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Moderate Interpretation with Attribute Analysis and 3d Visualization for Deeper Prospects of Balkassar Field, Central Potwar, Upper Indus Basin, Pakistan

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Abstract

Balkassar is an old field with considerable remaining potential. The 2d, 3d seismic and earlier vintages show that Balkassar is composed of two folds that impart heart shaped geometry. It appears likely the early Eocene age Bhadrar formation may provide commercial production with lower water cuts from the eastern lobe (yet untapped) of the structure that may have at least 30 million barrels of unrecovered oil. Horizontal drilling may have promise as an optimum technique for recovery of oil from Paleogene reservoirs. Encouraging oil indications have also been recorded from the early Permian age tobra formation from Balkassar oxy-1 that was not tested by Oxy. Tobra sandstone reservoir can have a matrix porosity approaching 8%. When fractured recoveries from it can be relatively better than the Paleogene reservoirs. The 2D and 3D seismic acquisition has confirmed that the eastern lobe (yet untapped) of the Balkassar field is structurally higher and steeper than the Western lobe which has thus far produced over 30 million barrels. The Eastern lobe thus offers good potential for recovery of oil from the Bhadrar reservoir. The entire field is likely to have potential for recovery of oil from the early Eocene aged Tobra formation. 2-d and 3-D Seismic data interpretation, attribute analysis and visualization for deeper prospect carried in Balksasar field. Tobra and Khewra formation studied for deeper potential drilling. Time contour and depth contour map shows potential for deeper prospects. Also attribute analysis and 3d visualization show good results for deeper potential of Tobra and Khewar formations. Seismic amplitude, Reflection strength, Apparent polarity attribute are visualized and interpreted to find the potential for Tobra and Khewra formation. 3-D visualization also showed positive results for Tobra and Khewra formations.

Keywords

Seismic Interpretation, Structure, Anticline, Fracture, Reservoir, Attribute Analysis, 3d Visualization

1. Introduction

Balkassar field is an exclusive D & P Lease **Figure 1** of Pakistan Oilfields Limited, was discovered in 1945 by Attock Oil Company. It is situated about 105 km southwest of Islamabad **Figure 2** in Chakwal District. The location of Balkassar is in the Central portion of Potwar sub-basin which basically represents

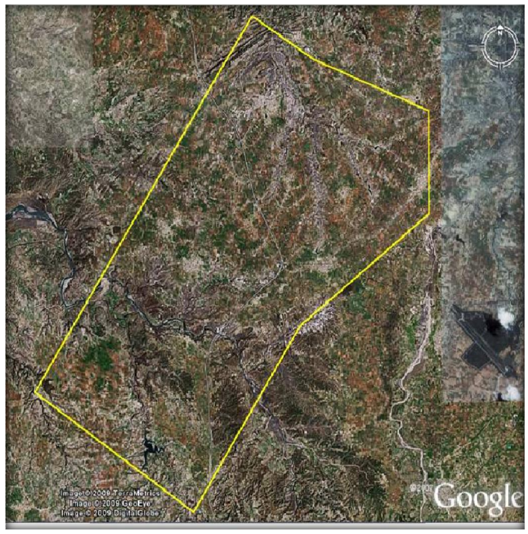

Figure 1. D&P lease of Balkassar Oil Field.

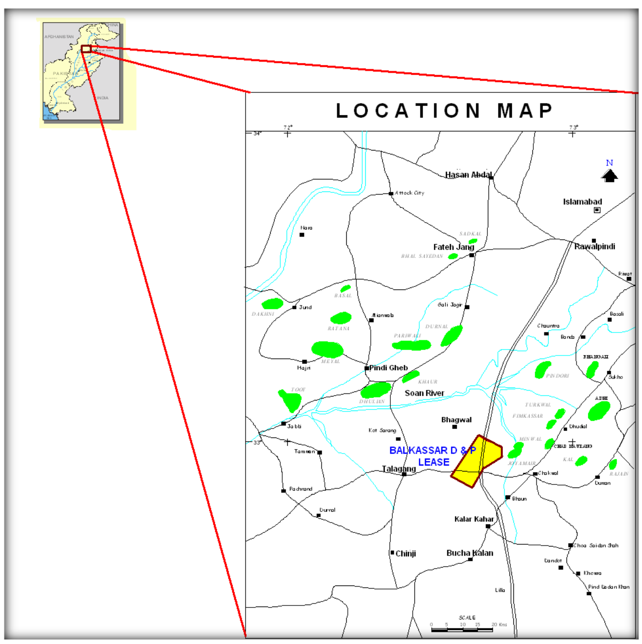

Figure 2. Location map of the study area (Highlighted), Potwar sub-basin.

the part of Himalayan foreland fold-and-thrust belt. This structure is situated on the southern appendage of Soan Syncline [1].

2. Seismic and Well Data

In 1996 CGG seismic crew acquired 70 sq. km 3D seismic data for POL in Balkassr Block. At that time Balkassar Field was producing about 750 BOPD from Eocene Carbonates. Oxy acquired the lease to evaluate the deeper potentials below 1982-meter subsea [2]. The Balkassar Oxy # 1 was the first exploratory well drilled by Oxy (Pak) in Pakistan. Primary objective of Oxy # 1 was Khewra Formation (Cambrian) while the secondary objectives were Lockhart Formation (Paleocene) and Tobra Formation (Permian) [3].

3. Stratigraphy of the Area

Stratigraphic segment is separated into three unconformity-limited groups. These unconformities in the review zone are Ordovician to Carboniferous, Mesozoic to Late Permian, and Oligocene in age **Figure 3** [4]. These unconformities are not effectively distinguished in the seismic profiles because of complex pushing. Seasoned arrangement infiltrated around there is the Infra-Cambrian Salt Range Formation, which is predominantly made out of halite with subordi-

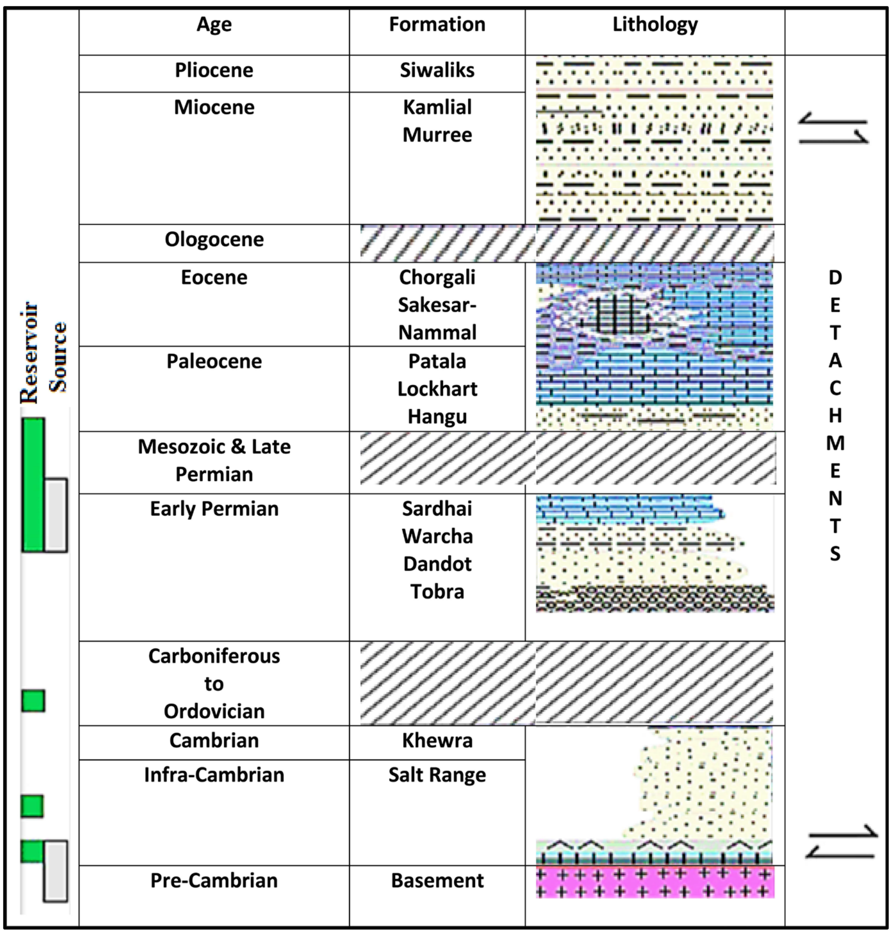

Figure 3. Schematic stratigraphic column of the study area.

nate marl, dolomite, and shales.

Potwar sub-bowl is loaded with thick infra-Cambrian evaporite stores overlain by moderately thin Cambrian to Eocene age stage stores took after by thick Miocene-Pliocene molasse stores. This entire segment has been seriously twisted by exceptional structural movement amid the Himalayan orogeny in Pliocene to center Pleistocene time [5].

The Potwar bowl was inspired amid Ordovician to Carboniferous; thusly no residue of this time interim was stored in the bowl. The second unexpected change to the sedimentary administration is spoken to by the total nonappearance of the Mesozoic sedimentary progression, including late Permian to Cretaceous, all through the eastern Potwar territory. A noteworthy unconformity is likewise found between the stage arrangement and overlying molasse area where the whole Oligocene sedimentary record is absent. The molasse stores incorporate the Murree, Kamlial, Chinji, Nagri, and Dhok Pathan Formations. The subsurface geometry of the Potwar sub-bowl in connection to structure and ensnarement can be found as shown in below Figure 4.

From infra-Cambrian to Cambrian age, the rock units are visible in the Potwar Province of the Indus basin where the Salt Range Formation with salt, marl salt creases and dolomite is the oldest predictable unit through surface and sub-

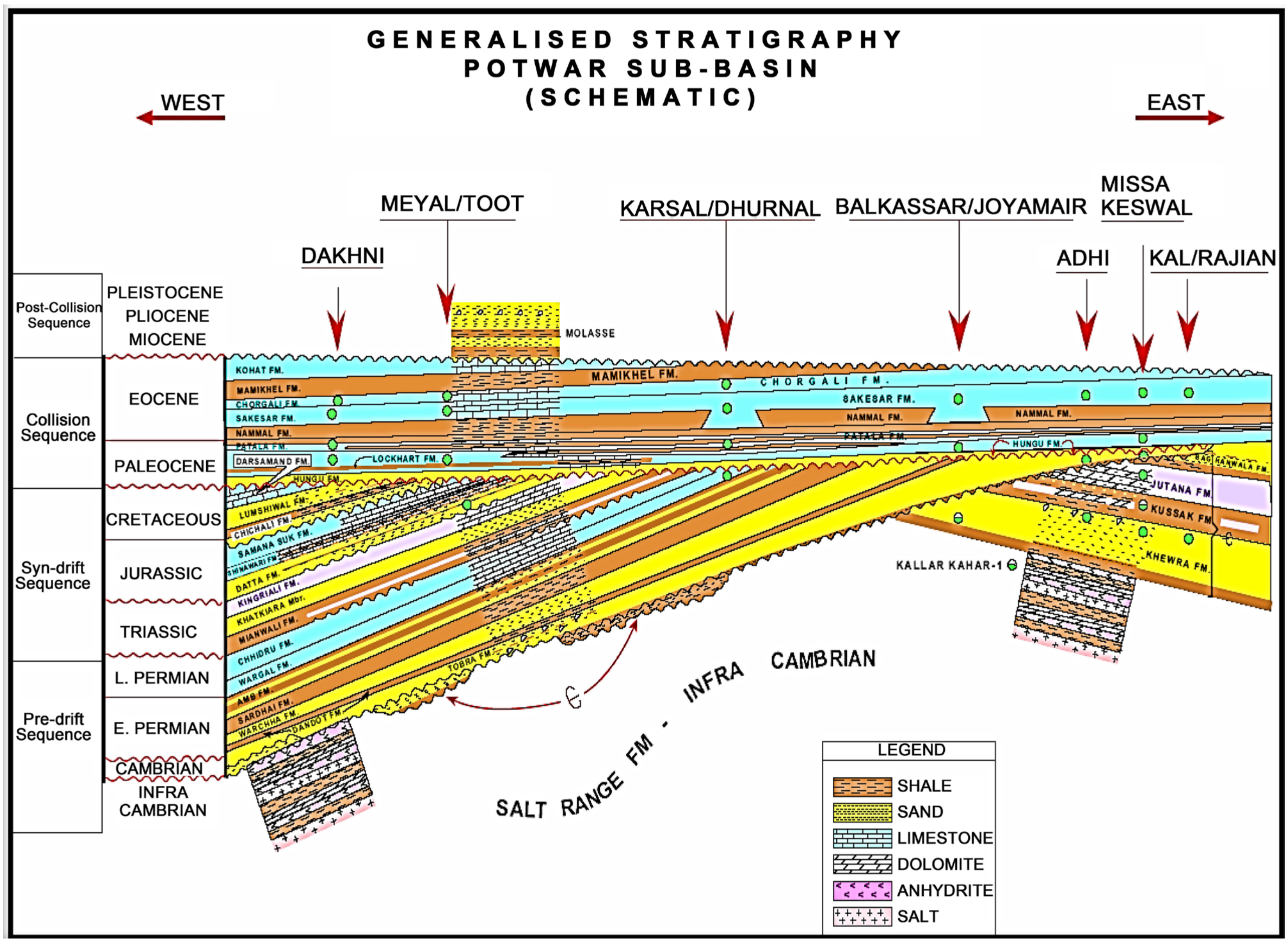

Figure 4. Subsurface geometry of Potwar Sub-Basin in relation to structure and entrapment [6].

surface geological information and frames the cellar for the fossiliferous Cambrian grouping [7].

Since the complete section of Salt Range Formation has not been penetrated in any of the wells of Potwar sub-basin and the formation is partially exposed along the Salt Range, it was therefore, assumed in the past that the Salt Range Formation is the oldest rock unit overlying the Pre-Cambrian basement [5].

However, the wells drilled up to the basement on Punjab Platform, Pakistan and Bikaner-Nagaur basin of India situated south of Potwar reveal that the Salt Range Formation is underlain by Infra-Cambrian sediments of Bilara Formation followed by Jodhpur Formation. Extent of these two formations toward north and examination of seismic data indicate that the mentioned formations may also be present in the eastern Potwar region.

4. Structure of the Area

Balkassar lies in Central piece of Potwar Sub-basin which is a piece of Himalayan foreland overlay and-push belt. This structure is situated on the southern appendage of Soan Syncline [8]. Potwar sub-bowl is one of the most seasoned oil territories of the world. The sub-surface picture dependably gives knowledge into casing work and basic styles of the bowl. This engineering is an element of complex interaction of compressional powers, incline of cellar, nearness of variable thickness of Pre-Cambrian salt over storm cellar and testimony of thick molasse and structural occasions. For the most part surface components don't reflect subsurface structures due to nearness of decollement at various levels [5].

The Balkassar structure Figure 5 is an "anticlinal pop-up" structures created by both compressional and shear stress regimes. The Eastern flank is bounded by a regional thrust fault, the regionally trends NE-SW along one complex of fault-bend folds. It is becoming narrow towards north where a fault bounded syncline plunges into the middle of anticline and hence resulted in compartmentalization. The anticline has two culminations separated by a small saddle. Most of the wells are drilled in western compartment that is structurally lower than eastern one. Whereas three wells are in eastern compartment that are all non-producers. The tectonic forces are intense in north as compared to south as seismic correlation shows that the throw of faults gradually dies out as we move

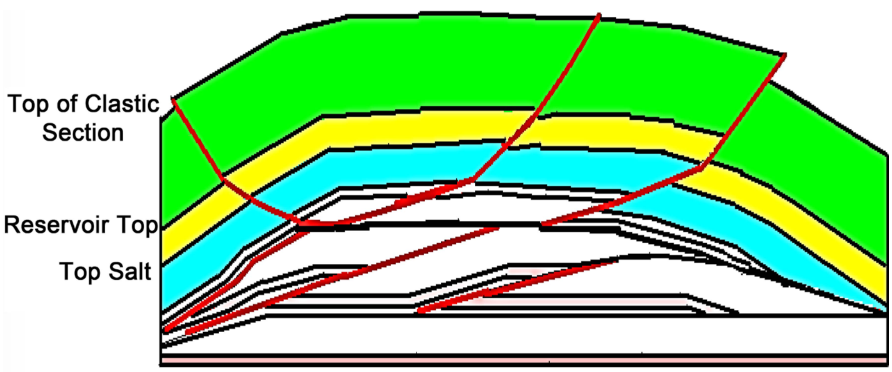

Figure 5. Balkassar structure model.

from north to south. These pop-up structures have a large thickness of evaporates below the crestal region, while the flanks which are typically reverse fault bounded exhibit salt with drawl [9]. This is quite evident on the seismic profiles.

In case of Balkassar, the map view of the structure typically looks like a "heart-shaped" structurally high flanked by reverse faults on both the east and the west shown in 3-D visualization as fault surfaces. As mentioned above the eastern fault is the major thrust fault of the regional significance. The western fault although having substantial throw is subsidiary fault. Two fault bend folds appear as the two lobes of the "heart shaped" Balkassar structure. The Eastern Lobe alone has accounted for the recovery of 33 million barrels of oil [2]. A structural low separates the two lobes (or structural highs). Based on the interpretation of 3-D (70 sq Km) seismic data this low was caused because of the withdrawal of the salt below, when it was laterally squeezed in the direction of the adjacent lobes during the compression phase of the structural evolution or both faulting (formation of a graben and withdrawal). Balkassar Oxy-1 drilled into the structural low and produced viscous oil during testing.

5. Petroleum Geology

5.1. Source Rock

Hydrocarbon Development Institute of Pakistan (HDIP), in collaboration with Federal Institute for Geosciences and Natural Resources (BGR) Hanover, Germany have identified a number of source rock horizons through Infra-Cambrian to Eocene in the Potwar Sub-basin and surrounding areas. These investigations suggest that the organic-rich shales of the Paleocene (Patala Formation) can be considered as the main contender for sourcing the Potwar oil fields [1].

In Potwar Basin, Patala shales of Paleocene have proven as the main source rocks. These organic shales were partly deposited in anoxic conditions prevailing Paleocene due to buckling of the basin floor. Pre-Cambrian Salt Range Formation also contains oil shale intervals, which show source rock potential. In Potwar the shales have average values of TOC as 1.57 and Hydrogen Index as 2.68 [10]. The oil to source correlation indicates that most of the oil produced in Potwar sub basin has been sourced through Patala Formation.

Shales of Khewra Formation are of lacustrine to marine origin and contain woody, coaly to variously amorphous (with significantly woody herbaceous) kerogen, which are capable of generating paraffinic to normal crude and gas.

5.2. Reservoir Rocks

Paleozoic-Tertiary dominantly marine sedimentary rocks form petroleum systems in Potwar and are exposed in Salt Range along the Frontal Thrust. The cracked carbonates of Sakessar and Chorgali Formations are the major generating repositories in Balkassar. The limestones of the Paleocene Patala Formation also contain good reservoirs of hydrocarbons. Khewra Formation is the main potential Cambrian reservoir. Khewra Formation is generally divided into three units. The basal unit consists of thin bedded, partly shaly, fine to medium grained sandstone with thin clay beds. These represent the products of arid environment to marginal marine environment. The upper and middle units of the formation are moderately porous and display intergranular primary porosity, which ranges from 10% - 12%. The uniform grain size and moderate sorting of the sandstone indicates its excellent reservoir nature [11]. The sandstone also displays fracture.

5.3. Traps

Traps have been developed due to thin-skinned tectonics, which has produced faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt. The clays and shales of the Murree Formation additionally give effective vertical and horizontal seal to Eocene reservoirs wherever it is in contact.

6. Data Interpreatation

The final step in seismic study of an area is to interpret the processed seismic section so that a geological model of sub-surface can be developed. Base map of the area is shown in Figure 6. Here the objective of seismic reflection interpretation is to study the sub-

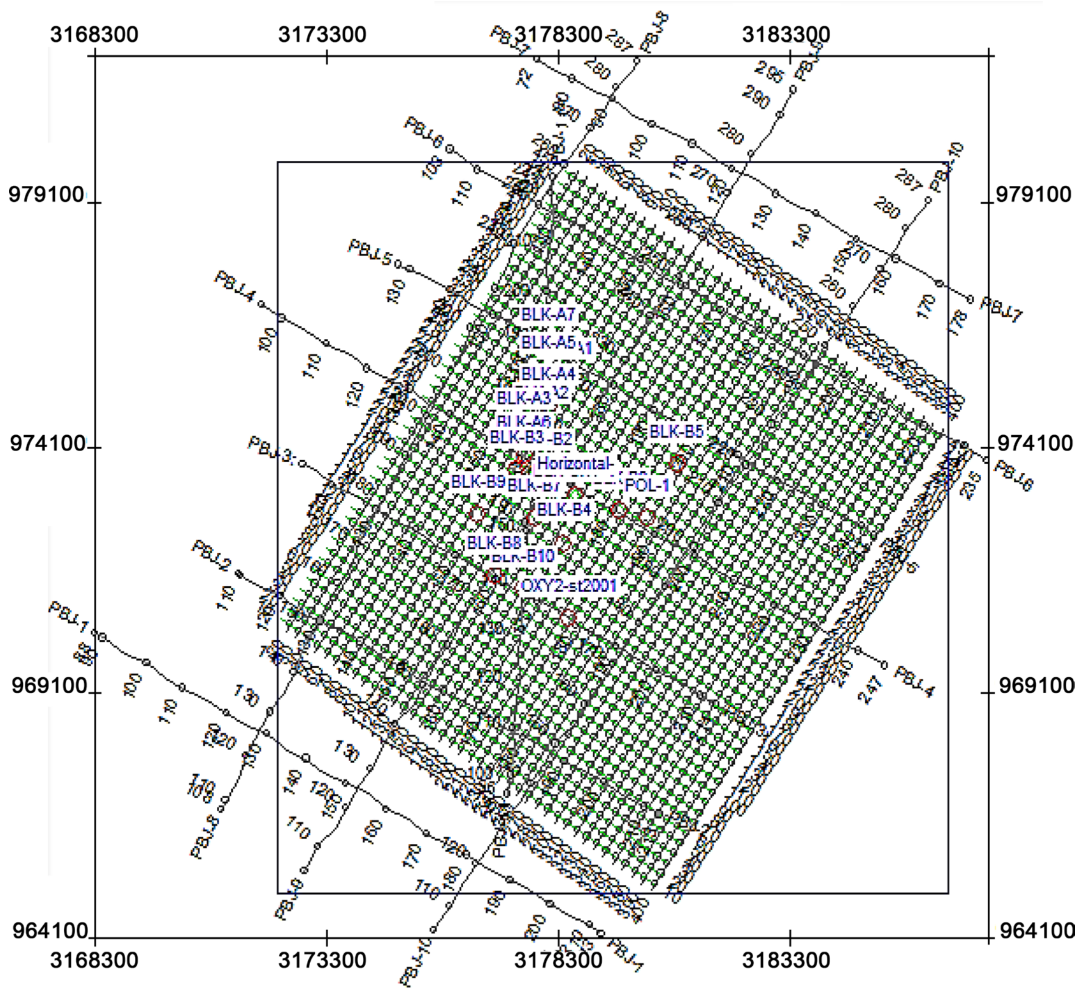

Figure 6. Base map view of 2-D and 3-D of Balkasar.

surface structures that help in discovering the hydrocarbon accumulation in the subsurface sedimentary rocks [12]. As science has not yet found the immediate strategy for finding the oil and gas or of surveying the amounts of hydrocarbons in the subsurface, so the seismic reflection method only indicates the geological situations where the hydrocarbons can accumulate [13].

7. Structural Analysis

It is the investigation of reflector geometry on the premise of reflection time. The primary utilization of the auxiliary investigation of seismic area is in the search for basic traps containing hydrocarbons [12]. The basic interpretation uses two-way reflection times rather depth. Furthermore, time-depth contour maps of Tobra and Khewra horizons are built to show the geometry of chose reflection events as shown in **Figures 7-10**. Some seismic areas contain pictures that can be deciphered without trouble. Discontinues reflections plainly demonstrate faults and undulating reflections disclose collapsed beds [14].

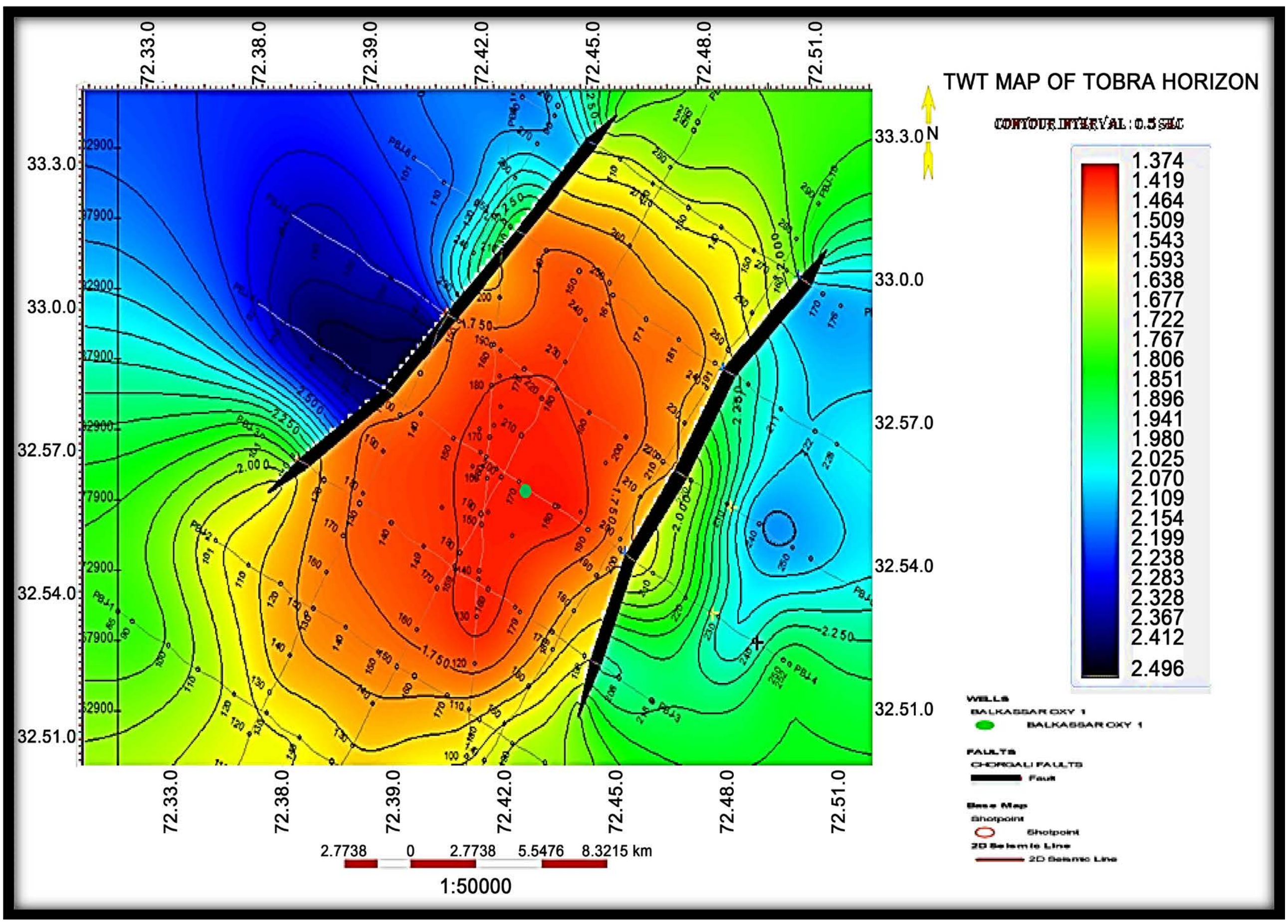

Figure 7. Two way time contour map of Tobra horizon.

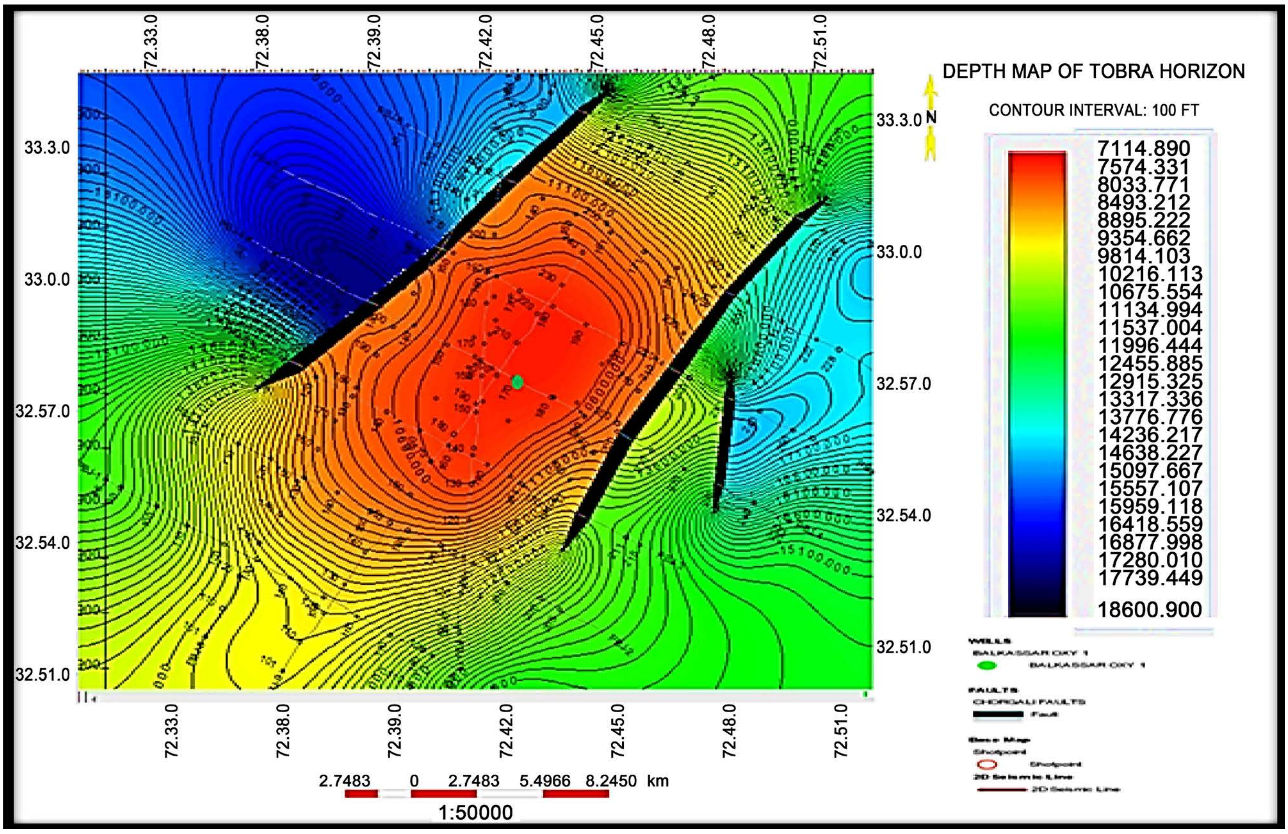

Figure 8. Depth contour map of Tobra horizon.

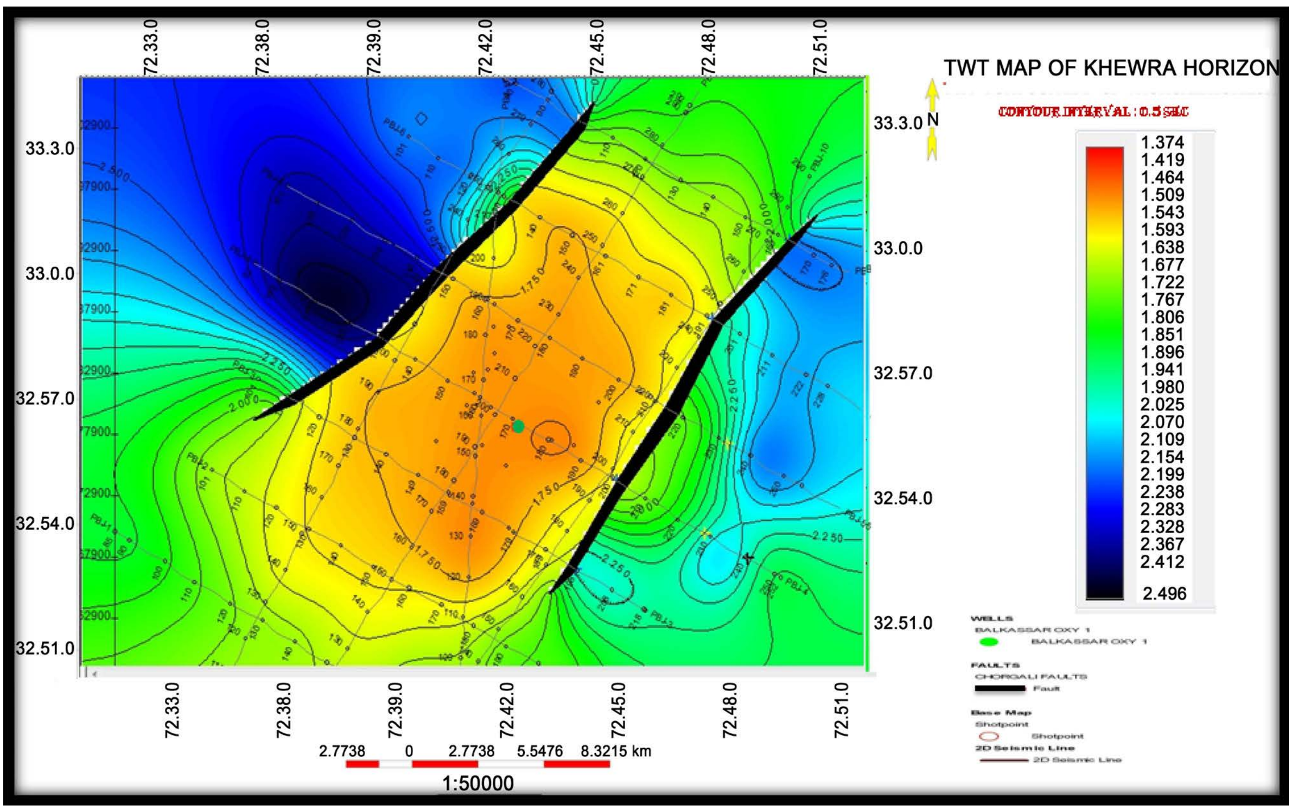

Figure 9. Two way time contour map of Khewra horizon.

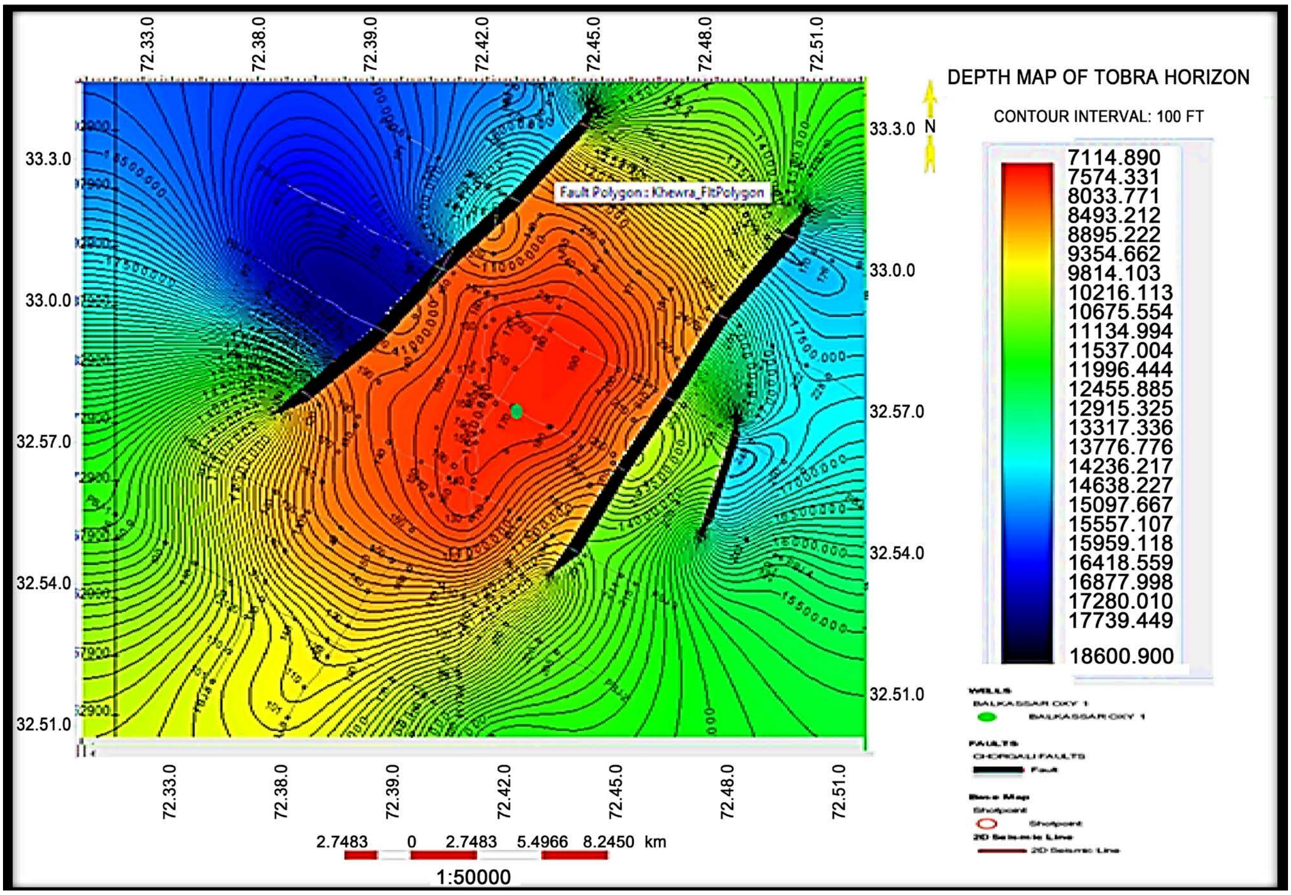

Figure 10. Depth contour map of Khewra horizon.

8. Attribute Analysis

An attribute analysis is widely used nowadays in the industries for qualitative and quantitative interpretation of seismic data for the investigation of reservoir characterization. As a working definition, we can state that seismic attributes are particular amounts of geometric, kinematic, dynamic, or statistical elements resulting from input seismic information [12]. These are utilized to outwardly upgrade or segregate elements of importance. They may likewise be aligned to well control for repository property forecast. Take note of that attributes can prompt to supply property gauges, however these properties are not themselves considered traits. The essential goal is to distinguish the attribute(s) that works best as an indicator for the reservoir prospect. The selection of seismic attribute plays a key role in the investigation, since it is not irregular to discover spurious or false connections that don't mirror any physical reason for the relationship. The likelihood of finding a false relationship increments with the quantity of seismic attributes considered and is conversely corresponding to the quantity of information control focuses. Seismic attributes are measurements calculated directly from the seismic traces. They characterize the wave form and the change of the wave form in the real, imaginary and complex space. Seismic attributes may ultimately be related to the geology and fluid content of the subsurface.

9. Surface Based Attributes

This extracts information from the seismic data at or near the picked horizon. For example, an amplitude map, this shows variations in amplitude along a particular surface.

Number of Seismic attribute examined Amplitude, Reflection Strength, and apparent polarity to be useful to detect lateral variation in reservoir anisotropy. Attributes are generated from Tobra surface.

10. Seismic Amplitude

It is used to identify bright spots/dim spots, often in conjunction with other attributes [14]. This function reads the trace's amplitude value at the horizon time or depth. If a seismic amplitude cube is used as input, the result is an amplitude map. The attribute computation is made at the horizon pick, at a fixed time or depth offset from the horizon surface, or by adjusting the horizon to an event (peak, trough, zero crossing).

Tobra seismic amplitude map displays in Figure 11 indicate that the values of amplitude are lower in western compartment compared with eastern.

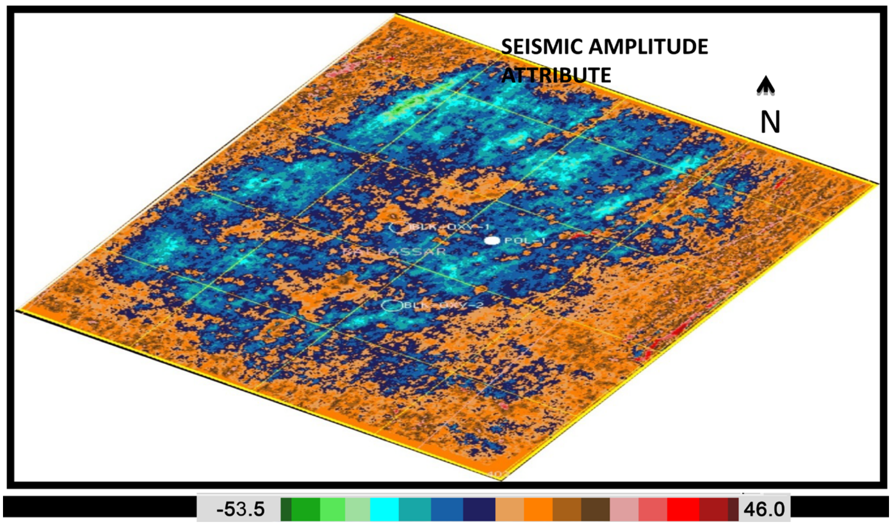

Figure 11. Seismic amplitude attribute from Tobra surface.

11. Apparent Polarity

Apparent Polarity is proportional to the acoustic impedance sensu stricto, and may thus be useful when evaluating bright spots. The reflection quality represents apparent polarity multiplied by reflection Strength. When the reflection quality of seismic has its most extreme esteem (+1 or −1) is the indication of polarity. The strength of the polarity is determined by A(t) at the time value of the interpretation. The assumptions of apparent polarity are: a specific reflector, wavelet zero-phase and no uncertainty because of phase reversal. Interference may result in the reflection strength maximum occurring near a zero-crossing of the seismic trace so that the polarity may change sign. Noise causes the zero-crossing of the trace, or the location of the reflection strength maximum to shift slightly. Apparent polarity from Tobra surface in Figure 12 indicates that higher values in western and middle compartment.

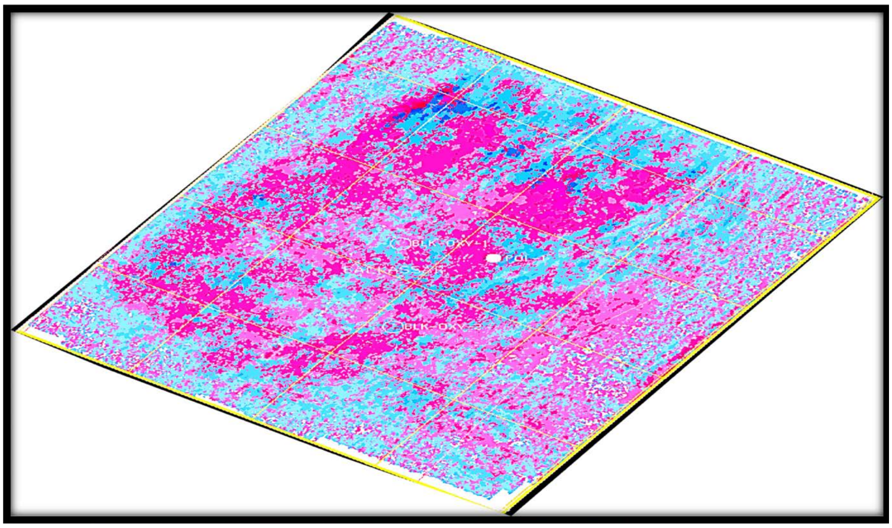

Figure 12. Apparent polarity attribute from Tobra surface.

12. Reflection Strength

Reflection Strength is often used for recognizing reservoir feature including flat/dim/bright spots or other adjacent changes in lithology, fluid content or stratigraphy. Reflection strength is also known as instantaneous amplitude. Reflection strength generated from Tobra surface in Figure 13 shows variation and strong reflection in western as well in eastern compartment.

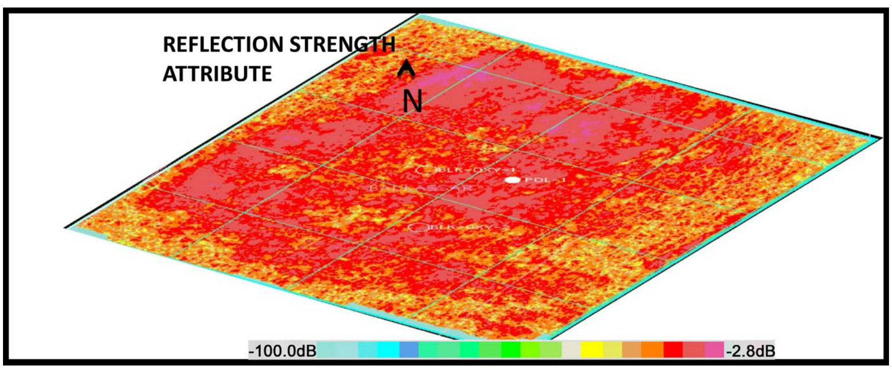

Figure 13. Reflection strength attribute from Tobra surface.

13. 3-D Visualization

Figure 14 shows that Tobra formation have potential as red color indicate the shallow time as compared with green and other colors.Oxy-01 and Oxy-02 are not as shallow in time domain then POL-01 as shown in Figure 14. Oxy-02 was not drilled up to Tobra while Oxy-01 drilled up to Tobra formation.

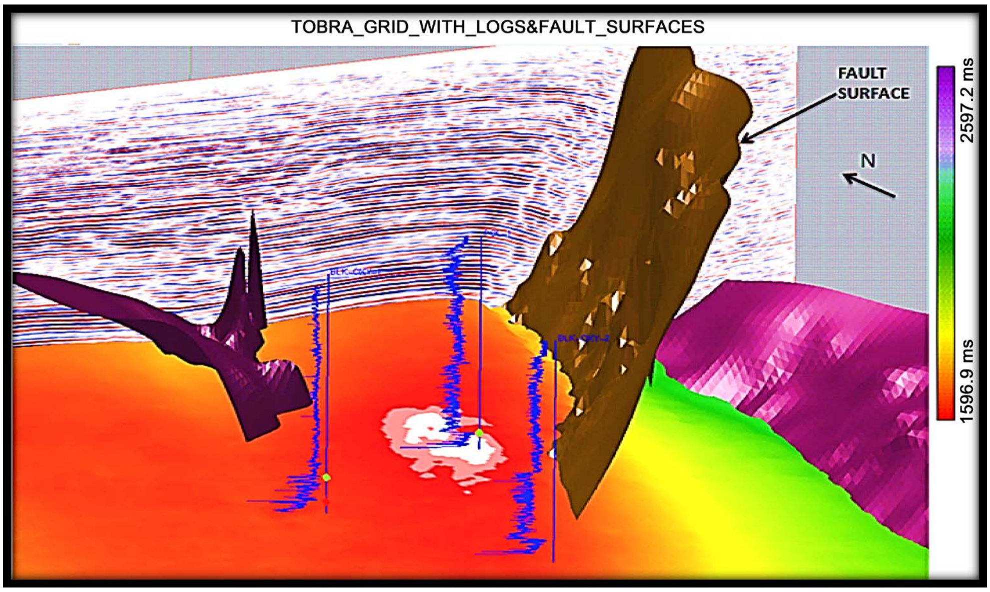

Figure 14. 3-D visualization of Tobra formation with logs and fault surfaces.

Khewra formation shows potential in 3D visualization. White/red color represent in **Figure 15** shallow time, compared with green and other colors. If well will be drilled on shallow time represented by white/red colors results can be fruitful.Oxy-01 and Oxy-02 were not as shallow in time domain compared with POL-01.

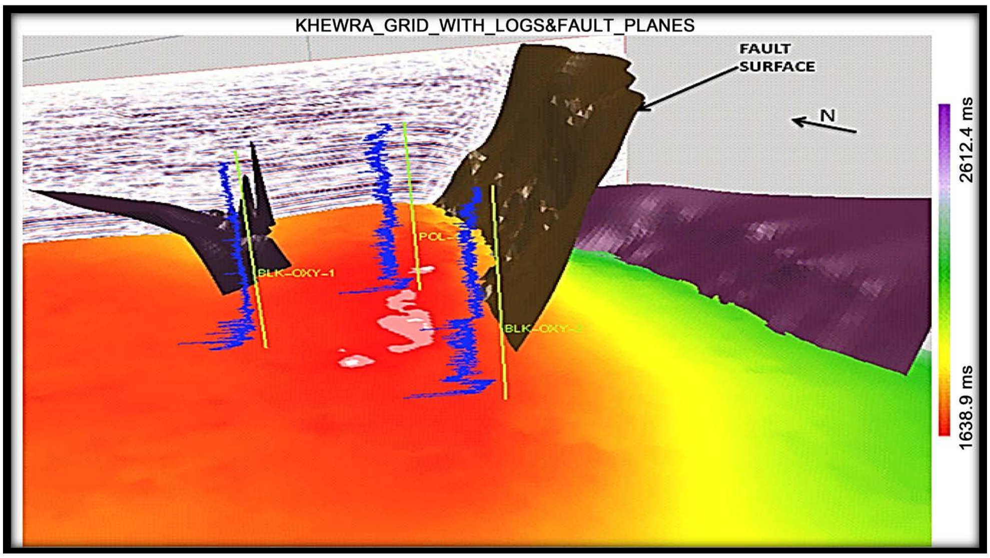

Figure 15. 3-D visualization of Khewra formation with logs and fault surfaces.

14. Result and Conclusions

1) Maps of Tobra and Khewra are compared with each other and watched variations and crestal shift as we move down to the core of anticline.
2) According to the picture reflected by Time Structure Map and Depth Structure Map, the salt cored, fault bounded, pop-up anticline is divided into two compartments, out of which the eastern compartment is structurally higher

than western.

3) The anticline becomes narrow towards north and the compartments are separated by a saddle.
4) The western and eastern compartments are separate compartments.
5) Khewra, the main producer of Adhi and Chak Naurang fields have never been tested in this area. While in Blk-Oxy-1, Tobra Formation has shown positive indication of hydrocarbons.
6) Fractures associated with compressional forces and thrust faulting might be present in abundance in the eastern compartment due to easterly bounding regional thrust fault.

15. Recommendation

From the above interpretation, 3-D visualization, attribute analysis of the primary objectives for new well should be Tobra and Khewra Formations, whereas Sakesar and Chorgali of Eocene are thought to be secondary objectives.

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