Himalayan-Induced Deformation and Kinematics of the Arcuate Nature of the Trans-Indus Salt Range, Northwest Himalayas, Pakistan*

Sajjad Ahmad[1], Irfan K. Mohammad[2], Amjad Ali Khan[3], and Nouman Shoukat[2]

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[1]Geology, Department of Geology, University of Peshawar, Peshawar, Pakistan (yahya_sajjad@yahoo.com)
[2]Exploration, MOL Pakistan Oil & Gas Co. B.V., Islamabad, Pakistan
[3]Exploration, Saif Energy Pakistan Limited, Islamabad, Pakistan

Abstract

The structural elements of NW Himalayan Pakistan include a chain of arcuate orogenic belts known previously as arcs, oroclines, syntaxis, and re-entrants. One of such belts is the Trans-Indus Salt Range which is the focus of this study. The Himalaya-induced deformation that has affected the Trans-Indus Salt Range is distinguished into three distinct episodes, including a) pre-molasse, b) syn-molasse, and c) post-molasse deformation. The pre-molasse episode of deformation is correlative with the Oligocene unconformity during which the region was eroded down to the level of Eocene in the eastern, up to Triassic in the central and to Paleocene in the western Trans-Indus Range.

The syn-molasse deformational episode is interpreted by the gradual south-younging deposition of molasse sediments in the Kohat Basin. The post-molasse deformational episode started in the region at the time the regional basal detachment underneath the Kohat Basin ramped at the site of Trans-Indus Salt Range producing the present-day frontal ranges. Based on the early paleomagnetic studies conducted in the Surghar Range, it is believed that the arcuate nature of the Trans-Indus Range is in-situ without any significant rotation. The arcuate geometry of the Trans-Indus Salt Range is probably controlled by pre-existing basement irregularities, down to the north basement normal faults and possibly strain partitioning. The strain partitioning may also be caused by synchronous multidirectional stresses produced by the oblique subduction of the northwestern indenter of the Indian Plate.

Introduction

The Trans-Indus Salt Range of the Northwestern Himalayas defines a sinuous fold-and-thrust belt (Figure 1). The Kalabagh Hills, the Surghar-Shinghar Range, the Marwat-Khisor Range, Sheikh Budin Hills and the Manzai Range are collectively known as the Trans-Indus Salt Range. The Precambrian to Cenozoic platform and Pliocene-Pleistocene fluvial strata outcrop along the Trans-Indus Salt Range with the present day ongoing deformation at the mountain front (Khan et al.,1988; M.P. Blisniuk, 1996; Alam et al., 2005, ATC proceedings). The Kalabagh Hills occupy the eastern part of the Trans-Indus Salt Range and are the Trans-Indus extension of the Western Salt Range, located north of Kalabagh City in Mianwali District. These hills occupy an important structural transect between the Western Salt Range and the Surghar Range, and can serve to establish the structural relationship between these two important tectonic regimes of Pakistan. The Surghar Range follows an east-west structural trend along the southern margin of the Kohat Plateau and changes to a north-south trend along the eastern flank of Bannu Basin. Along the Surghar Range, Paleozoic-Paleocene rocks are exposed at the surface.

Sedimentation and Deformation of the Trans-Indus Salt Range

The sedimentary rock assemblages outcropping along the Trans-Indus Salt Range indicate a fairly quiet period of continuous sedimentation in a shallow sea with the down-sagging of the Kohat-Potwar Trough, occasionally interrupted by localized block uplifts, resulting in disconformities (Figure 2). At the close of the Mesozoic there was widespread uplift, with a rise during Cretaceous times when terrestrial conditions prevailed in parts of the area of sedimentation. The block uplift led to the denudation of the newly emerged areas. Marine conditions again prevailed during early Tertiary times, but soon after the deposition of the Middle Eocene the initial phase of Himalayan orogeny set in and the sea receded from the Kohat-Potwar Basin leaving a fluviatile–lacustrine environment in the region. This event is marked by the widespread Oligocene unconformity in the region which has been responsible for a considerable denudation and erosion of the Eocene rocks in the area; pebbles and rolled fragments of Eocene limestone, therefore, form a widespread and prominent constituent of the conglomerates marking the Oligocene unconformity (Khan et al., 1988; Blisniuk, 1996; Alam et al., 2005, ATC proceeding).

In Mio-Pliocene and Pleistocene times the area received an enormous thickness of detrital material in a fluviatile and lacutrine environment of sedimentation and the rivers flowing down the rising Himalaya to the north poured their detrital matter into the molasse trough of the Kohat-Potwar Basin. In the late Pliocene the effect of Himalyan orogeny propagated southwards with the development of the Salt Range and its Trans-Indus extension. Erosion down to the level of Eocene limestone contributed to the detrital pebbles and boulders occurring in the conglomerate lenses of the Dhok Pathan and Nagri formations (Blisniuk, 1996; Alam et al., 2005 ATC proceeding).

At the close of the Tertiary Era the earth movements of considerable magnitude, defining the final phase of the Himalayan orogeny, affected the entire area and led to the development of the numerous folds and faults of the system. The Himalaya-related deformation that has affected the Trans-Indus Salt Range can be distinguished into three discrete episodes including pre-molasse, syn-molasse and post-molasse deformation. The three major episodes collectively represent the effects of Himalayan collision. The pre-molasse episode of deformation in the region is correlatable with the Oligocene unconformity during which the region was uplifted and was eroded down to the level of Eocene in the eastern, up to the Triassic level in the central, and to the Paleocene level in the western Trans-Indus Salt Range (Figure 2).

Arcuate Nature of the Trans-Indus Range

The Trans-Indus Salt Range consists of a couple of re-entrants including the Kalabagh re-entrant in the east and Tank re-entrant in the west. The origin of these re-entrants is debatable (Sarwar and DeJong, 1979). One hypothesis for the origin of Kalabagh and Tank re-entrants could be of wrapping of folds in a ductile manner along a pre-existing buried buttress of the basement, such as the main Sargodha-Waziristan Ridge. A buried buttress of basement rocks in the area close to the Kalabagh may have offered a strong resistance to the compressional forces of the Himalayan Orogeny directed from the northerly direction. This eventually may have led to the development of the arcuate outline of the folds in the regions closer to it, but in the distant areas the influence of this basement wedge gradually diminished (Klootwijk et al., 1986). Paleomagnetic rotation vectors (rotation relative to the Indo Pakistani shield) follow the observed rotations of the main structural trend (Figure 3). Another hypothesis regarding the arcuate nature of the Trans-Indus Salt Range is that the Kalabagh re-entrant has formed as a result of deep basement strike-slip faults (Johnson et al., 1979; Kazmi, 1979a).

Other possibilities about the curvature in an orogenic system include flexing of an initially linear mountain belt and an original curvature caused by the irregularities in the basement as well as strain partitioning. Paleomagnetism can be used as an effective tool for explaining the arcuate nature of an orogeinc belt (Eldredge et al., 1985; Vander et al., 1980). Two possible magnetic signatures can be expected in the analysis of arcuate mountain chain: a) magnetic declinations in case of original curvature should not correlate with a change in the fold axis trend, but remain parallel, and b) change in magnetic declinations should mimic the change in the fold axis trend on a one to one basis if the belt had an initially linear configuration. Unfortunately, little paleomagnetic studies have been conducted in the Trans-Indus Salt Range. However, some significant paleomagnetic work in the molasse sediments has been done in the eastern-most part of the Trans-Indus Salt Range (northern Surghar Range) that provide useful information in defining the arcuate nature of this part of the Trans-Indus Salt Range (Khan et al., 1985). According to these paleomagnetic studies the magnetic declinations do not correspond with the change in the fold axis trend but remain parallel, suggesting the in-situ nature of the curvature in the Surghar Range. Based on the above-mentioned observation, it is believed that the arcuate front of the Trans-Indus Salt Range does not record any rotation and is controlled by pre-existing basement irregularities, likely down-to-the-north basement related normal faults (Figures 4a and 4b) and possible strain partitioning caused by synchronous multi-directional stresses produced by the oblique subduction of the northwestern indenter of the Indian Plate (Figure 5).

Conclusions

• The Himalayan deformation in the Kohat foreland basin and associated Trans-Indus Salt Range is interpreted to be represented by an early phase of pre-molasse deformation followed by synmolasse and post-molasse deformation that is still active.

• The Trans-Indus Salt Range may have evolved as an in-situ arcuate orogenic belt controlled by the geometry of pre-existing basement irregularities.

References

Alam, I., S. Ahmad, A. Ali, and M. Irfan, 2005, Fold-thrust styles in the Marwat-Khisor Ranges, NWFP, Pakistan, PAPG, ATC 2005, conference proceedings, p. 80-93.

Blisniuk, M.P., 1996 Structure and tectonics of the northwest Himalayan frontal thrust system, Trans-Indus ranges, Northern Pakistan, Unpublished PhD thesis, Dartmouth College, Hanover, N.H., U.S.A.

Burbank, D.W. and R.A. Beck, 1989a, Early Pliocene uplift of the Salt Range; Temporal constraints on thrust wedge development, northwest Himalaya, Pakistan, Spec. Pap., Geol. Soc. Am., 232, p. 113-128.

Eldredge, S., V. Bachtadse, and R. Vander Voo, 1985, Paleomagnetism and the orocline hypothesis, Tectonophysics, 119, p. 153-179.

Johnson, N.M., J. Stix, L. Tauxe, P.F. Cerveny, and R.A.K. Tahirkheli, 1985, Paleomagnetic chronology, fluvial processes, and tectonic implications of the Siwalik deposits near Chinji village, Pakistan, J. Geol., 93, p. 27-40.

Johnson, G.D., N.M. Johnson, N.D. Opdyke, and R.A.K. Tahirkheli, 1979, Magnetic reversal stratigraphy and sedimentary tectonic history of the upper Siwalik Group, eastern Salt Range and southwest Kashmir, *in* Geodynamics of Pakistan, eds. A. Farah, and K.A. DeJong, Geol. Surv. Pakistan, p. 149-166.

Kazmi, A.H., 1979a, Active fault system in Pakistan, *in* Geodynamics of Pakistan, eds. A. Farah, and K.A. DeJong, Geol. Surv. Pakistan, p. 285-294.

Khan, M.J., N. Opdyke, and R. Tahirkheli, 1988, Magnetic stratigraphy of the Siwalik Group, Bhittani, Marwat and Khisor ranges, northwestern Pakistan and the timing of Neogene tectonics of the Trans Indus, J. Geophys. Res., 93:11, p. 773-790.

Klootwijk, C.T., R. Nazirullah, and K.A. DeJong, 1986, Paleomagnetic constraints on formation of the Mianwali Re-entrant, Trans-Indus and Western Salt Range, Pakistan, Earth Plan. Sc. Lett., 80, p. 394-414.

Sarwar, G., and K.A. DeJong, 1979, Arcs, Oroclines, Syntaxis: the curvatures of mountain belts in Pakistan, *in* Geodynamics of Pakistan, eds. A. Farah, and K.A. DeJong, Geol. Surv. Pakistan, p. 342-349.

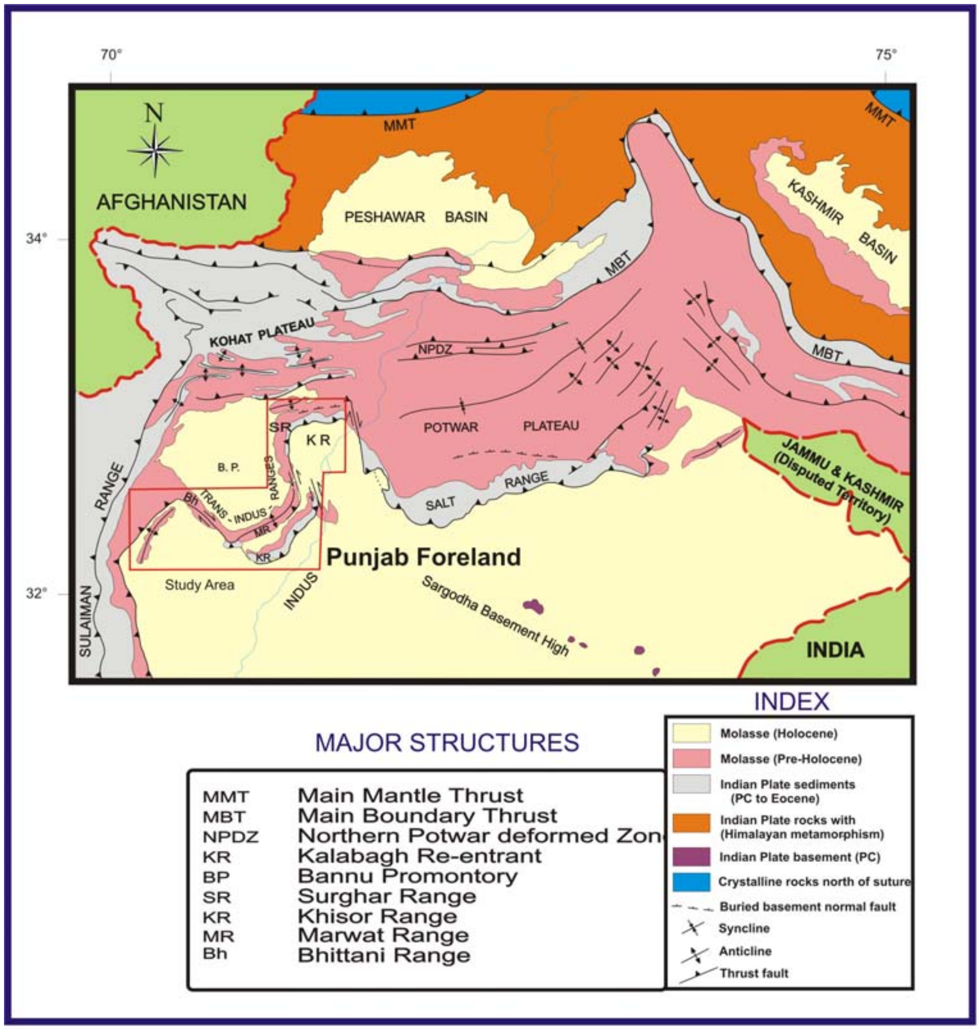

Figure 1. Generalized geological map of the NW Himalayan foreland fold and thrust belt. Inset shows the location of the Trans-Indus Ranges

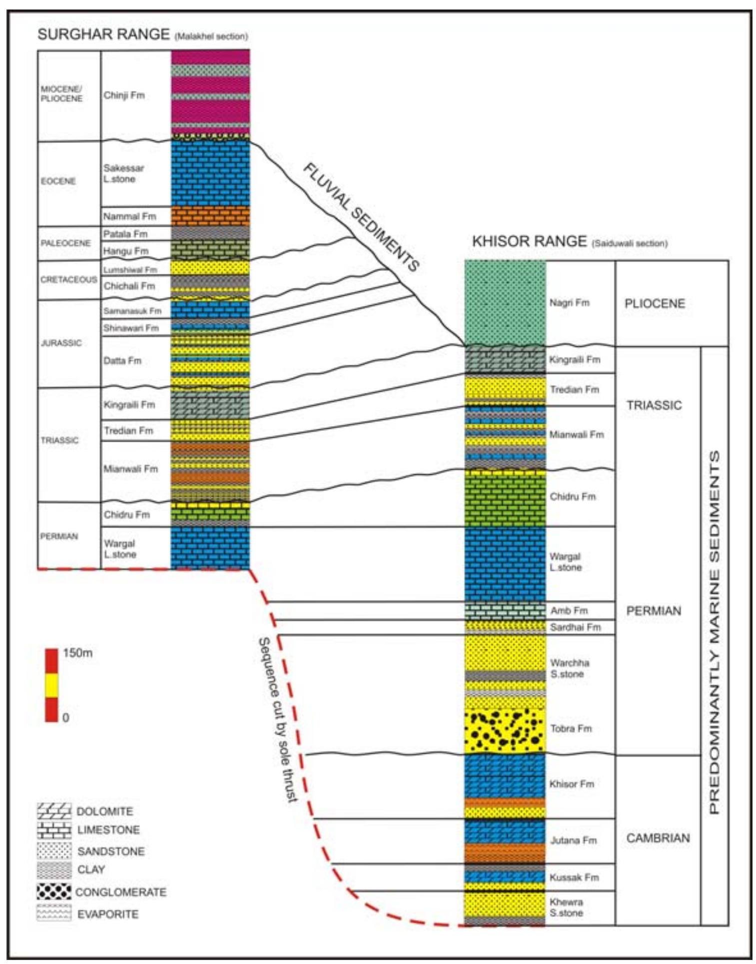

Figure 2. Stratigraphic column of the Surghar and Khisor Ranges, NW Himalayas, Pakistan

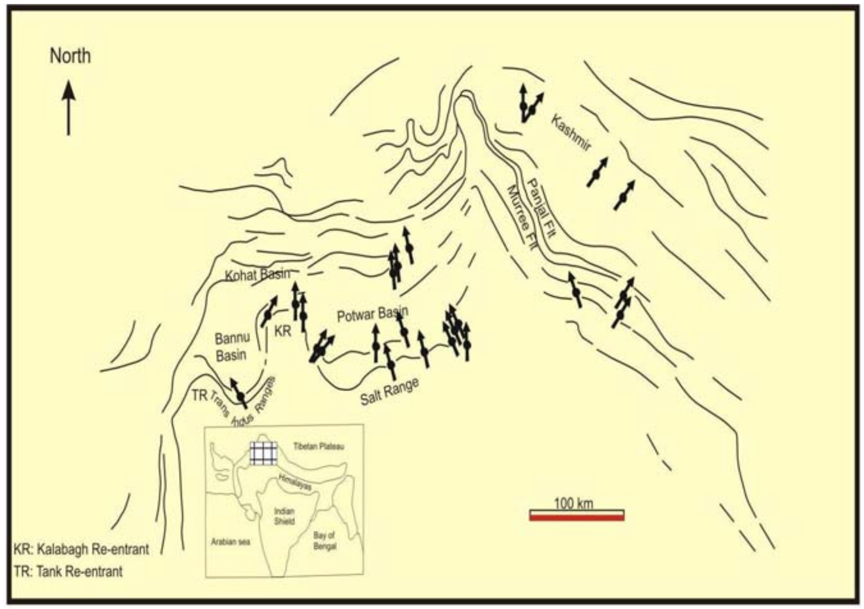

Figure 3. Paleomagnetic Rotation Vectors of early Tertiary and older formations after Klootwijk et. al., 1986. (The azimuths of rotation vectors indicate the magnitude of rotation with respect to the India n Shield), N W Himalayas, Pakistan

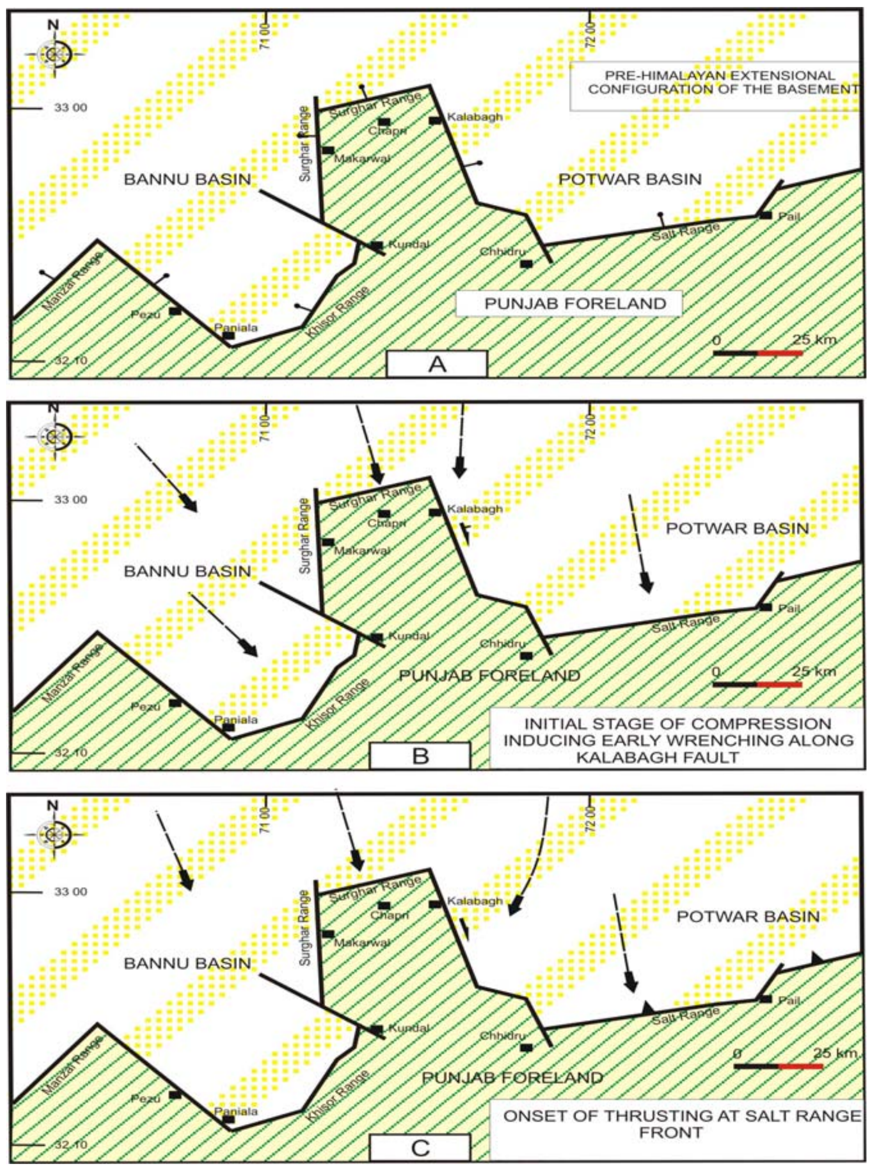

Figure 4a. Proposed m odel showing pre-existing basement irregularities and the Se quential Evol ution of the Trans Indus Ranges, NW Himalayas, Pakistan

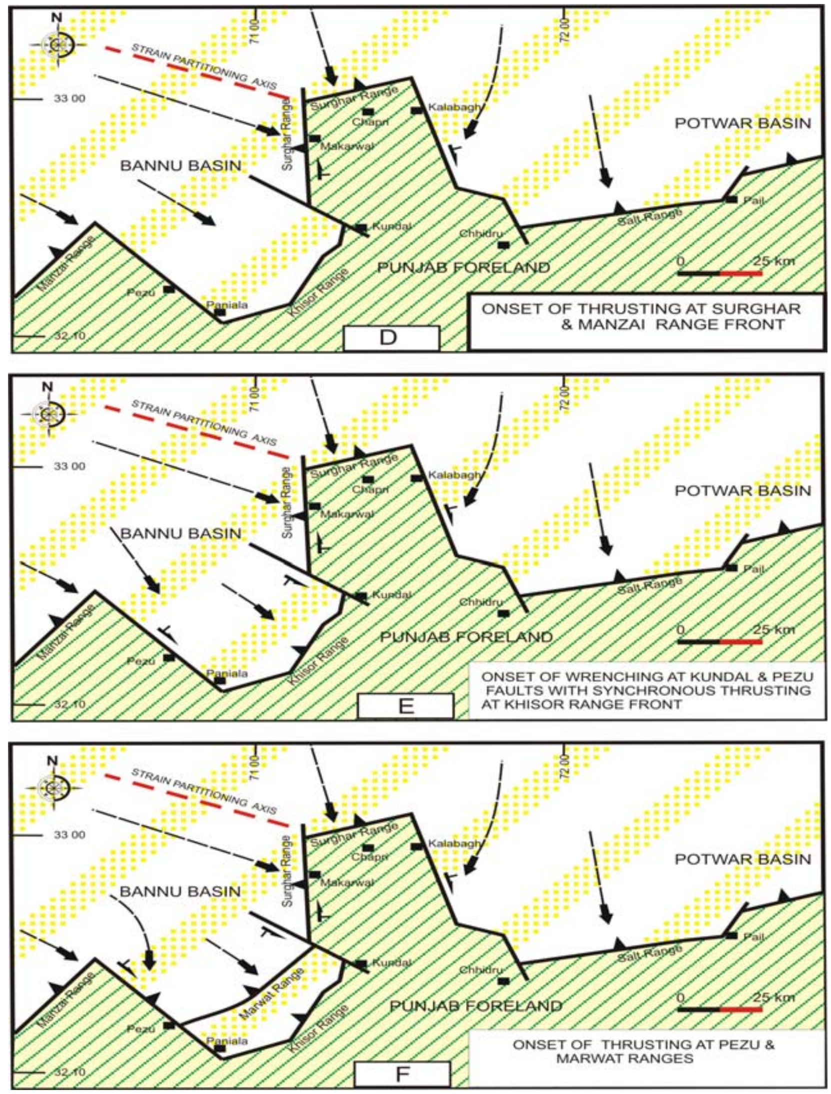

Figure 4b. Proposed model showing pre-existing basement irregularities and the Sequential Evolution of the Trans Indus Ranges, Pakistan

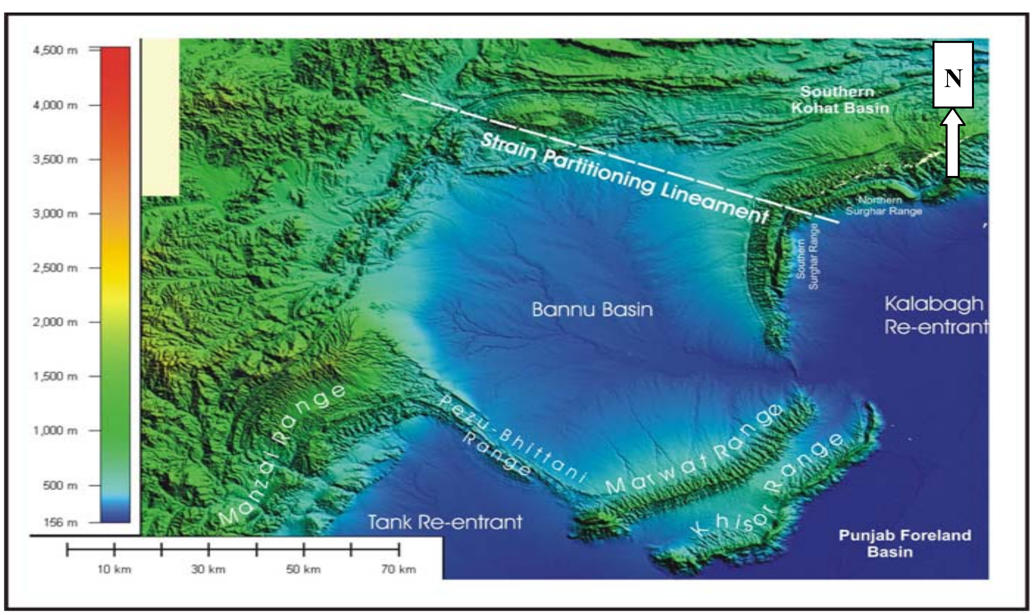

Figure 5. Digital elevation model of the southern Kohat-Bannu Basin & Trans Indus Ranges showing the location of the strain partitioning axis oriented in the Northwest direction, Pakistan