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Structural analysis and restoration of the Tolanj Anticlinorium, North Eastern Kohat Basin, Khyber Pakhtunkhwa, Pakistan

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Abstract

The mapped area includes the northeastern Kohat Fold and Thrust Belt (KFTB) and a part of the Kohat ranges separated by Main Boundary Thrust (MBT) which carries Mesozoic-Paleocene sediments in hanging wall. The rock sequence in KFTB generally consist of Paleocene-Eocene rock assemblages, which are unconformably overlain by the Miocene terrestrial synorogenic foreland basin deposits. This study is focused on understanding the structural kinematics of a portion of the Tolanj and Landiwal anticlinorium within the KFTB incorporating the surface data and construction of viable models using Move suite. The mapped coordinates have three major, east west trending structures comprised of the Bazid Khel anticlinorium in the north, followed by Landiwal and Tolanj anticlinorium in the south. Paleocene to Eocene rock assemblages have occupied the core of these structures. Bazid Khel and Tolanj anticlinorium host Panoba Shale whereas the Landiwal anticlinorium is cored by Kohat Formation as the mapped coordinates covers its western end. Several major thrust faults are mapped which include Tolanj-Tarkhobi Fault, Shahi Khel Fault, Bagh Fault, Shindand Fault and MBT (from south to north) which are mostly detached within Eocene strata except the MBT. Five balanced cross sections were created which helped in predicting the subsurface projection of the surface structures. These cross sections were restored which show about 50% overall shortening of the stratigraphic package involved in the deformation. The tight anticlinal and broad synclinal fold structures mapped within the Eocene rocks have evolved as detachment folds which have been truncated by unique thrust faults. These structures are detached from the deeper structures by incompetent formations which are Patala and Panoba Shale. As a result, these formations have played a major role in the structural evolution and disharmony between surface and subsurface formations of study area. Majority of the regional thrust faults are splays from a regional basal decollement which is translating southwards in response. The sub-surface model illustrates that variations in structures along the trend are result of fickle and variant slip vectors of thrusts along their strike.

Keywords: Structural evolution, Balanced cross section, Thrust kinematics, Detachment, Detachment folding, Restored section.

1. Introduction

(KFTB), Kohat Fold and Thrust Belt is an important portion of Himalayan foreland fold & thrust belt. KFTB is positioned towards the western extremity of lesser Himalayas. It is bounded by Kohat ranges in the north. The southern boundary is marked by Surghar Range and Bannu Basin. Kurram fault lies toward west while Indus River marks the eastern boundary and separates it from (PFTB) Potwar Fold-Thrust Belt (Fig.1). The KFTB is covered by different kind of sedimentary rocks which range from Paleocene to Pliocene. In early Miocene it has become terrigeneous Indo-Gangetic foreland basin (Wells, 1984). The oldest exposed rocks in KFTB are Paleocene which is predominantly limestone and shale and the site of deposition of is restricted fore-deep marine environment. During Eocene Indian-Eurasian plate collision caused deformation in Kohat and Fold Thrust Belt. As this is the external zone of Himalayan fold and thrust belt, it has recorded the deformational history in sedimentary strata and preserved the continental molasse sequence. (Abbasi, 1991) Deformation style is displayed by various structures at surface representing more intense deformation in Kohat (Pivnik and Sercombe, 1993) as compared to Potwar except NPDZ for which Eocene rocks (mami khel clays) are held responsible by various researchers (Ahmad, 2005; Abbasi, 1991) and considered the case of Kohat to deform on multiple detachment horizons. This study area is separated into two parts by a regional fault Main boundary Thrust (MBT). A northern part is Kohat Ranges and southern part is Kohat Fold-Thrust Belt (KFTB). Jurassic rocks are emplaced by MBT over Paleocene and Miocene rocks (Figure 8). KFTB consists, mostly of Paleocene, Eocene and Miocene rocks. Panoba Shale and Shekhan Formation are the oldest rocks exposed in KFTB. Recent hydrocarbon exploration success at Nashpa, Makori, Shakardarra, Gourgori and Manzalai within the vicinity of the study area had made it a favorable site for exploration of hydrocarbon. Main objective of this study is to integrate surface, subsurface and well bore data to recognize structural development of southern KFTB.

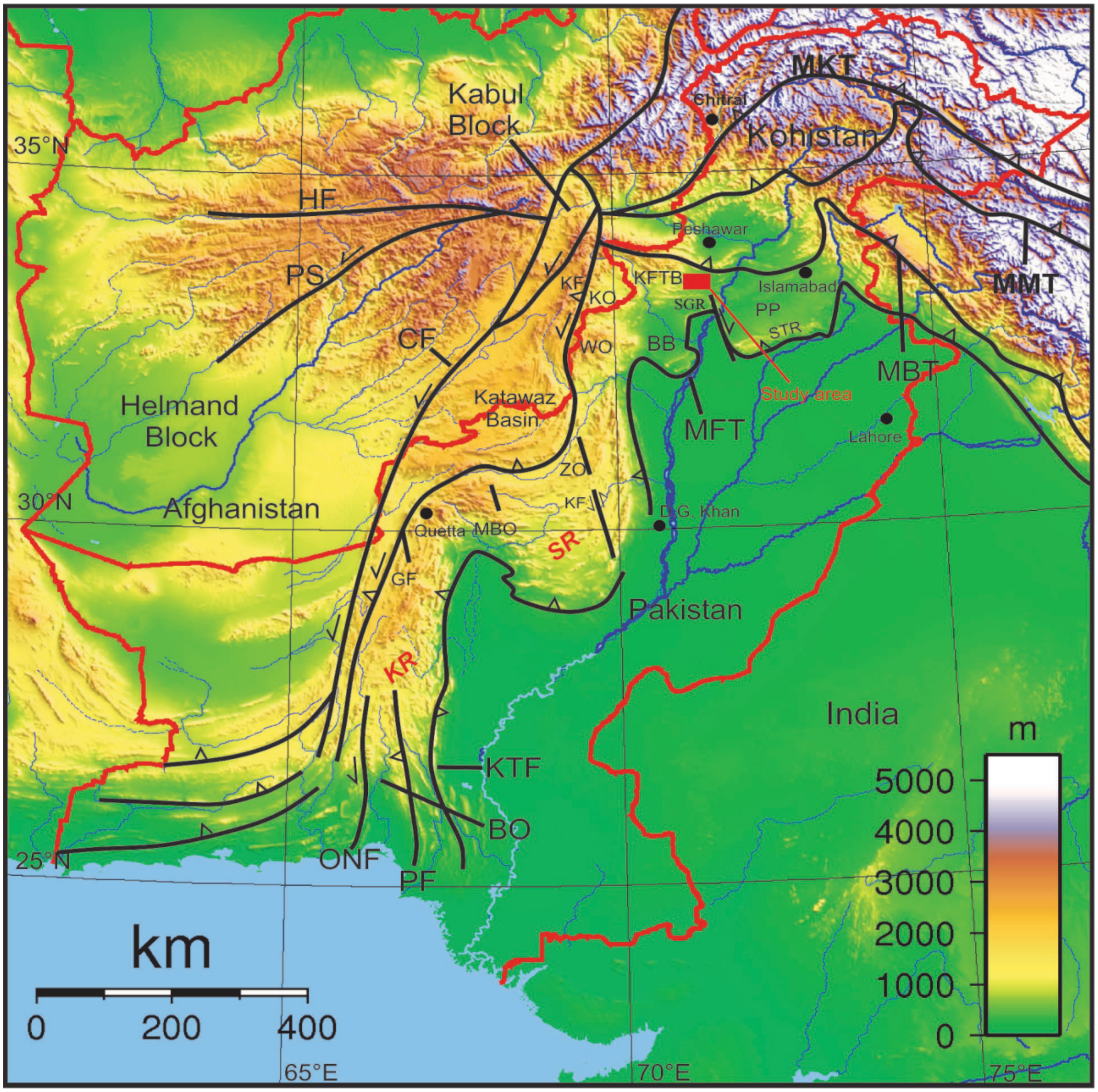
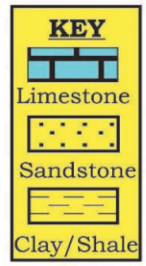


Fig. 1. Tectonic map of Pakistan, showing major structural boundaries. (Inset shows the location of the study area).

BB—Bannu Basin; BO—Bela ophiolite; CF—Chaman Fault; GF—Ghazaband Fault; HF—Herat Fault; KB— Kalabagh Fault; KF—Kurram Fault; KFTB—Kohat Fold and Thrust Belt; KO-Khost Ophiolite; KR—Kirthar Range; MBO—Muslim Bagh Ophiolite; MBT—Main Boundary Thrust, MFT—Main Frontal Thrust; MMT—Main Mantle Thrust; MKT—Main Karakoram Thrust; ONF— Ornach Nal Fault; PS—Panjao Shear; PF— Pab Fault; SGR—Sur Ghar Range; SR—Sulaiman Range; ZO—Zhob-Ophiolite; (after Ahmad et al., 2005)

Table 1. Generalized stratigraphic chart of the Kohat Basin.

Age	Formations	Lithology	Description	Hydrocarbon Importance	Tolanj X-1 (Thickness)
Miocene	Kamlial		Clay & Sandstone		
	Murree		Clay & Sandstone		
Eocene	Kohat		Limestone		
	Kuldana		Clay & Sandstone		319m
	Shekhan		Limestone		573m
	Panoba		Shale & Sandstone	Cap Rock	578m
Paleocene	Patala		Shale & Limestone	Cap Rock	383m
	Lockhart		Limestone	Reservoir Rock	358m
	Hangu		Sandstone	Reservoir Rock	90m
Cretaceous	Kawagarh		Marl & Sandstone		133m
	Lumshiwal		Sandstone & Limestone	Reservoir Rock	153m
	Chichali		Sandstone & Shale	Source Rock	162m
Jurassic	Samanasuk		Limestone	Source Rock / Reservoir Rock	



2. Aims and objectives

This research has helped in attaining the below mentioned objectives.

- To determine the structural architecture.
- To explore the fold and thrust kinematics of this study area.
- To understand the importance of detachment folds and evaluate the relation between various exposed and un-exposed rock sequences.
- To estimate amount of shortening in various structures.

3. Methodology

1. The above explained objectives were attained by analyzing the research area in quick bird Google Image. published geological maps were used to plot the surface structural patterns. Different formational contacts were plotted on the satellite image of 1.5m resolution. The study area was thoroughly investigated in a twenty-five days field trip. This field trip helped to map the geology and to collect field data including formational contacts.

2. GPS was used to record field coordinates. Silva Ranger Compass was used to record the dip and strike of bedding, faults and other mesoscopic structures.
3. The geological map was prepared in ArcGIS 10 (R) software at a scale of 1:50,000 by incorporating all field data.
4. MOVE software was used to prepare five balanced cross sections. Surface, geological and orientation data was imported in the software to prepare the structural model, which helped to understand the thrust kinematics and its effect on various structures. Cross sections restoration was performed in MOVE software to estimate the amount of shortening.

4. Geological setting

4.1. Structural cross sections

In order to know and understand surface and subsurface geology of Tolanj and Landiwal anticlinoria five balanced cross sections were constructed which are A-A', B-B', C-C', D-D' and E-E' (Fig. 2). The thicknesses of different formations in the cross sections are adopted from exploratory well of Amoco, Tolanj-1 (Ali, 1997). They are drawn towards parallel to tectonic transport direction. MBT or Main Boundary Thrust is present towards the north of these cross sections. It is a regional fault which plays a very significant role in shaping the structural architecture of the mapped area. MBT variably emplaces Jurassic to Paleocene rocks over the Miocene fluvial deposits along its east-west stretch. Towards south of MBT a major syncline lies in the western corner near Bazid Khel village. This syncline is covered by A-A', B-B' and C-C'. Murree Formation can be witnessed in the core of this syncline which is mostly covered with alluvium. A major Bazid Khel anticlinorium is present towards south of MBT (Fig. 2). This major anticlinorium is divisible into eastern, central and western parts on the basis of the variations with in surface geometries along its strike (Fig. 2). The eastern portion of Bazid Khel Anticlinorium is illustrated along the E-E' & D-D' traverses. From north to south various faults are present in these cross sections which include; Main Boundary Thrust, Shahi Khel Fault and Bagh Fault. Murree Formation is hosting the northern and southern limbs of this anticlinorium. The center of Bazid Khel Anticline exposes rocks of Shekhan Formation and Panoba Shale which are shown in cross sections B-B' & C-C' (Fig. 2). The axial trend of this anticlinorium is in east-west direction. Another major structure; Landiwal Anticlinorium is situated in the eastern part of the study area and is shown by E-E' (Fig. 7). A-A' covers the western portion of study area (Fig. 3). A-A' cross cuts MBT, Bazid Khel Anticlinorium and western portion of Tolanj anticlinorium.

Cross section B - B' (Fig.4) & C - C' (Fig.5) include MBT, Shahi Khel Thrust, central portion of Bazid Khel Anticlinorium, Shindand Fault, North Landiwal Syncline, Shindand Syncline and central portion of Tolanj Anticlinorium while moving from north to south. Tolanj Tarkhobi Fault is covered in cross section C - C' (Fig. 5) towards south. Tolanj Tarkhobi fault has thrusted Shekhan Formation on top of Murree Formation (Fig 9). The central portion of Tolanj anticlinorium is recognized by a steep northern limb while Tolanj-Tarkhobi Fault has sliced its southern limb.

The eastern portion of study area is explained by cross section D - D' (Fig. 6) and E - E' (Fig. 7). By following from north to south it includes Main Boundary Thrust, eastern portion of Bazid Khel Anticlinorium, Landiwal North syncline, Landiwal Anticlinorium, Shindand Syncline and eastern part of Tolanj Anticlinorium. Murree and Kamlial formations have cored the Landiwal North Syncline and Shindand North Syncline and at various places these rocks are shielded with alluvium. The general trend of these synclines is in east west direction and they separate major highs from each other.

4.2. Cross sections restoration

4.2.1. Methodology

Geological cross sections were restored with Move software. The restoration process was done in two detailed steps. First step covers restoring movement on faults via eradicating the movement on each fault. This algorithm is known as “Move on Fault”. Fault parallel flow method was implemented for restoration of faults. In this method various values were assigned with in algorithm until the beds represent continuation across a specific fault.

The second step covers unfolding of rock beds to their original un-deformed state by using unfolding algorithm. This method is called "Flexural slip". In this method various "Pins" are inserted at relatively un-deformed area. After pins are inserted these beds are then unfolded, showing the un-deformed state.

Due to different lithology various stratigraphic zones play a key role in disharmony of the surface and sub-surface structures. As Panoba and Patala formations represent soft horizons so many special steps were used to conclude a restored cross section.

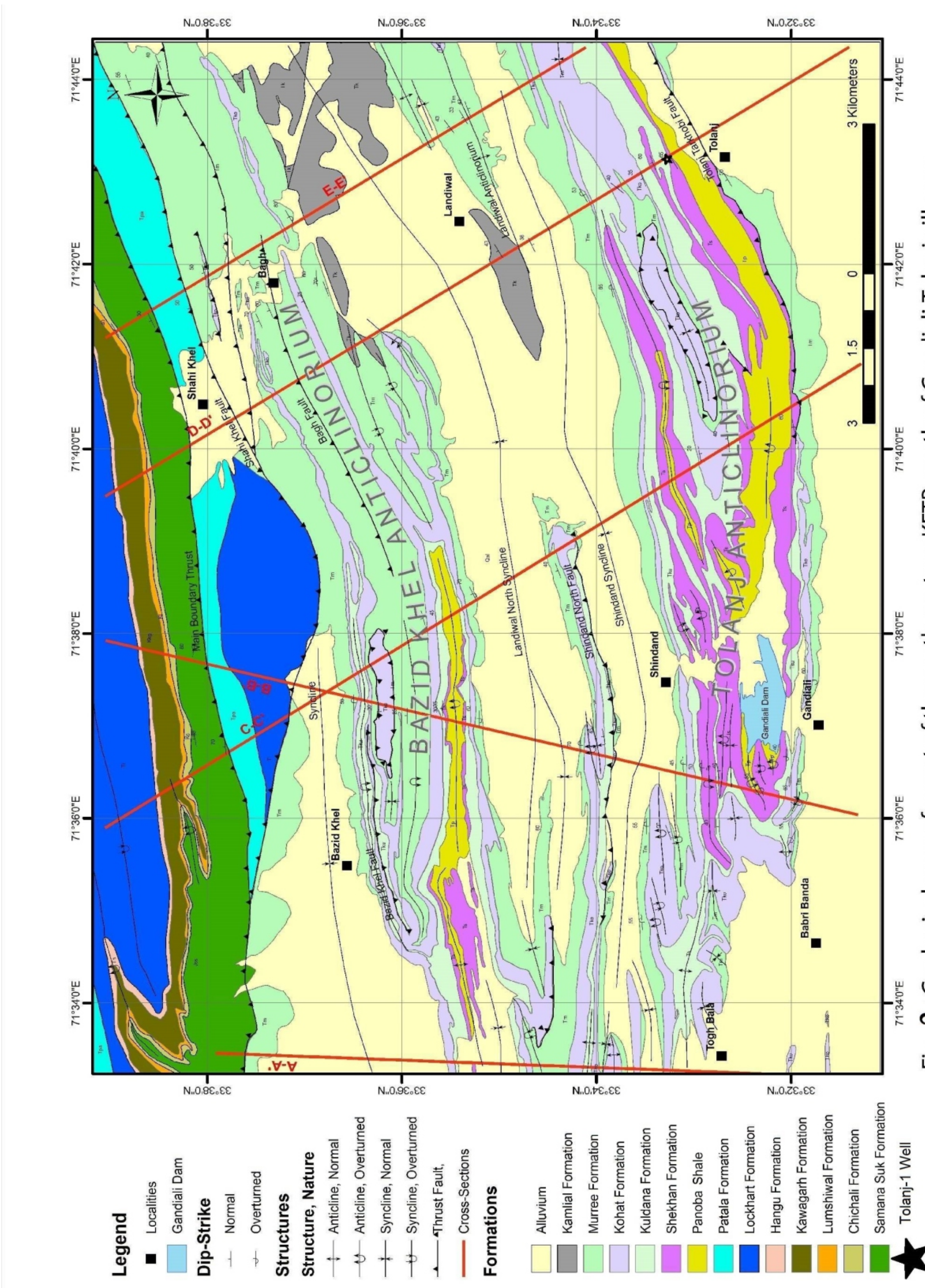


Fig. 2 Geological map of a part of the north-eastern KFTB, north of Gandiali-Tolanj villages

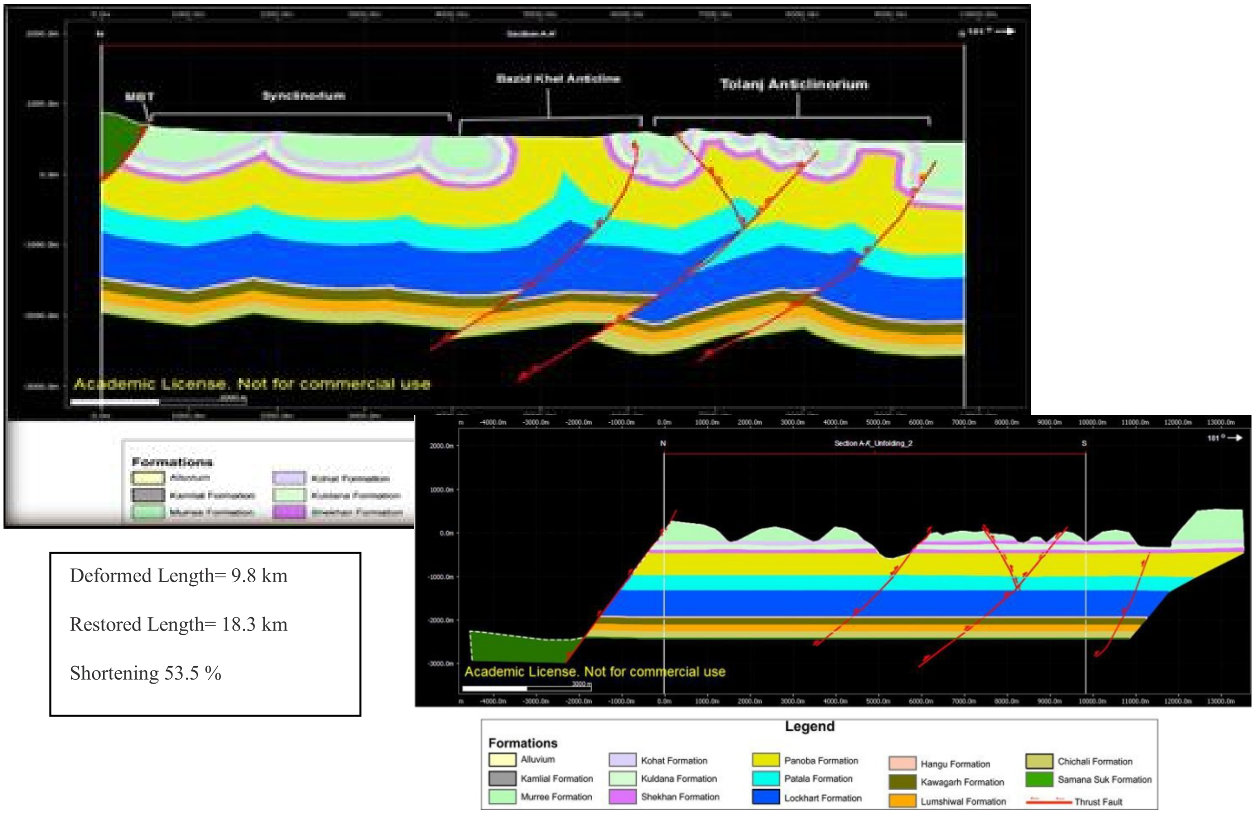


Fig. 3. Deformed and restored section AA/

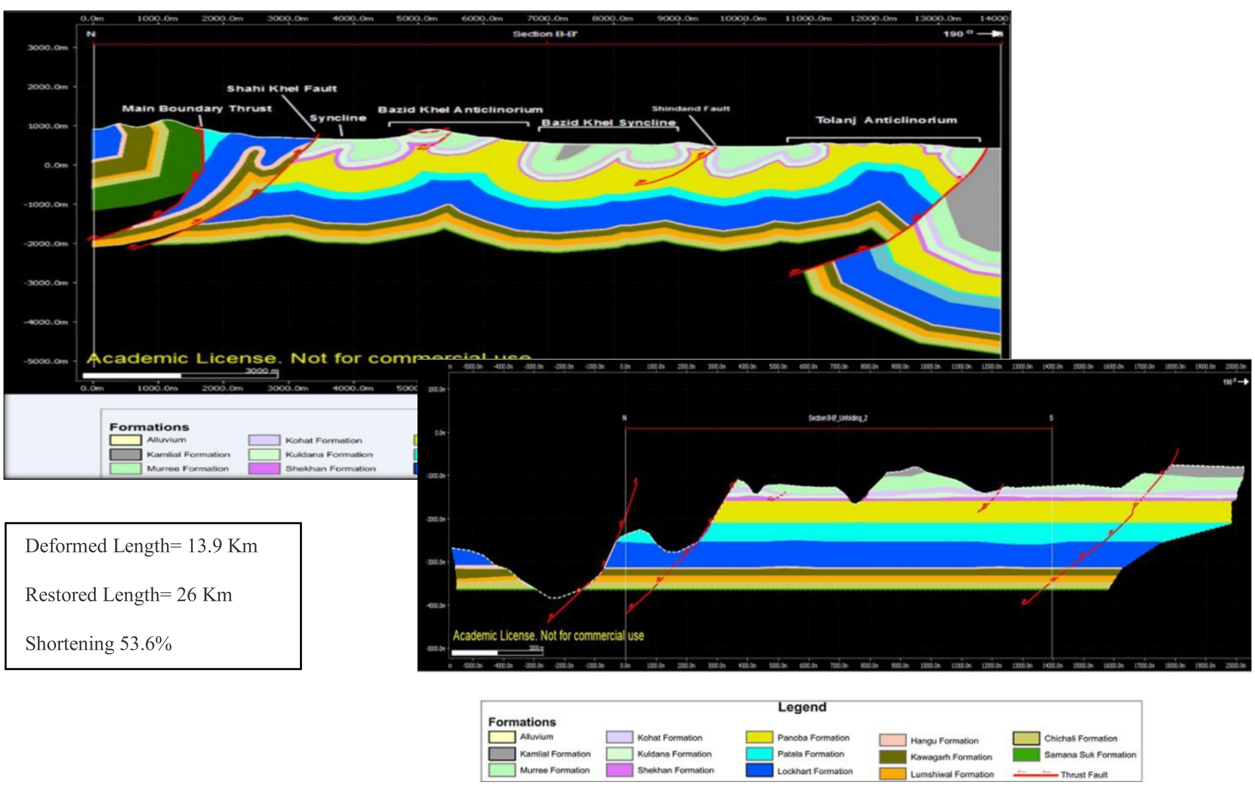
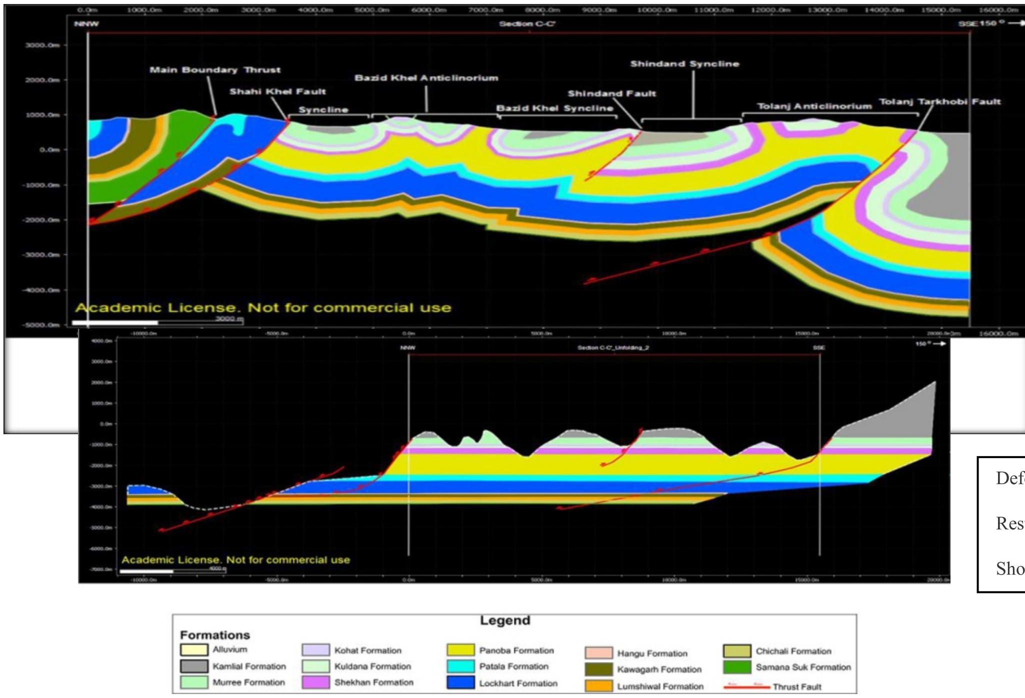


Fig. 4. Deformed and restored section BB/

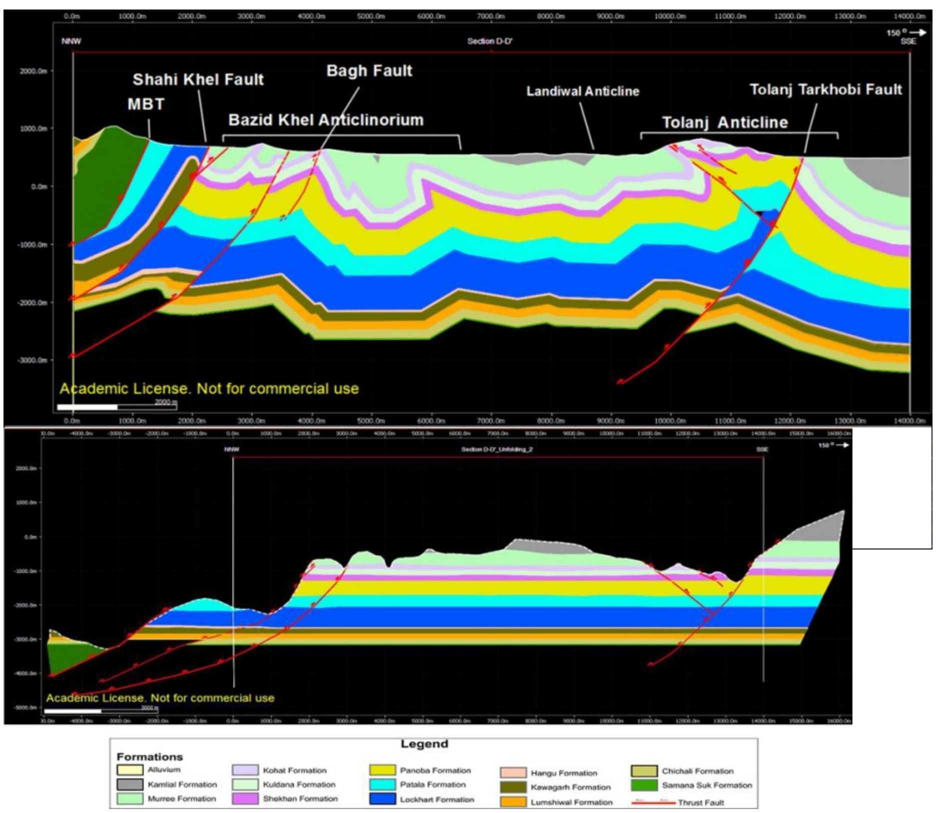


Deformed Length= 15.5 km

Restored Length= 31 km

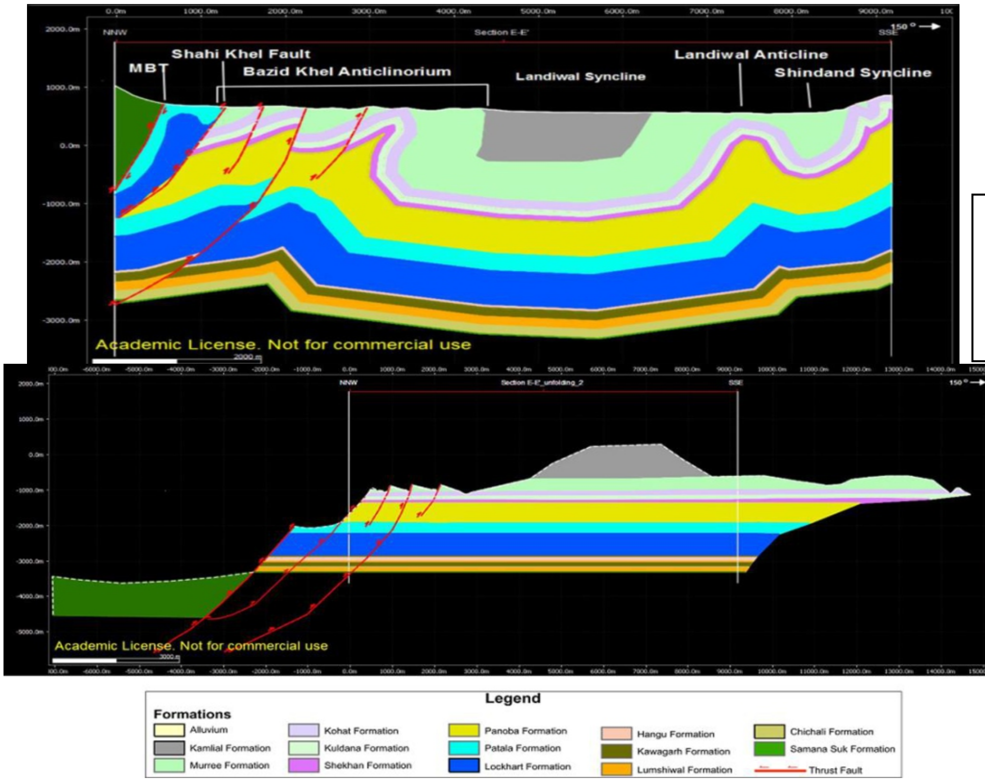
Shortening 50%

Fig. 5. Deformed and restored section CC/



Deformed Length= 14 Km
Restored Length= 21.3 Km
Shortening 65.6%

Fig. 6. Deformed and restored section DD/



Deformed Length= 9.2 Km

Restored Length= 22.1 Km

Shortening 41.7%

Fig. 7. Deformed and restored section EE/

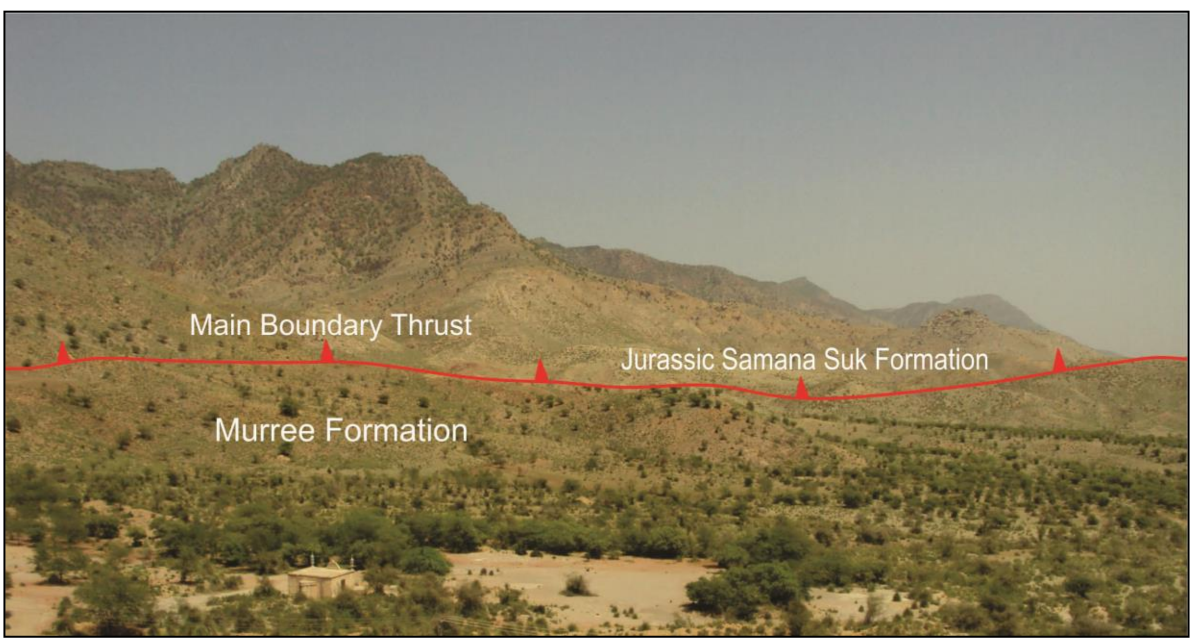


Fig. 8. Field photograph showing the Main Boundary Thrust fault where the Jurassic Samana Suk Formation is thrust over the Miocene Murree Formation

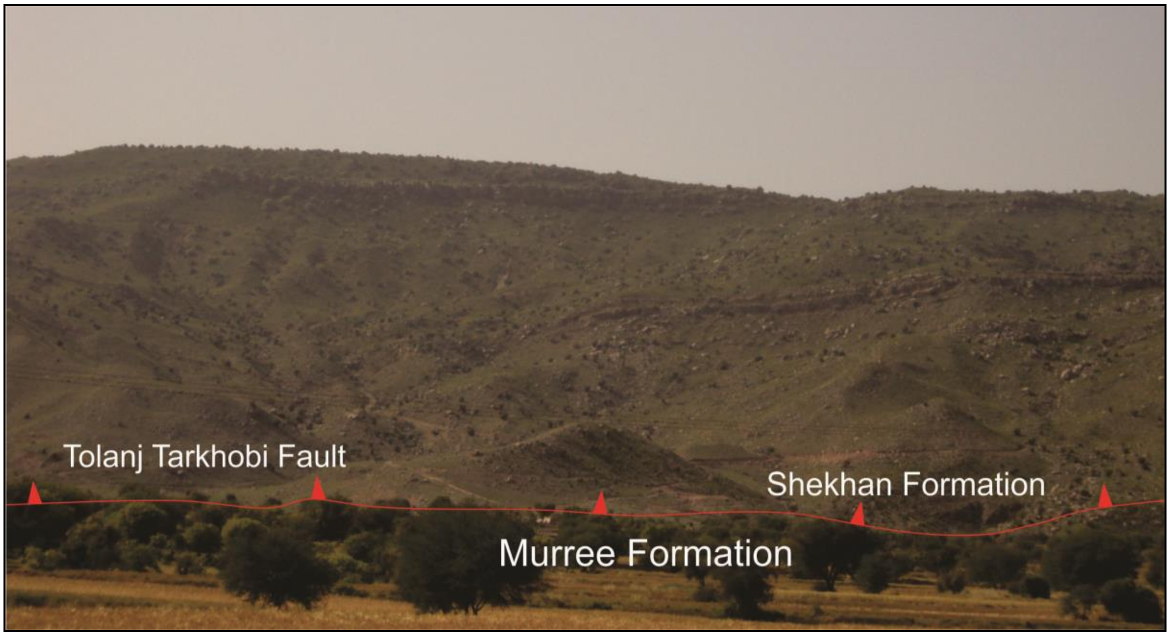


Fig. 9. Field photograph showing the Tolanj Tarkhobi Fault thrusting Eocene Shekhan Formation over The Miocene Murree Formation

4. Discussion

Structural analysis of study area shows that the area has been deformed in various episodes. From Paleozoic until recent stratigraphic packages have been altered. Thrust tectonics and shale diapirism has severely disturbed and affected the area.

The area of study is divided into structural regions which are distorted due to tectonic forces. Towards North, MBT is a major thrust fault where Jurassic rock assemblages are thrusted over Eocene and Miocene rocks. This is a regional fault which is unique for its variant distorted and deformed structures. Next to MBT Bazid Khel anticlinorium is present. It is trending northeast-southwest and is plunging towards the west. Two local thrust faults; Bagh Fault and Shahi Khel Fault are present towards eastern part, which slice the eastern plunge of Bazid Khel anticlinorium. These faults are thought to be a splay of MBT and has emplaced rocks of Patala Formation n top of Murree Formation. The core of Bazid Khel anticlinorium is covered by Shekhan and Panoba Shale.

Landiwal anticlinorium is situated on the southern side of Bazid Khel anticlinorium. In the study area only, the western plunge of this anticline has been mapped. This part is mostly dominated by Murree and Kamlial Formations. The central part of study area is covered by Tolanj anticlinorium which is a major regional anticline. To understand the anticlinorium, it has been separated into eastern, central and southern parts. Panoba and Shekhan formations are hosted in the core of this anticlinorium. Tolanj anticlinorium gradually plunges to the west (Fig. 2). Tolanj Tarkhobi Fault cut acrosses the southern limb of Tolanj anticlinorium. This fault is visible for 13 kilometers and juxtaposes the early Eocene Panoba shale and the Shekhan formation against the Miocene fluvial sediments. The steep dips of the north facing limb of this anticlinorium show that the fold is asymmetric towards north and is connected with a back thrust in the subsurface. Landiwal North syncline and Shindand syncline are major and broad synclines which are cored by Murree formation, which are also roofed with alluvium.

Cross section balancing reveals the complex sub surface geometries and behavior of folds and faults. Cross section restoration showing shortening accommodated by various structures is about 50%. There are two main reasons responsible for this, one is that the area has been deformed due to tectonic stresses since Mesozoic while the second reason is the existence of softer rock packages which are Panoba and Patala formations. These rocks have created structural disharmony and changed the geometry of rocks by providing the shallow mobility. The mentioned factors very clearly show that the area is affected due to diverse episodes of distortion.

6. Conclusions

This research work led us to conclude as follow,

1. The main governing forces which are responsible for deformation with in various structures are mainly thrust tectonics and shale flow.
2. The displacement of thrust faults deceases and perishes laterally in the cores of anticlines along their plunging ends, while it facilitates the overall uplift along the anticlinal structures in the central parts.
3. The amount of shortening observed by various structural features is around 50%.
4. Various structures show overturned bedding which is due to shale flow and it also gives us a clue about the local and regional tectonic transport which helped in placing the back-thrusts associated with them.
5. Bazid Khel, Landiwal and Tolanj anticlinoria are three major anticlines which provide a promising prospective for hydrocarbon exploration.

Author's contribution

Adnan Khalid proposed the main theme of topic and Sajjad Ahmad made a work plan for arranging field visit, preparation of geological map and cross sections. Adnan Khalid prepared the detailed geological map and cross sections using ArcGIS and Midland Valley Move suite under the supervision of Gohar Rehman and Nawaz Ikram. Field visit was made to the area where Fayaz Ali and Syed Burhan Hussain helped to collect field data. Afrah Sajjad was helped to draw the figures in Corel Draw and later on made important corrections in the final draft.

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