SUBSURFACE STRUCTURAL ANALYSIS AND PETROPHYSICAL INTERPRETATION OF JOYA MAIR OILFIELD

BY

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Abstract: *The Potwar basin is located in the Himalayan foreland and contains a large number of structural traps that resulted due to the Tertiary Himalayan folding and thrusting. Joya Mair area lies in the south-southeast of the Potwar basin that is considered to have hydrocarbon potential from Precambrian to Quaternary rock units. The principal objective of the study is to interpret the subsurface structure of Joya Mair area by using 2D seismic lines and well data. Triangular zone is an interpreted structure formed by the fore-thrust and back-thrust. These thrusts dip in opposite direction with northeast-southwest extension. Seismic interpretation, time structure maps and 3D modeling reveal that the area undergoes severe deformation caused by the southeast northwest compressive stresses. Petrophysical interpretation showed that rocks have significant clay volume and the main lithologies are sandstone, siltstone and limestone with some salt of Pre-Cambrian age. Furthermore, it also shows that Joya Mair-04 is an oil well with some gas shows.*

INTRODUCTION

Pakistan is, tectonically, an active zone and continuously thrusting due to the northward collision of Indian and Eurasian plates (Ahsan et al., 2013). Potwar basin is a part of Himalayan foreland that is developed due to the episodic collision of these plates and regarded as thrust sheet (Fig 1). Joya Mair area is located in the southeastern part of Potwar basin (Fig 1). It is bounded by the Soan Syncline and the Salt Range in north and south respectively (Aamir and Siddiqui, 2006). Joya Mair area was explored in 1944 with first well (Joya Mair-01) drilled by Attock Oil Company (Kadri, 1995). Estimated reserves of Joya Mair in 1944 were 98.01 million barrels but recovered oil reserves were only 8 million barrels. The production rate was at its peak in 1949 (Shami and Baig, 2002a). Potwar basin contains significant potential of hydrocarbons that trapped by various subsurface structures. The prime objective of this research is to interpret the subsurface structural geometry of Joya Mair area by integrating 2D seismic data with well data (Yeats et al., 1984; Telford et al., 1990).

Potwar basin lies in the sub-Himalayas and is an internally deformed fold and thrust belt (Jadoon et al., 2003). It is bounded by Main Boundary Thrust (MBT) (active since 15 my), and Salt Range Thrust (SRT) in the north and south respectively (Fig 1) (Ahsan et al., 2012). Left lateral Jhelum fault and right lateral Kalabagh fault mark its eastern and western boundary (Shami and Baig, 2002b).

Distinctive deformational conditions prevailed in the thick-skinned hinterland (complex duplex structures and imbricate sheets and thin-skinned foreland (simple fold and thrust structures) (Jadoon et al., 2008). In Potwar basin, frontal portion of Himalayan orogenic belt is affected by the presence of salt and gypsum bearing Precambrian Salt Range Formation, probably dispersed throughout the ductile sheet and major detachment along which deformation took place (Drewes, 1995).

Potwar basin is divided, on the basis of structural features and deformational history, into the North Potwar Deformed Zone (NDPZ) and South Potwar Deformed Zone (SPDZ) (Fig. 1). Soan syncline marks the boundary between NDPZ and SPDZ (Jaswal et al., 1997). NPDZ is more deformed and effected by tectonic forces than SPDZ. The structural features of NDPZ exhibit reasonable parallelism along strike and due to the variable

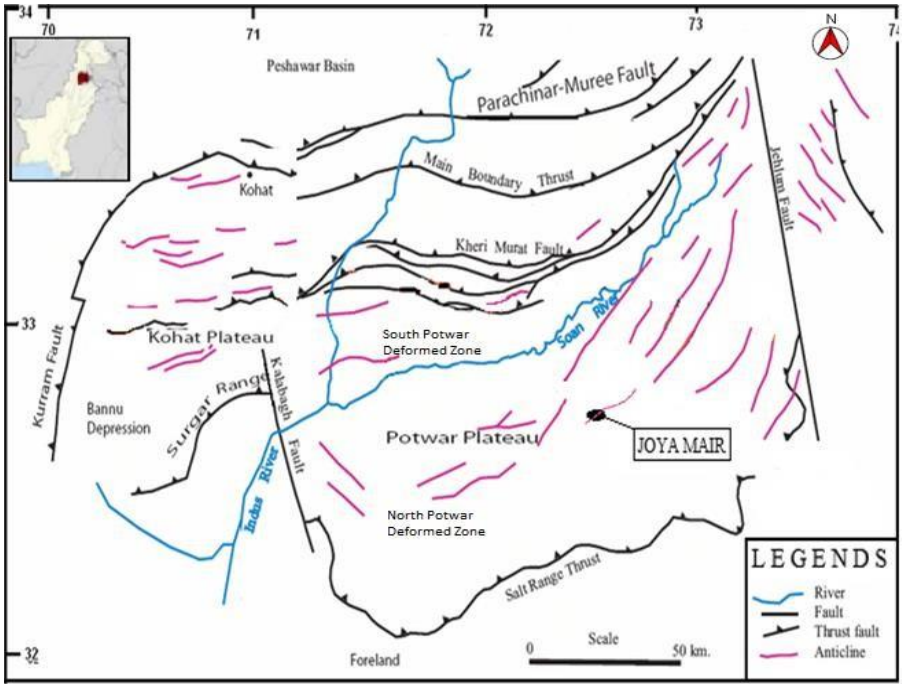

Fig. 19 Tectonic setting of Potwar region and location of study area modified after (Wandrey et al., 2004).

movement of thrust sheets, thrust front show irregular geometry from east to west. (Jadoon et al., 2003).

The stratigraphic sequence of Joya Mair area is well defined (Table 1) and is comprised of Precambrian Salt Range Formation to the Recent deposits (Shah, 2009). Jhelum Group of Cambrian conformably overlies the Salt Range Formation. Ordovician to Carboniferous strata is missing in the Potwar basin and Nilawahan group of Permian disconformably overlies the Jhelum group. Due to the Pre-Paleocene uplift, strata of Permian to Cretaceous eroded from east to west in the basin. Paleocene to Eocene carbonate-shale sequences is deposited because of the Early Paleocene marine transgression. Due to the initiation of Himalayan uplift, Oligocene is missing and a thick sequence of non-marine molasses of Miocene to Pleistocene age, named as Rawalpindi and Siwalik groups, were deposited (Kazmi and Jan, 1997). Most of the molasses acting as seal rocks for hydrocarbon accumulation (Ahsan and Chaudhry, 2008).

Table 6. Stratigraphic sequence of Joya Mair

Age	Formation	Thickness
Pliocene	Chingi	000.0
Miocene	Kamlial	1004.3
	Murree	116.8
Eocene	Chorgali	976.8
	Sakesar	33.3
	Nammal	27.4
Paleocene	Patala	54.2
	Lockhart	40
Permian	Sardhai	16.1
	Warcha	78.1
	Dandot	123
	Tobra	41
Cambrian	Khewra	36
Pre-Cambrian	Salt Range	128

Potwar basin contains approximately 48% of world known hydrocarbons due to the presence of favorable conditions and completes petroleum system (Khan et al., 1986). Shales of the Salt Range Formation, Mianwali Formation, Datta Formation and Patala Formation are potential source rocks (Khan et al., 1986) while shales/clays of Murree Formation and Kuldana Formation acts as seal rocks (Shami and Baig, 2002b). Reservoir facilities are provided by the strata of Cambrian, Permian, Jurassic, Paleocene and Eocene age. In Joya Mair area, the main producing reservoirs are fractured carbonates of the Sakesar Formation and Chorgali Formation (Shami and Baig, 2002b).

MATERIALS AND METHODS

Ten seismic lines were used to generate the base map of the project area and can be seen in Fig. 2. Well data of Joya Mair-03, Joya Mair-04 and Minwal X-1 was utilized to establish the stratigraphic sequence of the area. Kingdom Suite 8.8 software was used to delineated the subsurface structure of the Joya Mair area. Basement, Sakesar Limestone (Base), Sakesar Limestone (Top) and Chorgali Formation (Top) were the four main reflectors that were marked on the seismic lines to interpret the subsurface structure (Fig. 3).

In addition to this, Joya Mair-04 was selected for petrophysical interpretation. The Interactive Petrophysics (IP) 3.5 software was used for this purpose. For the completion of this project, different qualitative interpretations were made by using GR log, resistivity log and neutron-density logs. Both clay volume and lithology were evaluated with GR log while hydrocarbon zones are distinguished by evaluating resistivity logs.

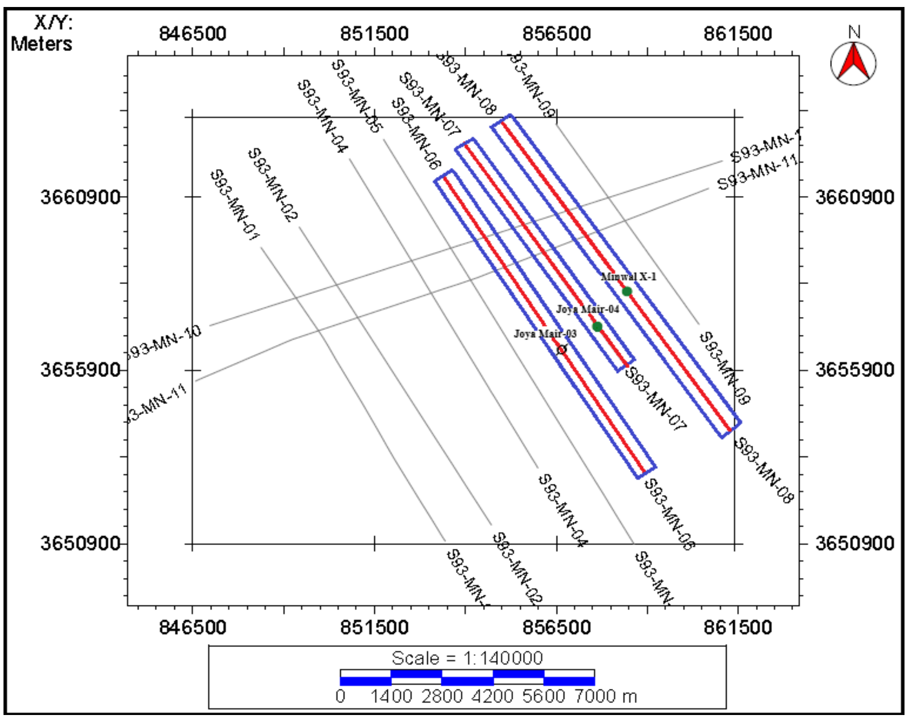

Fig. 20 Base map showing the position and orientation of seismic lines.

RESULTS AND DISCUSSION

Interpretation of seismic lines

The seismic interpretation of the Joya Mair area shows that there is a triangular zone in the subsurface. Basement reflector is representing the basement rocks are less or not disturbed by faults, which shows the thin skin tectonic regime. Hanging walls are arched up into an anticlinal structure on the surface due to back-thrust within the surface forming triangular zone.

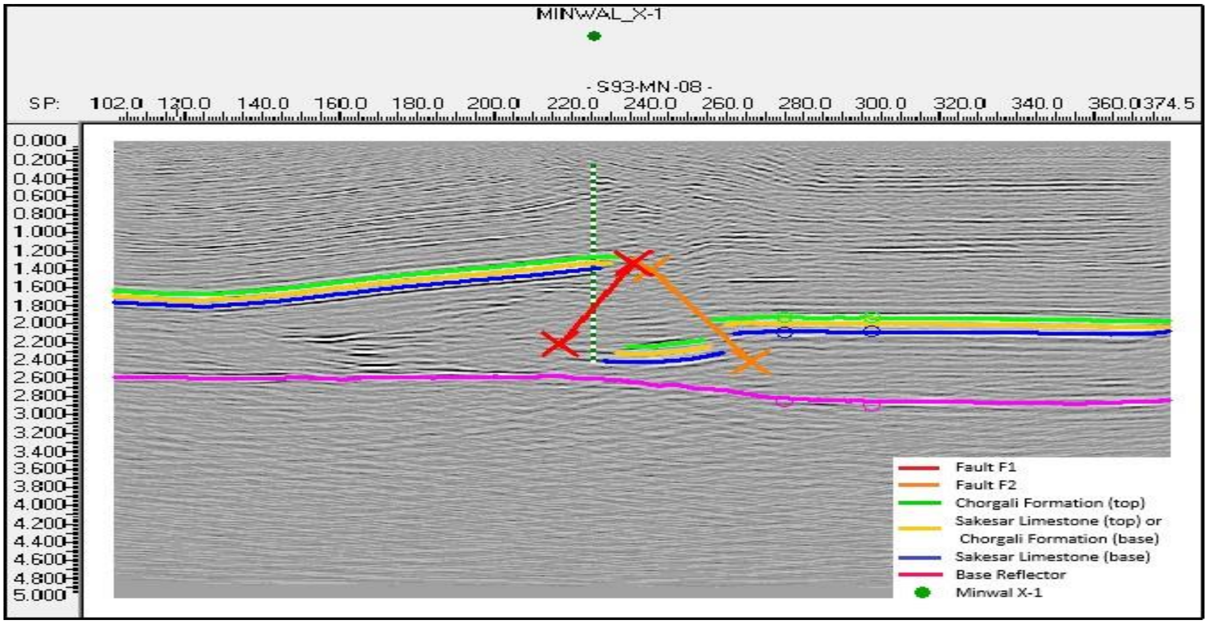

Fig. 21 NW-SE oriented dip line showing different horizons and interpreted structure.

Time Structure Maps

Four-time structure maps were developed on Basement reflector, Sakesar Limestone (Base), Sakesar Limestone (Top), Chorgali Formation (Top) and are given below:

Basement reflector

Basement reflector laterally extends in all the seismic sections. This reflector encountered between 2.491 to 3.027 seconds (TWT) and shows more TWT in the north as compared to the south. Maximum TWT is encountered in north-west direction due to the uplifting in the north. Overall relief of the basement reflector in this area is smooth (Fig.4).

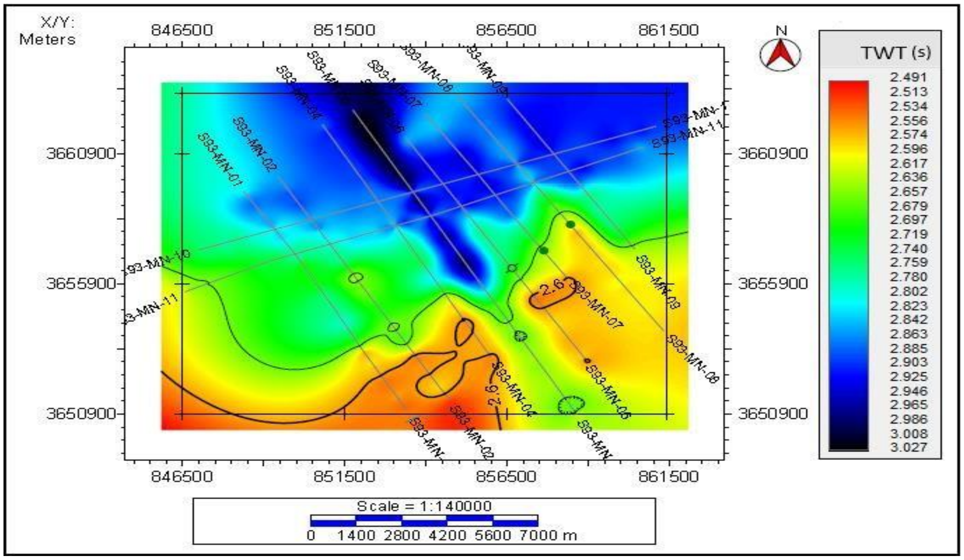

Fig. 22 Time structure map at the level of basement reflector.

Sakesar Limestone (Base), Sakesar Limestone (Top) and Chorgali Formation (Top)

The time structure map of these reflectors shows a general increase in TWT with depth in the northeast-southwest direction at the center while there is a gradual decrease in reflection time on either side of the centers of map (Fig. 5 to 7). These reflectors are present between 1.189 to 2.705 seconds of TWT. In time structure maps, Chorgali Formation (Top) is encountered at TWT between 1.189 to 2.543 second (Fig. 5) whereas, Sakesar Limestone (Top) and Sakesar Limestone (Base) are encountered at 1.286 to 2.609 seconds (Fig. 6) and 1.349 to 2.705 second (Fig. 7) respectively. Salt Range Formation provides decollement layer at the base and causes deformation above it. Two major thrusts (orange and red lines) (Fig. 5 to 7) resulted due to the two-phase thrusting, i.e., fore-thrust and back-thrust, in the Joya Mair area. These thrusts are extending in NE-SW direction and forming the triangular zone. Fore-thrust is dipping in northwest direction whereas back-thrust in southeast. North directed tectonic forces causes more movement along the fore-thrust of the triangular zone.

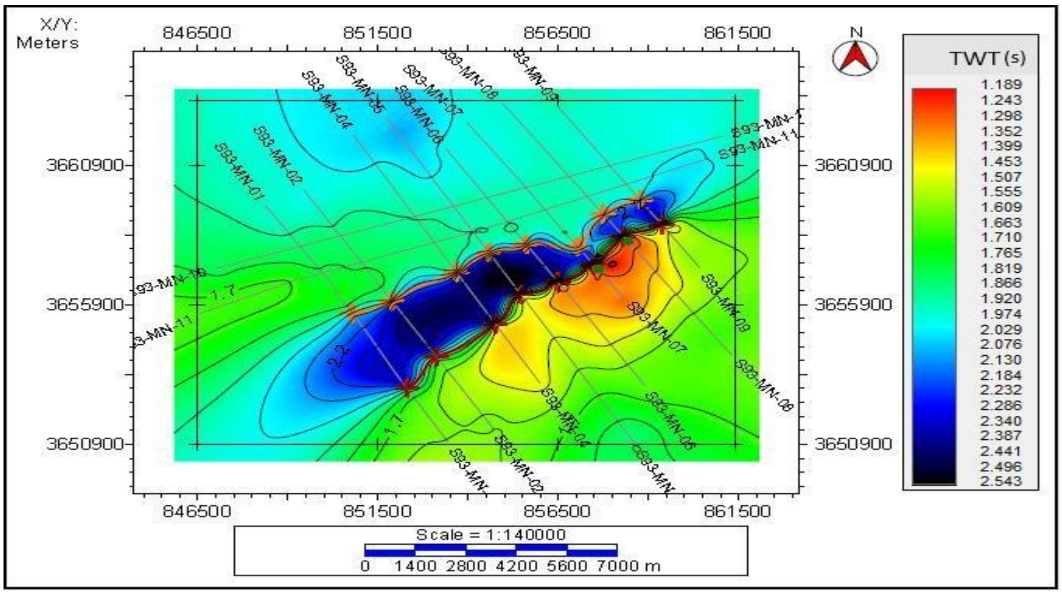

Fig. 23 Time structure map Joya Mair Triangular Zone at the level of Chorgali Formation (Top).

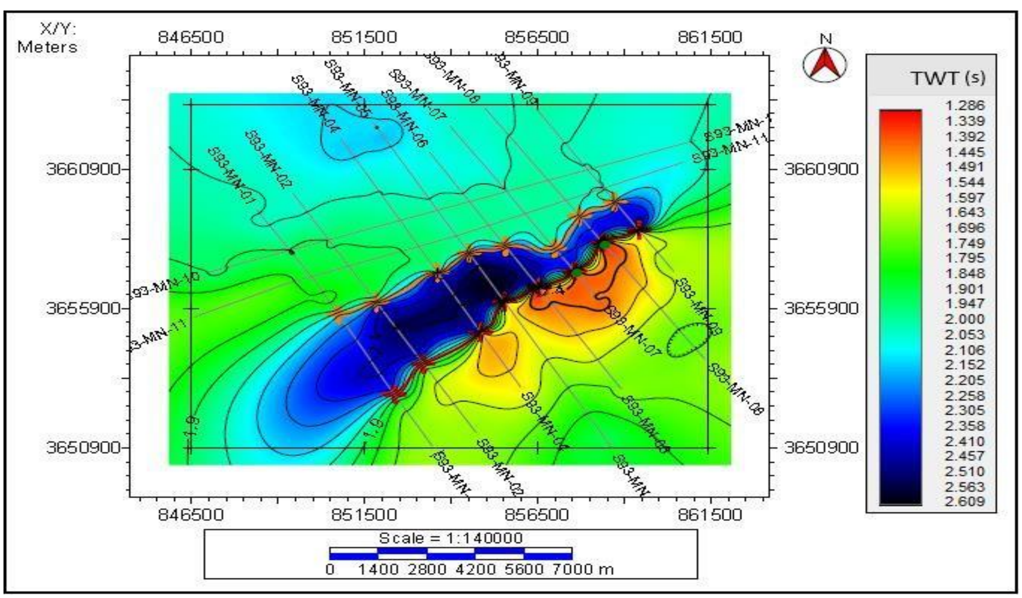

Fig. 24 Time structure map of Joya Mair Triangular Zone at the level of Sakesar Limestone (Top).

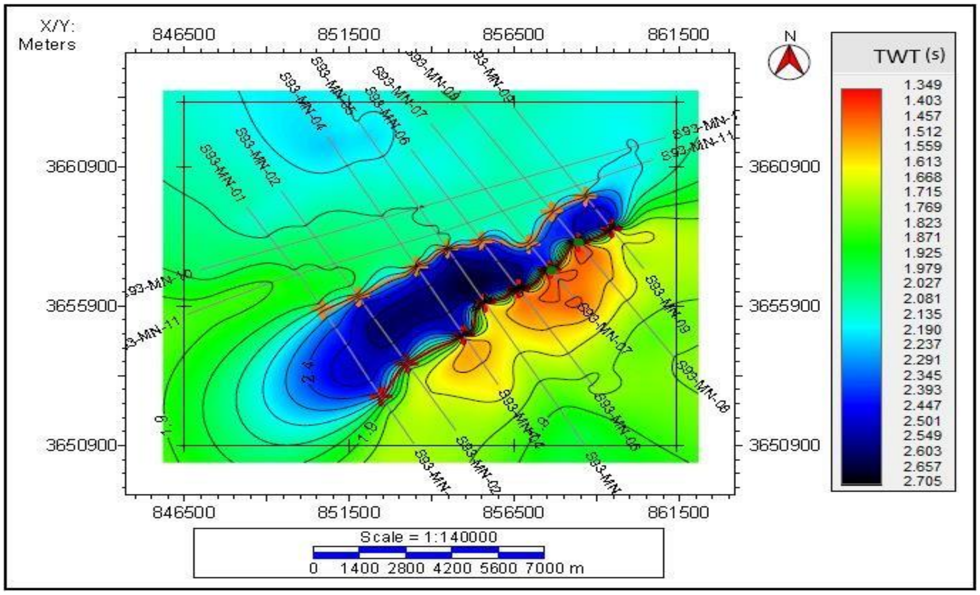

Fig. 25 Time structure map Joya Mair Triangular Zone at the level of Sakesar Limestone (Base).

3D Modeling of Joya Mair Triangular Zone

3D view of time structure map helps in the better understanding of the development of triangular zone in the time and space. 3D models of Chorgali Formation (Top) (Fig. 8), Sakesar Limestone (Top) (Fig. 9) and Sakesar Limestone (Base) (Fig. 10) are clearly showing two major thrusts that are forming triangular zone in the subsurface of the area. The center of each model is showing maximum depth and TWT whereas; depth is gradually decreasing away from the center. Maximum TWT of each model is same as that of time structure map. Two thrusts can be observed on this map by orange and red lines and are orientated on NE-SW direction (Fig.8 to 10). A clear 3D structure shows a triangular zone along with two thrusts marked by red and orange planes.

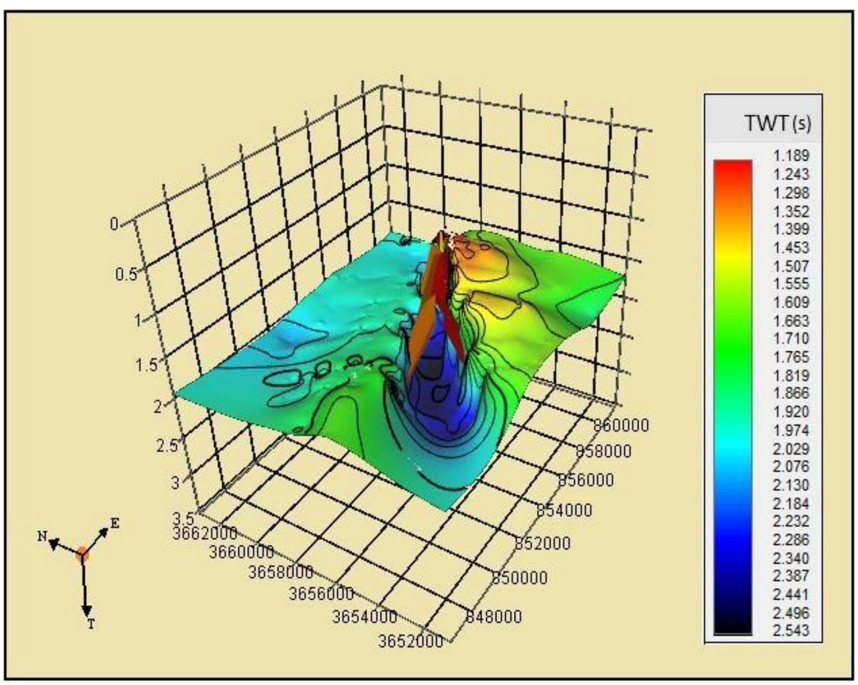

Fig. 26 3D model of Joya Mair Triangular Zone at the level of Chorgali Formation (Top).

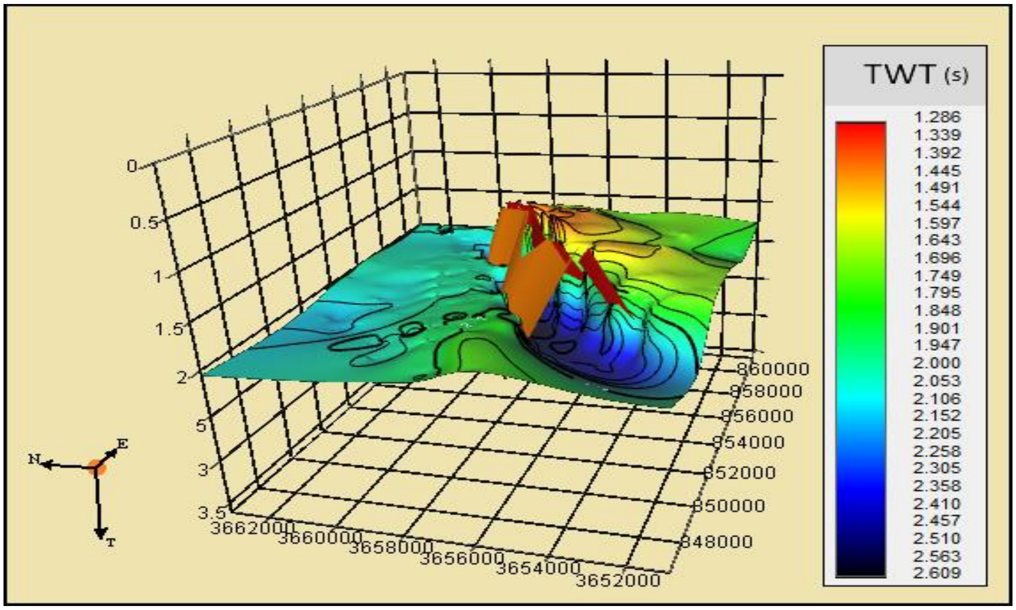

Fig. 27 3D model of Joya Mair Triangular Zone at the level of Sakesar Limestone (Top).

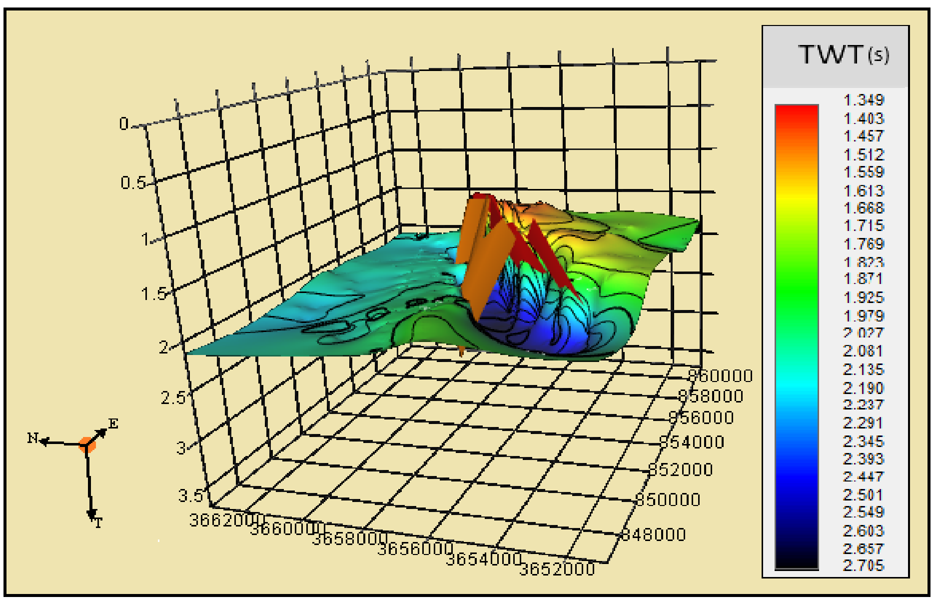

Fig. 28 3D model of Joya Mair Triangular Zone at the level of Sakesar Limestone (Base).

Petrophysical Interpretation

Joya Mair-04 is located at 32.9976670 and 72.8257500. It was drilled by POL and considered as the oldest oil well. It was drilled at approximate depth of 2644.1 meters.

For Petrophysical analysis, Gamma Ray (GR) Log, Resistivity Log and temperature gradient were used to evaluate the clay volume, lithology type and hydrocarbon zones. Firstly, Clay volume trend of different encountered formations was evaluated by using GR log curve. GR log measures the naturally occurring radioactivity of formations. As clay contains abundant concentration of K, U and Th, so the GR gives maximum values in clays. That's why, it is also known as "Shale log". Maximum clay volume was encountered in zone 3 (Warcha Sandstone) and zone 4 (Dandot Formation). Clay volume curve showed the blocky or cylindrical trends that represented the abrupt change in clay; low volume with high shoulders. Sharp peaks of GR in zones 4, 5, 6 and 7 were due to the presence of heavy minerals (mica, zircon, feldspar) and near shore deposits (glauconite and carbonaceous meter). In Figure 05, different zones were marked by observing GR values. These zones represented the shale bed, non-shale bed, coarsening upward (shallowing upward) and fining upward (deepening upward) sequence.

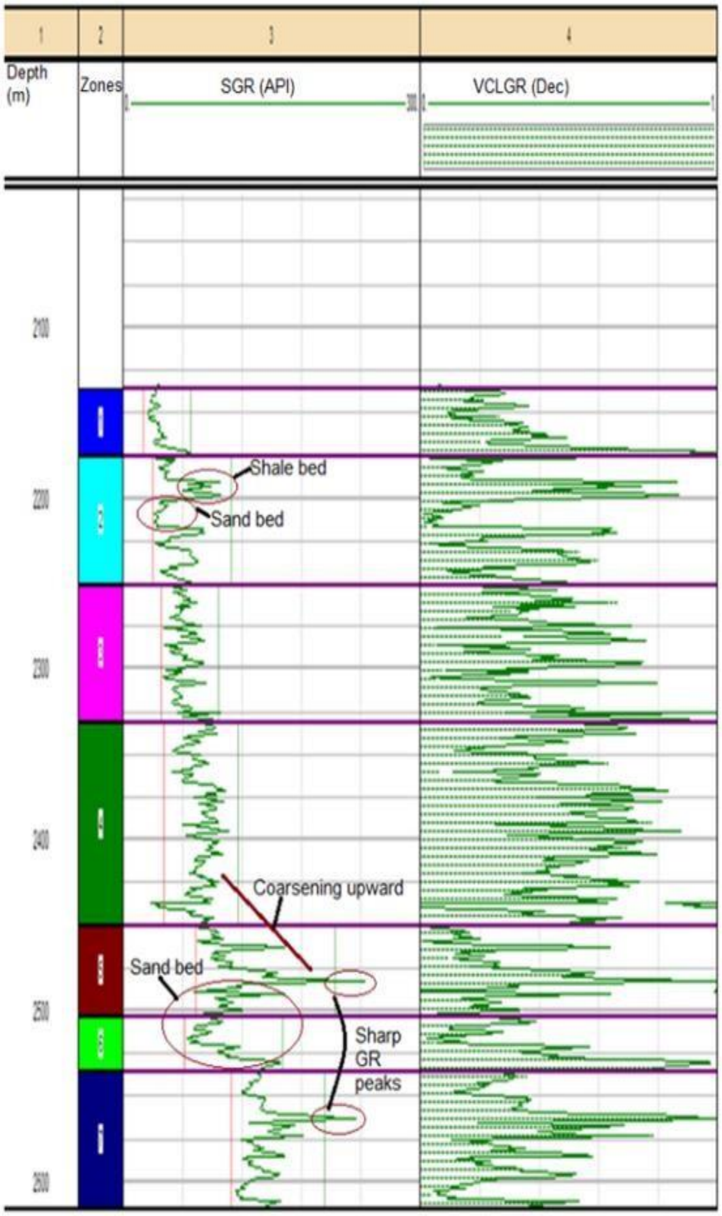

Fig. 11 Interpreted clay volume of Joya Mair 04.

Different types of lithologies encountered in Joya Mair-04 that were identified by using clay volume and temperature gradient of area. Main lithologies were limestone, sandstone and siltstone as shown in Figure 06. Hydrocarbon zones were marked by using resistivity log. Resistivity log measures the resistance of formation fluids. As hydrocarbons are non-conductive fluids, resistivity log shows maximum values in zones containing hydrocarbons. Due to high resistivity values in hydrocarbon zones, this log is used to mark the hydrocarbon zones. Oil bearing zone was interpreted in zone 2 and zone 3 while other zones have minor oil and gas shows with abundant water as shown in Figure 6.

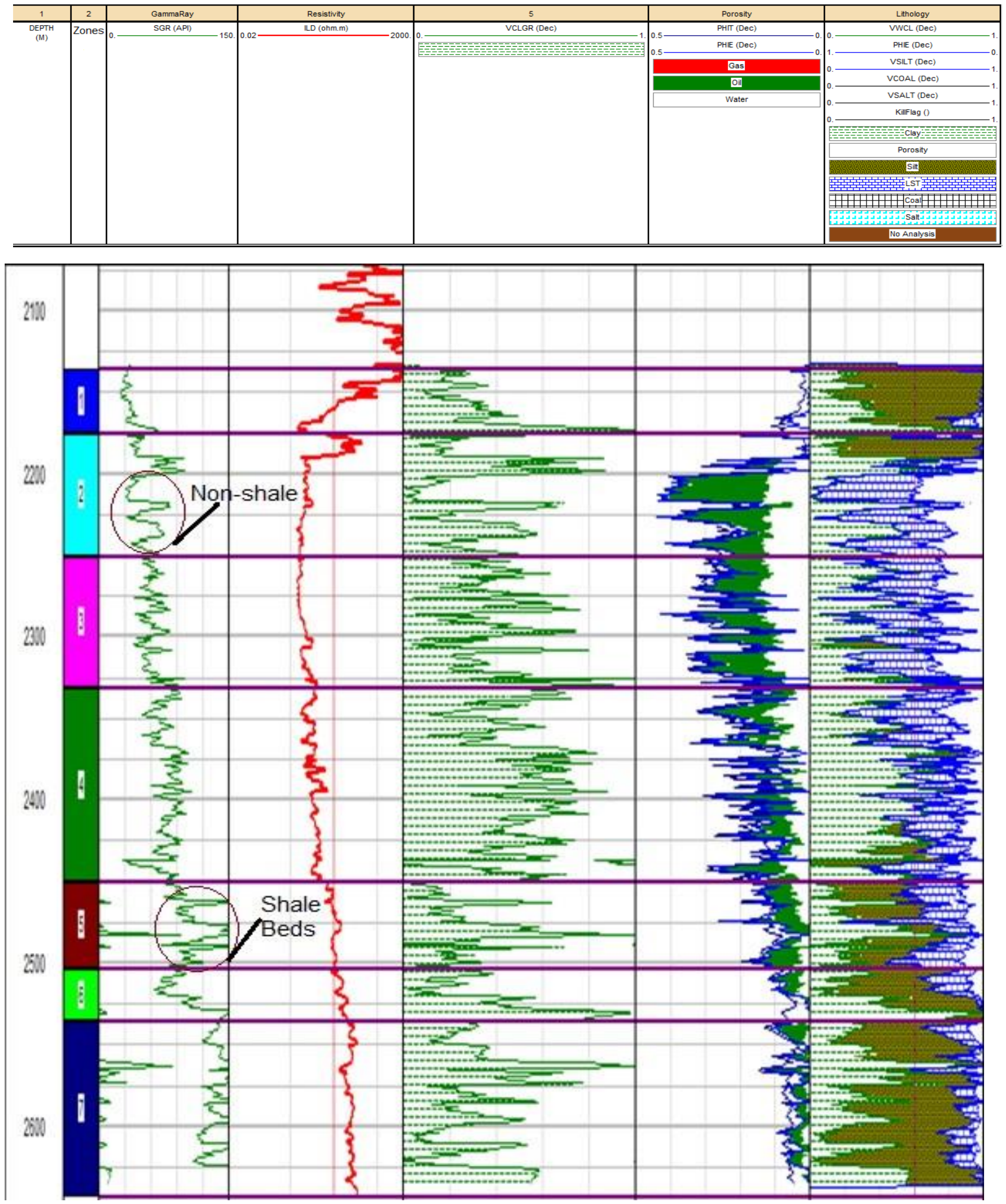

Fig. 12 Final Plot showing; Track-1: depth, Track-2: Porosity, Track-3: Resistivity, Track-5: Clay volume, Track-6: HC zones, Track-7: Lithology types.

The structure of the Joya Mair area is recognized as a triangle zone in the subsurface and while an open anticlinal structure at the surface (Zahid et al., 2014). Triangular zone has been formed by two phases of thrusting, i.e., fore-thrust and back-thrust. The tectonic forces are directed in northwest-southeast direction. The fore-thrust dip towards north-west and back-thrust shows opposite trend i.e. towards south-east (Ahsan et al; 2013). The thrusting behaviour resulted in the formation of fault-propagating fold in the form of Chak Naurang and Joya Mair anticlines (Tariq et. al., 2006). Salt range Formation is present as decollement in the studied area, the movement of these thrusts occurred above Salt Range formation.

Structural traps have been developed in Chak Naurang and Joya Mair anticline possibly due to their truncation against the basement fault (Tariq et. al., 2006). These traps were also developed due to the presence of Murree clays present above the Chorgali and Sakesar formations. The Joya Mair thrust deformed the structural trap in Joya Mair area (Basharat et al., 2004), that indicates the Joya Mair anticline is faulted into blocks rather than a single structure. Petrophysical analysis of Joya Mair well-04 shows clay volume, lithology types and hydrocarbon zones. Interpretations of logs showed that Joya Mair well-04 was an oil well, with oil and water saturated pore spaces.

CONCLUSIONS

The seismic interpretation of the Joya Mair area shows that there is a triangular zone in the subsurface whereas an anticlinal structure on the surface. Effect of tectonic forces on the basement rocks during Pre-Tertiary Himalayan tectonics is not significant that indicates thin skin tectonics. This triangular zone has been formed because of two phases of thrusts, i.e., fore-thrust and back-thrust. Southeastern and northwestern Himalayan thrusting originated these two major thrusts and forming a triangular zone. The forces from north formed fore- thrust in first phase of compression that dip in northwest direction while in the second phase, it formed a back-thrust that dip in southeast direction. There is high relief of the back-thrust in southeastern side of the triangular zone as compared to the fore- thrust in northwestern side. 3D models of selected reflectors are giving better insight view of the triangular zone development and relief with respect to TWT. Petrophysical analysis shows the maximum clay volume in zone 3 (Warcha Sandstone) and zone 4 (Dandot Formation) while zone 2 and zone 3 were interpreted as oil bearing zones by resistivity log. Moreover, limestone, sandstone and siltstone were the main lithologies in Joya Mair-04. Fractured limestones of Sakesar and Chorgali Formation providing the main reservoir facilities for hydrocarbons.

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