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Structural interpretation of Joya Mair oil field, south Potwar, Upper Indus Basin, Pakistan, using 2D seismic data and petrophysical analysis

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Abstract

The Joya Mair oil field lies in the south-southeast of the Salt Range-Potwar Foreland Basin (SRPFB). It is the result of Tertiary Himalayan collision between the Indian and Eurasian Plates. The SRPFB represents the Precambrian to Recent rocks of the Indian Plate which covers an area of about 2250 Km^2. The Himalayan thrusting and folding formed the structural traps in SRPFB. Seismic interpretation has resulted in time and depth contour map, which helps to understand the subsurface structural geometry. Seismic interpretation of the 2D data reveals that the study area has undergone severe deformation illustrated by the development of thrusts and backthrusts. The Joya Mair structure appears to be an open anticlinal structure on the surface. It is a combination of thrust and backthrust, forming a triangle zone in the subsurface. The general trend of these structures is northeast-southwest which is indicative of the fact that the area was subject to southeast northwest compressive stress. The decollement surface is provided by the Salt Range Formation. The reservoir rocks are of Eocene age that occurs at a depth of ~2023 m as interpreted from seismic data. The petrophysical analysis of Minwal X-1 well is done on the basis of well logs which gives approximately 75% hydrocarbon saturation in the reservoir rocks.

Keywords: Seismic interpretation; Petrophysical analysis; 2D Seismic data; Joya Mair oil field; Indus Basin.

1. Introduction

This study attempts to decipher the subsurface structural geology of the Joya Mair area by using 2D seismic data and well data. The Joya Mair oil field is located in the southeastern part of the Salt Range-Potwar Foreland Basin (SRPFB), bounded by Soan Syncline in the north and Salt Range in the south. The Joya Mair structure is a northeast southwest trending anticline on the surface and a triangle zone in the sub-surface. The fractured carbonates of the Sakesar and Chorgali formations are the major producing reservoirs in the Joya Mair area. The purpose of this research is to understand the structural style of the Joya Mair area emphasizing the southeastern Potwar and to identify the subsurface structure that has helped in the accumulation of hydrocarbons.

2. Objectives

The objectives of this research are:

1) Seismic data interpretation to decipher the subsurface structural geometry of the area.
2) Delineating the subsurface target horizons for hydrocarbons accumulations.
3) Integration of seismic and well data to enhance the precision of the interpretation process.
4) Conversion of the interpreted time section into depth section to identify the depth of key horizons and to construct depth surface maps of the reservoir rocks.

The following integrated geological and geophysical data have been used for structural and stratigraphic interpretation of sub-surface horizons.

1) Base map (Fig. 1).
2) Seismic sections (lines 93-MN-5, 93-MN-6, 93-MN-8, and 93-MN-9)
3) Wireline logging data of Minwal X-1

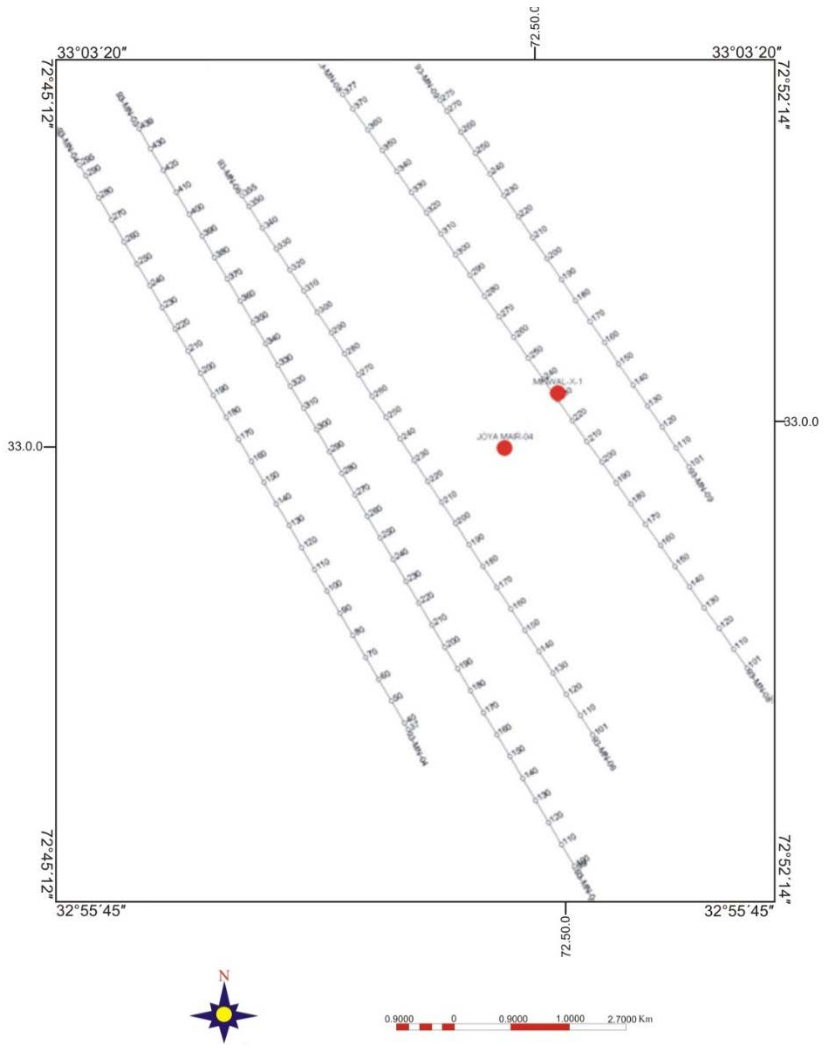

Fig. 1. Base map of the study area showing the location of the seismic lines and Joya Mair 4 and Minwal X-1 wells.

3. Interpreted seismic sections

The interpreted seismic sections lines 93-MN-5, 93-MN-6, 93-MN-8, and 93-MN-9 which are located in the studied area are roughly parallel to the tectonic transport direction (Fig. 1). These seismic sections were depth converted using velocity information provided in the seismic sections and using well logs from Minwal X-1 well. These seismic lines are dip lines as they are perpendicular to the strike of the major structures and are therefore most appropriate for geological interpretation.

4. Outline of the regional geology

The Salt Range-Potwar province represents a well-described fold-and-thrust belt, which developed south of the Himalayas as a result of ongoing collision between India and Eurasia (Baker et al., 1988). Because thrusting has progressively propagated southward, the Salt Range is considered to be the youngest and southernmost compressional structure within the Himalayan Foreland (Gansser, 1964; Powell and Conaghan, 1973; Molnar and Tapponnier, 1975). The Salt Range marks the emergent front of a tectonic wedge that has been translated passively on a basal decollement level located within a thick Precambrian salt layer. This frontal thrust brings to the surface allochthonous Cambrian to Quaternary sedimentary units, which have been thrusted southward over Quaternary deposits of autochthonous foreland basin (Crawford, 1974; Seeber and Armbruster, 1979). Because of the weak detachment at the base of the sedimentary cover, low strains are observed in the translated sedimentary rocks (Jaume and Lillie, 1988).

Anticlinal structures are well developed in the Southern Potwar Basin, and host productive petroleum accumulations. In Potwar area, the 200–500 m thick Cambrian to Eocene platform sequence constitutes quite a homogeneous ‘carapace’ (Butler et al., 1987). This platform sequence is very conspicuous on seismic sections and all source rocks as well as the main petroleum reservoirs of the Kohat-Potwar Basin are located within it.

5. Stratigraphy

Stratigraphy of the Joya Mair area is well established from the outcrop as well as from the wells drilled in the study area and the surrounding area (Fig. 3). The stratigraphy of the Joya Mair area comprises of the Precambrian Salt Range Formation, Cambrian to Eocene Platform Sequence. In SRPFB the early to middle Cambrian Jehlum Group lies on the Salt Range Formation. The Jehlum Group includes Khewra Sandstone and Kussak Formation. The basin was uplifted during Ordovician to Carboniferous; therefore no sediments were deposited in SRPFB (Shami and Baig, 2002). The Cambrian Jehlum Group is disconformably overlain by the Permian Nilawahan Group. It includes Tobra Formation, Dandot Formation, Warchha Sandstone and Sardhai Formation. The Late Permian to Cretaceous rocks from west to east in the basin are eroded due to significant Pre-Paleocene tectonic uplift in SRPFB (Shami and Baig, 2002). The Early Paleocene marine transgression resulted in the deposition of Palecene to Eocene carbonate-shale sequence. It includes the Lockhart Limestone**,** Patala, Sakesar and Chorgali formations. The Himalayan orogeny initiated the Eocene-Oligocene uplift and erosion in the SRPFB. The upper part of the stratigraphic section comprises of the Miocene to Pliocene non-marine molasse deposits. The Miocene molasse deposits include Murree, Kamlial, Chinji and Nagri formations.

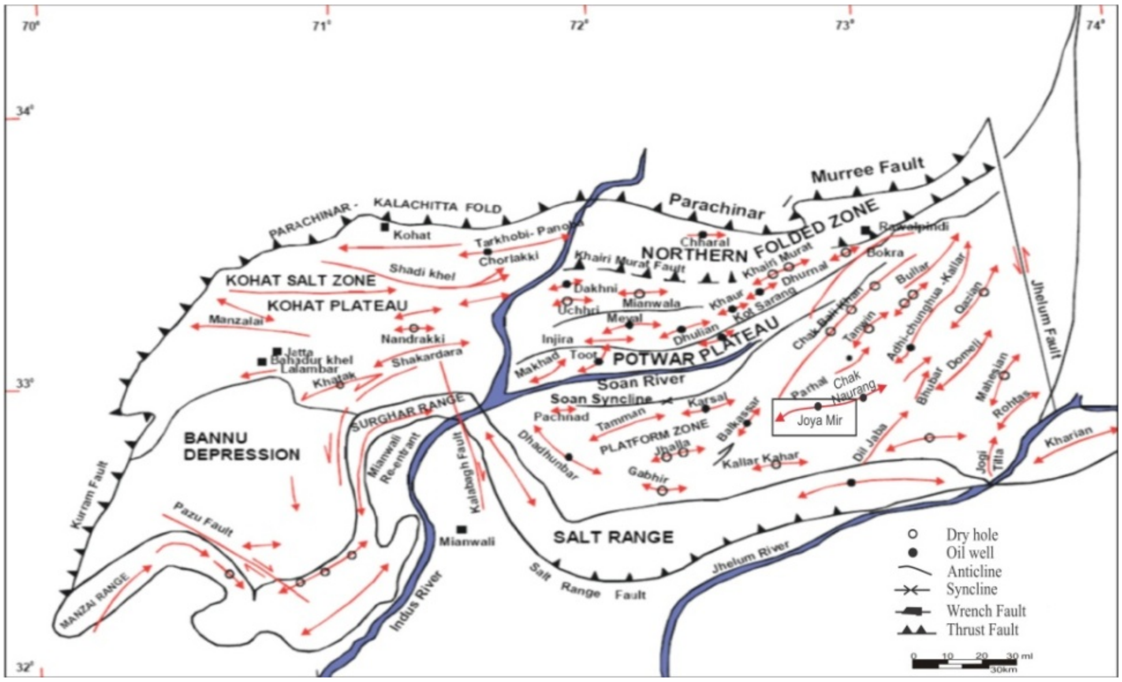

Fig. 2. Tectonic division of the Potwar Plateau (after Shami, 1998).

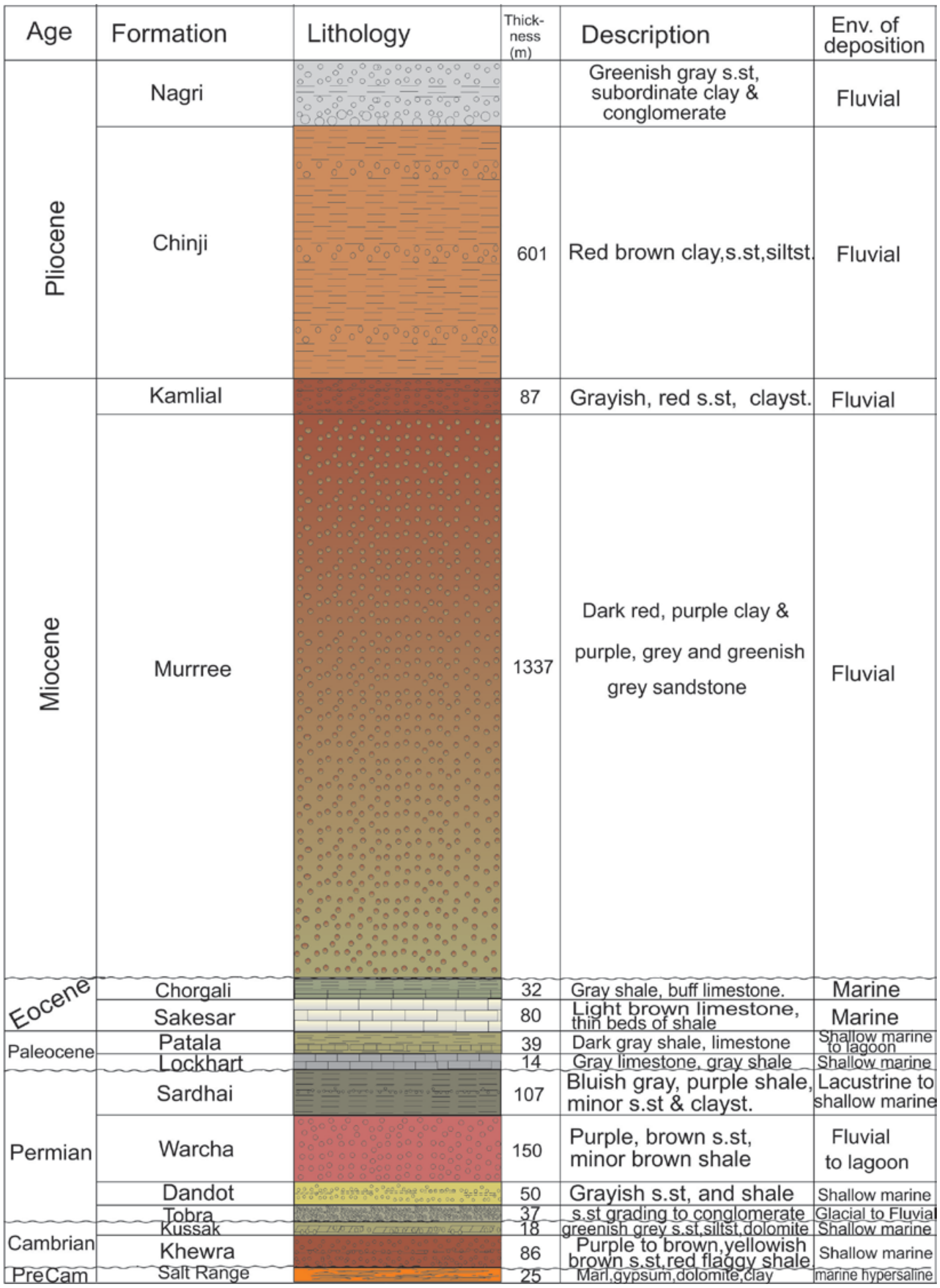

Fig. 3. Stratigraphic column of the Joya Mair area (after Shami, 1998).

6. Structural discription of the study area

The Joya Mair oil field is located in the southeastern part of the Salt Range Potwar Foreland Basin (SRPFB). The study area shows a complicated structural configuration. The Joya Mair area is basically an anticline at the surface and plunges 10° southwest and 4° northeast (Shami and Baig, 2002). The fold axis of anticline trends northeast-southwest forming northeast-southwest trending Joya Mair Anticline. The formations which are exposed at the surface are Chinji and Nagri. The Chinji Formation is exposed at the core of the anticline and the Nagri

Formation is exposed at the limbs and at places they are covered by alluvium. Seismic images of the Joya Mair oil field show that the Joya Mair structure is a triangle zone at the subsurface.

6.1. Joya Mair triangle zone

The Joya mair Triangle Zone is recognized on the basis of seismic survey which is a key structure for the exploration of hydrocarbons in foreland fold and thrust belts. The sedimentary rocks are deformed on the Precambrian evaporates of the Salt Range Formation in SRPFB. Borehole and seismic data shows that the Joya Mair structure is not a simple anticline. It is a triangle zone formed by the combination of thrust and backthrust, resulting in the triangle zone geometry at the subsurface (Fig. 4) and an open anticline at the surface (Fig. 5). These thrust and backthrust phases in SRPFB are the result of northwest southeast Himalayan compression.

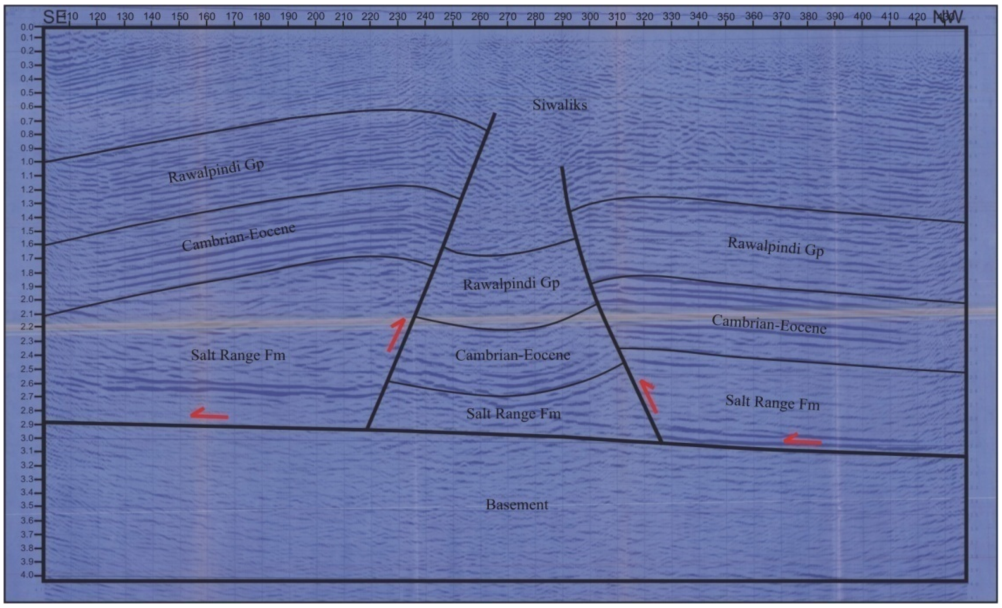

Fig. 4. Seismic section 93-MN-5 showing different reflectors.

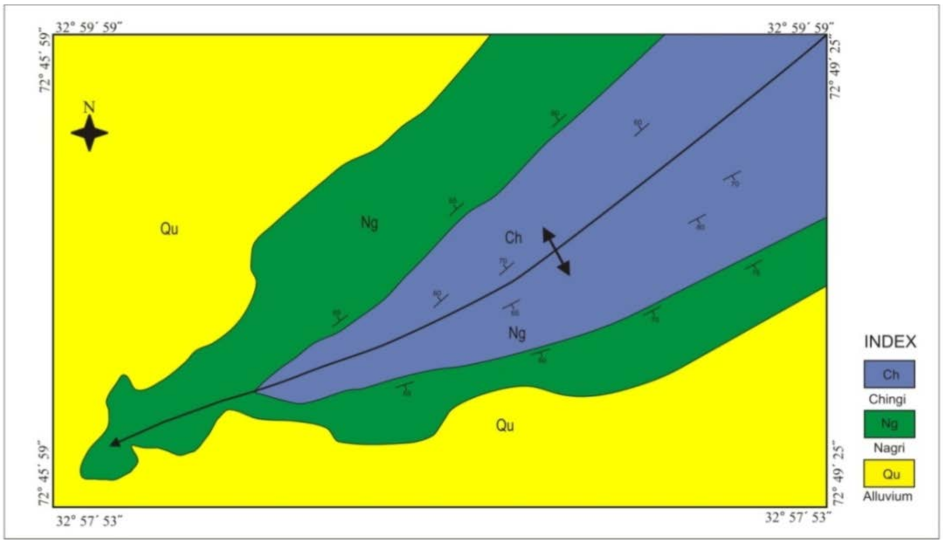

Fig. 5. The Joya Mair anticline at the surface.

7. Seismic interpretation

Seismic interpretation is the determination of subsurface geology using seismic data. The objective of seismic interpretation is to discover hydrocarbon accumulations in the subsurface. Interpretation is the transformation of seismic reflection data into a structural picture by the applications of corrections, migration and time depth conversion (Dobrin and Savit, 1988). Seismic reflection interpretation relies on identifying the reflectors and calculating their positions on the basis of geology of the survey area and correlations with the well data.

7.1. Structural interpretation

The structural geology of the area has been studied by utilizing seismic lines 93-MN-5, 93-MN-6, 93-MN-8 and 93-MN-9.

7.1.1. Seismic line 93-MN-5

Line 93-MN-5 is a 13.52 km, north-west oriented line and is to the west of Joya Mair 4 and Minwal X-1 wells (Fig. 1). The basement exists at a TWTT of 2.9 sec (Figs. 5-6). The decollement is provided by the Salt Range Formation above the basement. Two major blind thrusts originating from the basal decollement are visible in line 93-MN-5. The first major thrust occurs in the southeastern part of the section which has cut across the Cambrian to Eocene Carapace and the Miocene Rawalpindi Group and dies out in the Siwaliks. The Joya Mair triangle zone is visible approximately below the shot point 460 on line 93-MN-5. However, this line occurs towards the west of Joya Mair 4 and Minwal X-1wells and no well has been drilled on this line. Another blind backthrust exists to the north of the triangle zone. This thrust fault appears to die out in the Siwaliks Group. The arrangement of structures show that the forethrust is southeast verging while the backthrust is northwest verging forming a triangle zone.

7.1.2. Seismic line 93-MN-6

Seismic section 93-MN-6 is 10.13 km, north-west oriented line and is to the west of Joya Mair 4 and Mainwal X-1 wells (Fig. 1). The structures portrayed by this seismic line are very similar to those present in the line 93-MN-5 (Figs. 7 and 8). The Joya Mair structure is basically a triangle zone consisting of a forethrust verging towards southeast and a backthrust verging towards northwest. Both thrusts die out in Siwaliks Group.

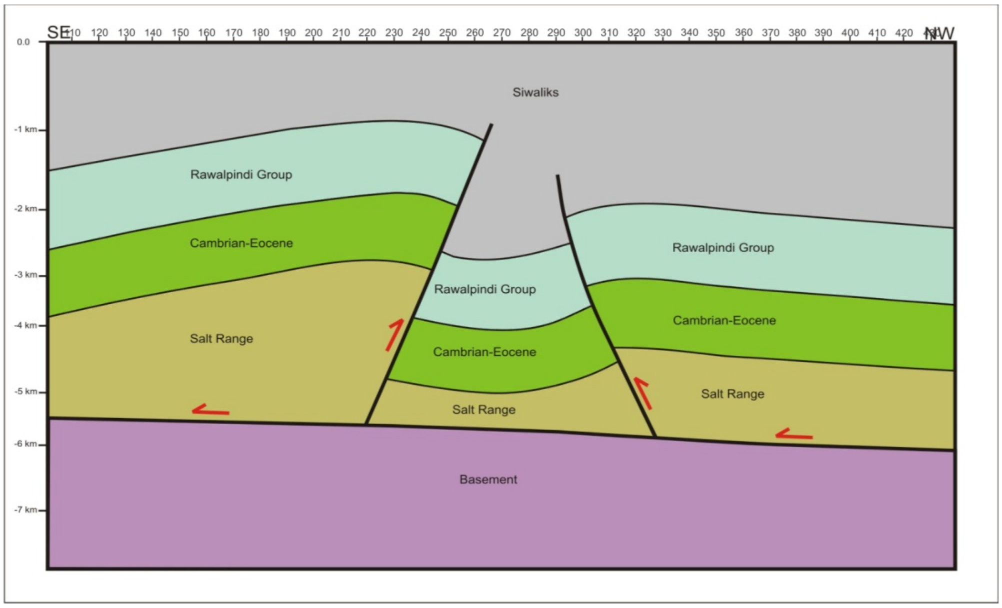

Fig. 6. Depth interpretation of the seismic section 93-MN-5.

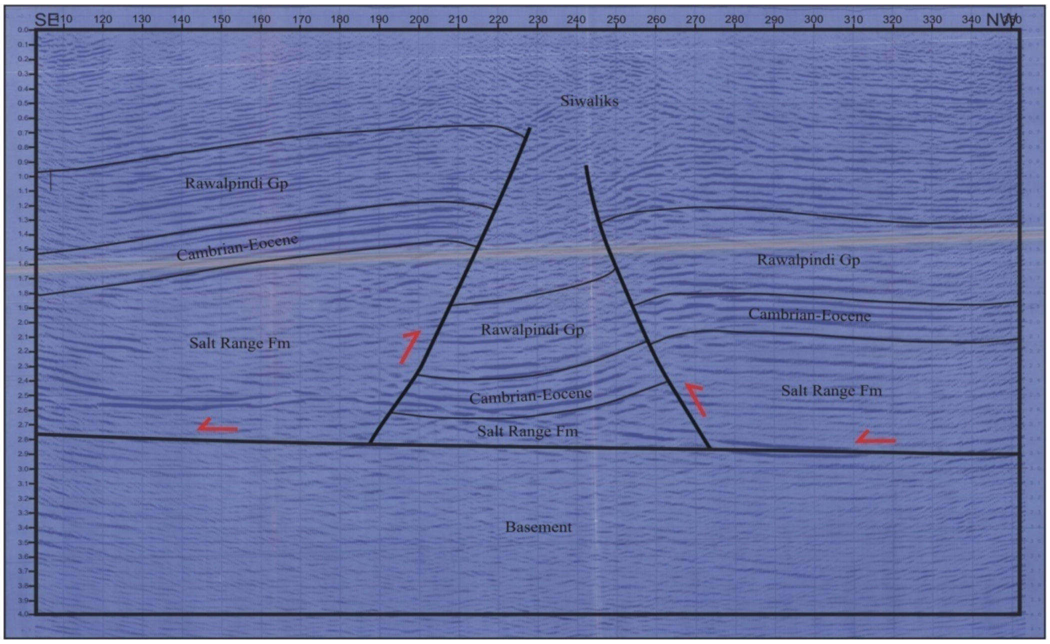

Fig. 7. Seismic section 93-MN-6 showing different reflectors.

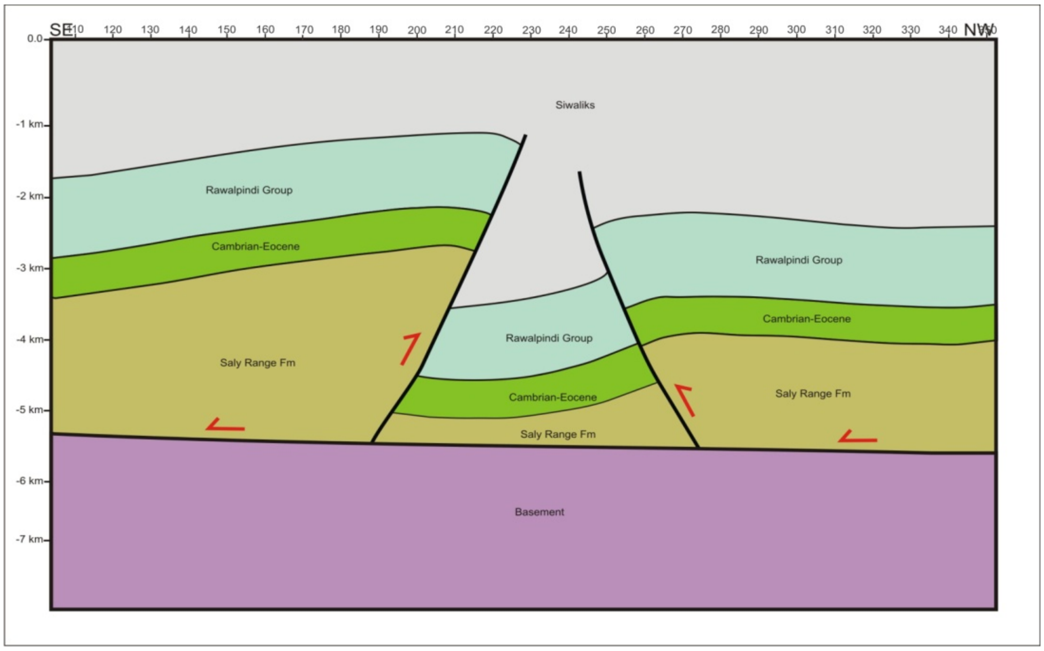

Fig. 8. Depth interpretation of the seismic section 93-MN-6.

7.1.3. Seismic line 93-MN-8

The line 93-MN-8 is 11 km, north-west oriented line and is perpendicular to the axis of the structure present in the area and parallel to the dip of the major faults present. It represents the northeastern extension of the structure observed in the previous two lines. Here the reservoir rocks of Cambrian to Eocene are at a TWTT of 1.5 to 1.81 sec arched upwards into an anticlinal shape due to the backthrust (Figs. 9-10). On this line, Minwal X-1 is drilled at shot point 230, to a TWTT of 1.15 sec which corresponds to a depth of ~2023 m on the southeastern flank (Fig. 1).

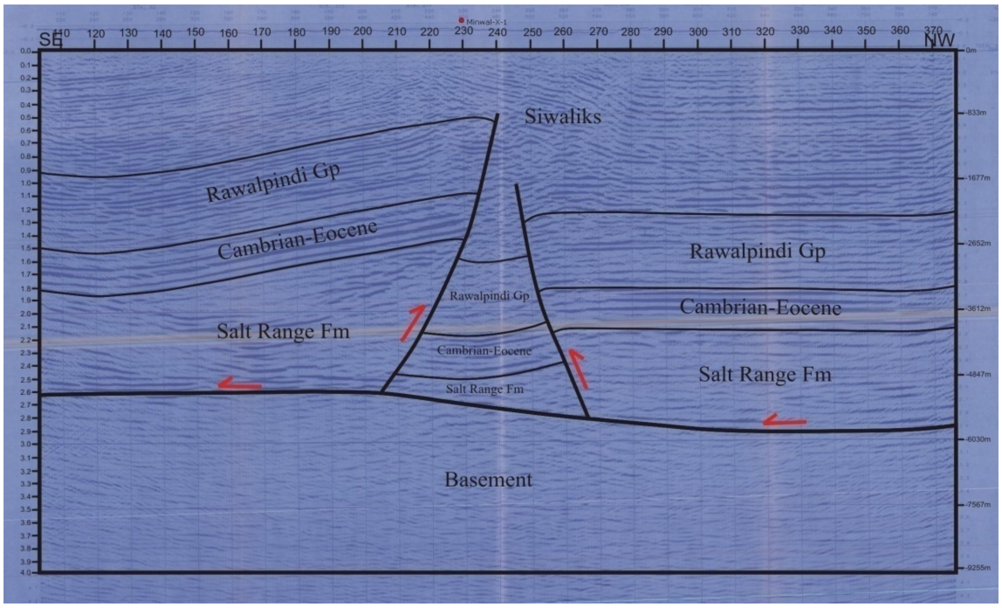

Fig. 9. Seismic section 93-MN-8 showing different reflectors.

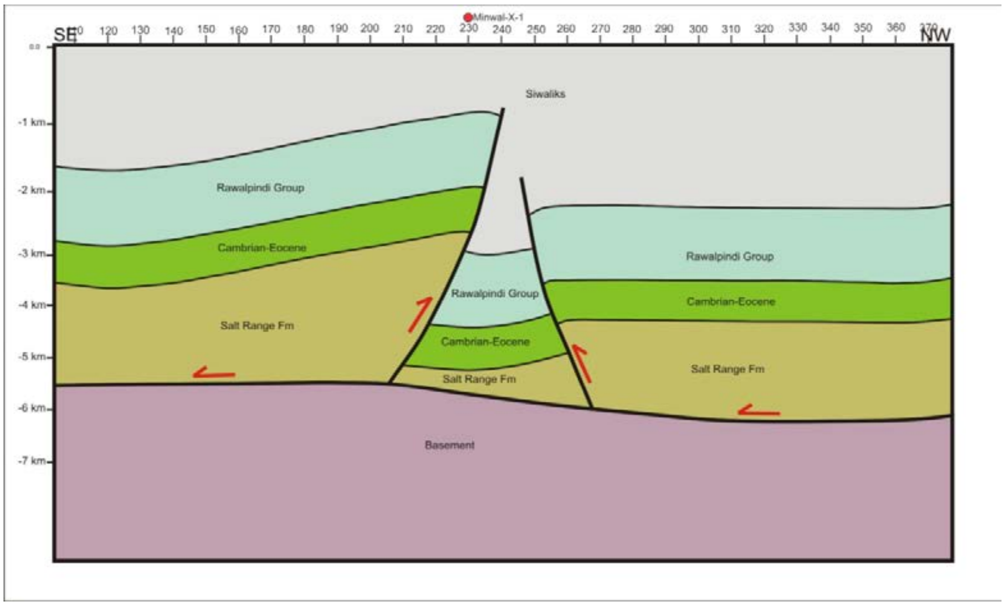

Fig. 10. Depth interpretation of the seismic section 93-MN-8.

7.1.4. Seismic line 93-MN-9

Line 93-MN-9 is a 6.98 km, north-west oriented line and is to the east of Joya Mair 4 and Minwal X-1 wells (Fig. 1). It also represents a triangle zone consisting of a southeast verging forethrust and a northwest verging backthrust. Both thrusts die out in Siwaliks Group (Figs. 11-12). It represents the northeastern extension of the structure observed on the previous seismic lines.

7. 2. Depth contouring

A contour is defined as the line drawn by joining points of equal values. From the seismic interpretation of the 2D data and the velocity analysis, the depth of different sedimentary packages below all the shot points were calculated and utilized to develop depth contour maps of the top Eocene sequence, which are proven reservoirs in the Joya Mair oil field (Fig. 13).

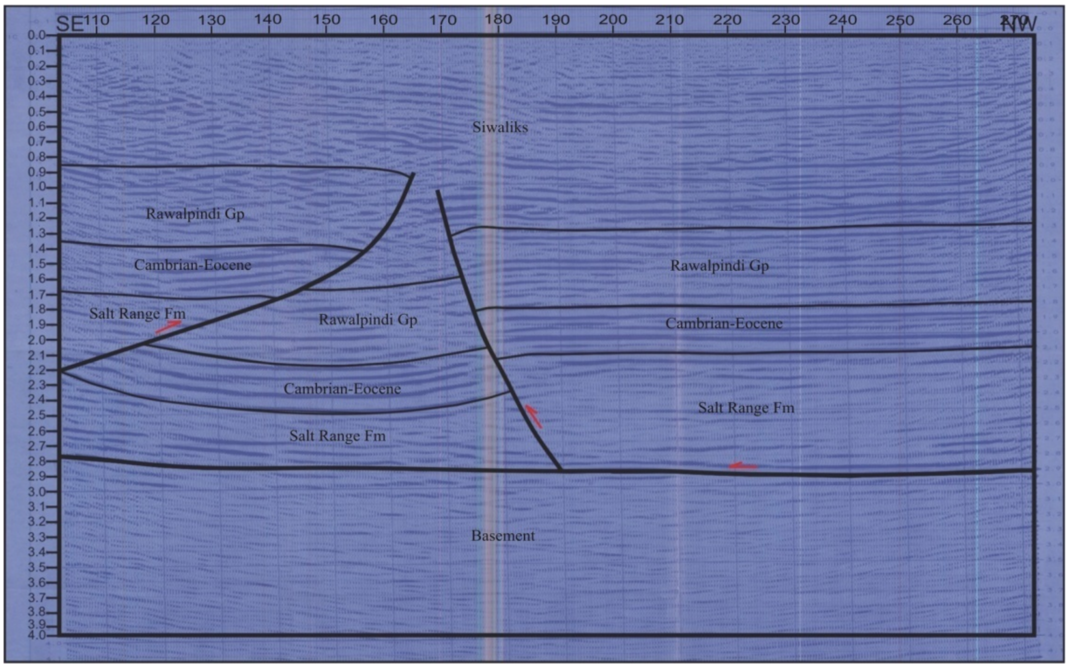

Fig. 11. Seismic section 93-MN-9 showing different reflectors.

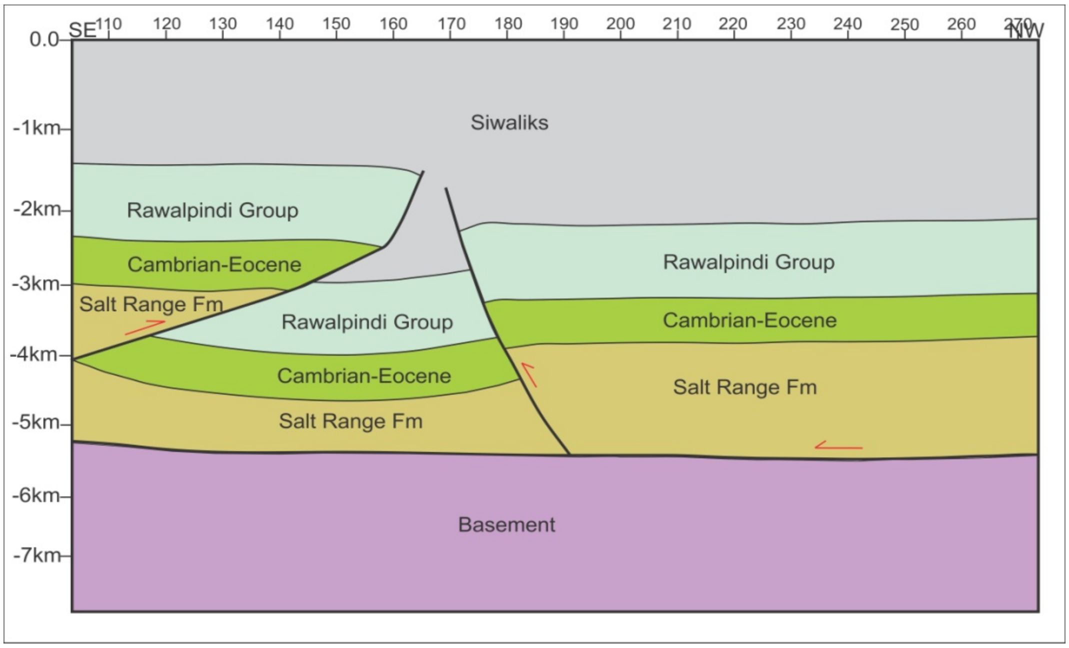

Fig. 12. Depth interpretation of the seismic section 93-MN-9

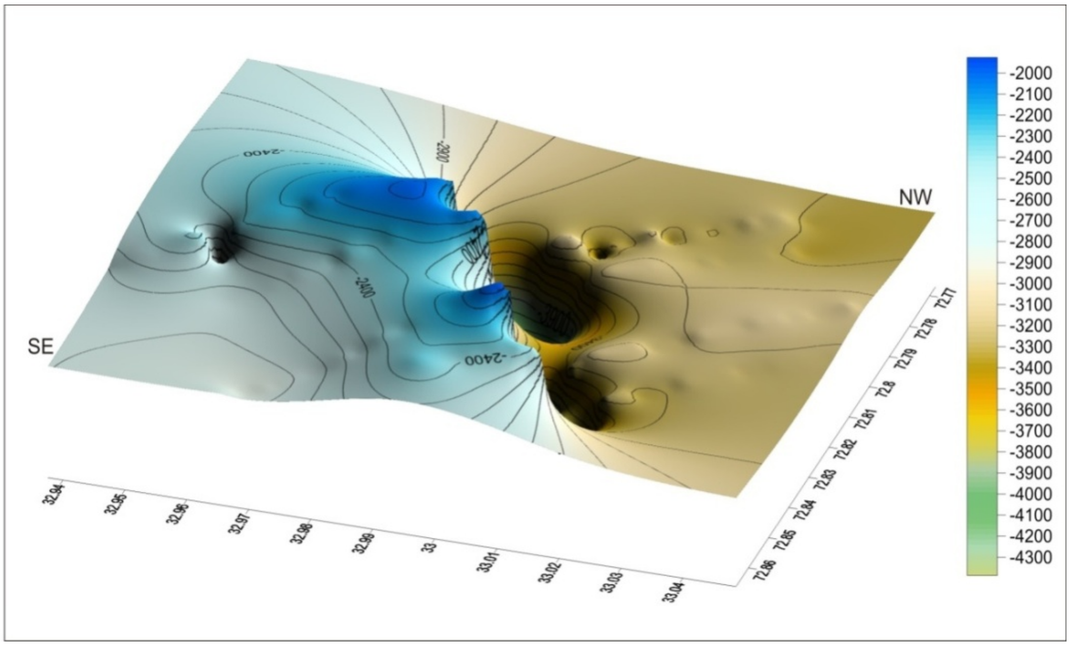

Fig. 13. Depth surface and contour map of the Top Eocene.

Table 1. Values of different parameters calculated during log analysis. Average S_H is 78.75%.

Depth(ft)	Temp	$Ø_N$ NPHI	RHOB	$Ø_D$	$Ø_{(N.D)}$	R_t LLD	SP	R_{We}	R_W	S_W	S_H	Lithology
6625	146.3	0.34	2.8	0.39	0.36	300	.28	0.40	0.70	14%	86%	Limestone
6638	146.5	0.03	2.1	0.35	0.19	300	.10	0.6	0.8	20%	80%	Limestone
6660	146.7	0.38	2.65	0.04	0.21	120	.30	0.44	0.6	37%	63%	Limestone
6685	147	0.01	2.45	0.15	0.08	300	.30	0.26	0.3	20%	80%	Limestone
6700	147.2	0..43	2.85	0.08	0.26	100	.30	0.26	0.3	9%	91%	Limestone
6800	148.4	0.01	2.7	0.006	0.05	1500	.13	0.67	1	50%	50%	Limestone
6985	150.4	0.02	1.95	0.44	0.23	2000	.35	0.33	0.43	6%	94%	Limestone
7033	151	0.45	2.35	0.21	0.35	100	.45	0.27	0.32	14%	86%	Limestone

8. Petrophysical analysis

The petrophysical analysis through wireline logs (Density, Neutron, Self-potential and Resistivity) for the Sakesar Formation of Eocene age in Minwal X-1 well is conducted. The analyses are made to calculate porosity, determine formation water resistivity, water saturation and oil saturation. These findings are very useful in investigating the hydrocarbon potential of the reservoir.

9. Procedure for finding different parameters from the log track:

The following parameters are directly read from the log track

1) Spontaneous potential of the formation (it is in the range of 20 to -80mv)
2) Bulk resistivity of the formation (scale 0 to 2000 ohm.m)
3) Formation depth (scale in feet)
4) Neutron porosity (NPHI) (scale 0.45 to -0.15)
5) Bulk density of the formation (RHOB) (scale 1.95 to 2.95)

10. Saturation of hydrocarbons (S_H)

Schlumberger Log Interpretation Charts and certain equations have been used to determine the unknown values in order to determine the saturation of hydrocarbons in Minwal X-1 well. The procedure followed is as under:

1) Determine the temperature of the formation T_F by using Fig. 14. The bottom-hole temperature of 152 °F and surface temp is 72 °F given on the wireline logs are used as references.
2) Correct the resistivity of mud filtrate R_{mf} and resistivity of mud R_m to T_F. Fig. 15 is used to correct the values.
3) Determine Spontaneous Potential (SP) by reading it directly from the SP curve on the log chart.
4) Determine R_{mf} / R_{We} ratio. Use Fig. 16 to determine this value.
5) Determine R_{We}. Divide the corrected value for R_{mf} by the ratio R_{mf} / R_{We} value.
6) $R_{We} = R_{mf} / (R_{mf} / R_{We})$.
7) Correct R_{We} to R_W by using Fig. 17 and the value of R_{We} in step 5 to determine the correct value of R_{We}.
8) The saturation of water is then determined with the help of the following formula: $S_W = (R_W / Ø^m * R_t)^{1/2}$
9) The saturation of hydrocarbon at a given depth can be determined with the help of the following equation $S_H = 1 - S_w$

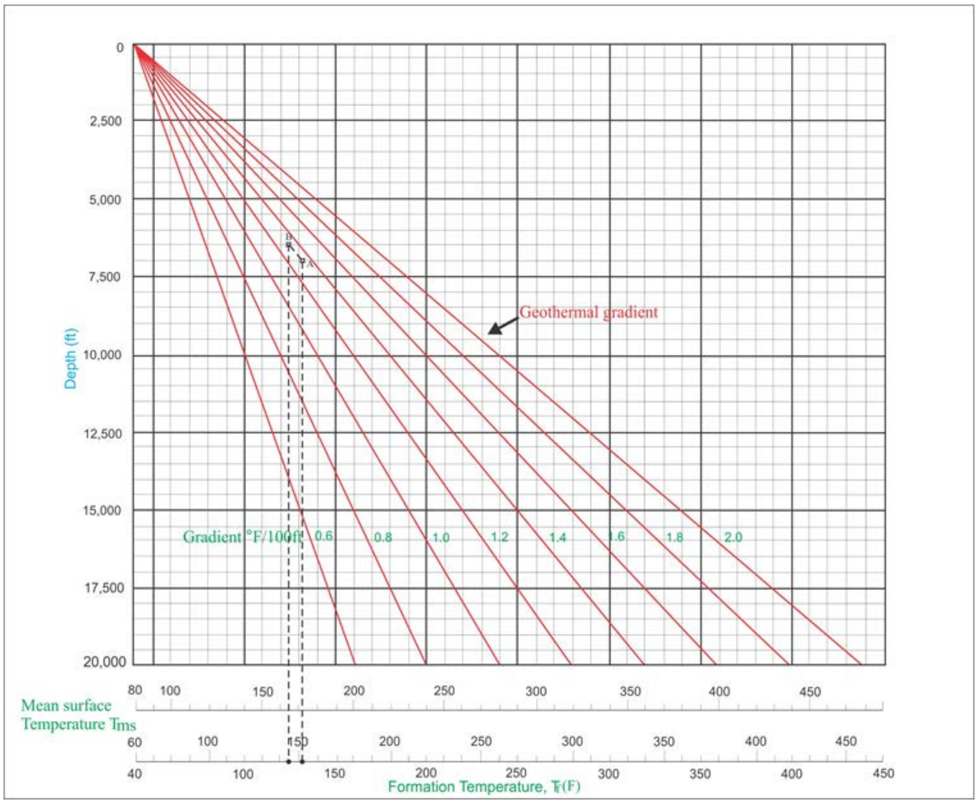

Fig. 14. Determinations of formation temperature through various depths (Schlumberger, 1977).

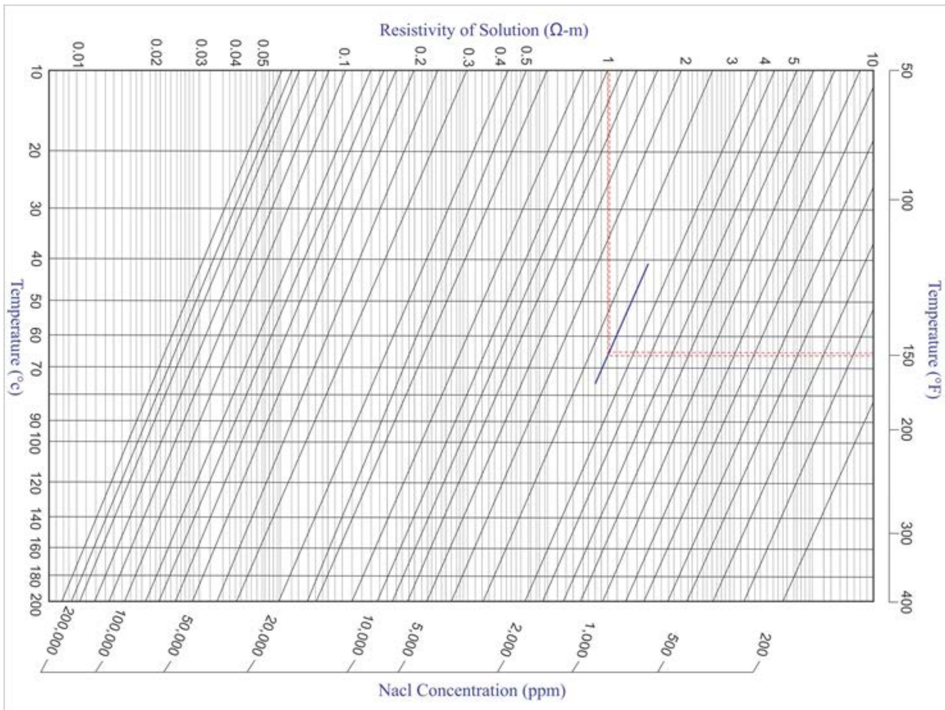

Fig. 15. Correction of R_{mf} and R_{we} according to temperature (Schlumberger, 1977).

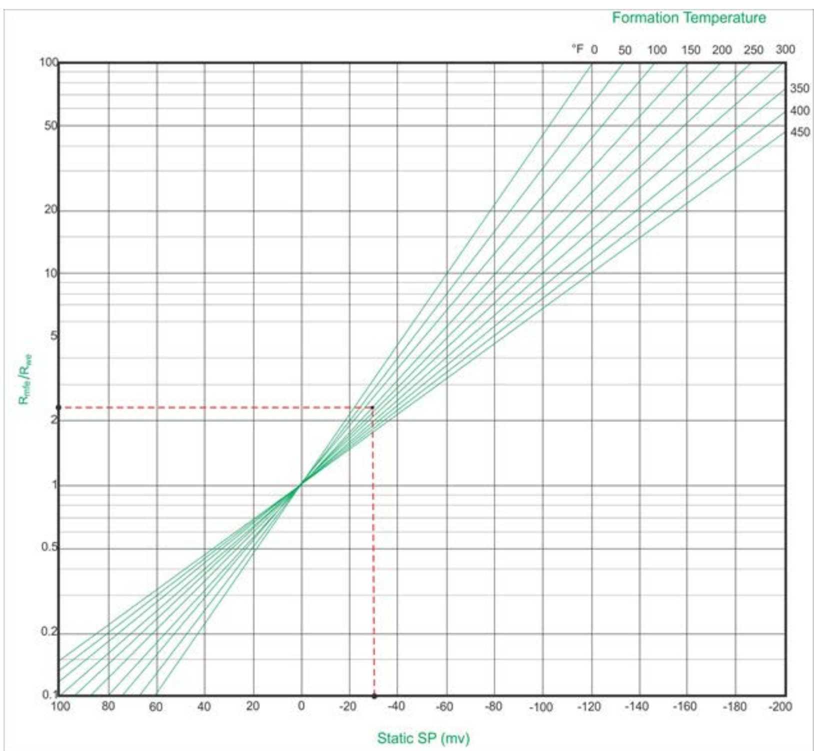

Fig. 16. Determination of R_{mf} / R_{We} from spontaneous potential (Schlumberger, 1977).

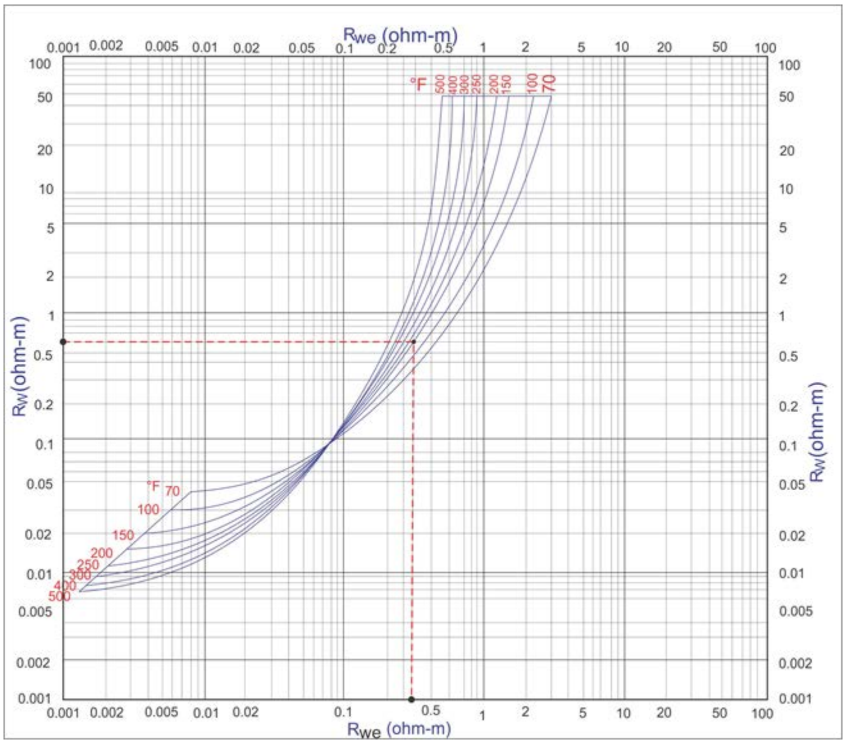

Fig. 17. Determination of R_W from R_{We} (Schlumberger, 1977).

11. Conclusions

1. The structure of the Joya Mair oil field is recognized as triangle zone in the subsurface and an open anticline at the surface. The triangle zone is formed by the combination of thrust and backthrust. The thrust and backthrust phases are the result of northwest and southeast successive Himalayan compression.
2. The thrust and backthrust of the triangle zone are found to be sealing on either side of the structure. The clays of the Rawalpindi Group act as a seal along these faults.
3. The reservoir rock is Sakesar Limestone that occurs at the depth of ~2023 m interpreted from seismic data.
4. The southeastern flank of the Joya Mair Triangle Zone has been exploited where the northwestern flank is untapped. It is therefore suggested that the northwestern flank of the triangle zone be drilled for further recovery of oil from the Eocene reservoir.
5. From the petrophysical analysis it is clear that the Minwal X-1 well is a hydrocarbon saturated well containing an average of about 78.75% oil in its pores spaces.

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