

# Range Front Structural Geometries and Décollement related Tectonics: An example from Sothern Surghar Range, Trans-Indus Ranges, NW Pakistan

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## Abstract

Structural reassessment is described for the eastern and southeastern flank of the north-south oriented segment of Surghar Range, representing the sub-Himalayan frontal structural signatures of northwest Pakistan. Acquisition of outcrop data and structural mapping in the area revealed that the Surghar Range is delimited by a prominent frontal thrust fault which is laterally extended from Kurrum River of Dera Tang in the south to Kalabagh Fault System in the east. Structural geometries describe the presence of an east to southeast vergent thin-skinned fold-and-thrust system developed in the Paleozoic-Mesozoic sequence overlying by a thick overstrain of the Cenozoic rocks. The north-south oriented segment of the range displays tectonics structures developed in response to the coordination of fold-and-thrust system. These variant tectonic structures, probably controlled by the east-west directed compressional regime. The study area has been mapped right of Dera Tang in the south to Malla Khel in the north. This segment is comprised of approximately NW-SE oriented thrust fault laterally extended along the range front exploiting different horizons for exhumation at surface. Three different kinds of structures have been developed from south to north as force folding including fault propagation and fault bend folds and transverse strike-slip faults to frontal thrust in the vicinity of Sirkai. A number of anticlinal structures have been mapped in this segment where Siwalik rocks are well exposed at both limbs but the same rocks observed omitted from the fore limbs of some other anticlines. Low to moderate uplifting and strike-slip tectonics are the significant structural style of the southern north-south segment while high uplifting, concentric overturned folding and thrust faulting are the dominant structural mechanism of the northern terminus of this segment. The strike-slip faults observed terminated against the Surghar Thrust in the vicinity of Sirkia. Maturity in tectonic progression, structural growth, maximum crustal telescoping and unearthing of older rock sequences observed from south to north in the mapped area. Chronologically the tectonic phase of transpressional regime observed younger or concurrent as proportional to compressional regime in the region. In general the faulting phase of both regimes is not older than Plio-Pleistocene to sub-Holocene.

**Keywords:** Surghar; Compressional; Transpressional; Décollement tectonics; Force folding

## Introduction

Surghar-Shinghar Range is the easternmost extension of the Trans-Indus Salt ranges bifurcated by the Kalabagh Fault System from the Salt Range of North Pakistan (Figure 1) [1]. The whole range displays bidirectional structural trend, north-south toward its southern segment from Qubul Khel to Malla Khel and oriented east-west from Malla Khel to its eastern terminus up to junction of Kalabagh Fault making two broad segments of the range. The north-south segment of the range has been focus for the current studies. This segment is dominantly composed of Siwalik Group rocks penetrated by décollement related thrusting with the emplacement of Eocene to Jurassic rocks in sequence from south to north. Structurally this segment of the range is comprised of force folds, thrust and strike-slips tectonics mostly generated in the middle Siwalik sequence in eastern flanks of the range. The north-south oriented segment of the range is dominated by east facing structural geometries in addition to west vergent active back thrusting and tectonic wedging [2]. Previous attention mostly attributed to stratigraphy, economic geology and geological mapping of the north-south segment [3,4] where as its frontal eastern flanks of this segment has been remained unaddressed since long. This segment is comprised from south to north as the Qubul Khel, Sirkai, Mitha Khattak, Makarwal and Malla Khel Anticline. The north-south oriented segment is dominantly controlled by the uplifts of Siwaliks and pre-Siwaliks sequences, where Chinji Formation is exposed in the core of Qubul Khel Anticline. Near Sirkai a broad anticline has been mapped in the Siwalik Group rocks where Mitha Khattak Formation and Sakessar Limestone are thrust in the hanging wall over the Dhok Pathan Formation in the footwall. The eastern flank of the north-

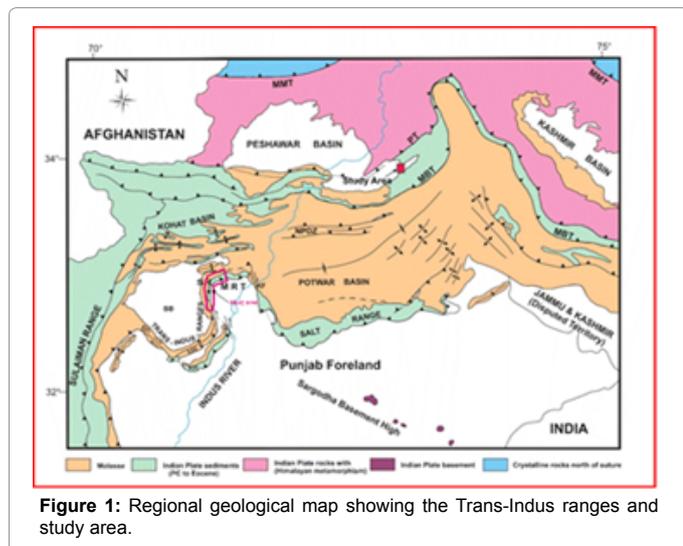
south segments is dominantly comprised of transpressional local scale faults with reasonable stratal offset between Qubul Khel and Sirkai Anticline. The structural geometries of the northern terminus of this segment are characterized by south facing overturned concentric anticlinal folds with a prominent south vergent thrust fault. The Mitha Khattak anticline is south plunging anticline where Paleocene rocks of Lockhart Limestone are exposed in the core of this anticline. The major overturned concentric geometric fold has been mapped in the vicinity of Malla Khel village designated as Malla Khel Anticline. The oldest rocks of the Datta Formation are exposed in the core of anticline. The frontal limb of fold is thrust over the Mitha Khattak and Chinji formations in the footwall. This thrust fault is observed laterally extended along the foothills of the range from Kurrum River in the south to the northern terminus of the mapped area. Basal décollement horizon observed at the base of Datta Formation. The lateral level of décollement toward south shifted in to the younger sequences and eventually observed as intraformational in the upper middle Dhok Pathan Formation (Figure 2). Additional to compressional tectonics, transpressional tectonics are the considerable structural style of the southern part, while overturned

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concentric folding and thrust faulting is the dominant structural mechanism of the northern part of this segment of the Surghar Range. Maturity in deformation style and variable stress regimes are observed from south to north in the form of tectonic progression, structural growth, maximum crustal shortening and unearthing of Mesozoic-Cenozoic rocks of the cover sequence. Chronologically the tectonic phases observed first force folding prior thrust faulting and finally the involvement of strike-slip tectonics in the region.

### Physiography and Location

The southern Surghar-Shinghar Range is laterally extended from Kurrum River, Qubul Khel area in the south to Malla Khel village in the north. This segment of the range is north-south oriented and extended up to Baroch Nala. Overall the range appears as an arcuate mountain belt and can be divided into bi-trending structural feature of the trans-Indus ranges. The range generally trending in east-west flanking the southern Kohat Plateau and changes to north-south trend along the eastern limits of the Bannu Basin [2] (Figure 1). The Surghar Range is having moderate to high relief ranging from 300 meter in the valley floor to south up to 1500 meter in the Baroch Nala section where the Eocene Sakessar Limestone forming the peak of the range above the mean sea level. The study area is accessible from Isa Khel via Sultan Khel/Makarwal and Bohr Sharif. The area is also accessible from Lakki Marwat to Qubul Khel to Mitha Khattak through a network of metal roads exists in proximity of the area. A network of nala and stream cuts, foot tracks, fair weather jeep-able roads provide good opportunity for geological and stratigraphic studies of the southern Surghar Range.

### Geological Setting

Pakistan contains the northwestern boundary of the underthrusting of the Indian lithospheric plate beneath the Eurasian Plate. This phenomenon has produced compressional thin-skinned tectonic features since Eocene on the northern and northwestern fringes of the Indian Plate. Continued underthrusting of the Indian Plate since Cretaceous produced the spectacular mountain ranges of the Himalaya and a chain of foreland fold-and-thrust belts as thick sheets of sedimentary rock were thrust over the Indian Craton [5] (Figure 2).

The Salt and Trans-Indus ranges constitute the mobile flank of the Kohat and Potwar fold and thrust belt which is frequently characterized by décollement related thrust-fold assemblages. The most recent

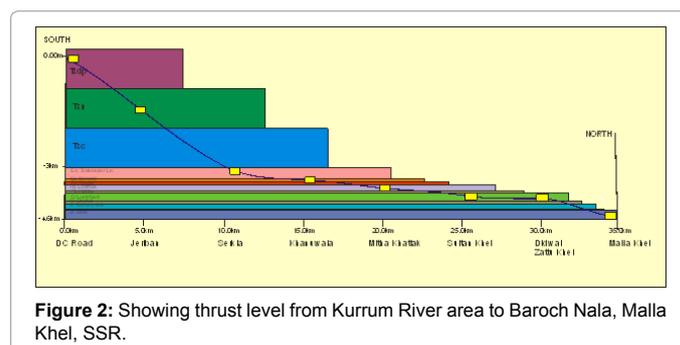
thrusting occurred along the frontal thrust system in the Salt Range to the east and in the Trans-Indus ranges to the west [6,7]. The Trans-Indus ranges represent the leading deformational front of the Kohat fold and thrust belt and Bannu Basin in North Pakistan. Underneath the Potwar Plateau and the frontal Salt ranges, the Precambrian Salt Range Formation forms a laterally extensive basal décollement at the basement-cover interface. As a result, the structural style is mainly thin-skinned and the basement is convex upward and gently north-dipping. Similar basement geometry has been interpreted for the basement underneath eastern Kohat Plateau and Bannu Basin [8,9]. The Trans-Indus ranges represent the western part of the northwestern Himalayan foreland fold-and-thrust belt that formed by progressive south-directed décollement-related thrusting of the sedimentary cover of Indian Plate crust during the ongoing collision between India and Eurasia. Structural modification generally advanced southward with time. It characterized the tectonic-stratigraphic margin among Kohat Plateau in the north, Bannu Basin in the west and Punjab foreland in the south (Figure 2). Along the Surghar frontal fault Paleozoic to Cenozoic platform sequence is thrust southward over the undeformed Quaternary sediments of the Punjab foredeep.

### Stratigraphic Setting

Detailed field mapping of the southern Surghar-Shinghar Range shows stratigraphic framework of the area that includes Jurassic to Eocene platform sediments unconformably overlain by Plio-Pleistocene fluvial sediments of Siwalik Group (Figure 3). The platform sediments become thicker and more complete from west to east excluding Lumshiwal Formation in the Surghar Range. The stratigraphic succession was studied along Baroch, Karandi, Lumshiwal, Mitha Khattak, Darsola and Harpian nalas of the Surghar Range as shown in (Figure 3). In this area, the base of stratigraphic succession is occupied by the Jurassic sequence of Datta Formation overlain by the Shinawari and Samana Suk Formation [10-12]. Overlying is a sequence of Cretaceous rocks that consists of the Chichali and Lumshiwal Formation unconformably overlain by Paleocene sequence that comprised of Hangu, Lockhart and Patala formations. In turn the sequence is overlain by the Eocene Nammal Formation and Sakessar Limestone which is unconformably overlain by the Mitha Khattak Formation and Siwalik Group rocks of Chinji, Nagri, Dhok Pathan and Soan Formation.

### Structural Geometry

The study area is extended from Kurrum River Bridge in the south to Malla Khel in the north and comprised of four major anticlinal folds of different attitudes, a prominent Frontal Thrust fault and number of local strike-slip faults evolved in the Siwaliks mapped along the eastern flank of the range [13,14]. The anticlinal structures are described from south to north as the Qubul Khel, Sirkai, Mitha Khattak, Makarwal and Malla Khel anticlines (Figure 4).



Era	Period	Epoch	Group	Formation
Cenozoic	Tertiary	Pliocene	Siwalik	Dhok Pathan
				Nagri
				Chinji
		Miocene	Equivalent Rwp. gp	Mitha Khattak
				Sakessar limestone
		Eocene	Chharat	Nammal
				Patala
				Lockhart Limestone
		Paleocene	Makarwal	Hangu
				Lumshiwai
Chichali				
Samana Suk				
Mesozoic	Cretaceous	Early	Surghar	Shinawari
				Datta
	Jurassic	Middle	Baroch	Shinawari
				Early

Figure 3: Stratigraphy of the southern Surghar-Shinghar Range (after Danilchik et. al. 1987).

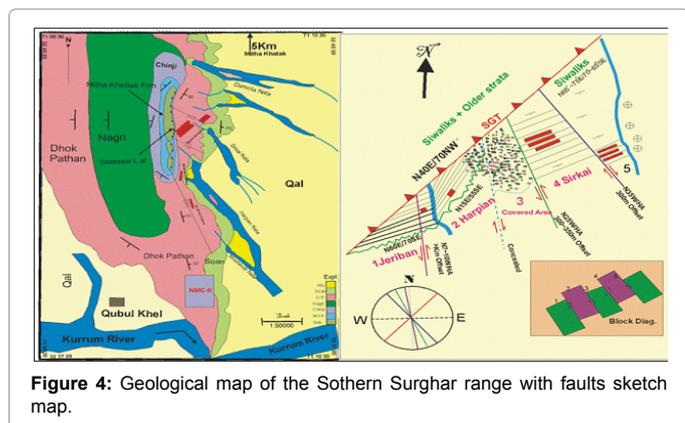


Figure 4: Geological map of the Sothern Surghar range with faults sketch map.

### Qubul khel anticline

This anticline is evolved in Siwalik Group rocks oriented in north south direction and laterally extended from Qubul Khel to south upto Sirkai village in the north. It is moderate to wide amplitude and moderate to high altitude anticline where Chinji Formation is exposed in core of the anticline. Nagri Formation is making cliff towards the western limb of the anticline while the same formation is absent at the eastern limb. This limb of the anticline is dominantly occupied by the Dhok Pathan and occasionally the Soan Formation. This anticline is overturned and plunging to the southern terminus of the range [15]. Overall it is domal structure where the frontal limb is observed faulted against the Main Frontal Thrust. Significant part of the eastern / frontal limb is observed underthrust below the back / western limb. The western limb translation calculated more than 04km above the frontal limb, consuming fore parts of the Chinji, whole Nagri and up to upper middle part of the Dhok Pathan Formation (Figures 5 and 6).

### Sirkai anticline

In continuation from south to north this anticline is located west of Sirkai village. The western limb of anticline is dipping moderate to steep angle and comprised of entirely Siwalik Group rocks including the Mitha Khattak Formation exposed in the core. The eastern limb is comprised of Dhok Pathan and Soan formations. Sakessar Limestone of Eocene is exhumed in the core and thrust eastward against the Dhok Pathan Formation in the footwall creating the Sirkai Thrust fault [16,17].

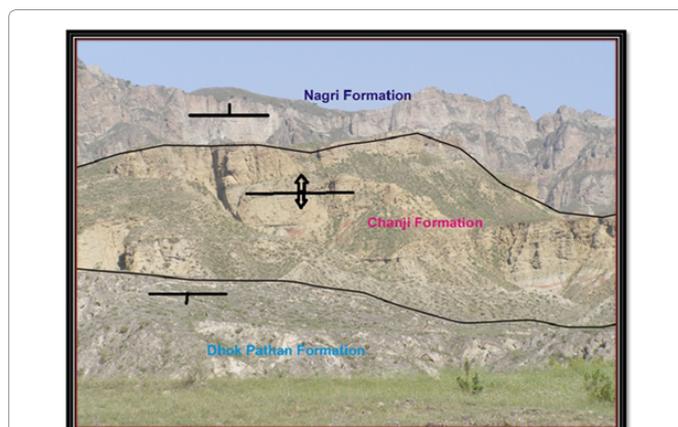


Figure 5: Showing Qubul Khel anticline of the Sothern segment of study area.

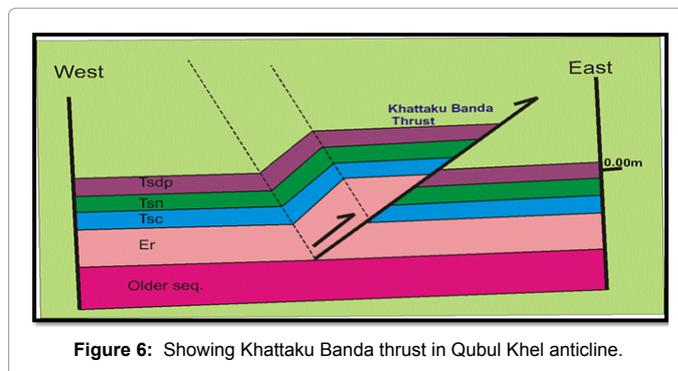


Figure 6: Showing Khattaku Banda thrust in Qubul Khel anticline.

Whitish to creamy color thick bed of marl is mapped in between the Mitha Khattak Formation and Sakessar Limestone in core of anticline. The Sirkai Thrust is laterally extended along the range front (Figure 7). A set of local strike-slip faults is mapped in Dhok Pathan Formation in the eastern limb trending oblique to right angle to fold axis (Figure 4). This anticline is viewing the second phase of force folding (Figure 8).

### Mitha khattak anticline

The Mitha Khattak Anticline is mapped west of Mitha Khattak village and north of Sirkia Anticline. This anticline is evolved in Cenozoic rocks. Eastern limb of the anticline is comprised of Chinji, Mitha Khattak, Sakessar and Nammal formations. Core exposes thick Paleocene Lockhart Limestone. It is an asymmetrical anticline where the Eocene rocks are plunging southward under thick Siwaliks horizon resulted termination of the southern extension of the Mitha Khattak Anticline (Figure 9).

### Makarwal anticline

The major topographic expression of the Surghar Range is attributed to uplift of the western limb of Makarwal Anticline whereas the eastern limb is maximum eroded. The oldest Cretaceous Chichali and Lumshiwai formations are exposed in its core. The remnant frontal steep to overturned limb is thrust eastward on the relic parts of the lowermost Siwaliks. It is an overturned, doubly plunging anticline with steeper forelimb dipping at 70° and gentler back limb. Like other fold structures, its forelimb is wrecked against a Surghar Thrust fault (Figure 10). Trend of the Makarwal Anticline is northeast near Karandi village. Middle and upper Siwaliks rocks are found lacking on the eastern limb of Makarwal Anticline [18].

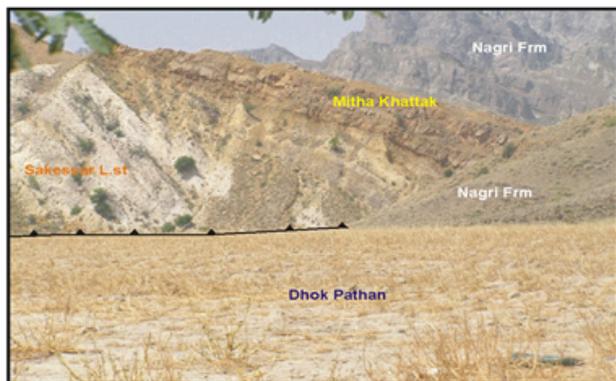


Figure 7: Showing Serkia anticline of the N-S Segment of study area.

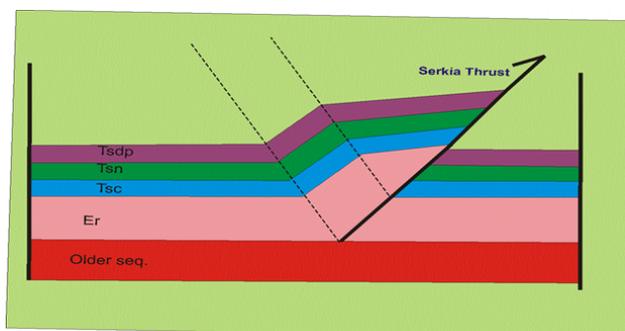


Figure 8: Showing Serkia thrust towards fore limb of Serkia anticline.



Figure 9: Showing Mitha Khattak anticline where core exposing Lockhart Limestone.



Figure 10: Showing Makarwal anticline of the E-W Segment of study area.

### Malla khel anticline

This anticline is located north of Malla Khel village next to Makarwal Anticline along the range extension. It is a prominent structural feature of the region. The frontal limb of the anticline is overturned. The back limb is gently dipping to northeast while its forelimb is asymmetrical to overturned and dipping at high angle ranging from 80-85° northeast, the oldest Datta Formation is exposed in its core. The frontal flank is thrust in a hanging wall over Siwalik Chinji Formation in the footwall (Figure 11). Geometry of the anticline revealed as concentrically fault bend-fold.

### Strike-slip faults

The eastern limb of the Qubul Khel and Sirkai Anticline comprised of number of strike-slip faults. From south to north four different strike-slip faults of different stratal offset were mapped from Jeriban to Sirkai area. Offset in the blocks observed ranging from 300 meter to 3 kilometers offsetting the Siwalik Group rocks especially the Dhok Pathan Formation. These faults are trending against the trend of the major thrust fault in the region and observed all the mapped strike-slip faults are terminated at the intersection with the major thrust fault (Figure 7). The east-west segment of the Surghar Range is comprised of few prominent anticlinal structures and a major Surghar Thrust faults runs all along the sothern frontal outside edge of the range. The outcropping rocks become older progressively from west to east in cores of these anticlines. Intensity of deformation gradually increases from west to east that reflects maturity in structures in the outcropping rocks (Figure 8).



Figure 11: Showing Malla Khel anticline last element of the north-south segment of study area.

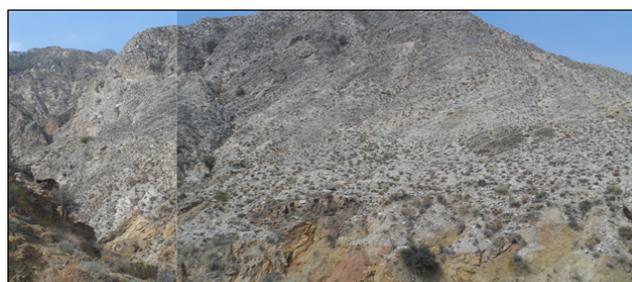


Figure 12: Showing Sakesar limestone are thrust over the Chinji formation in Karandi Nala.

## Malla khel thrust fault

Malla Khel Thrust fault was mapped just west of Malla Khel village in the Baroch Nala where Jurassic to Eocene sequence is thrust over the Chinji Formation in the footwall. The thrust is south-southeast vergent facing toward the foreland basin. This thrust fault is observed gentle dipping toward north-northwest but the same thrust observed steep in the Baroch Nala probably due to lateral ongoing movements and bending backward in the course of continuous compressional stresses (Figure 12). Further east in the vicinity of Kutki along the range front a thrust fault was mapped where Lockhart Limestone was thrust in the hanging wall against the Chinji Formation in the footwall. Intraformational tight folds and back thrust faults were observed in the Chinji Formation against the forethrust. Mitha Khattak Formation and rest of the Siwalik sequence were observed absent at the frontal flanks of the Surghar Range. The thrust fault was observed well established and more mature towards the eastern parts of the Surghar Range.

## Discussion and Conclusions

Two different directed orientations of the two board segments of the Surghar Range have been recognized. The north-south oriented segment of the range is comprised of mostly of the younger rocks dominantly Siwaliks while the east-west oriented segment is dominantly composed of pre-Siwaliks rocks. The north-south segment is southward plunging making nose of the Surghar Range and reveals product of the younger contractile deformation compare to its eastern terminus. The Surghar Range is a broad Anticlinorium comprised of different local anticlines younging toward south. The eastern most part of the range reveals that this part is detached from the Salt Range by the Kalabagh Fault System and moved north-northwest up to the present location. The southern terminus of the range reveals that this part of the range is detached from the Marwat Range as a result of Kundal Strike-Slip fault and moved to the present location. The offset along both the strike-slip faults observed different due to presence of gliding horizon in the form of Salt Range Formation beneath the Kalabagh region and found very thin or absent below the Kundal fault area, therefore interface abrasion variations is significant. In fact two kinds of tectonic deformations have been observed for the evolution of Surghar Range, contractile and strike-slip. The transpressional movements are younger or contemporaneous to the compressional regime because the western most extension of the Salt Range Thrust is cut by the Kalabagh Fault. The orientation of the massive and local scale structural features in the east-west trending segment of range are south vergent as consequence of north-south directed tectonic transport regime shifted along a basal décollement that exhumed at the range front [2]. The orientations of the structural elements in the north-south segment of the range became east vergent subsequent to activation of Kalabagh transpressional stresses at the eastern fringes of the range to create a band in middle of the range demarcate the extension of the salt basin below the Surghar and Salt ranges of north Pakistan. Both segments of the range explicit that force folding style generated in response to the compressional stresses. The east-west trending segment is more matured and constructing high profile asymmetrical to overturned anticlinal folds structures. These anticlines reveal fault-bend folding phenomenon while anticlines evolved in the north-south segment reveal fault-propagation mechanism. Outcrop structural appearance of the Surghar Range demonstrates that the fault-bend folds are older than the fault-propagation folds. Regional to local scale strike-slip faults mapped in the north-south oriented segment probably evolved concurrently during the propagation phase of compressional deformation toward the frontal flank of the segment excluding the Kundal Strike-Slip fault Jeriban (Figure 3). Most of the frontal flank

of both segments observed eroded due to frontal ramping from the basal décollement horizon. Parts and lenses of the frontal limb are intact at places viewing variance in tectonic stresses and flatness of the ramp at different depth. Maximum stratal telescoping observed in the central part of the east-west segment of the range. Intensity of tectonic encroachment, structural augmentation, maximum crustal shortening and exhumation of sequential rocks of the cover sequence observed from south to north in the north-south segment and from west to east in the east-west segment of the range. Chronologically the tectonic phase of transpressional regime observed younger or synchronized as compare to compressional regime in the region. Overall the faulting phase in both regimes is not older than Plio-Pleistocene.

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