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Research Article

3D-Kinematic Modelling and Hydrocarbon Potential of the Gurguri Block, Kohat Fold and Thrust Belt, Pakistan Using MOVE

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Abstract

The Gurguri block represents the foreland fold and thrust belt at the southern margin of Himalayan orogen, Pakistan. This research is a part of exploration study carried out to discover new oil and gas resources under highly deformed Gurguri block structures. The study area is strongly buckled and is outlined by thrust faults and folds due to north-south compressional stresses devised from the later northward movement of Indian Plate. This study comprises acquired two-dimensional data surface data integrated into an internally logical 3-D workflow in move suit 2013.1.0, which was then easy to assimilate and attain beyond known points to validate structural constraints within the area. The rocks exposed in the Gurguri area, are relatively more ductile and deformed into, tight, doubly plunging, overturned, and inwardly faulted E-W trending anticlines interceded by broad synclines and underlain by a thick sequence of Panoba shales of Eocene age. The 3D model suggests the study area is dominantly, a south-verging structural system propagating southward. Overall, the displacement along the thrust fault is up to 850 meters and the percent shortage calculated in the area is up to 60%.

Keywords: Tectonics of gurguri block; 3D structure modeling; MOVE; Gas resources

Abbrivations: MBT: Main Boundary Thrust; KF: Kurram Fault; KBF: Kalabagh Fault; PF: Panoba Fault; MKSF: Mir KhelSar Fault; WF: Walai Fault; SIF: Shiwakki Fault; HF: Huknal Fault; GF: Ghorm Fault; SMF: Sawye Mela Fault; ZF: Zarwam Fault; NPF: Nari Panaoa Fault; KKF: Karak Fault; VF: Visor Fault; BKSF: Basia Khel Surdag Fault; DF: Daryoba Fault; SBF: Sumarl Bala Fault; SF: Surghar Range Fault; KPBZ: Kohat Plateau Boundary Zone; PAM: Panoba Anticlinorium; BA: Buraka Anticline; SA: Sher Kot Anticline; SPA: Sumari Payan Anticline; SRA: Sundag Anticline; SAA: Sammana Anticline; DA: Darsmand Anticline; KDA: Khadmik Anticline; TS: Tsapparal Syncline; KKA: Karak Anticline; KA: Kuema Anticline; GTAM: Gurgalot Anticlinorium; MKAM: Mami Khel Anticlinorium; SKAM: Shakar Khel Anticlinorium; JA: Jatta Anticlinorium; MGAM: Manzalai Ghar Anticlinorium; NPS: Nari Panos Syncline

Introduction

The study area lies in the western part of Central Kohat Plateau, primarily a subdivision of the Kohat Fold and Thrust Belt (KFTB)(Figure 1). Kohat Plateau lies in the apex, almost 52-mile southwards to the core of western Himalayan foothills Pivnik, et al. It characterizes the southern boundary of the collisional margin within N-Pakistan and has sound traces of the Himalayan orogen.

The geographical perimeters of study area adjoin Kohat Range with Indus River on the east, surghar range across southeast, Samana range in northwest and Bannu basin in the south. Kohat Fold and Thrust Belt (KFTB) preserves extensive sedimentary record of Himalayan convergence comprehending the western part of the foreland fold and thrust belt of the north Pakistan Sercombe, et al. [1].

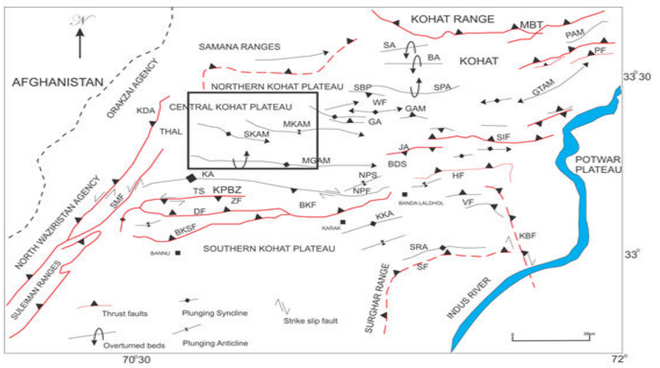

Figure 1: Generalized structural map of the Kohat Fold and Thrust Belt (KFTB).

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The KFTB comprises Paleocene to Eocene sedimentary rocks in a complex assemblage succeeded by an unconformity and overlaid by Miocene terrestrial, syn-orogenic foreland deposits Sameeni, et al. and Kifayat, et al. These lithologies have a strong impact on controlling the structural style of the Plateau. The Gurguri area within Kohat Plateau serves as forth-coming petroleum prospect and has been found to be a hybrid terrain of complex structural geometries, which can be attributed to salt and shale diapirism, thrust faulting, complex folding and wrench faulting Gardezi, et al. Earlier studies of the structural evolution of Gurguri area within Kohat Foreland is based on field observations and integrated surface geology. Past models and series of possibilities have been problematic to merge, partly because of incomplete structural mapping and structural history of fold and fault zones. A structural model of the Gurguri area (KFTB) in three dimensions to justify the sub-surface structural geometry is currently lacking [2]. Therefore, in this paper, we present a comprehensive structural map to develop sub-surface cross sections and a three-dimensional structural model of the Gurguri area in western KFTB [3].

Geology of the study area

The 50-65 Ma collision between northern Indian and southern Eurasian plate resulted in the genesis of the 1500 miles long-Himalayan mountainous belt. This continent-continent collision is the youngest and possibly the most impressive event on Earth. The detachment and northward translation of Indian plate from Gondwana land started at 130 Ma Johnson, et al., which resulted in the closure of the Neo-Tethys ocean, between these two plates McKenzie and Sclater. The Himalayas in Pakistan have been divided into five litho-tectonic Domains. They are the Krakuram Block, Kohistan Island Arc, Northern Potwar Deformed Zone (NPDZ), Southern Potwar deformed Zone (SPDZ) and Punjab foredeep. Additionally, there are five regional scale thrusts *i.e.*, (MKT) Main Karakorum Thrust, (MMT) Main Mantle Thrust, (MBT) Main Boundary Thrust, (SRT) the Salt Range Thrust and Trans (TIRT) Indus Range Thrust Ahmad, et al. The research area itself is a part of (SPDZ) which is situated in kohat plateau, that comprises of fold and thrust belts trending in east-west direction formed because of north-south oriented stresses covering the Gurguri and contiguous areas. The study area has undergone thin-skinned deformation, which is characterized by the presence of folds and faults resulted from the northward and clockwise movement of the Indian Plate. Based on stratigraphic sequence, Panoba shales of Eocene is considered the oldest unit whereas well data suggests that early jurassic datta formation is the non-exposed primitive rock unit [4].

Stratigraphic record of KFB reveals three principal evolutionary phases. Phase one is identified by paleozoic-mesozoic sedimentary rocks over the northern passive margin of the Indian Plate. Second phase starts with the formation of paleogene foredeep which was later filled during early Cretaceous to early Eocene. The last stage comprised the genesis of miocene-pliocene foredeep basin which has mostly north-south compression and east-west trending geologic structures. Most of the stratigraphic detail has been acquired through literature review and published well data information with the oldest exposed rock being Panoba shale and Early Jurassic Datta formation respectively. There is only one well-bedded unit exposed throughout KFB *i.e.* Kohat formation. The formations such as Kohat limestone, Kamlial formation and Nagri formation, being competent, form high ridges. The additional units including Panoba, Gurguri, and Chinji Formations are non-competent and subject to weathering hence forming low profile ridges and low dipping valleys. The largest synclinal valley within study area comprises Chinji Formation. DEM (Digital Elevation Model) of the research area shows an overall east-west trend of the major structures with some local variations (Figure 2) [5].

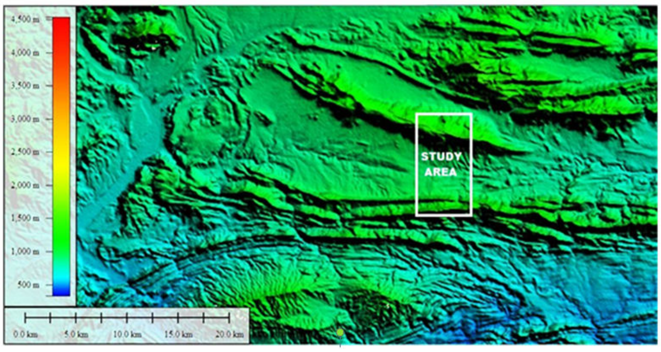

Figure 2: Digital elevation model of the KFTB showing the average elevation of approx. 1500 m along with the east-west structural orientation and structural closures due to plunging nature of the folds.

Materials and Methods

The structures and formations have been marked during extensive field work with all the points taken by GPS. Bedding has been measured along exposed outcrops of different lithologies using Silva compass. Later, these points were projected on Global mapper and Arc GIS for further evaluation. The geological map of the area has been developed and digitized on Arc GIS. Different folds and thrust faults developed due to the N-S directed compressive stresses have been mapped in the area (Figure 3) with their major axis and fault planes trending in east-west direction (Figure 4) [6].

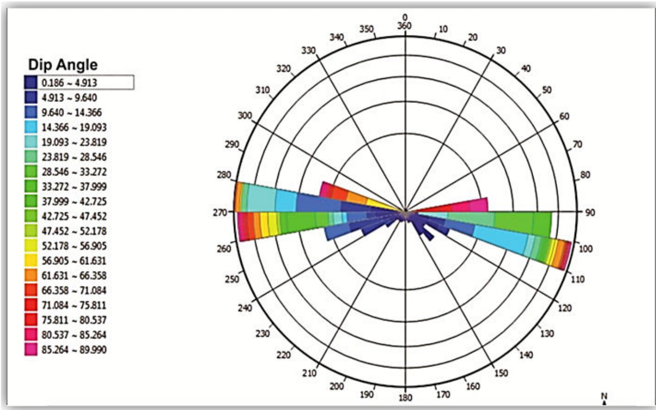

Figure 3: Rose diagram showing the hinge line orientation of different folds *i.e.* east west, along with the dip angles each limb of the different fold structures. The overall structural trend is east west with north south shortening component.

Cross-sections were drawn in "MOVE" structural modelling and analysis software by © 2011 Midland Valley Exploration Ltd. Data was loaded to it in form of shape files. Initial surface intersections were made after loading DEM file and different horizons were projected according to their surface angles. All horizons were joined after interpreting the subsurface structures. Faults were being drawn according to their dip angles. Other subsurface and above surface

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structures were drawn after whole structural interpretation. Different formation polygons were given their respective colours [7].

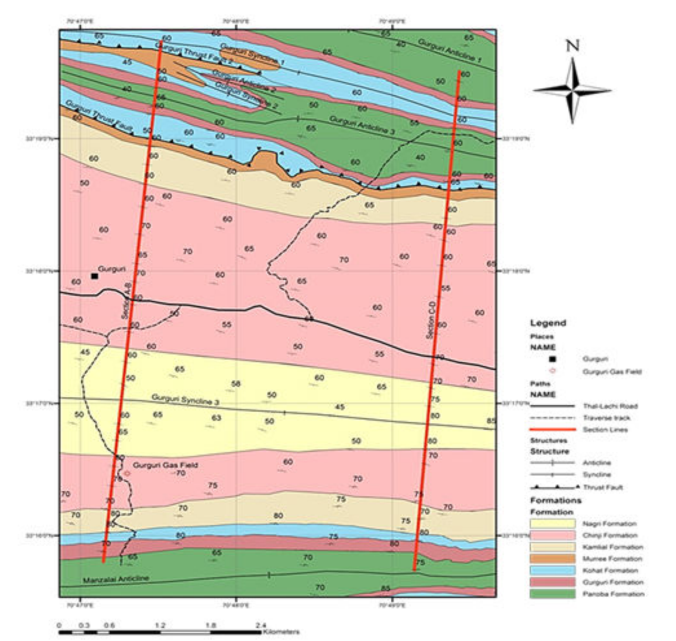

Figure 4: Displaying the structural map of the study area with major faults and folds along with the two north south cross-sections. The map has been developed and digitised using ArcGIS.

Results and Discussion

Based on the acquired field data it is suggested that the Gurguri area in KFB is complexly deformed, characterized by several folds and faults. Most prominent features of the area are the Gurguri Syncline 1 (GS1), Gurguri Syncline 2 (GS2), Gurguri Anticlinorium 2 (GA2) and Manzali Anticline. The northern most part of the study area is marked by a NW-SE trending having Panoba formation in the core with Gurguri and Kohat formation towards the limbs. The anticline has a width of one and a half kilometre. Northern limb of the anticline is overturned with dip angle of 65° in the south-west direction. The southern limb is normally inclined dipping 50° to 60° also in south-west direction.

The Gurguri Syncline 1 (GS1) is NW-SE trending fold with Murree formation in the core and Kohat formation at the limbs. Its northern limb is dipping south-westward with the dip angle ranging from 65° to 60° and southern limb is dipping in north-eastward direction with dip angle 65° to 60°. The width of this syncline is less than half a kilometre. Fold axis is almost steeply inclined throughout the study area [8].

The Gurguri syncline 2 has an approx. width of 5 kilometres with an east-west oriented fold axis. Nagri formation is in the core and the limbs of the syncline are marked by Murree and Kamlial formations in the north and Kamlial and Kohat formations in the South. The northern limb is dipping southward at 65° to 75°, while the southern limb is also dipping towards south from 80° to 85° which indicates an overall overturned behaviour.

Another structural feature in the study area is Gurguri anticlinorium 2. The overall trend of the Gurguri anticlinorium 2 is NW-SE, having width up to one kilometre. (Figure 5). In the eastern part, Panoba formation is in the core and Gurguri and Kohat formations are residing at its limbs. But, in the western part the fold, it is marked by alternate sequences of Gurguri and Kohat formations. The southern limb of the anticlinorium is overturned having dip angles of 60° and is marked by a thrust fault. The northern limb is divided into eastern and western part. In eastern part, the beds are normally inclined dipping 50° to 60°, while in the western part a localized thrust fault is present. A thrust fault has propagated in the southern limb of the Gurguri Anticlinorium juxtaposing Kohat Formation of Eocene age over the Murree Formation which is of Miocene age. The strike of the fault plane is in the WNW-ESE direction and dip direction of the fault plane is towards the NE. Another localized thrust fault is present in the area marking the north western part of the Gurguri Anticlinorium. Kohat formation of Eocene age has been brought up over the Miocene Murree formation by this thrust fault. The fault is not thoroughly extended in the study area but only restricted to the western part [9].

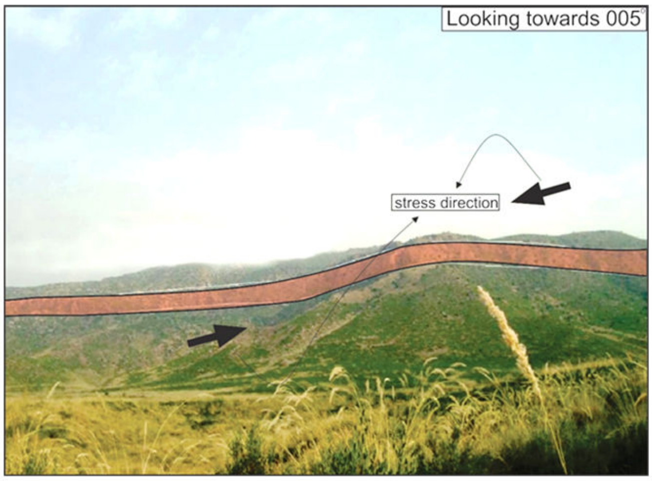

Figure 5: Field view of Gurguri anticlinorium represented by E-W directed stresses (Image not to scale).

The Manzalai anticline is present in the southernmost part of the study area. The Manzalai structure is east-west trending, with the Panoba shales in the core and Gurguri and Kohat limestone at the limbs. Width of the Manzalai anticline is 1 kilometre. The northern limb of the anticline is overturned with dip angles as high as up to 85° dipping towards south. The dip angles of the southern limb are also 80°-85° but are normally inclined. The structure is closing towards the east direction. Fold axis sinuosity is almost negligible [10].

Most of the fault splays explained by Gardezi, et al. tip out at the base of the Eocene rock sequence. Previous models suggest that the anticlines and synclines in the study area are developed due to the shortening underneath Precambrian to Palaeocene unexposed sequence. The fold geometry in the western KFB specifies that the folds are open to tight, mostly asymmetrical, overturned and plunging with fold axis vergence in the direction of north or south (Figure 6).

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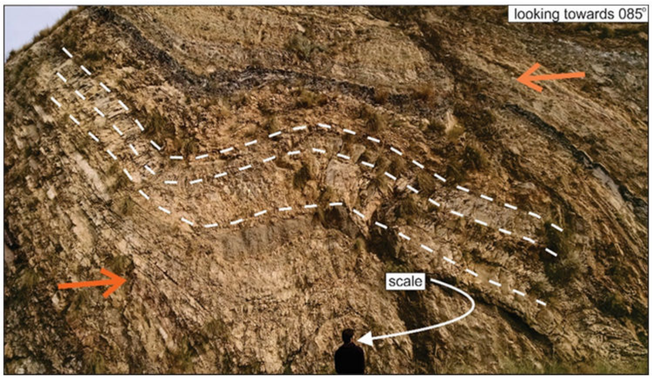

Figure 6: Tight folding due to N-S stresses at the apex of Manzali Ghar with the person standing as a scale.

Geological cross sections

Cross section A-B: Section line A-B starts from Gurguri syncline 1 in the north right down to Manzalai anticline in the south of the study area. The cross section extends up to 7.32 kilometers right from top to bottom seizing different fold and fault structures. The displacement along the thrust fault is up to 850 meters (Figure 7).

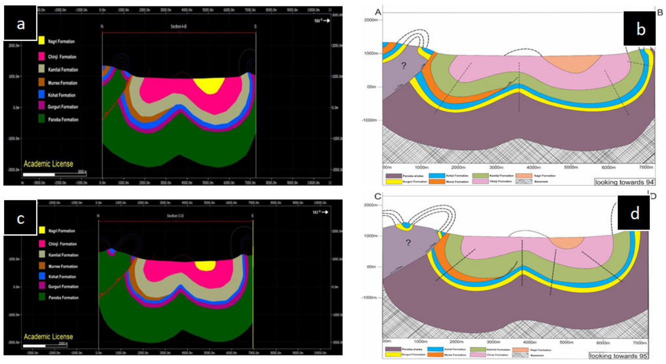

Figure 7: Cross Sections constructed on MOVE software using the field data helped us to configure the behaviour of different lithologies in the subsurface. The highs comprised of limestone (competent units) while the valleys and troughs constitute the sand and shales. The overturned behaviour of the limbs in cross section 7b and 7d shows high degree of shortening. Cross sections 7b and 7d are the interpreted sketches of the original cross sections (7a and 7c) developed on MOVE.

Cross section C-D: This cross section is 7.04 kilometer-long consisting of Southern limb of Gurguri anticline 1 in the north right down to northern limb of Manzalai anticline in the south. The displacement of the Gurguri thrust fault is up to 500 meters [11].

Cross-section restoration

Two structural cross-sections have been constructed regionally along the line A-B and C-D of the Figure 4 to recognize the kinematics of the structures in the base. Cross-section A-B represents the western part while C-D represents eastern part of the study area. The western part was inaccessible due to certain law and order conditions. The depth of crystalline basement revealed by well data is 10 km deep Abbasi and McElroy within study area with a regional northward dip of 1.4° to 1.5°. Restoration and balancing of the acquired cross sections along line A-B and C-D is done using MOVE® software to calculate percentage shortening of the area. The actual length of the cross-section A-B before restoration is 7348 m and it increases to 10948 along the faults and folds after restoration. The calculated shortening is 3600 m and percentage shortening is 49% along the cross-section line A-B (Figure 8) [12].

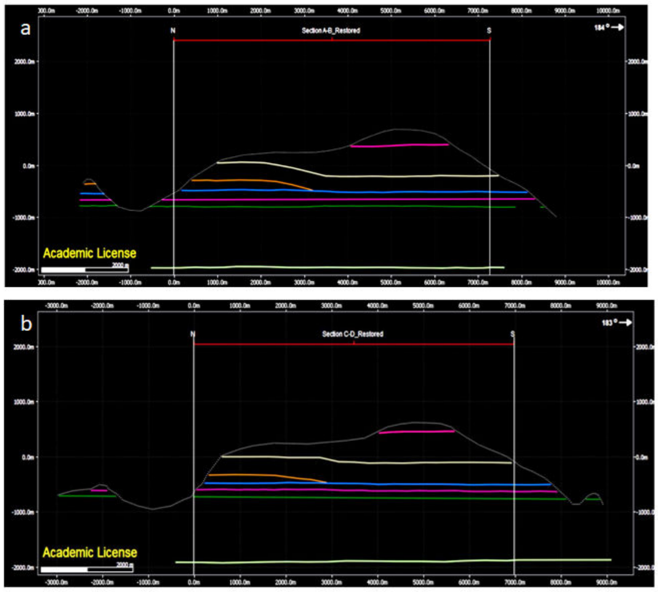

Figure 8: a) Cross section A-B restored, and the estimated displacement enhancement is calculated to be 3600 m, while the estimated displacement enhancement for the cross-section C-D; b) is calculated to be 4840 m.

The cross-section C-D is 6915 m in length, which after restoration changes to 11755 m. The amount and percentage of shortening along C-D is 4840 m and 70%, respectively. According to the restored sections A-B and C-D the mean shortening percentage within the study area is 59.9%. The area is interpreted to be deformed under thin skinned style of deformation because no rock older than Panoba shales of Eocene was exposed at the surface. The well drilling went right through the Jurassic, which attributed to the ductile nature of the ductile behaviour of the Panoba shales [13].

3D model of gurguri block

A 3D model of the study area has been generated in between the section lines A-B and C-D. The main purpose of the model is to understand the geometry and behaviour of fold and fault structures. 3D model helps us to interpret the structural closures of different folds present in the study area. Most of the synclinal folds present in the study area terminate in the east direction. Furthermore, when the 3D model is subjected to different data analysis, it confirms the interpreted model. The sub-surface structural geometry of the Gurguri area in western KFB is depicted by three Dimensional (3D) structural model. These 3D models explicate the reduction and retreat of the regional structures *i.e.* Gurguri syncline (up to 5.43 km) in the sub-surface along with the correlation of the surface data. It illustrates disharmony among the structure styles and termination of surface and sub-surface structures. Series of listric fore and back, to emergent and traceable blind thrusts faults are also identified in Gurguri area in the western KFB possibly emerging from Eocene crystalline basement rocks. The model is characterized by dip amounts on different layers, which shows the areas of low and high curvature. The depth curvatures for synclines are closing in east direction, which means that the synclines are plunging in east direction while for anticline the scenario is vice versa (Figure 9) [14].

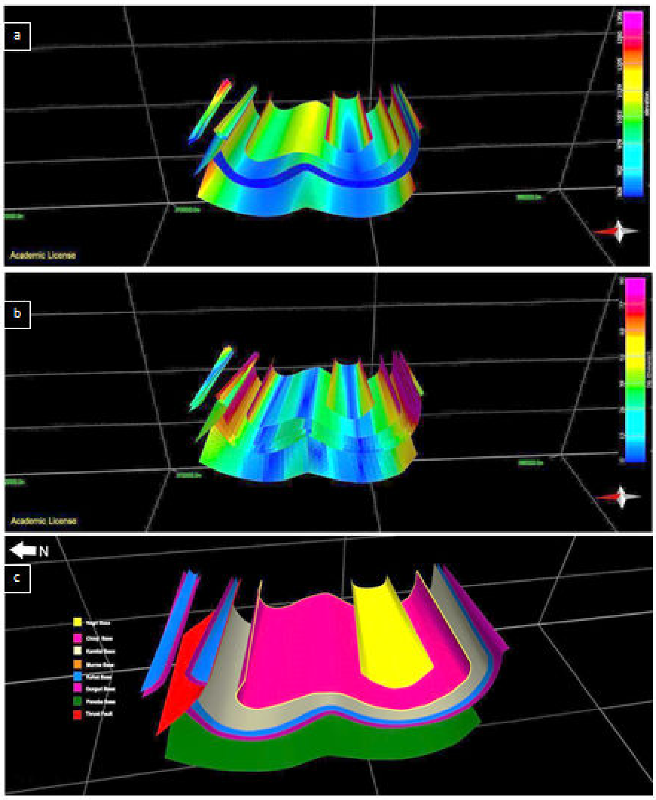

Figure 9: 3D projections of different layers across cross section A-B and C-D further clarify the understanding of the plunging nature of the folds. As in figure 9a the fold limbs are broad towards the west but becomes narrow and tighter towards east of the study area as in the following figures (9b and 9c). Thus making it the east-ward plunging structure. Plunging folds are very good source of oil and gas deposits and most of the discoveries in Karak area have been made at down plunge anticlines.

Economic significance of gurguri block

The first exploratory well for hydrocarbons in Gurguri block was first drilled by MOL (Magyar OLaj-es Gazipari Reszvenytarsasagvt Ltd) in 2006 at Gindai Ghar area. The first discovery of oil was made in 2009 by MOL at Manzalai block with the completion of 5829 m well in the Murree formation (Miocene sandstone). Six oil and two gas fields have been discovered in the duration of just 8 years. Many wells drilled by either oil company in the Gurguri block have been abandoned due to structural and drilling complications e.g. bump thickness of the seals, high pressure in wells, blind faults and dips variation. One of the most successful well drilled (Manzalai-1) is producing 200 MMscfd natural gas and 4,000 BPD condensate MOL Panorama. This research is a part of exploration study carried out to discover new oil and gas resources under highly deformed Gurguri block structures. A detachment fold is observed evolving into a fault-propagation fold and transforming into a pop-up structure. These implications lead to the favourable host setting for highly concentrated oil and natural gas reserves within these structural units. Therefore, substantial exploration is needed to improve the reserves especially when oil fields are at notable depletion [15].

Conclusion

Gurguri area in western Kohat fold belt is dominated by complex folding and Eocene-Pliocene deformation with obvious nature of the thin-skinned style of tectonics. Exposed surface structures are defined by N-S oriented stresses featuring E-W trending anticlines, separated by broad synclinal valleys. The propagation of overall Gurguri block structural system is southwards. A structural disharmony is present within the Gurguri area of KFB as the structural interpretation of surface rocks does not resemble the sub-surface rocks. Shale and salt diapirism in the area shapes the whole tectonic scenario. Another interesting finding is the exposure of extra faults on western side compared to eastern side, which clarifies the intensity difference of deformation between the two areas. Moving from north to south in the project area, stratigraphically younger sequence indicates the propagation of thrusting towards south because of northward translation of the Indian plate in eocene. The structures on the top are formed because of detachment thrusting, consisting of doubly plunging, overturned, tight and faulted anticlines with broader synclines. The development of fault propagation folds in the base encompasses the major petroleum play of the region. The deformation of rocks in western part of the Gurguri area is more penetrating than its eastern extensions. The area represents overall 59.6% shortening, most of which is associated with the deformational overturned anticlines, as synclines are wide and broad featuring less deformational characteristics. The Gurguri area is a well-developed future petroleum prospect with possibly fruitful outcomes.

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References

1. Ahmad A (2004) Structural transect of the western Kohat fold and thrust belt between Hangu and Basia Khel, NWFP, Pakistan. Proceed Ann Tech Conf Islam 37-50.
2. Burbank DW, Tahirkheli RK (1985) The magneto-stratigraphy, fission-track dating, and stratigraphic evolution of the Peshawar intermontane basin, northern Pakistan. Geo Soc Amer Bullet 96: 539-552.
3. Fatmi AN (1974) Lithostratigraphic units of the Kohat-Potwar Province, Indus Basin, Pakistan. Memo Geo Surv Pak 10: 1-80.
4. Fraser JE, Searle MP, Parrish RR, Noble SR (2001) Chronology of deformation, metamorphism, and magmatism in the southern Karakoram Mountains. Geo Soc Amer Bullet 113: 1443-1455.
5. Gansser A (1964) Geology of the Himalayas, Wiley-Interscience, New York, USA, pp. 289.
6. Gardezi SAH (2016) Geological constraints on central kohat foreland basin, Khyber Pakhtunkhwa, Pakistan: Implication from 2d and 3d structural modelling. Proceed Int Conf Exh Bar Spain 286-286.

7. Gee ER (1945) The age of the Saline Series of the Punjab and of Kohat. Proceed Nat Acad Sci India 14: 269-310.
8. Ibrahim Shah S (1977) Stratigraphy of Pakistan: Memoirs geological survey of Pakistan, Memoirs, Pakistan, 12: 1-138.
9. Johnson B, Powell CM, Veevers J (1976) Spreading history of the eastern Indian Ocean and Greater India's northward flight from antarctica and Australia. Geo Soc Am Bull 87: 1560-1566.
10. Le Fort P (1975) Himalayas: The collided range present knowledge of the continental arc. Am J Sci 275: 1-44.
11. Pivnik DA, Wells NA (1996) The transition from Tethys to the Himalaya as recorded in northwest Pakistan. Geo Soc Am Bull 108: 1295-1313.
12. Sameeni SJ, Haneef M, Rehman O, Lipps J (2009) Paleogene biostratigraphy of Kohat area, northern Pakistan. Geo Bull Punjab Univ 44: 27-42.
13. Sercombe WJ, Pivnik DA, Wilson WP, Albertin ML, Beck RA, et al. (1998) Wrench faulting in the northern Pakistan foreland. Am Assoc Petro Geo Bull 82: 2003-2030.
14. Ullah K, Arif M, Shah MT, Abbasi IA (2009) The lower and middle Siwaliks fluvial depositional system of western Himalayan foreland basin, Kohat, Pakistan. J Himal Earth Sci 42: 61-85.
15. Wells N (1984) Marine and continental sedimentation in the early Cenozoic Kohat basin and adjacent north-western Indo-Pakistan. Thesis University of Michigan, USA.