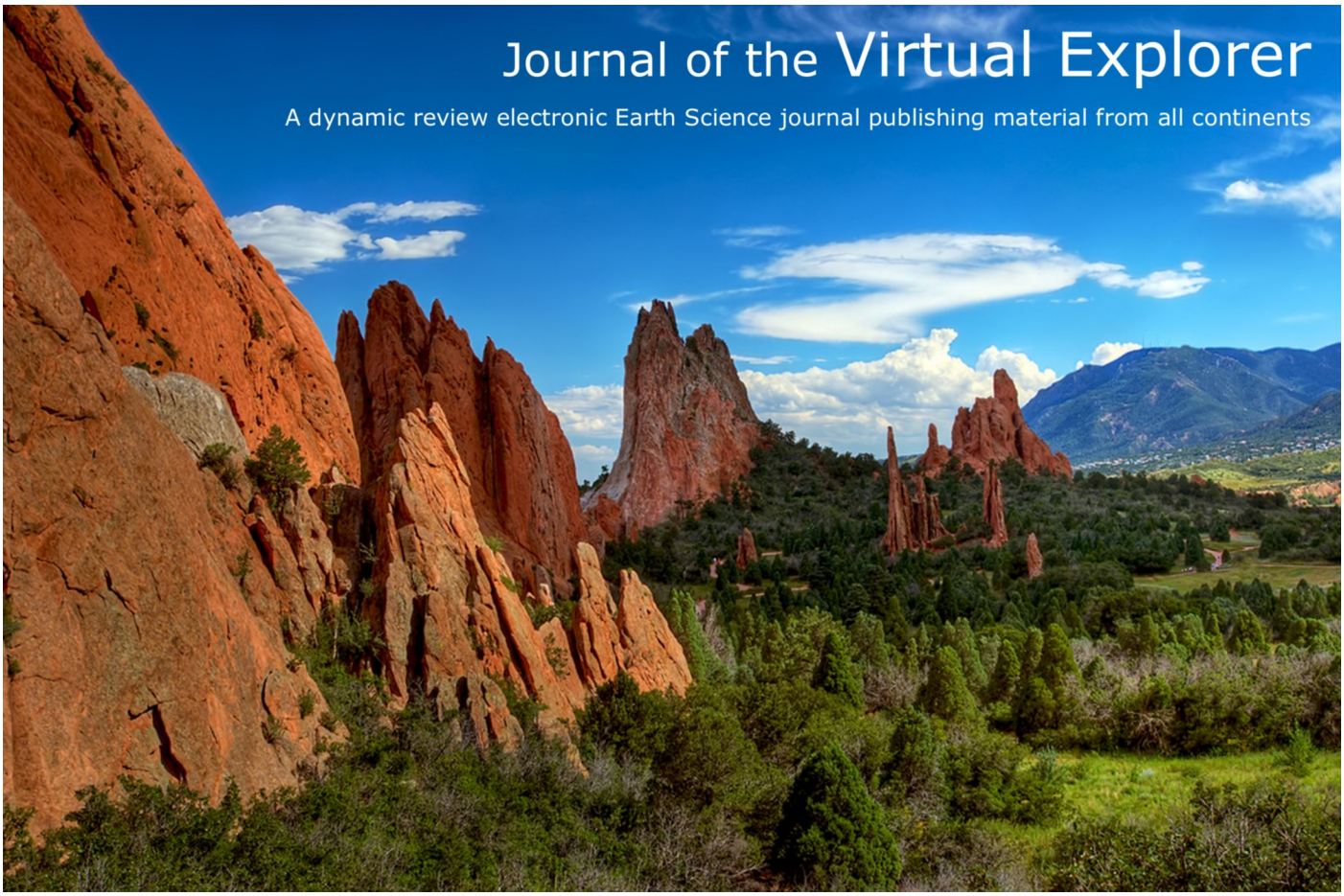

Structural Interpretation of Potwar Sub-basin, Western Lesser Himalayas, Pakistan

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Journal of the Virtual Explorer, Electronic Edition, ISSN 1441-8142, volume **23**, paper 6
In: (Eds.) Shahina Tariq, Zia Ul Hasan Shah, M Zafar, M Shah, and S Qureshi, Geology and Geophysics of Pakistan, 2006.

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Abstract: The present study includes seismic and structural interpretation of Chak Naurang and Joya Mair area, which lies in the Potwar sub-basin in the of western lesser Himalayas in Pakistan. The main objectives include to delineate the subsurface structure and to locate the prospective zones in the study area and to assess the remaining recoverable reserves of Joya Mair Oilfield. The total estimated reserves of Joya Mair Oilfield are 23-25 million US barrels (mmbbl), whereas, at present the recoverable reserves are only 10.45 mmbbl. To achieve these objectives, reinterpretation of four seismic lines O/881-CW-06 (Strike line) and O/881-CW-08, O/881-CW-09, and O/881-CW-10 (Dip lines) was carried out. Four prominent reflectors namely Kamlial Formation (Miocene), the target horizon of Chorgali Formation (Top Eocene), a very thin layer of Permian age and the basement consisted of Pre-Cambrian Salt were marked. Two thrust faults were marked which showed fault-propagating folds in the form of anticlines of Chak Naurang and Joya Mair. A time contour map for the Upper Eocene Chorgali Formation was also developed which shows a long east-west oriented fault that is continued along the Pre-Cambrian basement

Upper Eocene Chorgali formation has been used for contouring and average velocities to find the depths of the formations for the geoseismic section. Well data of Joya Mair was used to mark the thicknesses of the individual formations on the geoseismic section from Cambrian to Recent. The geoseismic section showed that the area was structurally deformed due to salt decollement and compressional tectonic movements.

Restoration of the depth sections using Fixed Pole method for dip lines help to know the mechanism of the tectonic movements in the area. The major causes have been the thrust faults in the area that invoked the basement salt movement and eventually form the anticlines (as they truncated against the basement fault). Salt probably moved into these anticlines due to compressional movements indicating thin-skinned tectonics in the study area that doesnot

involve the basement. Hydrocarbon traps were probably developed in these anticlines and thus the prospective zones for hydrocarbons in Chak Naurang and Joya Mair area. Furthermore, on the basis of this seismic and structural studies and correlating the results with availble gravity and magnetic data: it is concluded that Joya Mair thrust and Mengan thrust deformed the structural trap in Joya Mair area. It also indicates that Joya Mair anticline is not a single structure, rather, it is faulted into blocks. That is why the expected reserves potential of Joya Mair Oilfield are not recovered so far.

Citation: 2006. Structural Interpretation of Potwar Sub-basin, Western Lesser Himalayas, Pakistan. In: (Eds.) Shahina Tariq, Zia Ul Hasan Shah, M Zafar, M Shah, and S Qureshi, *Journal of the Virtual Explorer*, volume **23**, paper 6, doi: 10.3809/jvirtex.2006.00155

Introduction

The Himalayas, subdivided into Sub Himalayas, Lesser Himalayas and Higher Himalayas, represent the most extensive and active collision zone in the world, extending westward from Burma, through northern India, Nepal and southern Tibet, into northern Pakistan. The study area lies in the southeastern part of the Potwar Plateau (Figure 1), which is a broad zone of Himalayan foreland thrusting in northern Pakistan. The Potwar Plateau is the foreland fold-and-thrust belt, lies to the north of the Salt Range Thrust. The post collisional molasse deposits, the Kamlial, Chinji, Nagri and Dhok Pathan formations cover the study area.

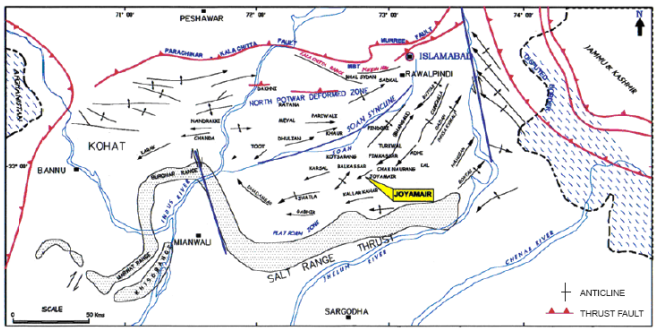
Many geological and geophysical studies have been carried out in this area. This area was initially mapped by Gee (1934) and the oil discovery was made by Attock Oil Company (AOC) in 1944. The anticlinal structure of Joya Mair was delineated by AOC purely on the basis of surface geology. Later on Pakistan Oilfields Limited (POL) conducted geological and seismic survey in the area and defined the structure on the basis of these studies. The total estimated reserves in Joya Mair Oilfield are 23-25 million barrels (mmbbl). The recoverable reserves are estimated as 10.45 mmbbl (Pakistan Energy Yearbook, 2004). The main objectives of the current study include to delineate the subsurface structure and to locate the prospective zones in the Chak Naurag and Joya Mair area and to assess the remaining recoverable reserves of Joya Mair Oilfield.

Pennock et. al. (1989) incorporates more than 1600 km of multi-channel seismic reflection lines from the Eastern Salt Range/ Potwar Plateau (SR/PP), released by Amoco and Chevron. The interpretation of this seismic data reveal a variety of structural styles that may be related to several factors, including changes in distribution and thickness of a basal evaporite sequence, basement faults and flexures, and low dip of the basement. Shami and Baig (2002) focus on the remodeling of the Joya Mair Oilfield to find out the possible remaining reserves. The work represents the geomodelling of Joya Mair oil field by using geologic, structural, borehole, seismic and fracture data. The Joya Mair structure appears as an open anticlinal structure on the surface. It is concluded on the basis of the study that the Joya Mair structure is the combination of thrust and back-thrust, forming a triangle zone at subsurface. The triangle zone is the result of two phases of Himalayan thrusting. These thrust and antithrust phases in Salt Range/Potwar Fold Belt (SRPFB) are the result of northwest-southeast Himalayan compression.

Geology of the Area

Chak Naurang and Joya Mair area lie in the Potwar Plateau sub-basin, which is the northern most structural feature of Indus Basin, bounded by Main Boundary Thrust and Kala Chitta Range in the north and Salt Range to the south. The rocks of Miocene – Pliocene age known as Nagri Formation and Chinji Formation are exposed in the core of the structure and its flanks. A prominent thrust cum tear fault Chak Naurang-Wari fault is passing through the study area (Shami, 1986). There is general disharmony between the younger molasses sequences and the lower older sequences due to thrust tectonics, which are playing a dominant role in the Potwar region. Thus Joya Mair is not an exception to this disharmony and the Chinji Formation in the core of the surface structure must have been brought up by thrusting. The lithologically territories are laying unconformably over Paleozoic and the whole Mesozoic section is absent in and around the area. The Sakesar Limestone and Chorgali Formation of Eocene age are the primary reservoir objective while Permian and Cambrian sandstone are secondary objectives. The Eocene, Paleocene and Permian shales are supposed to be the potential source and cap rocks. The sedimentary sequence ranging from Precambrian to Recent is exposed in the Salt Range and the Potwar Plateau (Table 1).

Figure 1. The study area



The study area lies in the southeastern part of the Potwar Plateau

Figure 7. Table 1

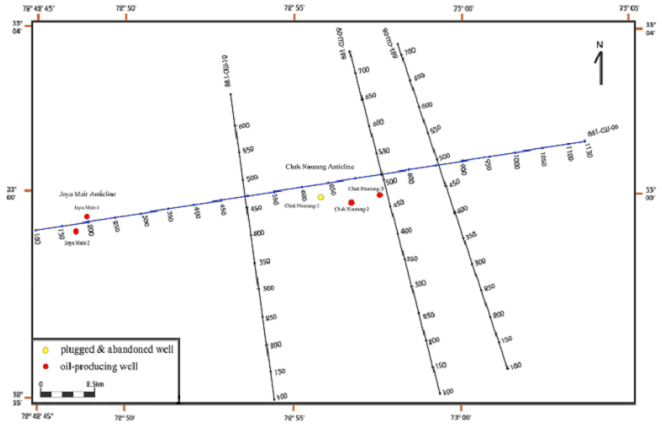
AGE	FORMATION	LITHOLOGY	THICKNESS	LITHOLOGICAL DESCRIPTION
PLEIST-OCENE	LEI CONGLOMERATE		600m	Conglomerate
	SOAN		300m	Siltstone, Sandstone and Rare Conglomerate
PLIO-CENE	DHOK PATHAN		1500m	Claystone, Siltstone and Minor Sandstone Rare Intraformational Conglomerate
	NAGRI		1500m	Rare Intraformational Conglomerate
MIO-CENE	CHINJI		750m	Predominantly Claystone, minor Siltstone and Sandstone Rare Intraformational Conglomerate
	KAMLIAL		345m	Predominantly Sandstone, minor Claystone, Siltstone and intraformational conglomerate
	MURREE		3100m	Claystone, Sandstone and Basal Conglomerate
			100m	Foraminiferal Limestone and Marl, possible reservoir rock
EOCENE	KULDANA		150m	Anhydritic Shale, Claystone, minor Limestone, cap rock
	CHORGALI		150m	Foraminiferal Shale, Limestone and Dolomitic, Anhydritic reservoir rock
	SAKESER HILL / NAMMAL L.ST.		90m 75m	Bioclastic Limestone and Dolomitic reservoir rock Foraminiferal Shale, limestone, Source rock potential
PALEO-CENE	PATALA		70m	Bioclastic Limestone, dolomitic, anhydritic, carbonaceous shale
	LOCKHART		90m	Bioclastic Limestone, dolomitic, anhydritic
	HANGU		100m	Shale, sandstone, fine clay and bauxite
CRETA-CEOUS	KAWAGARH		90m	Limestone, Shale
	LUMSHIWAL		80m	Sandstone, potential reservoir rock
JUR-ASSIC	CHICHALI		60m	Belemnite Shale and glauconitic Shale potential reservoir rock
	SAMANA SUK		90m	Limstone, Dolomitic, Minor Dolomite
	SHINWARI		200m	Limstone
	DATTA		180m	Sandstone and variegated reservoir rock
	KINGRIALI		80m	Dolomite
TRI-ASSIC	TREDIAN CHAK JAMAL		60m	Sandstone and Limestone
	MIANWALI		50m	Dolomite, limestone, Shale
	CHIDORU		60m	Shale Dolomitic Limestone, source rock
LATE PERMIAN	WARGAL		160m	Limsetone, reservoir rock
EARLY PERMIAN	AMB		70m	Shale and Sandstone
	SARDHAI		50m	Shale, potential source rock
	WARCHHA		90m	Sandstone, Shale
	DANDOT		50m	Sandstone, Shale
	TOBRA		60m	Conglomerate, Polymictite, Diamictite
ORDO-VICIAN to CARBON-IFEROUS				
CAMB-RIAN	BAGHANWALA		100m	Shale, Siltstone, Anhydrite
	JUTANA		60m	Sandy Dolomite
	KUSSAK		50m	Shale Dolomite
	KHEWRA		150m	Sandstone, Shale
EO-CAMBRIAN	SALT RANGE		850m	Anhydrite, Dolomite, Marl, Salt
PRE-CAMBRIAN	BASEMENT			Quartzite, Schist, Phyllite

Generalized stratigraphy of Salt Range - Potwar Foreland Basin (After Shami and Baig, 2002).

Geophysical Studies

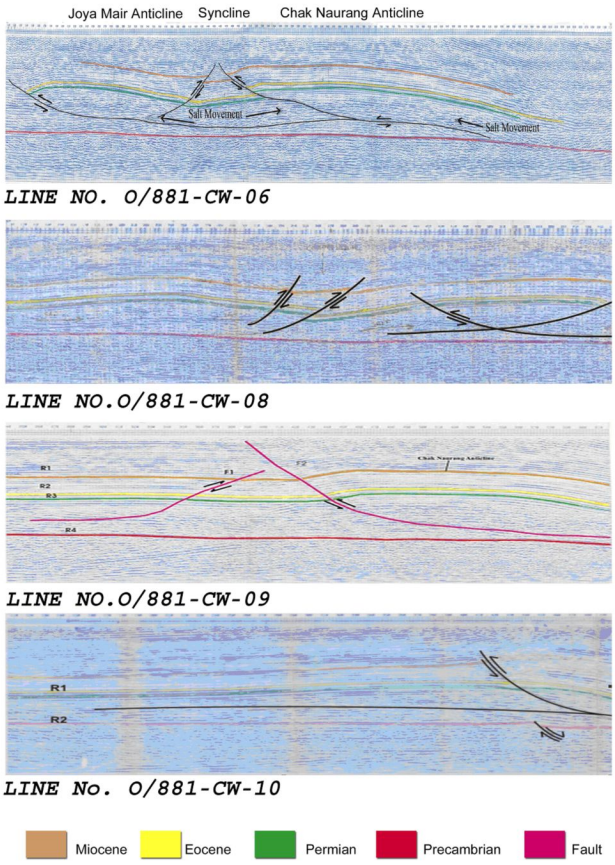
2D-Seismic interpretation of Chak Naurang and Joya Mair area has been carried out with the objectives to delineate the subsurface structure and to locate the prospective zones. To achieve these objectives, reinterpretation of four seismic lines O/881-CW-06 (Strike line) and O/881-CW-08, O/881-CW-09, and O/881-CW-10 (Dip lines) were carried out. These lines were shot during the seismic survey conducted by OGDCL in 1988. The purpose of the survey was to locate the prospective zones in the anticlines of Chak Naurang and Joya Mair and to understand the role of fault-propagating folds in hydrocarbon entrapment. The base map (Figure 2)shows the seismic lines under study and location of nearby wells whose data has also been employed in the interpretation of this study. The interpreted seismic sections along the seismic lines O/881-CW-06, O/881-CW-08, O/881-CW-09, and O/881-CW-10 have been shown in (Figure 3).

Figure 2. Base Map



Base Map

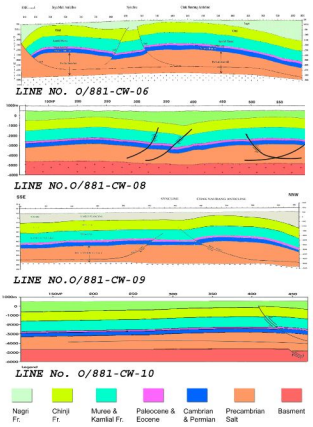
Figure 3. Interpreted seismic sections



Interpreted seismic sections along the seismic lines O/881-CW-06, O/881-CW-08, O/881-CW-09, and O/881-CW-10

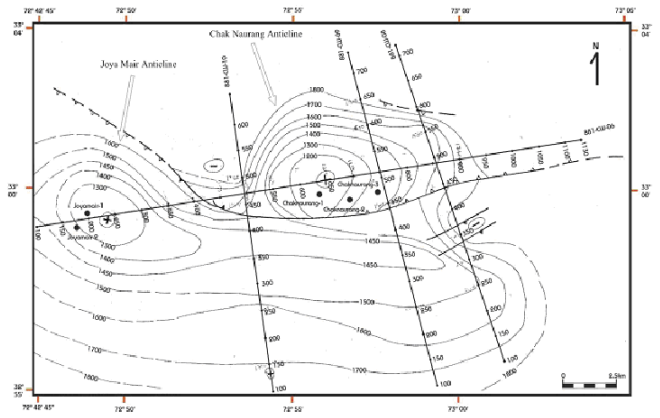
Four prominent reflectors namely R1, R2, R3 and R4 were marked on the seismic sections on the basis of observed reflection events. These reflectors were interpreted as Kamlial Formation (Miocene), the target horizon of Chorgali Formation (Top Eocene), a very thin layer of Permian age and the basement consisted of Pre-Cambrian salt respectively. A fault was marked which continued along the Pre-Cambrian basement. Two more thrust faults were marked which showed fault-propagating folds in the form of anticlines of Chak Naurang and Joya Mair. The geoseismic sections along the seismic lines under study have been shown in (Figure 4). Average velocities of the Upper Eocene Chorgali Formation and the Pre-Cambrian basement were used to find the depths of the formations for the geoseismic section. Well data of Joya Mair was used to mark the thickness of the individual formations on the geoseismic section from Cambrian to Recent. The geoseismic section showed that the area was structurally deformed due to salt decollement and compressional tectonic movements. On the Geoseismic Section of line O/881-CW-06 the Upper Eocene formation, which is our target horizon, is almost at a depth of 2000 meters within the anticlines of Chak Naurang and Joya Mair, which is favorable for drilling. The TWT were also posted on the base map to develop a time contour map for the Upper Eocene Chorgali Formation, as it was continuing throughout the study area (Figure 5).

Figure 4. Geoseismic sections



Geoseismic sections

Figure 5. Time contour map

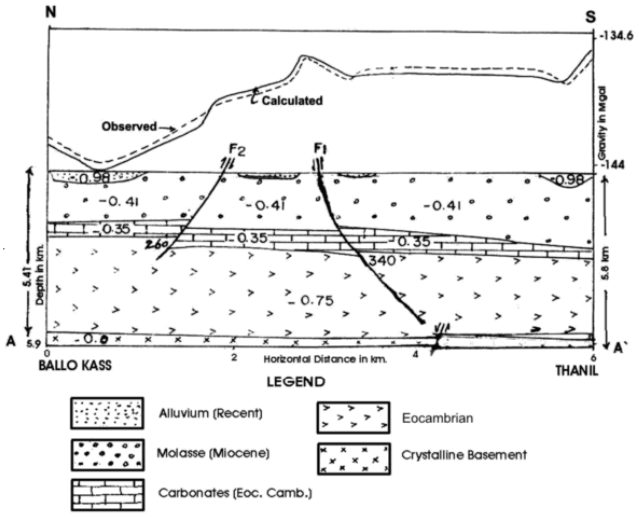


Time contour map for the Upper Eocene Chorgali Formation

Balancing of depth sections using Fixed Pole method for dip lines help to know the mechanism of the tectonic movements in the area. The major causes have been the thrust faults in the area that invoked the basement salt movement and eventually form the anticlines (as they truncated against the basement fault). Salt probably moved into these anticlines due to compressional movements and a syncline was formed. Hydrocarbon traps were probably developed in these anticlines and might be the prospective zones for hydrocarbons in Chak Naurang and Joya Mair area.

As mentioned earlier, POL delineated the Joya Mair Oilfield as structural trap on the basis of surface geology and seismic data. According to POL, Joya Mair structure is a simple anticline. The current study based on geophysical techniques negates the POL findings and suggests that Joya Mair anticline is not a single structure but it is faulted into blocks. The thrust and back thrust in the study area have been developed due to the stresses which are caused by the collision of Indian and Eurasian plates and the presence of salt, incompetent strata and basement fault. Shami and Baig (2002) also suggest that Joya Mair structure is not a simple anticline, it is a triangle zone, which is formed by the combination of Mengan thrust and Joya Mair thrust resulting in the triangle geometry at subsurface and faulted anticline structure. Khan and Ali (1994) indicated similar structures in the northern Potwar near Rawalpindi, which are Rawat thrust and Kahutta backthrust. They suggested that Rawat thrust and Kahutta backthrust have been developed due to SSE ward stress, decollement and the extensional basement fault present in the upper crystalline basement. Basharat et al. (2004) carried out an integrated gravity and magnetic survey for the modelling of Joya Mair structure (Figure 6). They concluded that faults F1 and F2 deformed the structural trap in Joya Mair area. It also indicates that Joya Mair anticline is not a single structure but it is faulted into blocks, due to which the expected reserves potential of Joya Mair Oilfield are not recovered so for.

Figure 6. Joya Mair area



Gravity modelling from Ballo Kass to Thanil Fatui in Joya Mair area (After Basharat et al., 2004).

Conclusions

Following conclusions were deduced based on the current studies:

• The Upper Eocene (Chorgali Formation) is continuous throughout the area of Chak Naurang / Joya Mair and it contains good reservoirs of hydrocarbons. That is why it was made the target horizon in the interpretation.

• The thrust faults in the area show that it was deformed by compressional tectonic movements thereby causing the salt-decollement. The thrusting resulted in the formation of fault-propagating folds in the form of Chak Naurang and Joya Mair anticlines.

• The fault along the Pre-Cambrian basement has caused movements in the Pre-Cambrian salt.

• The compression caused the salt to squeeze into the anticlines, letting the strata in between to sink, forming a graben structures.

• Structural traps have developed in the Chak Naurang and Joya Mair anticlines possibly due to their truncation against the basement fault.

• The Upper Eocene Chorgali Formation is found almost at a depth of 2000 meters within the anticlines, which is favorable for drilling. Both the anticlines are producing because the compression and the salt movement have caused the reservoirs to rise into shallower depths.

• On the basis of this geological and seismic studies and correlating the results with qualitative and quantitative interpretation of gravity and magnetic data by Basharat et al. (2004), it is suggested that Joya Mair thrust and Mengan thrust deformed the structural trap in Joya Mair area. It also indicates that Joya Mair anticline is not a single structure, rather, it is faulted into blocks. That is why the expected reserves potential of Joya Mair Oilfield are not recovered so far.

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