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3-D Structural Modeling of Meyal Field, Potwar Sub-basin, Pakistan using Seismic and Well Data

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ABSTRACT

Meyal Field is located near Pindi Gheb, District Attock in Upper Indus Basin, Pakistan. In this paper, 2-D seismic and well data of Meyal-17 is interpreted to construct a 3-D structural model using the Kingdom Interpretation Software Suite. After identifying the horizons on seismic lines with the integration of well and seismic data, faults were mapped. With the help of fault polygons, time contour maps were generated which were then converted to velocity and depth contour maps. Finally, 3-D structural model was generated from these maps. It is interpreted that there are two possible structural traps which are suitable for accumulation of hydrocarbons in the study area. One is present in the southwestern part of the Field with two fault bounded closure and the other is one fault assisted in the central part as indicated with dotted circles A and B respectively. Closures on depth contour maps of two fault bounded trap are 777 m, 845 m, 752 m and 750 m at the level of top Kohat, top Sakesar, top Lockhart and top Datta respectively. While, closures of one fault assisted trap are 150 m, 250 m, 200 m and 250 m at the level of top Kohat, top Sakesar, top Lockhart and top Datta respectively. The closure due to down thrown block is smaller than closure due to two faults (F2 & F3) in the southwestern part of the field. 3-D Model shows that all four horizons are confirmable at one another.

1. Introduction

Geoscientists use various geological and geophysical techniques for exploration of hydrocarbon mainly the seismic reflection geophysical method. The first commercial discovery of oil was successfully made in 1915 in Potwar Basin in Pakistan [1]. However, a number of wells were unsuccessful due to complex subsurface geological structures. Potwar basin situated in Sub-Himalayan domain contains significant quantity of hydrocarbons trapped in post Himalayan orogeny related compressional/transpressional subsurface structures [2].

Hasany and Saleem [3] study indicates that the sub-surface structure is east-west trending pop-up, salt cored, doubly plunging, gentle dipping anticlinal fold bounded by thrust faults in the north and south at the level of Eocene. The eastern portion of the fold is slightly tighter than the western portion. Trapping mechanism in the Meyal Field is structural.

Meyal Field in Pakistan is one of the major oil and gas producing fields in the Potwar Basin and was discovered by Pakistan Oilfields Limited in 1968. Meyal Field is located near Pindi Gheb, District Attock in an active foreland and thrust belt in the Central Potwar Plateau of the Upper Indus Basin [3] (Fig.1) and base map is shown in Fig. 2.

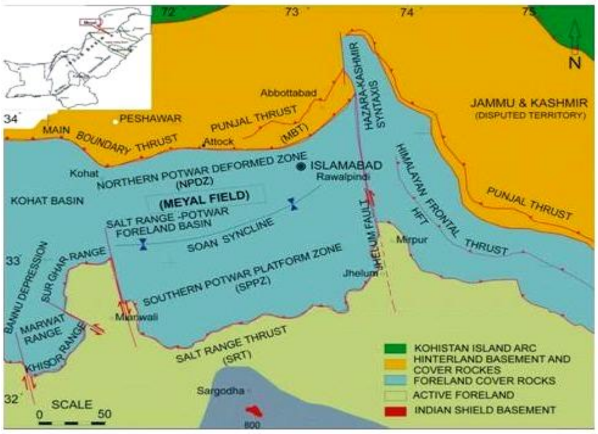

Fig. 1: Tectonic map of the study area (Modified from Shami and Baig) [4]

With recent developments in software industry, 3-D Geological Modeling has become an important tool to understand subsurface structures for hydrocarbon prospecting picture by integration of mud logs, wireline logs and seismic data [2, 5]. The overall aim of seismic interpretation of the migrated 2-D seismic lines is an aid to construct the most accurate sub-surface 3-D structural models for understanding the subsurface structure for hydrocarbon production.

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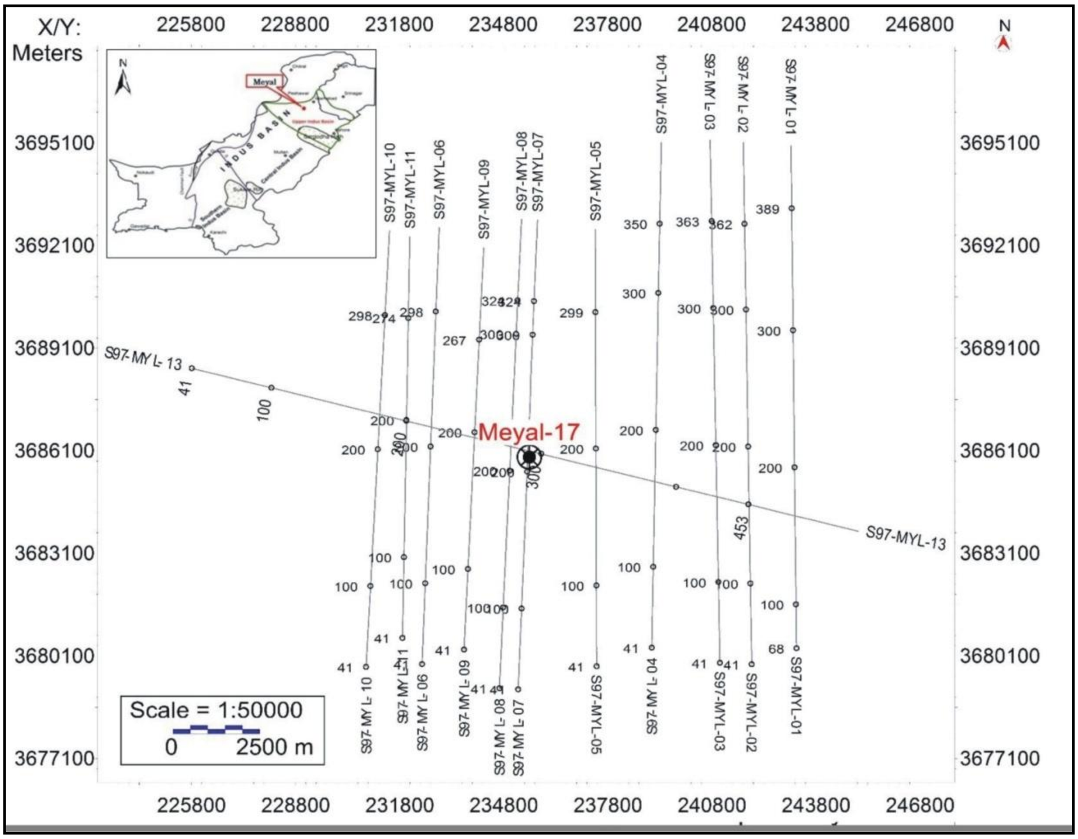

Fig. 2: Base map of Meyal field

Potwar Sub-basin is the sub-basin of Upper Indus Basin and after the discoveries of hydrocarbons in the Potwar sub-basin has become more important [6]. In this study, an attempt has been made on the Meyal Field using geophysical and check shot data in order to understand the subsurface structures. This study is performed in the Department of Geological Engineering, University of Engineering & Technology (UET) Lahore-Pakistan as a part of M.Sc. research work by principal author.

2. Tectonics and Geology

Tectonically, the Himalaya is the world's youngest and highest orogenic belt which is evolved in the result of continent-continent collision. The collision between Indian and Eurasian plates occurred during the Eocene time along the Indus Suture Zone which was subsequently shifted southward due to thrusting along Main Central Thrust (MCT) and Main Boundary Thrust (MBT). The Salt Range/Potwar Plateau (SR/PP) represents the Himalayan forelands fold and thrust belt in south of MBT [7] (Fig. 1). Potwar is bounded by the Kala Chitta and Margala Hills in the north, the Indus River and Kohat Basin in the west, and the Jhelum River in the east. It is divided into Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ) by the Soan Syncline. The NPDZ is more intensely deformed than the SPPZ [8]. The sedimentary rocks are deformed during thin-skinned Himalayan tectonics, forming the structural traps structurally suitable for hydrocarbon accumulation [4].

Geologically, the Indus Basin is covered with 15,000 m thick sediments ranging from Pre-Cambrian to recent age [9]. Upper Indus Basin covers approximately 50,000 km^2 of area [10] and is further divided into Potwar Sub-basin and Kohat Sub-basin. Potwar Sub-basin is an elevated but nearly flat region, located about 100 km north of the Salt Range. The sedimentary rocks exposed in the Potwar Sub-basin are limestone, evaporites, and red beds (Eocene), fluvial sediments (Miocene), terrace gravel and loess (Pleistocene), and alluvium (Holocene). Most of the area is covered by terrestrial Neogene deposits [3]. The generalized stratigraphy is shown in Fig. 3.

3. Database and Methodology

The geophysical and well data of the Meyal field used in this study is shown in Table1 and Table 2 provided by the Directorate General Petroleum Concessions (DGPC), Islamabad-Pakistan. Migrated 2-D seismic data in digital (Seg-Y) format is interpreted to identify the structure of the study area. The well data includes Check Shot Data of Meyal-17. The following database was used for generation of structural maps by using Kingdom Interpretation Software Suit.

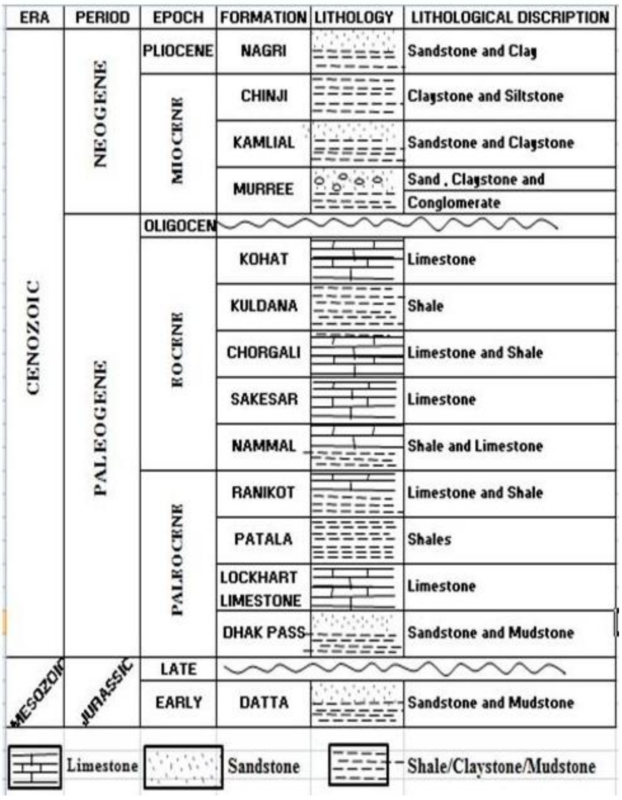

Fig. 3: Generalized stratigraphy of Meyal field [3]. Datta (Early Jurassic), Lockhart (Paleocene), Sakesar (Eocene) and Kohat (Eocene) horizons are used in the study

The criteria used for picking of horizon tops and fault networks are summarized below;

i. Identification of seismic horizons on dip line (S97-MYL-07) which passes through Meyal-17 using time from Check Shot Data.

ii. Transferring of these Horizons on strike line, S97-MYL-13 which is crossing all other dip lines from S97-MYL-01 to S97-MYL-11.

iii. Transferring of horizons from strike line on each dip line.

iv. Identification of faults networks with the help of reflector's discontinuity.

Using above horizons, the time contour maps were generated which were then converted to velocity maps after loading control points data generated at different location using slope equation i.e. $Y=0.0015X-2.5568$ ($y = mx + c$)where Y= TWT and X=Velocity. Finally, the depth structure maps were generated from the velocity maps using the basic equation of motion i.e. $S= V*T$. At the end, structural model was constructed using these seismic horizon maps.

4. Results and Discussion

4.1 Horizon and Fault Interpretation

Four key horizons (Kohat, Sakesar, Lockhart and Datta) and faults were picked on N-S dip oriented seismic lines (S97-MYL-07 and S97-MYL-02) as shown in Fig. 4. It is observed that Tops of Kohat, Sakesar and Lockhart horizons were identified due to high amplitude reflections with moderate to good continuity. However, Top of Datta is characterized by low to high amplitude, with moderate to good continuity reflections. The disturbance in the high amplitude at some places was observed due to faults rather than lithologic heterogeneity in Kohat Horizon and Datta Horizon. Several reverse faults were mapped on seismic sections and labeled as F1 to F8 (Fig. 4). It is observed that F1, F2 and F3 were observed in all seismic sections, while other faults (F4 to F8) were missing on some seismic sections. Major structure building faults (F2 and F3) formed the pop-up structure in the study area.

Table 1: Seismic lines of Meyal field used

Sr. No.	Line Name	Length (km)	Shot Points	Direction	Nature
1	S97-MYL-01	12.9	68-389	N-S	Dip line
2	S97-MYL-02	12.9	41-362	N-S	Dip line
3	S97-MYL-03	13.0	41-363	N-S	Dip line
4	S97-MYL-04	12.4	41-350	N-S	Dip line
5	S97-MYL-05	10.4	41-299	N-S	Dip line
6	S97-MYL-06	10.3	41-298	N-S	Dip line
7	S97-MYL-07	11.3	41-324	N-S	Dip line
8	S97-MYL-08	11.3	41-324	N-S	Dip line
9	S97-MYL-09	09.0	41-267	N-S	Dip line
10	S97-MYL-10	10.3	41-298	N-S	Dip line
11	97-MYL-11	09.3	41-274	N-S	Dip line
12	97-MYL-13	16.6	41-453	NW-SE	Strike line

Table 2: Check shot data of well Meyal-17

Formation	Depth SS (m)	TWT (s)	Velocity (m/s)
Chinji	-27.939	0.322	-173.534
Kamlial	-1458.365	1.173	-2486.556
Murree	-1674.469	1.293	-2590.053
Kohat	-3193.897	2.075	-3078.455
Kuldana	-3236.569	2.095	-3089.803
Chorgali	-3273.450	2.111	-3101.326
Sakesar	-3336.543	2.138	-3121.181
Nammal	-3425.545	2.173	-3152.826
Ranikot	-3455.415	2.183	-3165.749
Patala	-3565.753	2.228	-3200.855
Lockhart	-3584.650	2.235	-3207.740
Hangu	-3632.504	2.255	-3221.733
Datta Variegated Shale	-3647.439	2.261	-3226.395
Datta Sands	-3703.216	2.283	-3244.166
Triassic	-3744.365	2.300	-3255.970

4.2 Structure Maps

After identification of horizons, time structure maps were produced by fault polygons (Fig. 5a & 5b). Then, these time structure maps were converted to velocity maps and finally depth structure maps were generated (Fig. 6a & 6b). Structural highs were observed in the southern part of the field including south western, central and south eastern parts while the structural lows were stretched in the northern zone including north eastern to north western parts shown in Fig. 5a, 5b, 6a & 6b.

Identified faults (F1 to F8) are trending from east to west with curved shape and almost parallel to one another. Since the fault F4 is very small in size as compared to Fault F2 & F3, therefore its lateral extent does not effect on the structure of the proposed anticline. Faults distribution indicates that the deformation effect was more severe in the northeastern part which is indicated due to lack of closure between Fault F3 to Fault F8 except Fault F4 which is in the southwestern part.

Further, no closure is identified between Fault F1 and Fault F2 in the south. Reverse faults F2 and F3 are dipping towards each other resulting in a two faults bounded pop-up anticlinal structure in southwestern part of the Meyal Field as shown by dotted circle A in Fig. 5a, 5b, 6a & 6b. This pop-up structure was also indicated by Hasany and Saleem [3]. Other trap is supported by one fault in central part of the field as shown by dotted circle B in Fig. 5a, 5b, 6a & 6b.

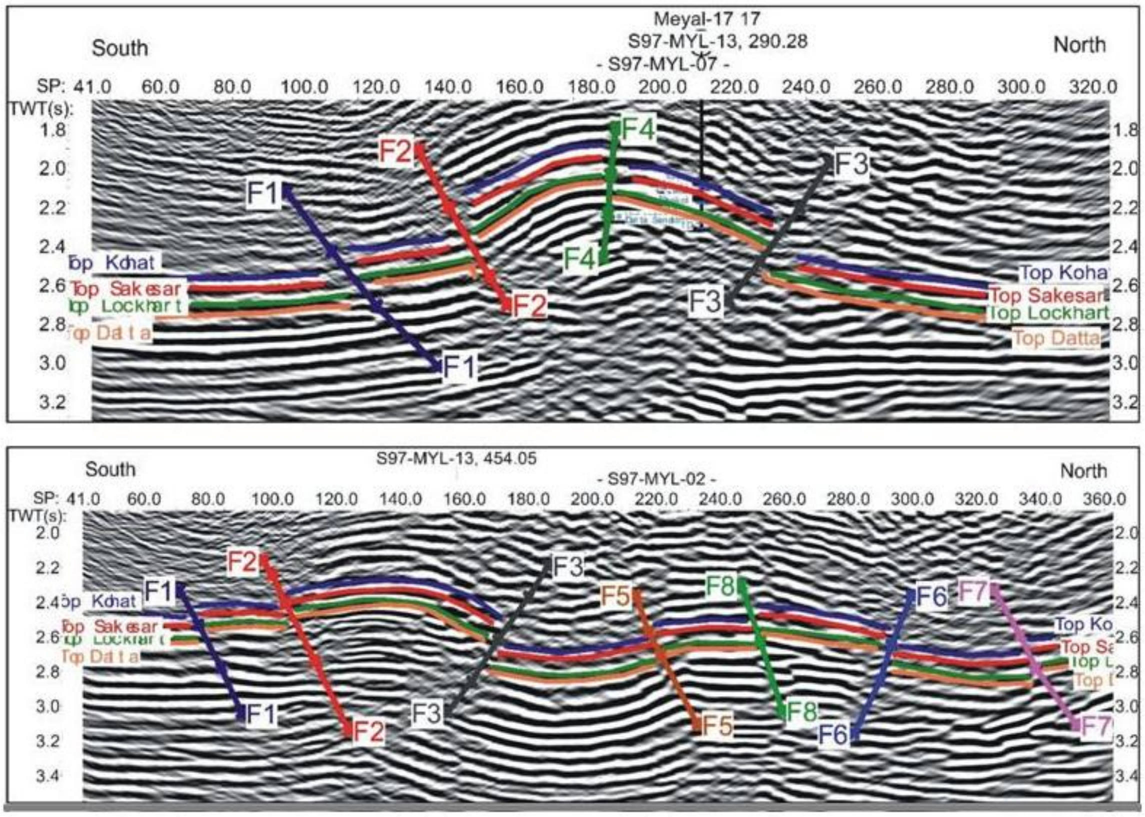

Fig. 4: Marked horizons and faults on N-S dip oriented seismic line S97-MYL-07 (upper) and S97-MYL-02 (Lower)

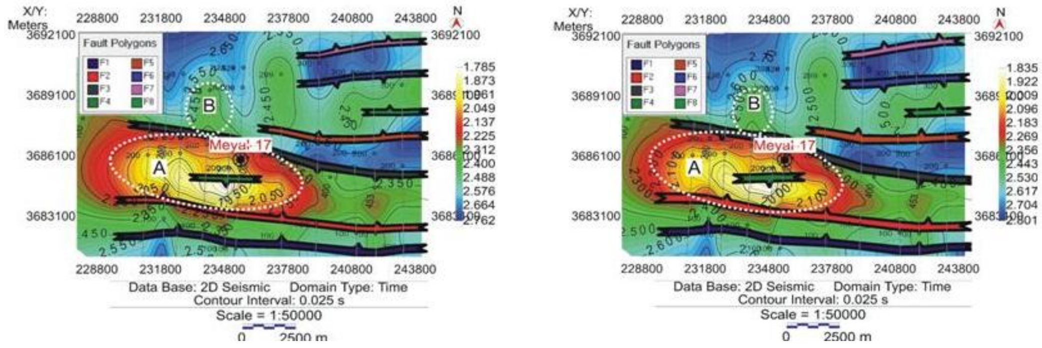

Fig. 5a: Time Contour Maps (TCM) of Kohat (Left) and Sakesar (Right)

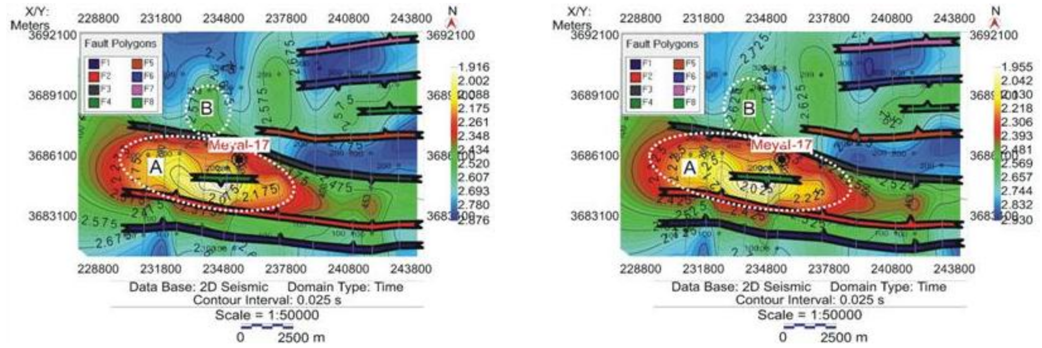

Fig. 5b: Time Contour Maps (TCM) of Lockhart (Left) and Datta (Right)

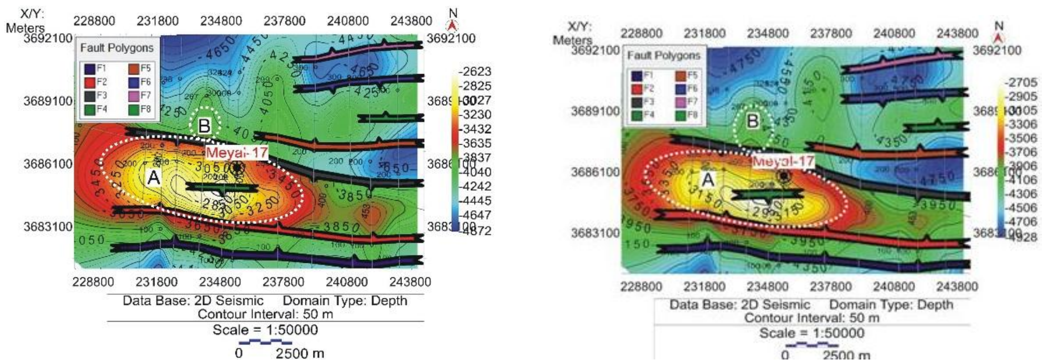

Fig. 6a: Depth Contour Maps (DCM) of Kohat (Left) and Sakesar (Right)

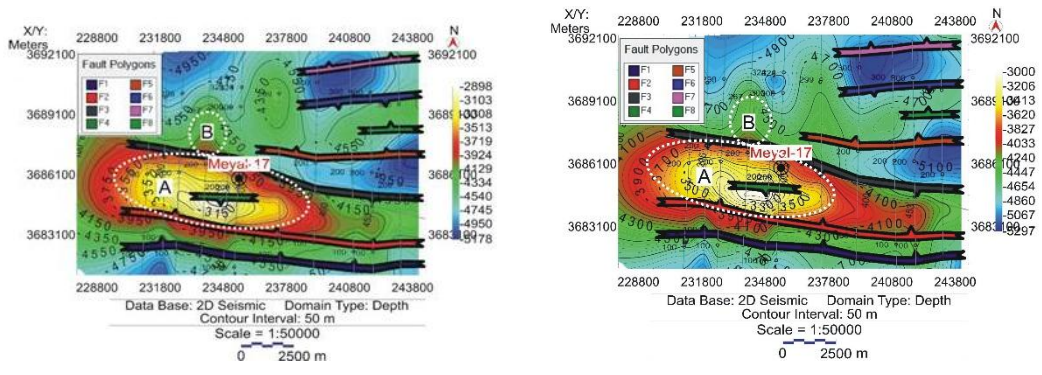

Fig. 6b: Depth Contour Maps (DCM) of Lockhart (Left) and Datta (Right)

The closures of all horizons in southwestern and central part of the study area are shown in Table 3 and indicated in Fig. 5a, 5b, 6a & 6b. The vertical displacements of the major faults (F2 & F3) were measured from seismic. The amount of throw varied from line to line with an average value in the range of 400 m.

Table 3: Closures due to fault bounded in the study area

Horizon	Closure			
	Southwestern		Central	
	TCM	DCM	TCM	DCM
Kohat	0.365s	777m	0.125s	150m
Sakesar	0.390s	845m	0.150s	250m
Lockhart	0.334s	752m	0.175s	200m
Datta	0.370s	750m	0.175s	250m

4.3 Structural Model

A 3-D model of the closure area is generated at different levels (Top Kohat, Sakesar, Lockhart and Datta) using F2, F3 and F4 faults and depth contours to understand the clear subsurface picture of the Meyal Field (Fig. 7). A composite 3-D model for faults and folds at the level of all horizon tops depicts that F2 is dipping towards SE. The 3-D model suggests that the subsurface structure is composed of two compartments, one is two fault bounded closure and the other is one fault assisted closure for the hydrocarbons accumulation as indicated with dotted circles A and B respectively. It is suggested to explore the central part i.e. one fault assisted closure of the study area. It is further observed that the two faults bounded closure structure narrows in the eastern part and widens in western side as shown in Fig. 7. It is clearly observed from 3-D model that all four horizons are placed on one another and are narrowing with depth (Fig. 7).

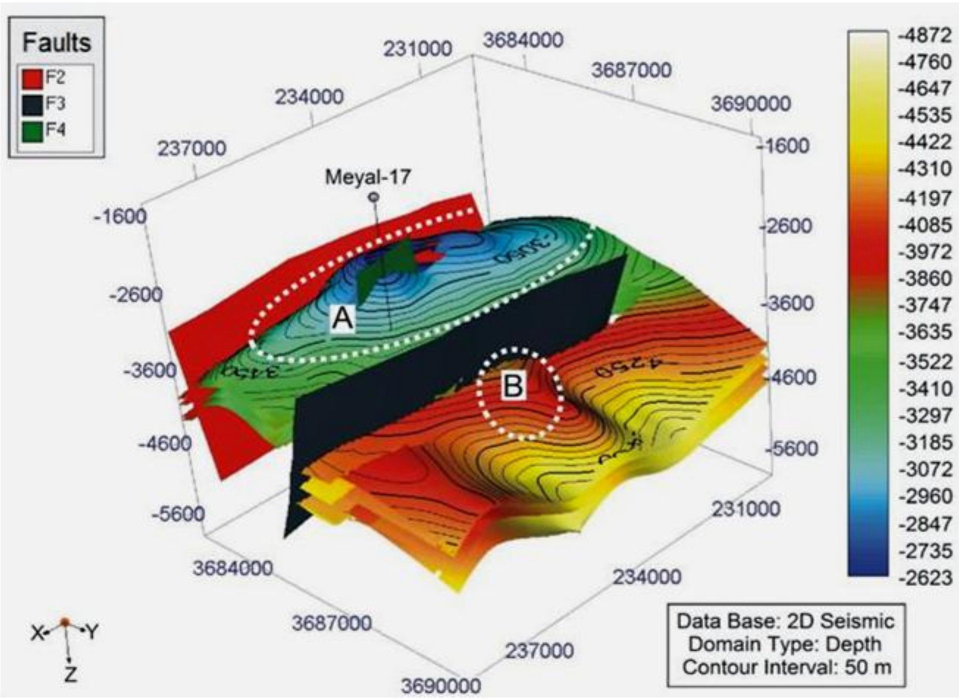

Fig. 7: 3-D model of four horizons, Meyal Field, Pakistan

5. Conclusion and Recommendation

- 3-D model was prepared using four horizons and three faults (F2, F3 and F4) from the seismic and well data after generating time and depth contour maps. This shows that the structural highs at the south-western and central part of the field which resemble to the crest of pop-up structure in the field.
- 3-D models indicate the pop-up structure at the southwestern side has steep limbs
- The 3-D model shows that the structure is an elongated and trending east to west with two fault-bounded closure in southwestern part and one fault assisted closure in central part for the accumulation of hydrocarbons. Size of two faults bounded structure narrows in the eastward and downward and widens in the westward and upward because these are dipping toward each other.
- 3-D model clearly indicates that horizons were placed on one another.
- It is recommended to carry out 3-D seismic survey due to complicated tectonic area for better resolution to explore further structure in the area.

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