in general an east-west structural trend while bordering the southern Kohat Plateau and switches to north-south trend along the eastern flank of the Bannu Basin. Being an active range front it preserves variety of structural styles in the outcropping and non-outcropping rocks. The east-west trending segment of the range owes its evolution to frontal ramping from basal décollement thrusting within the Paleozoic-Mesozoic rocks and emerges as a low angle frontal thrust named as the Surghar Thrust. The hanging wall of Surghar Thrust is moderately to tightly folded with Surghar Anticline being the most prominent fault bend fold structure. The structural geometries along the frontal thrust fault suggest that it is weakly emergent in the west and changes its character to strongly emergent to tip-stick thrust front progressively towards east. This part of the range dominantly reveals a south verging structural system impinging upon the Punjab Foreland in the south.

In contrast the north-south trending segment of the Surghar Range has evolved as an easterly tapering tectonic wedge of Paleozoic-Paleocene rocks inserted underneath the Eocene-Pliocene rocks. The tectonic wedge comprises north-south trending Makarwal Anticline that has developed above a ramp from basal décollement within Paleozoic-Mesozoic rocks and forms the base of the wedge. The ramp beneath the Makarwal Anticline instead of emerging out at erosional surface gets flattened at an approximate depth of 800 meters to form a shallow level flat. The eastern flank of the Makarwal Anticline is steeply east dipping along the range front and is thrust over by a west verging active back thrust namely the Makarwal Active Back Thrust that forms the upper part of the tectonic wedge. The Makarwal Active Back Thrust is linked with the east verging basal fault in the subsurface at the hanging wall cut off of the Jurassic rocks located at the tip line of the basal fault. The Makarwal Active Back Thrust along with another east vergent active back thrust splays from the forelimb of a buried anticline underneath the Makarwal Anticline forming the top of a second tectonic wedge. The term active back thrust is applied to the west verging faults because their hanging and foot wall strata is actively deforming in response to wedge insertion.

Keywords: Tectonic wedging; Surghar Range; Back thrusting.

1. Introduction

Surghar Range of the outer Himalayas represents the eastern end of the Trans-Indus Salt ranges of North Pakistan (Fig. 1) (Powel, 1979). The range exhibits east-west structural trend along the southern margin of the Kohat Plateau and changes to north-south trend along the eastern flank of the Bannu Basin (Fig. 2) (Khan and Opdyke, 1993). Along the Surghar Range the non-outcropping Cambrian-Paleocene rocks underneath the Kohat Plateau and Bannu Basin are exposed. Being

located in close proximity to the western transform border of the Indian Plate it has well preserved imprints of south as well as east directed contractile deformation (Fig. 1). The range exhibits arcuate geometry in plan and display contrasting mountain front geometries along its trace. It is characterized by south verging structures along its east-west trending segment. Whereas in contrast the north south trending segment of the range is dominated by east vergent structural geometries in addition to west verging active back thrusting and tectonic wedging.

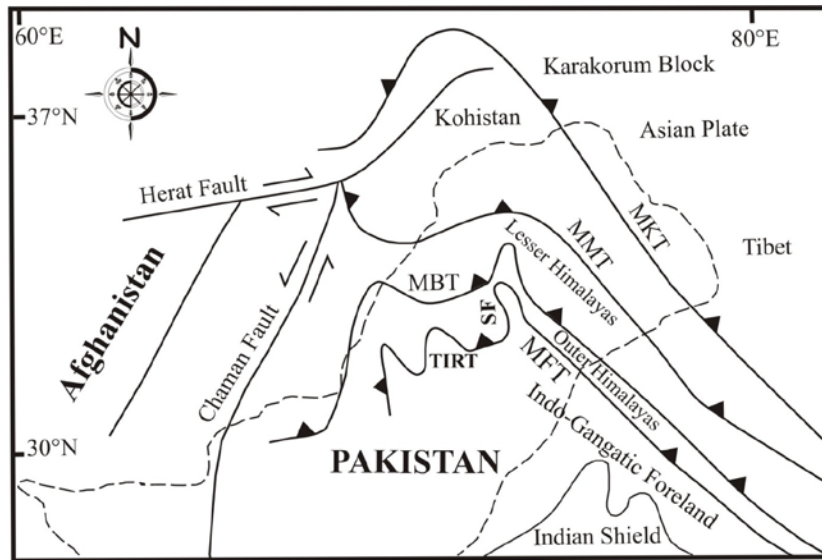


Fig. 1 Tectonic map of the north west Pakistan, Modified after Ahmad et al., 1999. MKT: Main Karakoram Thrust, MMT: Main Mental Thrust, MBT: Main Boundary Thrust, MFT: Main Frontal Thrust, SF: Surghar Fault, TIRT: Trans Indus Ranges Thrust.

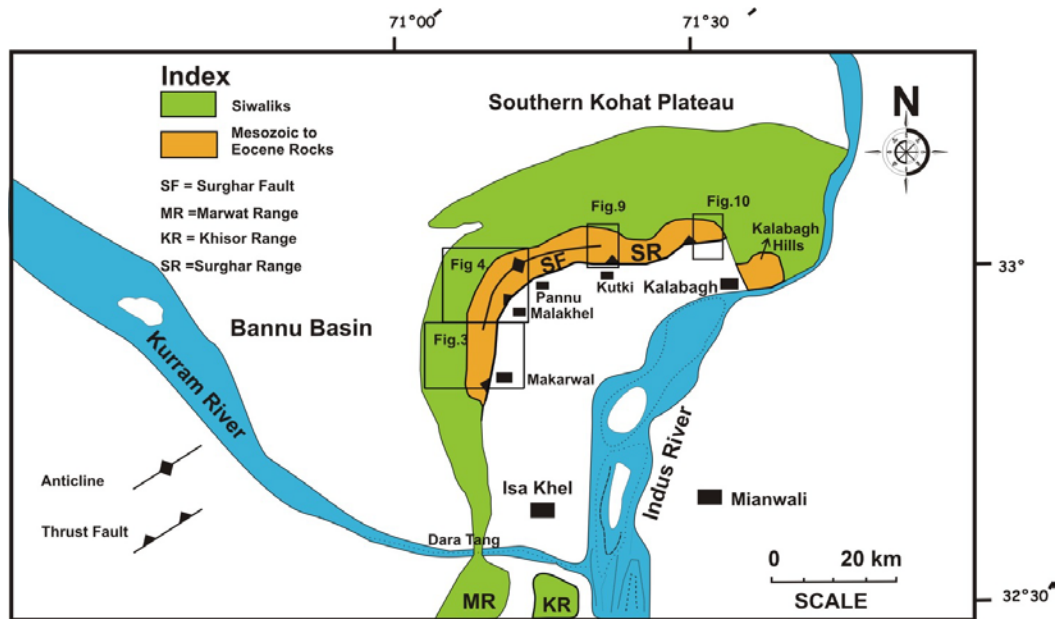


Fig. 2. Geological map of the Makarwal Kheji area, north south trending Surghar Range.

Previous studies in the Surghar Range mainly refers to the stratigraphic framework, geological mapping and economic geology of its north-south trending segment (Khan et al., 1993., Wynne, 1880, Simpson, 1904, Danilchik 1961, Danilchik et al., 1987) where as its east-west segment has been neglected since long. The structural account of a part of the eastern end of the east-west segment of the range was first referred to by McDoughal (McDoughal et al., 1990) as a

strongly emergent thrust front translating along an evaporite horizon. Later on Ahmad et al. (Ahmad, Ali, Sayab, Ahmad and Hamidullah, 1999) discussed the detailed structural account of Chichali Pass area and interpreted that the topographic expression of the range is attributed to a south verging anticline namely the Surghar Anticline that is detached at the base of Jurassic sequence. The fore limb of this anticline is characterized by a south vergent thrust fault

namely the Surghar Thrust with its hanging wall deformed by break backward sequence of thrusting.

The Surghar Range of North Pakistan provides excellent opportunity for understanding the structural evolution of a mountain range that represents the leading front of an orogenic belt where deformations are still in progress. It is key in order to assess the subsurface structural style of the Kohat Plateau and Bannu Basin as no rocks older than Paleocene crops out in the Kohat Plateau whereas the Bannu Basin is a flat lying basin with almost no out crops older than Holocene. It is believed that the recent success of oil and gas wells in the Kohat Plateau needs better understanding of its subsurface structures that can be best accomplished by the structural understanding of the Surghar Range, which is the focus of this paper. This paper also addresses the nature of mountain front structure of the Surghar Range that was poorly understood in the past.

2. Geological setting

The spectacular Himalayan mountain chain produced as a result of continent-continent collision of Eurasia and India that started some 55 million years ago (Powell, 1979, Molnar and Tapponier 1975., Patriat and Achache, 1984., Bech, Burbank, Sercombe, Khan, Lawrence, 1996). In north Pakistan, the Lesser as well as Outer Himalayas trend east-west, switching to a north-south trend in the west (Fig. 1). The Kohat and Potwar fold and thrust belts along with the Trans Indus ranges and the Salt Range of the Outer Himalayas were initiated subsequent to the collision of Indian and Eurasian plates. The Trans Indus ranges and the Salt Range represents the southernmost part of the outer Himalayas in North Pakistan and constitutes the active deformational front of the Kohat and Potwar plateaus. The Surghar Range is the eastern most of the Trans Indus ranges and is cross the Indus River continuation of the Salt Ranges. It marks the tectono-stratigraphic boundary between Kohat Plateau in the north, Bannu Basin in the west and Punjab foreland in the south (Fig. 2). Along the Surghar frontal thrust Permian to Eocene platform sequence is thrust southwards over the undeformed Quaternary sediments of the Punjab Foreland.

The oldest rocks outcropping in the Surghar Range belongs to the Zaluch group of Permian age conformably overlain by the Mianwali, Tredian and Kingriali Formation of Triassic age. The Triassic sequence is in turn overlain by a thick succession of Jurassic rocks including Datta, Shinawari and Samana Suk Formation. The Jurassic sequence is overlain by Cretaceous to Eocene rocks that is in turn unconformably overlain by the Chinji Formation of Lower Siwalik Group (Table 1) representing the end of marine deposition and onset of fluvial sedimentation in the region.

Table 1. Stratigraphic framework of the Surghar Range (Modified after Danilchik et al. 1987).

System	Series	Surghar Range		
TERTIARY	Miocene - Pliocene	Siwalik Group		Dhok Pathan Formation
				Nagri Formation
				Chinji Formation
				Unconformity
	Eocene		Sakessar Formation	
			Nammal Formation	
	Paleocene		Patala Formation	
			Lockhart Limestone	
			Hangu Formation	
	MESOZOIC	Cretaceous	Upper	Lumshiwal Formation
Lower			Chichali Formation	
Jurassic		Upper	Sama Suk Formation	
		Middle	Shinawari Formation	
		Lower	Datta Formation	
Triassic			Kingriali Dolomite	
			Tredian Formation	
		Mianwali Formation		
PALEOZOIC	Permian	Late	Zaluch Group	Chhidru Formation
				Wargal Formation

3. Structural style in the north-south trending segment of Surghar Range

This part of the range displays north south structural trend with small undulation, located between Mala Khel in the north to Dara Tang in the south (Fig. 2). The topographic expression of the range is mainly the result of a north south oriented, asymmetric box anticline named as Makarwal Anticline (Figs. 3, 4 and 5). It is cored by Jurassic rocks along its map trace and consists of moderately west dipping back-limb and a steeply east dipping fore-limb suggesting that it is a typical ramp anticline formed due to bending in the underlying fault. Along the southern exposure of the Makarwal Anticline a couple of east verging thrust faults having gentle westward dips are mapped. The hanging wall stratigraphy of these faults suggests a shallow level detachment at the base of Lumshiwal Formation of Cretaceous age. The hanging as

well as footwall of these faults is openly folded and both the orientation of folds and thrust faults suggest eastward translation of the range. The forelimb of Makarwal Anticline along the entire range front is occupied by Makarwal active back-thrust that is observed to be steeply east dipping (60-70°). The fault is oriented north south and emplaces Eocene rocks on top of Jurassic in the south while moving towards north, the footwall cut offs become younger (Fig. 6). The hanging wall cut-off along the fault is characterized by the Eocene sequence throughout its exposure whereas its footwall cut offs are older in the south in the vicinity of Makarwal Kheji and progressively becomes younger towards north in the vicinity of Mala Khel area. Another back thrust with steep eastward dip is mapped east of the Makarwal active back thrust and is characterized by Eocene rocks in its hanging wall emplaced westward over the Siwalik Group rocks in the foot wall (Fig. 4).

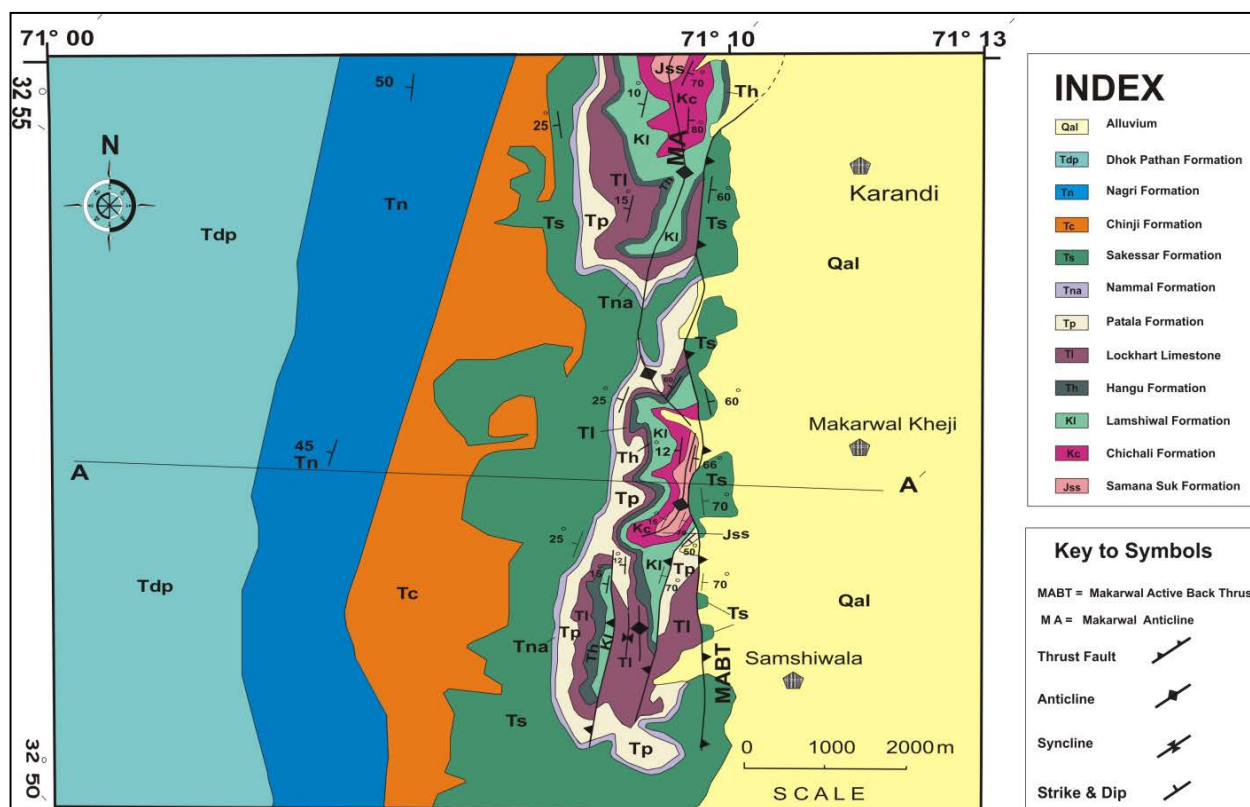


Fig. 3. Generalized geological map of the Surghar Range. (Modified after Banks et al., 1985)

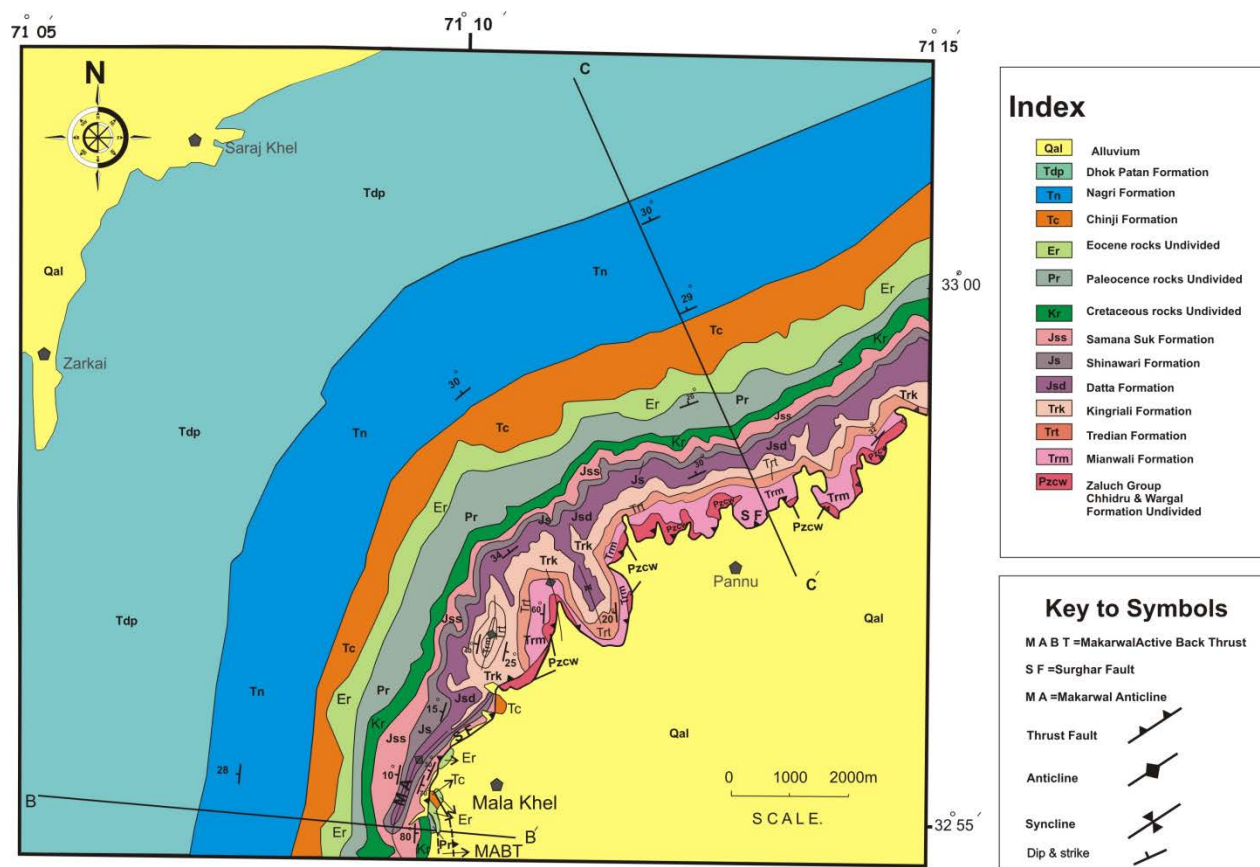


Fig. 4. Geological map of the north western apex of the Surghar Range in the vicinity of Mala Khel and Bannu areas.

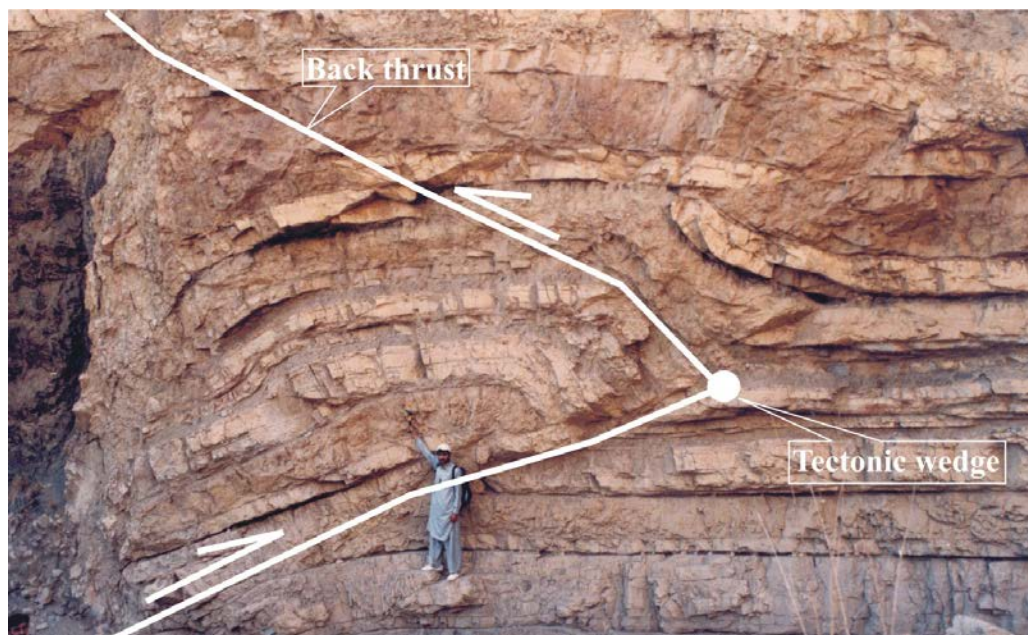


Fig. 5. North looking view of the core of Makarwal Anticline showing box fold geometry and tectonic wedging at mesoscopic scale.

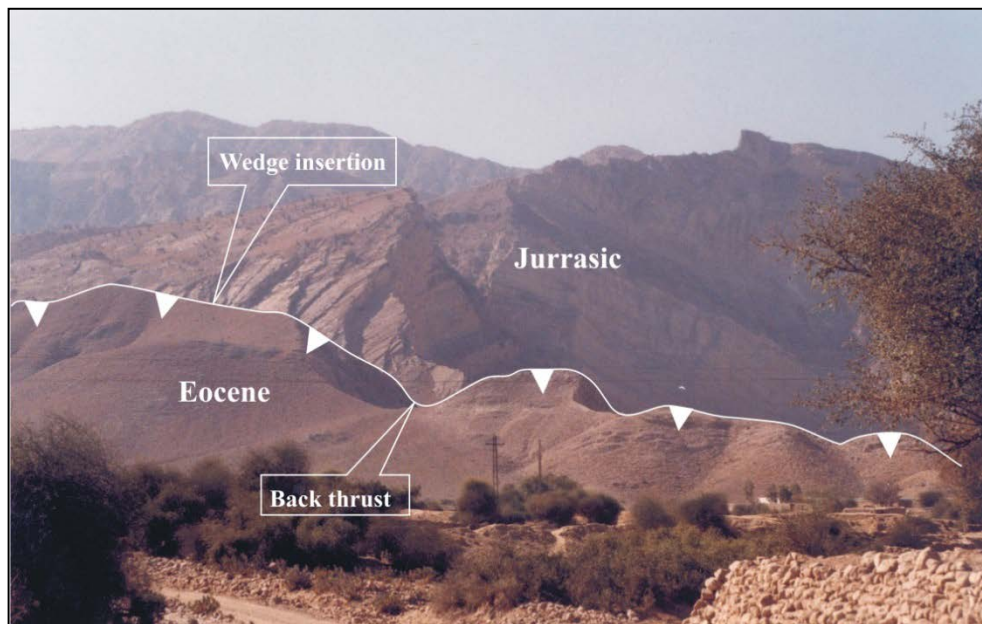


Fig. 6. West looking view of the Surghar Range in the vicinity of the Makarwal village showing Makarwal active back thrust along which the Eocene strata is thrust over the forelimb of Makarwal Anticline.

4. Structural transects

Cross section along line A-A' has been drawn across the range in the vicinity of Makarwal in order to understand its subsurface style of deformation (Figs. 3 and 7). The structural model depicts that this part of the range has been evolved as the result of a pair of east directed frontal ramps from a basal décollement within the Paleozoic-Mesozoic rocks. The attitude data on the limbs of Makarwal Anticline is indicative of its association with the subsurface non-emergent ramp and is a typical fault bend fold. The ramp beneath the Makarwal Anticline does not emerge at surface but flattens at a shallow level till its tip line is thrust over by the Makarwal Active Back Thrust. The Makarwal Anticline is stacked upon a non-outcropping anticline that has also evolved as the result of frontal ramping from basal décollement within Paleozoic-Mesozoic rocks. The antiformal stack comprising Makarwal Anticline along with its subsurface analogue are in fact the result of tectonic wedging inserted beneath the Punjab Foreland. The base of tectonic wedge below the Makarwal Anticline consists of basal ramp and its top is made up of the Makarwal Active Back-Thrust. East of another active back thrust is interpreted based on similar stratigraphic

relationship mapped in the north. Another cross section drawn along line B-B' in the vicinity of Mala Khel area in the extreme north of the range shows more or less similar structural geometry with the exception that the footwall cut offs along the Makarwal Active Back-Thrust has become younger indicating decrease in the rate of wedge insertion (Fig. 8).

5. Structural geometry of the east-west trending segment of Surghar Range

This part of the range extends from Pannu in the west up to north of Kalabagh Hills in the east (Fig. 2). It exhibit east west structural trend and the main topographic expression of the range is attributed to a south facing asymmetric anticline named as Surghar Anticline. The Surghar Anticline is well developed in Kutki and Chichali Pass area whereas elsewhere only the back limb of this anticline is preserved and its forelimb is dissected by a south verging fore thrust along the entire range front (Figs. 4 and 9). The oldest rocks exposed in the core of Surghar Anticline belong to Jurassic rocks along most of its trace (Fig. 9). Along the frontal Surghar Fault Mesozoic to Eocene rocks are thrust southwards over Punjab Foreland (Figs. 4, 9 and 10).

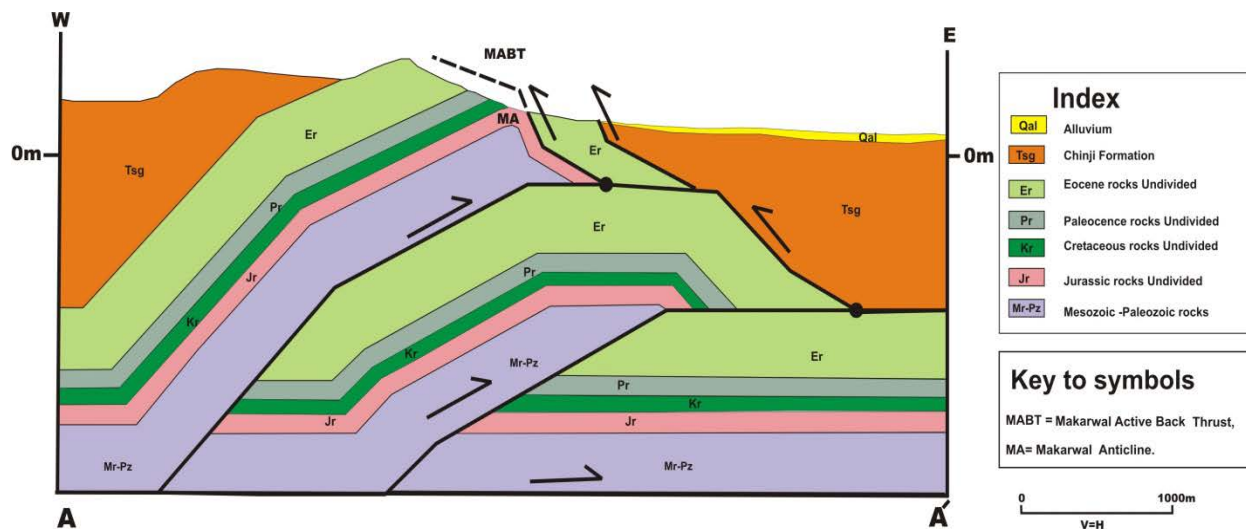


Fig. 7. Geological cross section along line A-A' of Fig. 3.

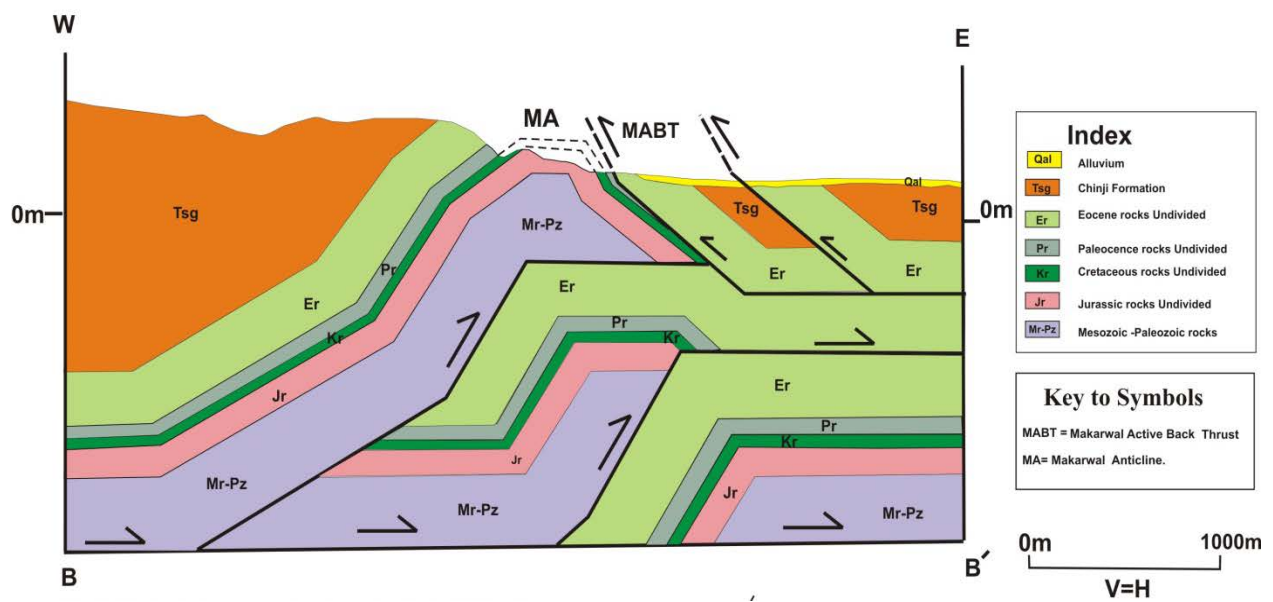


Fig. 8. Geological cross section along line B-B' of the Figure 4.

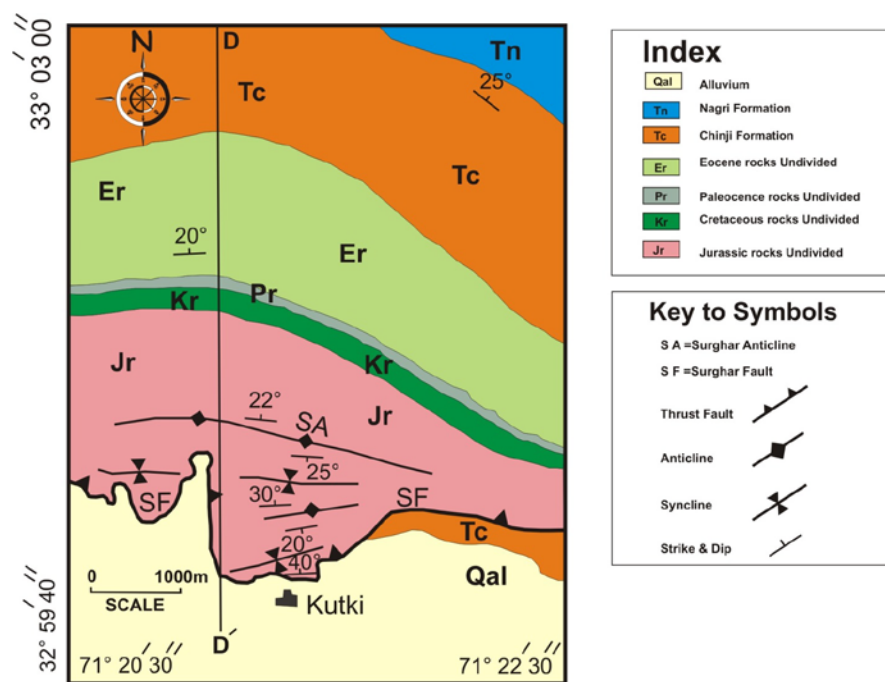


Fig. 9. Geological map of the east west trending Surghar Range, north of Kutki village.

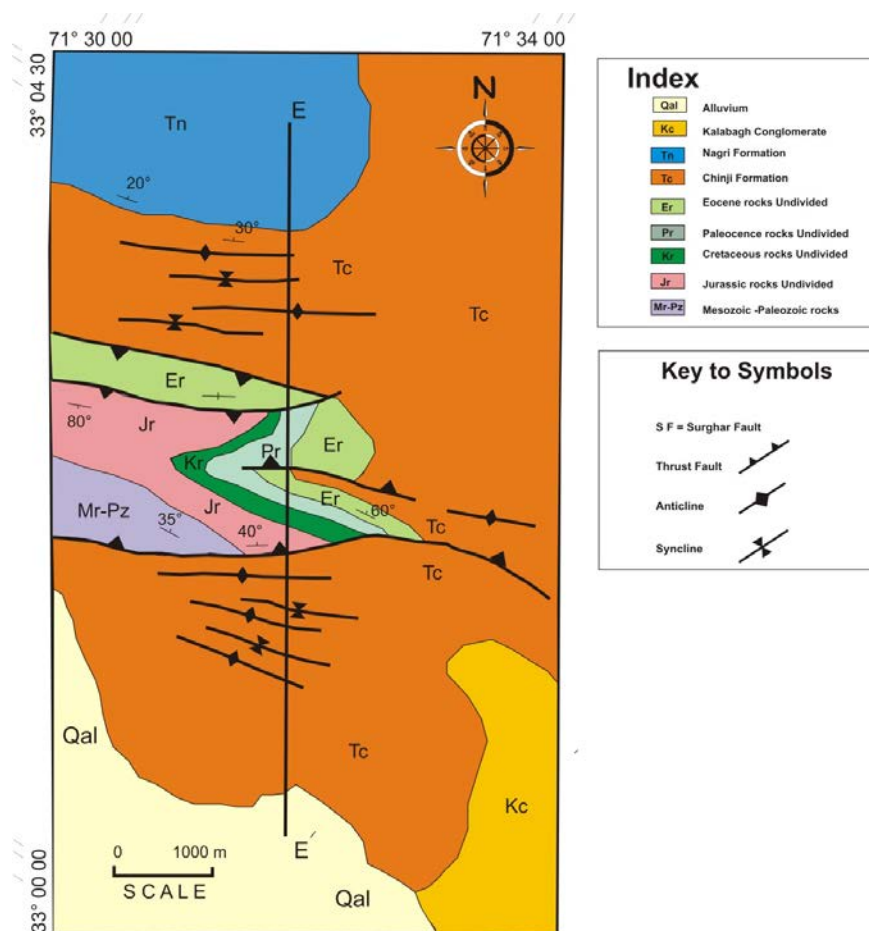


Fig. 10. Geological map of the eastern Surghar Range, north of Kalabagh Hills.

6. Structural model

Three cross sections has been constructed across the east west segment of Surghar Range, located in the east, center and west in order to work out the style of deformation. From north to south along section C-C' of (Fig. 4), a stratigraphic succession of Permian-Siwalik Group rocks makes the hanging wall strata of the Surghar Fault that is thrust over the Chinji Formation (Fig. 11). The Surghar Fault is detached at the base of Zaluch Group rocks as evident from its hanging wall stratigraphy. The thrust sheet of this frontal fault monoclinaly dips towards north without any significant deformation and belongs to the backlimb of the Surghar Anticline. South of the Surghar Fault in the subsurface a buried anticline is present that is believed to be a fault bend fold. The frontal Surghar Fault is weakly emergent in this part of the range (Morely, 1986). North to south traverse along line D-D' shows that the Surghar Anticline is the prominent structural feature of the range (Figs. 9 and 12). The Surghar Anticline along with a pair of south facing anticline and syncline constitutes the hanging wall sequence of the Surghar Fault. The Surghar Fault has evolved as ramp from basal décollement is detached within or at the base of Triassic sequence. Instead of cutting through Surghar Anticline, it flattens at a shallow level and emerges at the surface 2 km

foreland ward, ahead of the bend in ramp. The structural geometry indicates easy propagation of thrust sheet towards the foreland (Morely, 1986).

The structural style portrayed in cross section E-E' shows remarkable contrast to the rest of structures in the range (Figs. 10 and 13). From hinterland towards foreland along the section line the moderately folded Siwalik Group rocks of the Southern Kohat Plateau are in fault contact with the heavily deformed strata of Surghar Range along a vertical to sub vertical fault found to be transpressive in nature.

South of this fault another fault of similar nature is present. Both these faults appear as splay from a south verging high angle reverse fault present in the south. The southernmost tectonic boundary of the range is the Surghar Fault that is moderately south dipping and emplaces Jurassic rocks over the shallowly folded Siwalik Group rocks of the Punjab Foreland. Most of the faults in this section are steeply dipping, having strongly folded hanging walls. The displacement is distributed through several thrust splays instead of a single frontal thrust as is the case in the rest of the range reflecting tip-stick style of deformation. The steep nature of the faults is a clear indication of lateral motion with all the faults in addition to thrust and reverse slip motion.

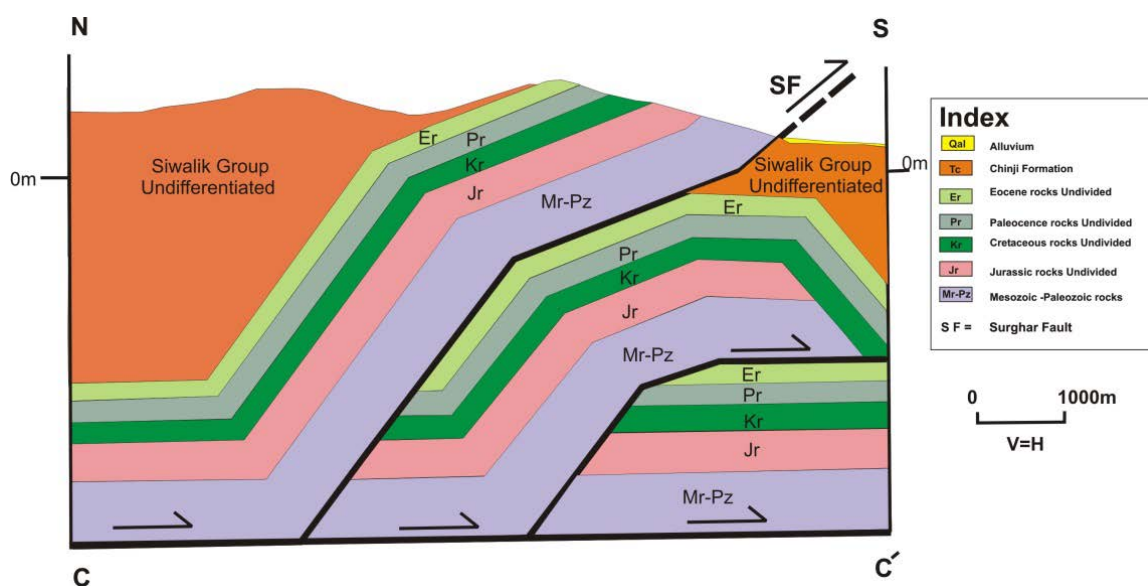


Fig. 11. Geological cross section along line C-C' of the Figure 4.

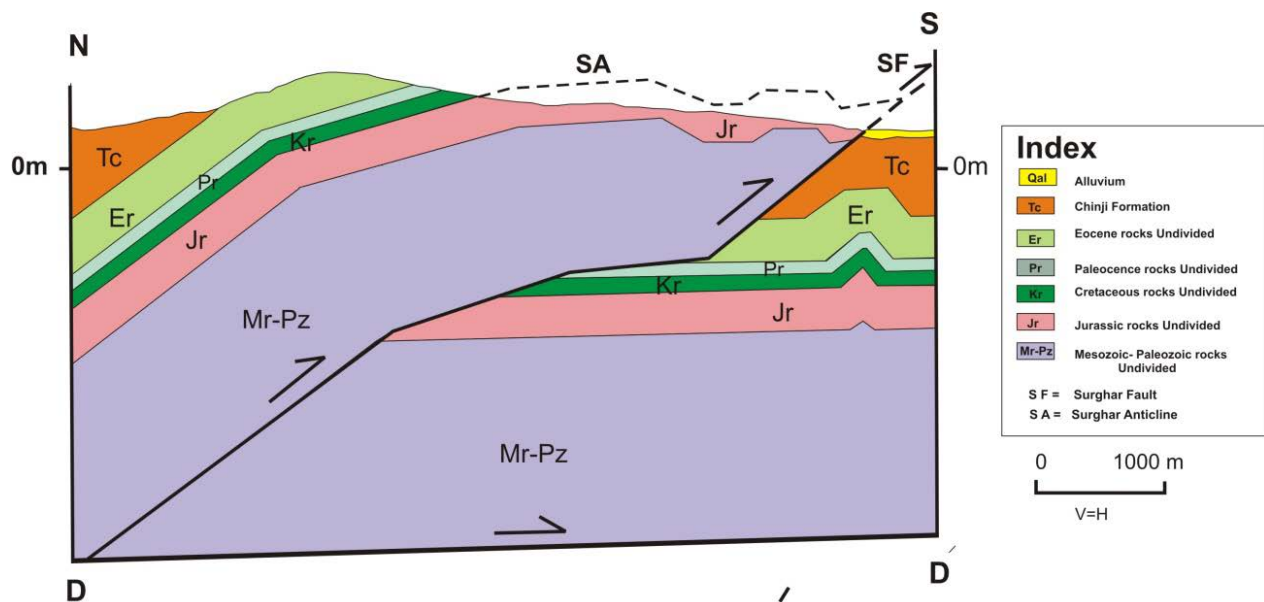


Fig. 12. Geological cross section along line D-D' of the Figure 9.

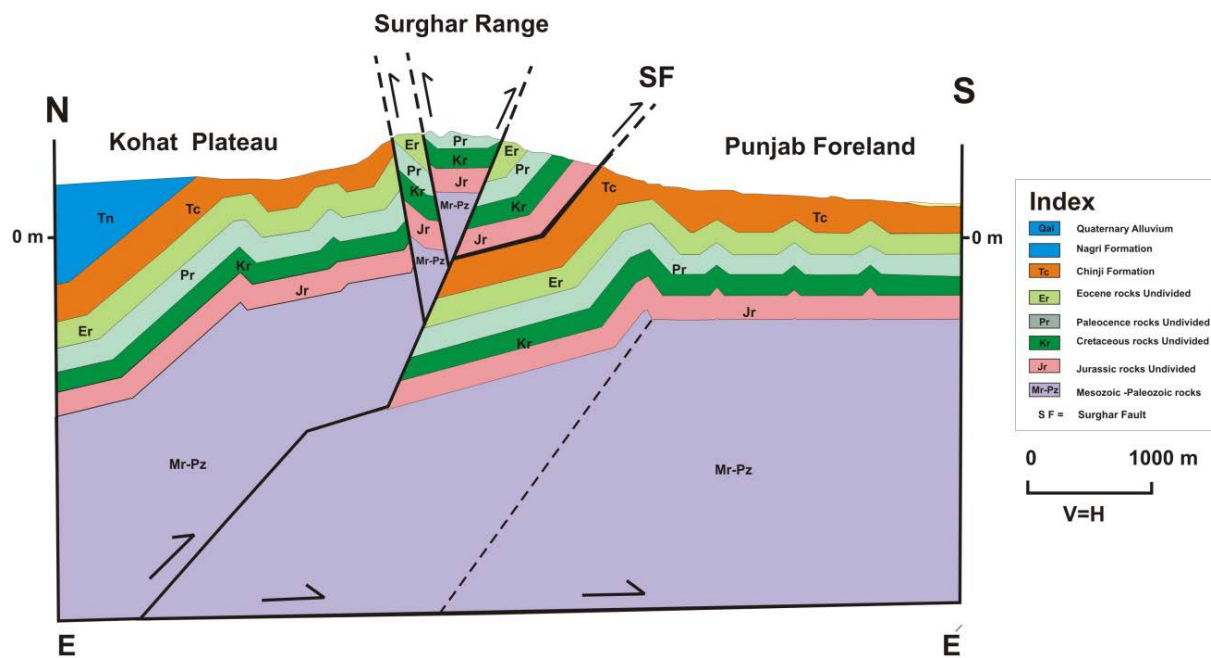


Fig. 13. Geological cross section along line E-E' of the Figure 10.

7. Discussion and conclusions

We have demonstrated from the above account of structures in the Surghar Range that mountain front structures vary considerably along strike despite similar stratigraphic and tectonic setting. In fact these variations are largely controlled by the kinematics of ramping and by the changes in the orientation of tectonic stresses. The orientation of both large and small scale structures in the east west trending segment of the Surghar Range are typical of a south vergent structural system deformed as result of north south oriented tectonic stresses and translates along a basal décollement that ramps out at the range front. Thrust variations in structural geometry along strike of the range can be explained in terms of ramping nature and motion along thrust sheet. The mountain front in the west in the vicinity of Pannu is interpreted as a fault bend fold that lacks its frontal limb (Suppe, 1983). A frontal limb forms as a ramp flattens at shallow level after cutting up section from a basal décollement. In this area the décollement ramp does not flattens at shallow level but rather emerges at surface with little horizontal translation like that of a weakly emergent thrust front (Morely, 1986). This style does not continue eastward along the strike but rather switches to a strongly emergent thrust front in the center of the

range where the frontal limb of the major fault bend fold is present and the ramp from basal décollement gets flattened at shallow level to form a flat. The thrust sheet is mildly folded indicating simple translation along the frontal fault. This style of deformation is inconsistent with structural style in extreme east where the Surghar Range initially evolved as a ramp from basal décollement but later on assumed tip-stick style because the motion along the frontal fault was stuck after its initial emplacement. The thrust sheet was later on folded and tightened to accommodate the strain build up and finally failed by a couple of north vergent back thrusts. The steep nature of these back thrusts and the presence of East West vergent drag folds within the thrust sheet of Surghar fault (Fig. 14), leads to the idea of lateral motion as well in addition to thrust slip motion. The idea of strike slip motion is also supported by the fact that these faults are located near the junction of Kalabagh Fault Zone and Eastern Surghar Range and accommodated some of the displacement associated with the Kalabagh Fault. The above mentioned structural account of the Surghar Range can be applied to the questionable subsurface structural style within the non outcropping Paleozoic to Mesozoic rocks of the Southern Kohat Plateau as both domains have similar tectonic and stratigraphic setting.

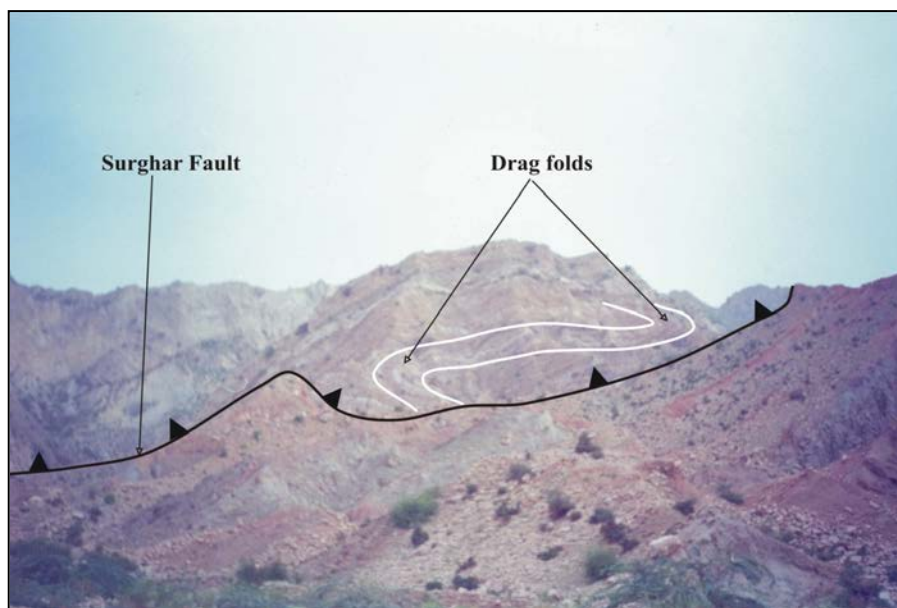


Fig. 14. North looking view of the Surghar Thrust sheet with drag folds, showing lateral movement along Surghar Fault located at the eastern terminus of Surghar Range.

In contrast the north-south trending segment of the Surghar Range has evolved as an easterly tapering tectonic wedge of Paleozoic-Mesozoic rocks inserted under the Tertiary strata of Punjab Foreland. This part of the range consists of a couple of box anticlines, forming antiformal stack type geometry. These anticlines are considered as tectonic wedges bounded by basal and roof thrusts of opposing vergence. The Makarwal Anticline being the upper and exposed one is characterized by a steep foreland ward dipping forelimb that has been actively deformed by a west vergent back thrust referred to as Makarwal Active Back-Thrust. The term active back-thrust is herein introduced to differentiate it from the term passive roof thrust and passive back thrust as it actively deforms its footwall strata whereas passive roof thrust and passive back thrust are known as passively translating thrusts above a tectonic wedge without deforming underlying substratum (Banks et al., 1986). The above-mentioned structural account clearly indicates that this segment of the range front structure is typified by foreland ward dipping monocline inserted below sediments of the Punjab Foreland. The north south trending segment of the Surghar Range is dominantly an east vergent structural system developed due to east west oriented tectonic stresses. Similar deformational style can be inferred for the non-outcropping rocks beneath the eastern Bannu Basin as well.

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