Journal of Himalayan Earth Sciences Volume 48, No. 2, 2015 pp.1-8

Structural evolution of southern Kohat fold and thrust belt, a case study from Karak area, Pakistan

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Abstract

Structural evolution of Southern Kohat fold and thrust Belt is interpreted through a structural model and two geo-seismic balanced cross sections prepared by integrating dip domain data, seismic data of 96-SHD-313 and well bore data of Makori East 1. The model and sections reveal the surface and geometries of folds and thrusts and variation of structural style along trend in relation to fold and thrust kinematics. Samana Suk Formation of Jurassic is taken in subsurface seismic data for which time to depth conversion is done and the values are extrapolated to cross sections. The geo-seismic balanced cross sections show that the thrust faults emanating from the sub-basal detachment within the sedimentary cover sequence, because the crystalline basement is not seen in the seismic reflection data. The tight anticlinal and broad synclinal folded structures evolved on Eocene evaporites as detachment folds were truncated by thrust faults along their limbs at surface which relates that folds formed earlier than faults. The structural models show that variation of surface structures along the trend is proved to be the result of variable displacement of thrusts along their strike. The restored cross sections show approximately 7-8 Km of shortening accommodated within the cover sequence by deformation. The research suggests that the Southern Kohat fold and thrust belt is structurally evolved in two distinct of deformation along the multiple detachment horizons. In the first phase detachment folding along Eocene evaporites had accommodated horizontal stratal shortening which is superimposed by vertical crustal telescoping by thrusting emanating from basal detachment.

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

1. Introduction

The Kohat Fold and Thrust Belt (KFTB) at the western extremity of the lesser Himalayas represent the south-western part of Himalayan foreland fold and thrust belt in Pakistan (Abbasi, 1991; McDougal and Hussain, 1991). KFTB is bound to the North by the Main Boundary Thrust (MBT) and to the South by Bannu Basin and Surghar Range Thrust. River Indus borders the eastern side separating it from Potwar foreland basin and Kurram Fault terminates its western boundary (Fig.1). The fold and thrust belt had gone through extensive deformational phase after the Eocene collision of Indian with Eurasian plate. Being the external zone of Himalayan fold and thrust belt, the KFTB has recorded deformation in sedimentary strata and preserving the continental molasse sequence resulting from Himalayan orogeny (Abbasi, 1991; Kifayatullah et al., 2006).

Deformation style is displayed by various structures at surface representing more intense deformation in Kohat (Pivnik and Sercombe, 1993; Pivnik and Well, 1996) as compared to Potwar except NPDZ for which Eocene evaporate strata is held responsible by various researchers (Ahmad, 2005; Abbasi,1991; McDougal and Hussain, 1991) and considered the case of Kohat to deform on multiple detachment horizons. Evaporite sequence of Eocene comprising Bahadur Khel Salt and Jatta Gypsum are the oldest rock units exposed in the study area overlain by Kuldana Formation and limestone of Kohat Formation. Kamlial Formation lies unconformably over the Kohat Formation. These units are overlain by stratigraphic sequence of the Siwalik Group comprising of Chinji and Nagri formations (Meissner et al., 1974) (Fig. 2). Recent hydrocarbon exploration success at Nashpa, Makori, Shakardarra, Gourgori and Manzalai in proximity of the study area had put it a favorable site for research and exploration of hydrocarbon. The aims of the present study are to integrate surface, subsurface and well bore data to understand structural evolution of southern KFTB.

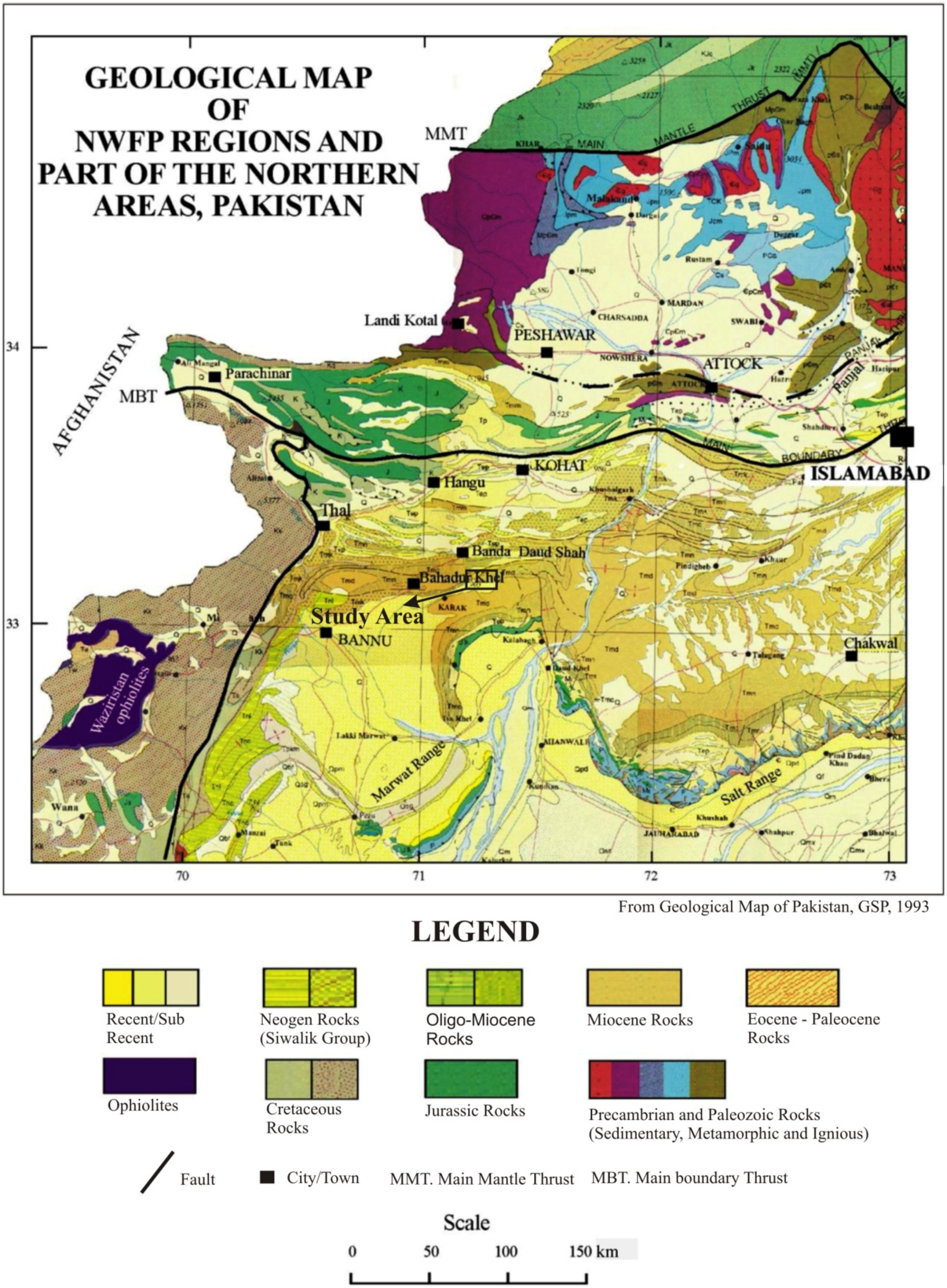


Fig. 1. Geological map of west and northwestern parts of Pakistan (Qureshi et al., 1993).

Age			Formation	Lithology	Thickness
Era	Period	Epoch			
CENOZOC	Tertiary	Miocene	Nagri Formation	Sandstone , Conglomerates and Clays.	1800
			Chinji Formation	Sandstone and Clays	1000
			Kamlial Formation	Sandstone and Clays	700
		Eocene	Kohat, Kuldan and Jatta Gypsum Formation	Limestone, Shale, Gypsum and Salt	164 M
		Paleocene	Panoba, Patala Fm	Limestone, Shale	227
			Lockhart Fm	Limestone	63
MESOZOIC	Cretaceous		Lumshiwal Fm	Sandstone	145
			Chichali Fm	Shale	88
	Jurassic		Shinawari Fm Samanasuk Fm	Limestone,Sandstone	295
			Datta Fm	Sandstone	

Fig. 2. Stratigraphic column proposed for study area based on surface measurements and well bore data; column is also used in construction of cross-sections.

The current research work was aimed at achieving the following objectives:

1. To develop a comprehensive structural model of the area to understand the kinematics of deformation and its variation along trend.
2. Construction of balanced cross sections to infer the geometry of structures at surface and subsurface.
3. To work out total amount of shortening accommodated by structures in the cover sequence of the area.

2. Methodology

1. The geological map is prepared at scale 1:50,000 by transferring all the details from Google Earth imagery published geological map and field data in to ARC GIS 9.2 (R) software.
2. Seismic line 96-SHD-313 and well tops of Makori are used for interpretations of subsurface structures and stratigraphy.
3. Seismic data of Makori is used to identify the Jurassic Samana Suk horizon in the seismic section.
4. Balanced cross sections are constructed by integrating dip domain data, extrapolation of Samana Suk horizon depth values from seismic data and well data of Makori under the corresponding shot point location at surface in the cross section.
5. Structural model is prepared by the integration of three fold information including the cross sections seismic and well data.
6. Cross section were restored manually and

amount of shortening is calculated using line length balancing for competent lithologies and area balancing for Eocene and Paleocene , evaporates and shale.

3. Geological setting

3.1. Structural cross sections

Structure of the area is controlled by thrust tectonics and detachment folding. Open synclines and tight anticlines are present at surface transected by imbricated and blind thrust faults (Fig. 3). Section AA$^{/}$ is constructed along seismic line 96-SHD-313 while section BB$^{/}$ is constructed across well data of Makori. The Samana Suk Formation was demarcated as principle reflector in 96-SHD-313. The methodology adopted to mark the reflector was extrapolation of sonic data of Makori well to pick the time for Samana Suk Formation in 96-SHD-313. The time for Samana Suk Formation was picked at 1.58 TWT in 96-SHD-313 under the correlated shot point location with reference to well at surface (Fig. 4). The time section was prepared for the reflector and later on converted to the depth section

3.2. Section AA$^{/}$

It is north-south oriented 14 km in length. Karappa Anticline and syncline fold pair is present as tight anticline and open synclinal structure in north of section. In subsurface these folds are developed between steeply dipping fore and back thrusts, emanating from basal detachment terminating in core of tightly folded Manzai Anticline. Nashpa Banda Fault (NBF) is a high angle thrust fault cutting up-section from basal detachment brought Jatta Gypsum at surface. ?fault and NBF is occupied by tight synclinal structure containing Chinji Formation in core. Idal Khail Fault is the splay of NBF bringing Jatta Gypsum on surface in faulted contact with Chinji Formation in the footwall. Idal Khail Anticline and Banda Lakhoni Syncline are exposed in South. In subsurface blind thrusts cuts up-section terminates in the core of Banda Lakhoni Syncline. The back blind thrusts originating from these fore blind thrusts had uplifted and folded the strata (Fig. 5).

3.3. Section BB$^{/}$

This structural transect along line BB$^{/}$ is north-south oriented of 13.5km length, almost perpendicular to the structural trend of the exposed rocks and located west of x-section AA$^{/}$. The section is constructed across Makori well. Karappa Syncline and Manzai Anticline are transected by blind thrust in the cores. Makori well is drilled in the southern steeper limb of Manzai Anticline which accounts for anomalous thickness of Kamlial Formation in the well. Attitude of NBF in this section is very steep at surface thrusting Jatta Gypsum to surface and transecting the syncline in the footwall. Idal Khail Fault splays from NBF at deeper level as compared to section AA$^{/}$ transecting the northern limb of Idal Khail Anticline. Banda Lakhoni Syncline is exposed in south of the section having two fore blind thrusts restrained in its core. Three back blind thrusts are emanating from a fore blind thrust losing their displacement in the core of an anticline containing Eocene evaporites and shales of Chichali Formation (Fig. 6).

3.4. Section CC$^{/}$

It is 9.5km NW-SE oriented section drawn towards the western flank of study area. The section is constructed to show the structural variation along trend where the section line cut across different structures exposed at surface as compared to section AA$^{/}$ and BB$^{/}$.

An open synclinal structure known as Kul Banda Syncline is exposed in north of the section. The syncline comprises Nagri Formation in the core and Chinji Formation at flanks. In subsurface the whole sequence is folded down to the Datta Formation. Spina Banda dome containing Jatta Gypsum in the core and younger rocks at flanks is exposed in south of the Kul Banda Syncline. Northern limb of the fan/box fold is overturned in the section. Back blind thrusts facing northward and diapirism in Eocene sequence is reason for the overturning of northern limb of Spina Banda dome. Spina Banda Syncline is exposed in the hanging wall of Ghundkai Fault containing Chinji Formation in the core and Kamlial Formation at limbs. Ghundkai Fault is exposed in south of the section emanates from basal detachment cuts up-section thrusting Kamlial Formation over theChinji Formation at surface.

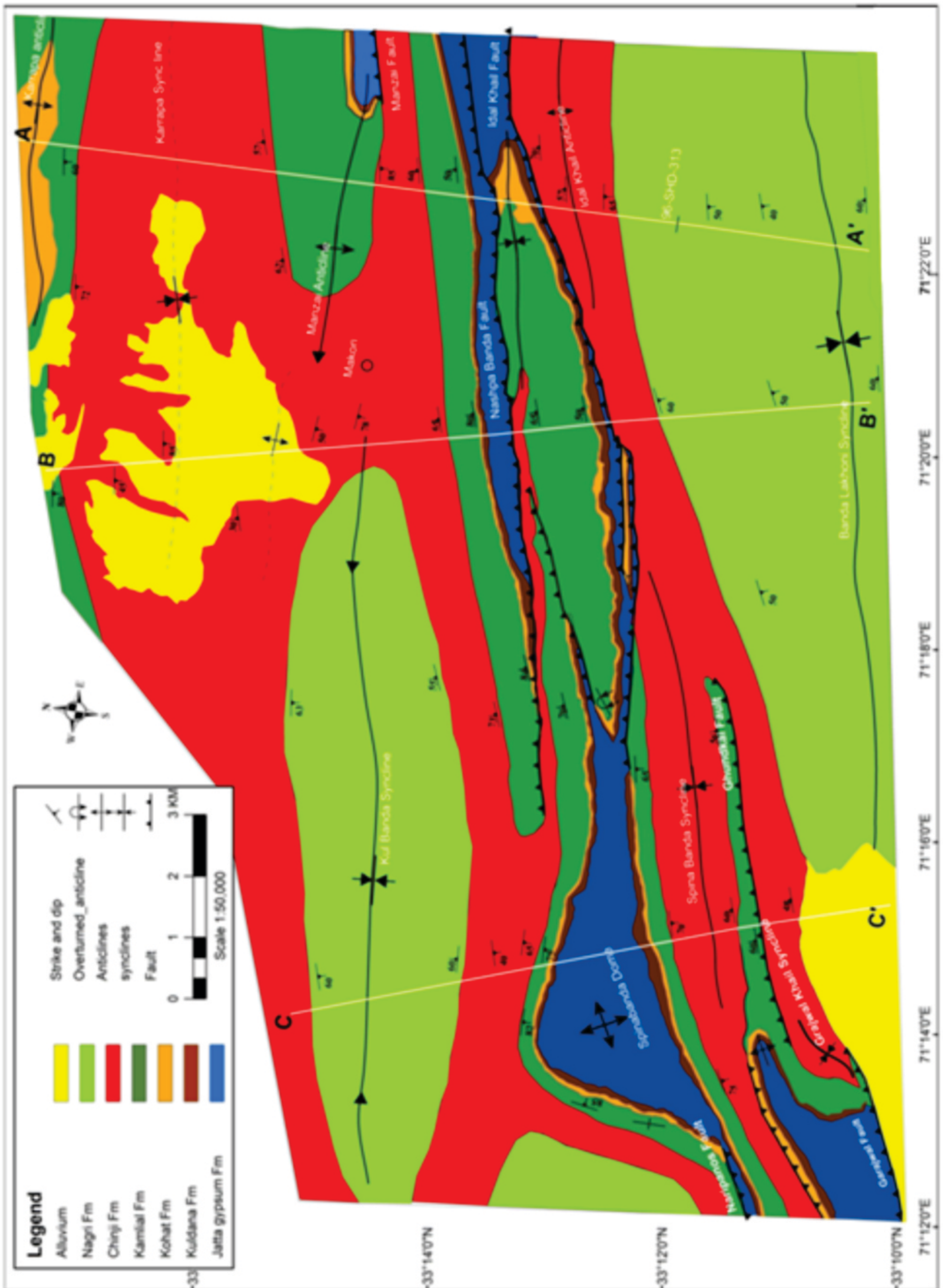
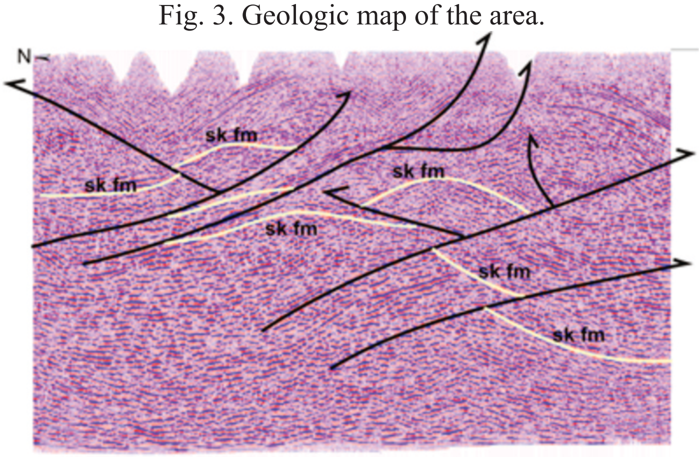


Fig. 3. Geologic map of the area.



sk fm= Samana Suk Formation

Fig. 4. Interpreted seismic section 96-SHD-313.

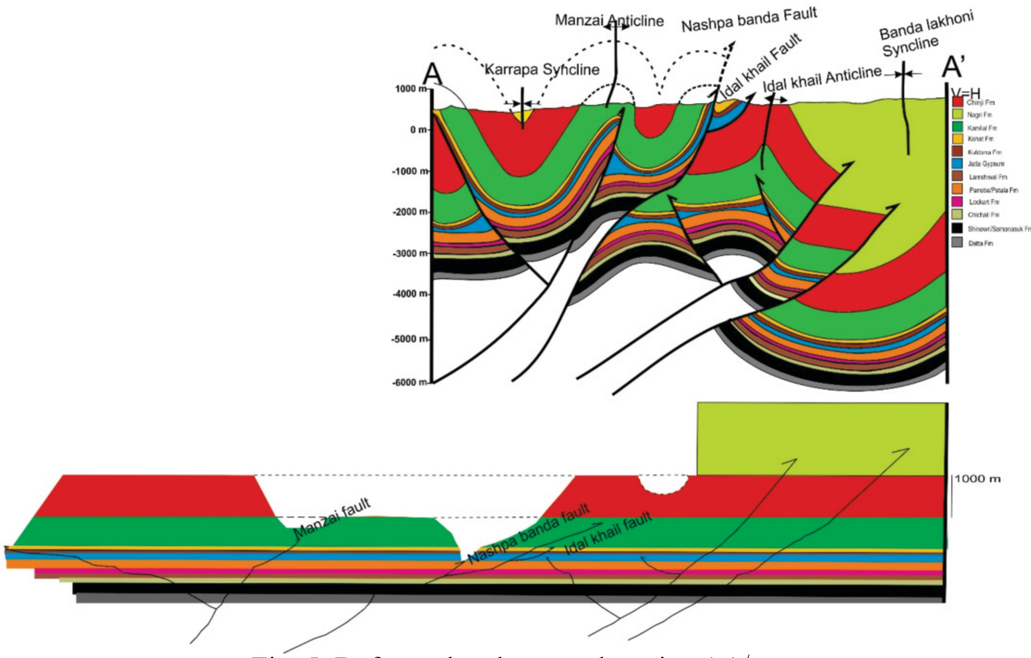


Fig. 5. Deformed and restored section AA$^{/}$.

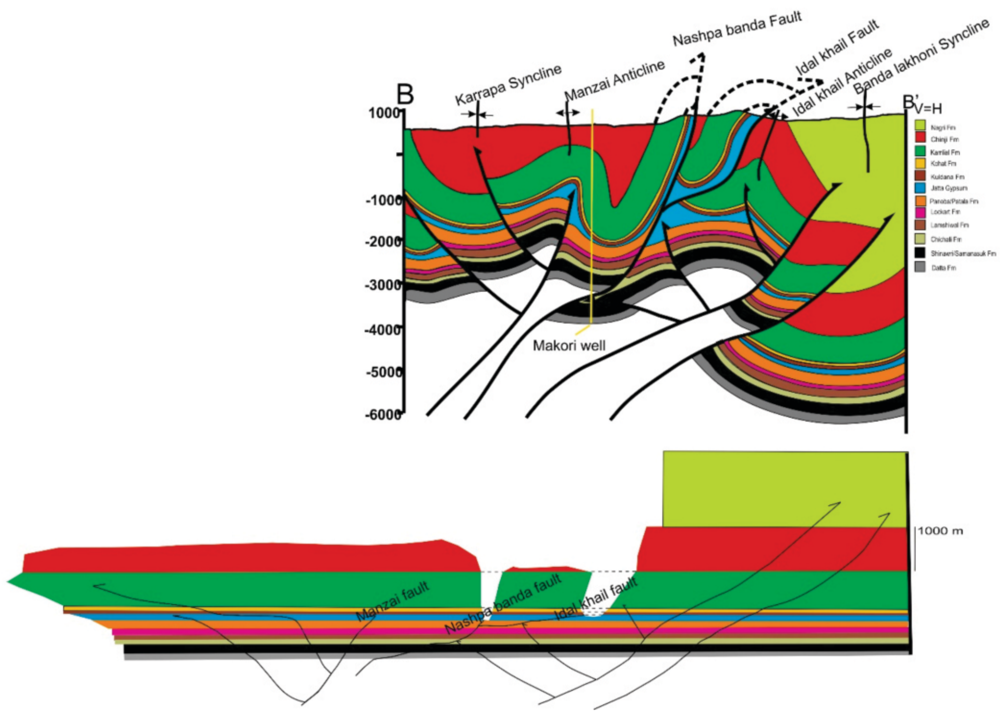


Fig. 6. Deformed and restored section BB$^{/}$.

3.5. Cross sections restoration

Two cross sections AA$^{/}$ and BB$^{/}$ are restored to their undeformed state down to Datta Formation. Cross sections are pinned at local pin lines in Banda Lakhoni Syncline exposed in the south of study area. All formations are line length balanced except Jatta Gypsum, Kuldana and Nagri formations. These three formations are area balanced for both sections. Total deformed area for Jatta Gypsum, Kuldana and Nagri Formations was measured (A). The regional undeformed thickness (T) for these three formations was then estimated from regional studies (Kifayatullah et al., 2006; Meissner et al., 1974). The estimated thicknesses are 200 m for Jatta Gypsum and Kuldana Formations and 1800 m for Nagri Formation. The undeformed average line length (l) for both units was determined using the relation:

$$L=A/T$$

The restored section AA$^{/}$ reveals approx. 8-9 km of shortening while restored section BB$^{/}$ had revealed 6-7 km of shortening accommodated by deformational structures in the area.

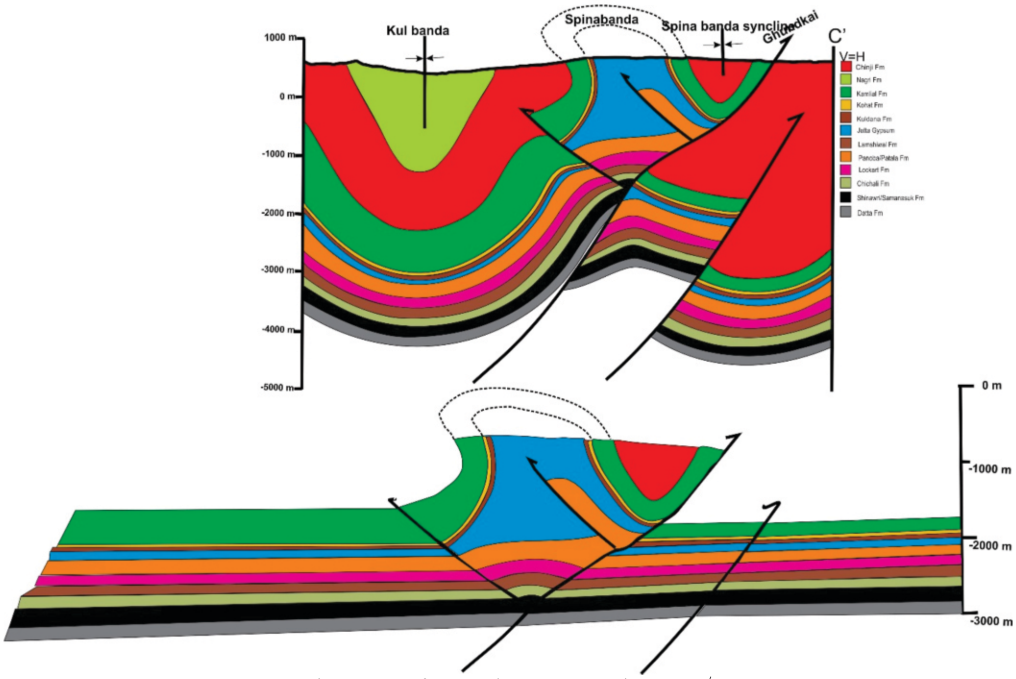


Fig. 7. Deformed cross section CC/.

4. Discussion and Conclusions

Structural model of the study area is discussed in relation to fold and thrust kinematics. The folds in the area are predominantly formed as detachment fold on Eocene detachment horizon which is later on transected by high angle thrust faulting at surface and subsurface. Manzai Fault (MF) exposed in east of study area bringing Jatta Gypsum to surface loses the displacement toward west along the strike and ultimately terminating in the core of Manzai Anticline in subsurface as shown in section BB/. A back thrust emanating from Manzai Fault in east gets gentler toward west in section BB/. The change in attitude of this back thrust is because of development of another back thrust from Manzai Fault cutting northward at shallower depth in section BB/ and terminating in core of Karappa Syncline. The slip of lower back thrust is transferred to upper back thrust along section BB/ in west of section AA/. The complete variation of structure along trend occur in west of BB/ where a synclinal structure is exposed at surface with complete absence of back thrust in subsurface. Nashpa Banda Fault in the east is thrusting Eocene Jatta Gypsum to surface, along the strike toward west near the Nashpa Kali village it cuts up-section steeply transecting the entire northern limb of syncline present in the footwall. The fault further westward loses the displacement up section depicted by thrusting Kamlial Formation over the Chinji Formation. Idal Khail fault (IKF) is a splay fault emanating from NBF in east had very little displacement in Eocene strata shown in section A/. However, toward west the fault gains the displacement elevating the southern limb of syncline as shown in section BB/. It is clearly seen in section AA/ and BB/, the reduction in stratigraphic throw of Manzai Fault in west is due to the transfer of deformation to NBF toward the foreland. This transfer of deformation resulted in shortening and elevating the structures at their hanging wall (Fig. 8). In south the deformation is achieved through blind thrusts present in subsurface. In west the structure style is different at surface and subsurface. Deformation is accommodated by Spina Banda Dome and Ghundkai Fault, the fault had greater displacement in west where it is bringing Eocene rock to the surface while toward east along the strike the fault loses the displacement up-section by only thrusting Kamlial Formation over the Chinji Formation.

The present study in Southern Kohat Fold and Thrust Belt suggests that the area is evolved in two distinct episodes of deformation. The first phase of deformation is controlled by Eocene evaporites sequence acting as a detachment horizon. In first phase of deformation the area is folded above Eocene detachment horizon as narrated by their presence in the cores of anticlinal folds and domes. In the second phase of deformation, the high angle thrust faults cut up-section steeply bringing Eocene rocks to the surface. The thrust faults transect limbs and cores of folds which is evident that faults are emplaced later in the deformational history of the area. The variable displacement of thrusts along their strike gives rise to structural variation at surface.

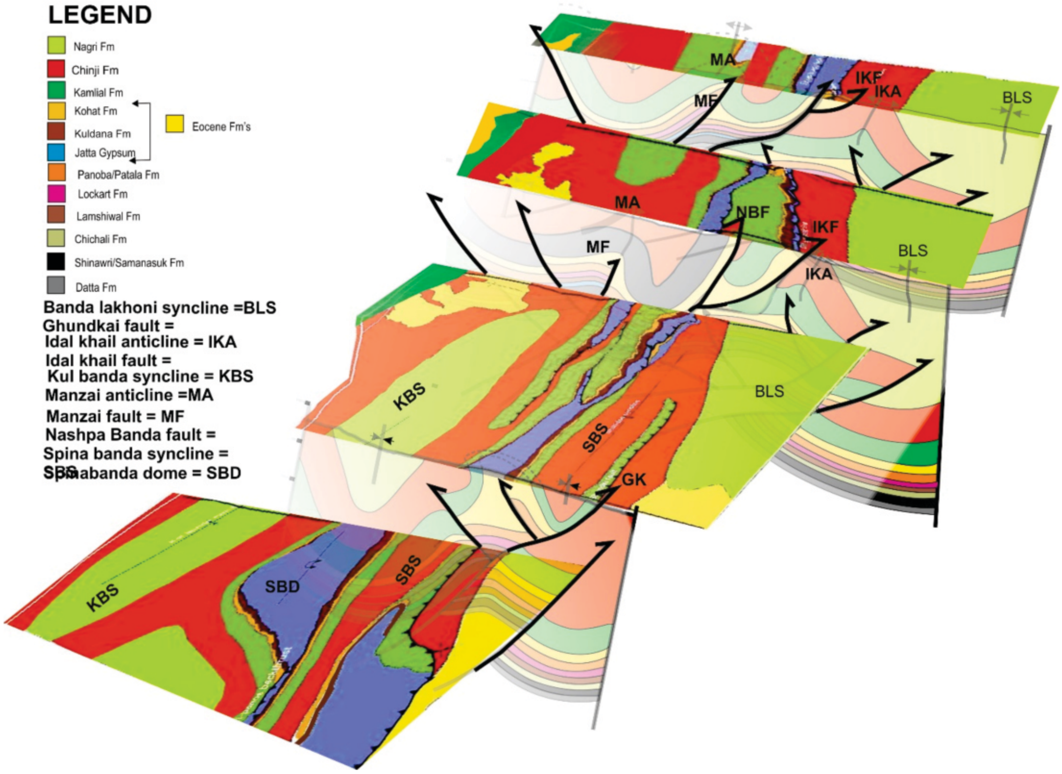


Fig. 8. Structural model showing thrust kinematics.

Current research concludes that deformation in the study area is completely controlled by detachment folding and thrust tectonics or fold-thrust tectonics. Thrust fault dies out laterally and up-section in the cores of anticlines resulting in elevating the structures above them. Variation of structures along strike is dependent on the variable rate of throw displayed by thrust faults along their strikes. Lateral decrease in throw of fore-thrust is accommodated by back thrust and fore thrust developed in front of these thrusts. Folded structures are truncated by faults at surface which suggests that faults are emplaced later than the folds in the deformational history. Total shortening accommodated by structures in study area is approximately 7- 8 Km.

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