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# Prospect Generation Studies of Cretaceous Sands, Khipro Area by Integrating Seismic and Well Data

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## ABSTRACT

*Khipro block is located in southern Indus Basin, Pakistan. Khipro area possesses good hydrocarbon potential, which is confirmed by several oil and gas discoveries in this area. This research paper is focused to delineate the subsurface structures favorable for hydrocarbon accumulation and remaining reservoir potential through integrated seismic structural analysis and petrophysical interpretation of Naimat Basal-01 and Siraj South-01 wells. Seismic structural interpretation confirms the normal faulting, in which elevated horst blocks are providing suitable trap for hydrocarbon accumulation. Mapping at Basal and Massive Sands level revealed that the existence of two compartments at reservoir level. The southwestern compartment is relatively shallower and has a great potential for future hydrocarbon explorations, as compared to northeastern compartment. Low shale volumes, good porosity values and high hydrocarbon saturation prove Massive Sands as a good reservoir in both wells.*

**Keywords**: *Porosity maps, Horst and graben, Basal Sand, Isopach maps*

## 1. Introduction

The Lower Indus Basin of Pakistan is enriched with oil and gas resources and has a proven petroleum system. A significant amount of gas has been trapped within the conventional reservoirs. More advanced techniques are required to explore these conventional reservoirs. This research paper is focused on the prospect generation studies of Cretaceous sands of Khipro area. The Khipro block is situated in southern Indus basin, which is part of Sindh Province, Pakistan as shown in Fig. 1. Khipro block, administratively falls in Sanghar District, which is situated 35 Km from Mirpur Khas in north with approximate same distance from Nawabshah. Fourteen wells had been drilled in Khipro area and half of them turned out as prospect for hydrocarbon generation. The current study is focused on evaluating the reservoir potential of Cretaceous sands by an integrated approach.

A correlation between the results of structural, petrophysical and reservoir analysis has been established, which is considered an accurate way to cross check the hydrocarbon potential of reservoirs in the absence of geochemical and core data. The integrated technique is also helpful in reducing the drilling risks. The concession block with highlighted one (khipro) along with other blocks is shown in Fig. 2.

## 2. Geology of the Area

Khipro is situated in Thar Platform, Lower Indus basin, which is the major producing basin of Pakistan. In this area extensional regime structures like horst and graben lies beneath the unconformity present in the in the Paleocene

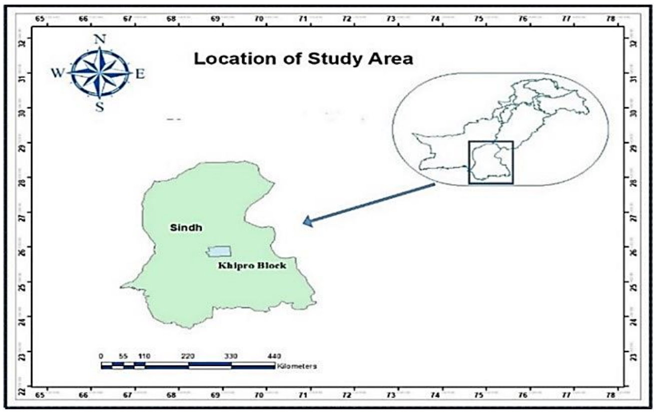

Fig. 1: Location map of study area generated in ARC GIS.

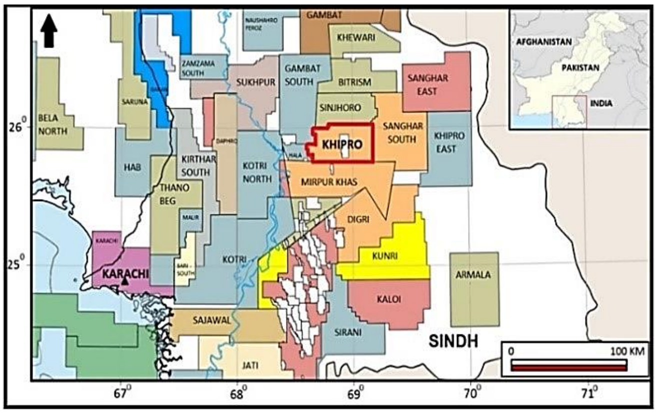

Fig. 2: Concession block of Khipro (Pakistan Petroleum Information Service (PPIS)).

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age [1]. These structures are the results from the reformist rifting of the Indo-Madagascar plate. The Sembar Formation of Lower Cretaceous age was deposited under restricted circulation which belongs to the initial phase of development of this rifting system. The cretaceous sands of the Lower Goru formation are oil producing in this area [2].

In Lower Indus Basin, the Sembar Formation and Basal shales of Lower Goru Formation are acting as major source rocks [3]. With further progression in the rift system, at mature half Graben stage, formation of tilted fault blocks over the Thar slopes are resulted due to this tectonic extension phenomenon [4]. During this rift system development, the lithosphere underwent reformation causing subsidence and then uplifts [5]. As a result, extensional regime structure comprises of a normal fault blocks on the west dipping Indus Plain, came into existence. The Lower Goru Formation is structurally bounded by regional normal faults, trending in NW-SE direction and dipping to the east which helped in the entrapment of hydrocarbons [6].

Khipro concession area extends towards north-south throughout the length of Indus River and down from Khairpur-Jacobabad High to Arabian Sea. Thar Slope Platform lean westward and northwestward, where basin is lucrative for hydrocarbon exploration [8]. This study area from its regional tectonic perspective, is confined by Indian Shield from east, Kirthar fold belt from west, Karachi Trough from south and Mari-Bugti Inner Folded Zone from north as shown in the basin architecture of Southern Indus basin [9, 10] (Fig. 3). After Paleocene time, the steady oblique convergence of Asian with Indian plate caused the tilting of this whole region [11, 12] (Fig. 4).

The oldest Formation drilled in Khipro belongs to Jurassic age that is the Chiltan Formation. This Formation is overlain by Lower Cretaceous age, Sembar and Goru Formations [13]. The Lower Goru Formation lies on the Sembar Formation. The Upper Goru Formation unconformably enwrap the Lower Goru Formation and consists of marl and calcareous claystone [14-16]. The generalized stratigraphic column of the southern Indus basin is shown in Fig. 5; while the borehole stratigraphy of the both wells is shown in Figs. 6 (a, b).

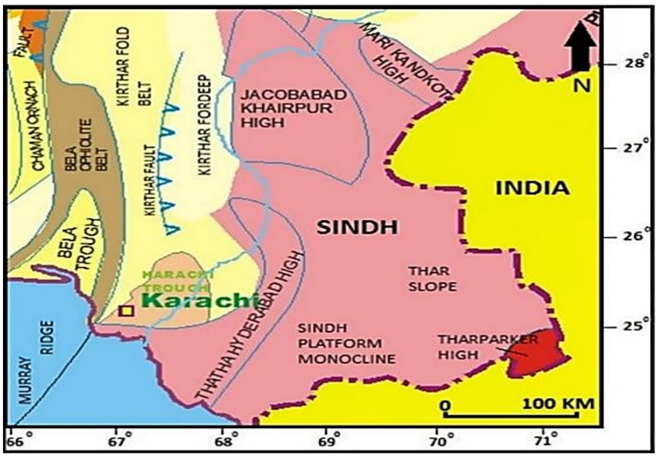


Fig. 3: Basin architecture of the Southern Indus Basin [9].

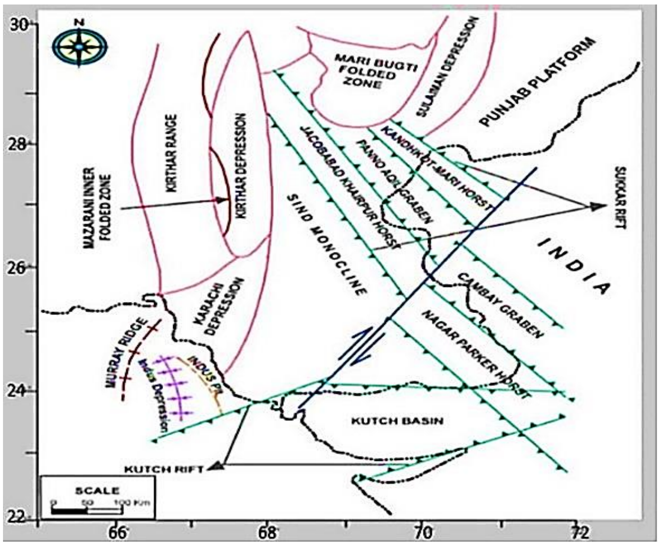
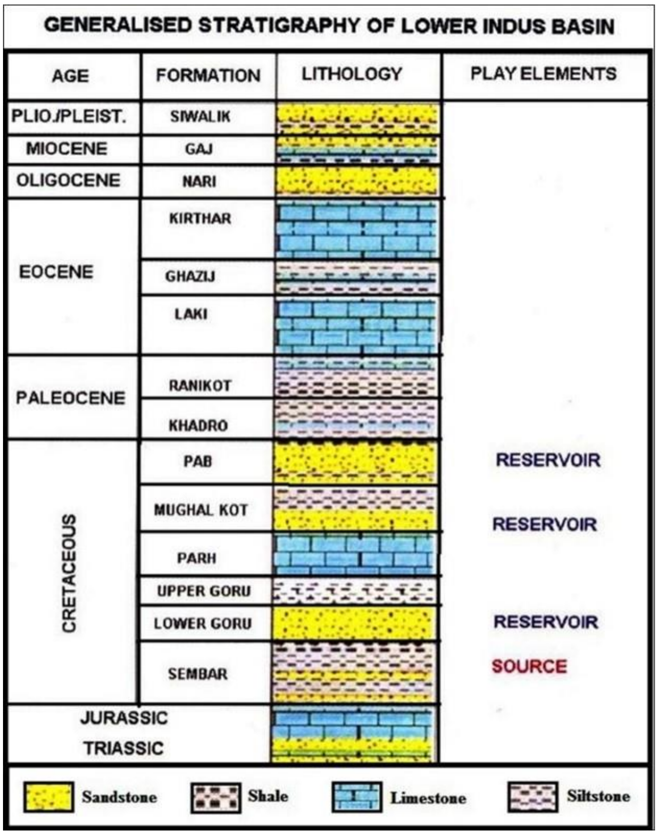


Fig. 4: Tectonic setting of Lower Indus Basin [7].



**GENERALISED STRATIGRAPHY OF LOWER INDUS BASIN**

| AGE | FORMATION | LITHOLOGY | PLAY ELEMENTS |
|---|---|---|---|
| PLIO./PLEIST. | SIWALIK | | |
| MIOCENE | GAJ | | |
| OLIGOCENE | NARI | | |
| EOCENE | KIRTHAR | | |
| | GHAZIJ | | |
| | LAKI | | |
| PALEOCENE | RANIKOT | | |
| | KHADRO | | |
| CRETACEOUS | PAB | | RESERVOIR |
| | MUGHAL KOT | | RESERVOIR |
| | PARH | | |
| | UPPER GORU | | |
| | LOWER GORU | | RESERVOIR |
| | SEMBAR | | SOURCE |
| JURASSIC | | | |
| TRIASSIC | | | |

Sandstone Shale Limestone Siltstone

Fig. 5: Basin architecture of the Southern Indus Basin [14].

## 3. Materials and Methods

To carry out the present research, eight 2D seismic lines including two strike and six dip lines along with complete log suits of two wells have been utilized, as shown in the base map (Fig. 7). Naimat Basal-01 well was drilled near the intersection of seismic lines 2000-KH-08 and 2003-KH-35 with a total depth of 3621.6 m. While the Siraj South-01 well was drilled on seismic line 2003-KH-39 close to 330 shot point with a total depth of 3218.5 m.

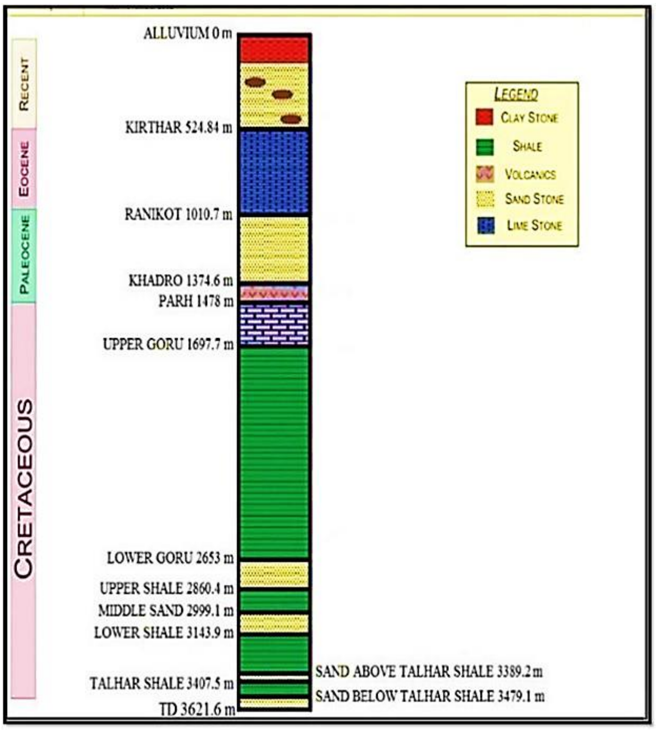


Fig. 6a: Borehole stratigraphy of Naimat Basal-01 (courtesy by LMKR).

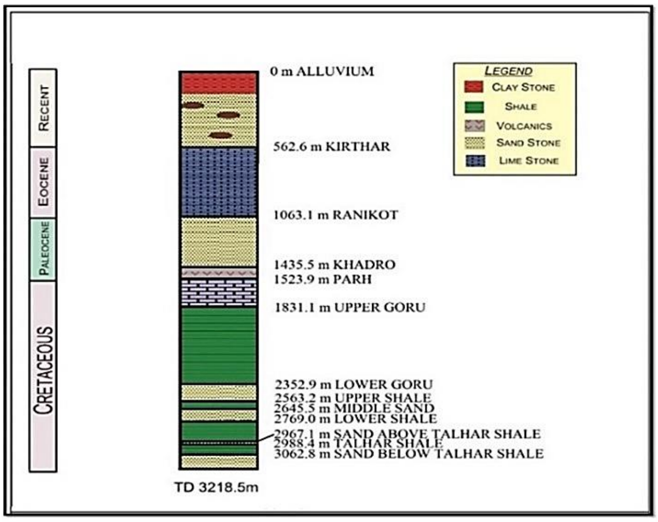


Fig. 6b: Borehole stratigraphy of Siraj South-01 (Courtesy by LMKR).

This research is carried out to enhance and visualize the prospective zones of Basal and Massive Sands of Lower Goru Formation in Khipro block for hydrocarbon exploration. To accomplish the desired output; following methodology has been adopted to relate the reservoir properties of sands. The targeted reservoir horizons that is Basal Sands and Massive Sands were marked with the help of synthetic seismogram. On the seismic reflection profiles, the normal faults are established on the basis of discontinuities present in reflections patterns. Then time and depth mapping were done after average velocity calculation. Petrophysical analysis of both the wells was done by using different types of standard cross-plots and mathematical charts to evaluate the hydrocarbon potential and physical characteristics of the reservoir formations. Litho-stratigraphical correlation is done to observe the thickness variations and depositional environments of reservoir sands. Thickness variations are further studied by carrying out isopach mapping. Lateral and vertical variation of porosity in reservoir sand is predicted with the help of seismic data, which is calibrated with the well data, for accuracy of results.

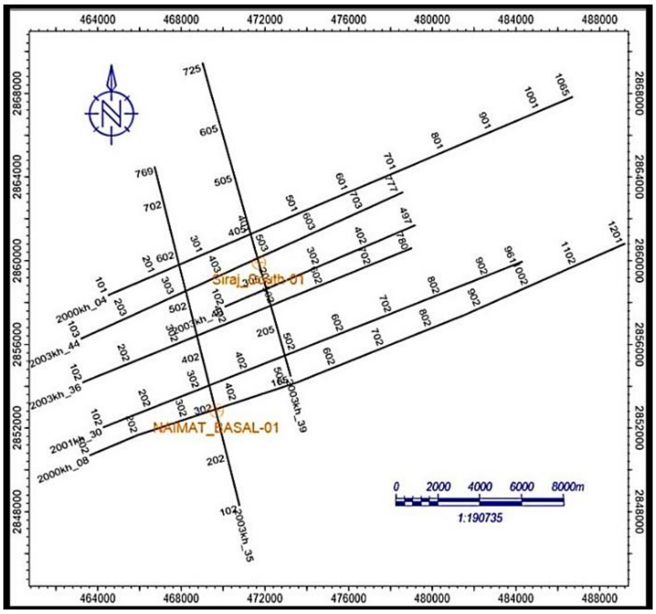


Fig. 7: Base map of study area (Generated on Kingdom Software).

First of all, the synthetic seismograms of Siraj South-01 (Fig. 8) and Naimat Basal-01 (Fig. 9) were generated using the sonic and density logs of both wells. These synthetic seismograms are then correlated on their respective seismic profiles to identify Basal and Massive Sands.

## 4. Interpretation of Seismic and Well data

### *4.1. Interpretation of Seismic Lines*

Seismic data interpretation relies both on the well data as well as structural information, which help to better understand and interpret subsurface structural features [17]. The reflection pattern is a combination of polarity, amplitude and waveform. It represents the physical properties (geological properties) lies at the top and beneath the reflecting interference [18, 19]. On the basis of reflection patterns geoscientist becomes able to understand the variations in the [20] nature of the rock lithologies about their type and features.

Based on the discontinuities present in reflections time, steeply dipping normal faults have been identified and marked on the seismic sections forming horst and graben structures starting from the Late Cretaceous to the Paleocene age. Negative flower structures are observed on high resolution seismic profiles of the study area. Throw of faults are comparatively high at cretaceous level as compared to Jurassic. The heaves of the faults become more prominent on the north-east side of seismic lines due to the gentle dip of the faults. Normal faulting has been interpreted on the available seismic sections (Figs. 10 and 11). The age of extensional event in the area that resulted normal faults is identified as Paleocene because these faults are extending up to Paleocene time. Root Mean Square (RMS) velocities have been computed for all the seismic lines by averaging out all the velocity information provided on each seismic line. The smooth trend line is obtained showing there is not much velocity variations in the area (Fig. 12).

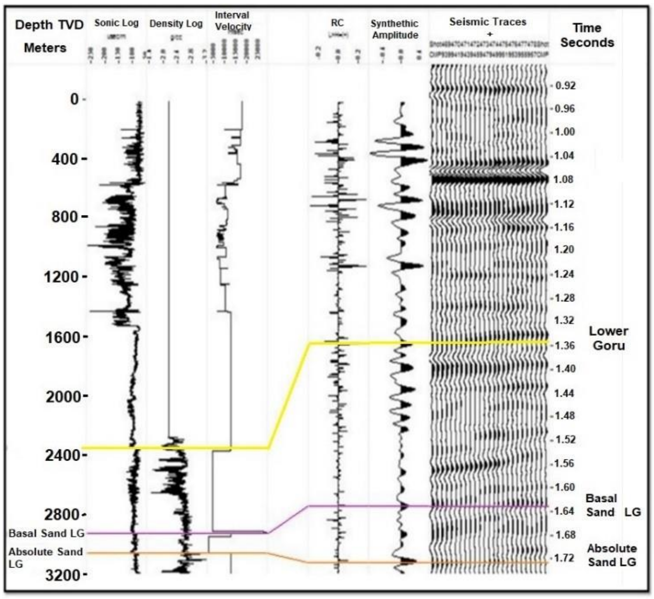


Fig. 8: Synthetic seismogram generated using well data of Siraj South-01 showing the time of different formations for control line 2003-KH-35.

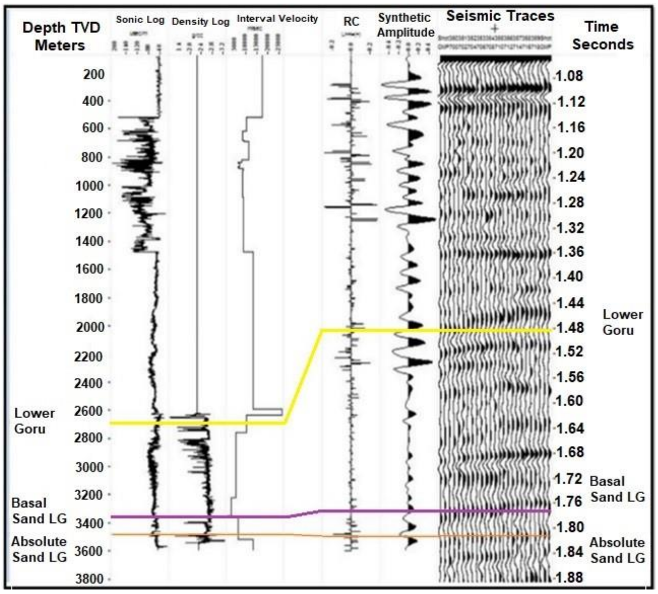


Fig. 9: Synthetic seismogram generated using well data of Naimat Basal-01 showing the time of different formations.

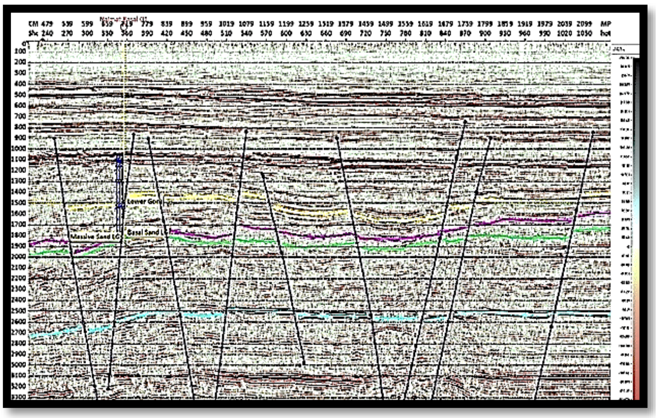


Fig. 10: Interpreted section 2000-KH-35.

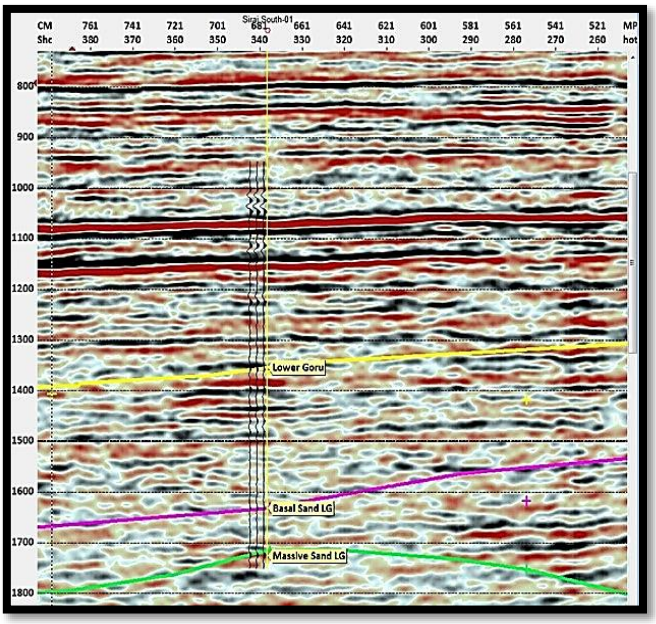


Fig. 11: Time vs RMSs velocities graph.

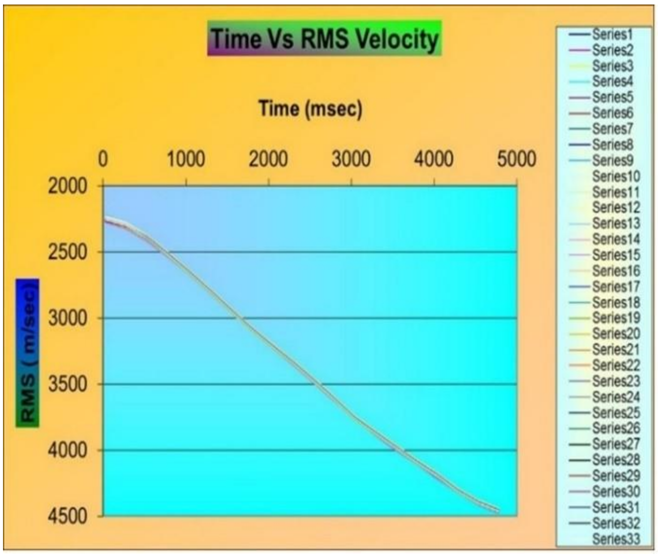


Fig. 12: Time vs RMSs velocities graph.

### *4.2 Time and Depth Contour Maps*

Mapping of Basal and Massive sand is carried out, as displayed in Figs. 13-16. Contour interval for time maps is kept as 20 milliseconds (msec) while for depth it is 25 meters. Little smoothing factors have also been taken in to account to smooth the contours. Nine normal faults are interpreted in all contour maps, justifying horst and graben geometries which are the potential zones for the presence of hydrocarbons. These faults bear very prominent throw ranges from 20 to 70 milliseconds, while at some levels it is much less. Contour maps show some very promising closures. The contour values decrease from South-West to North-East direction indicating that these formations are becoming shallower towards North-East direction. A uniform trend of heaves pattern, along all the faults, is observed on all the available seismic lines. A profound closure is present at the middle part of the contour maps that forms a horst block and shows the shallower surface, which may be the potential zone for the upcoming wells locations. Time contour map at Basal Sand shows the average time range between 1490 msec to 2000 msec while it is 1700 msec to 3000 msec for Massive Sands. The depth contour maps show the depth ranges from 2100 m to 3400 m and 2800 m to 3600 m for Basal and Massive sands, respectively. On the basis of contour maps, two different structural compartments are identified which are separated by horst and graben features. One structural compartment was identified at the north-northeast and the other at south-southwest direction.

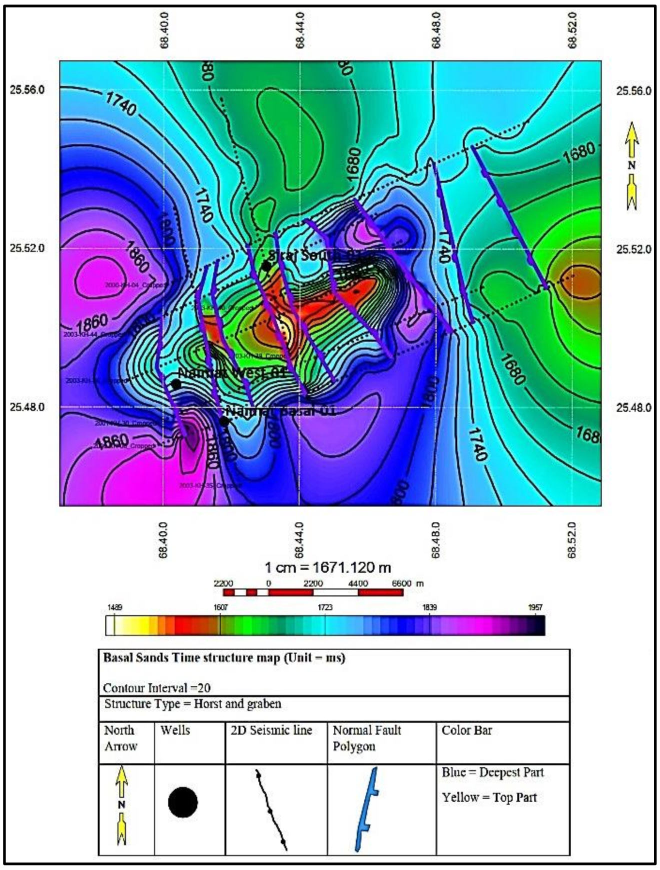


Fig. 13: Time contour map of basal sands.

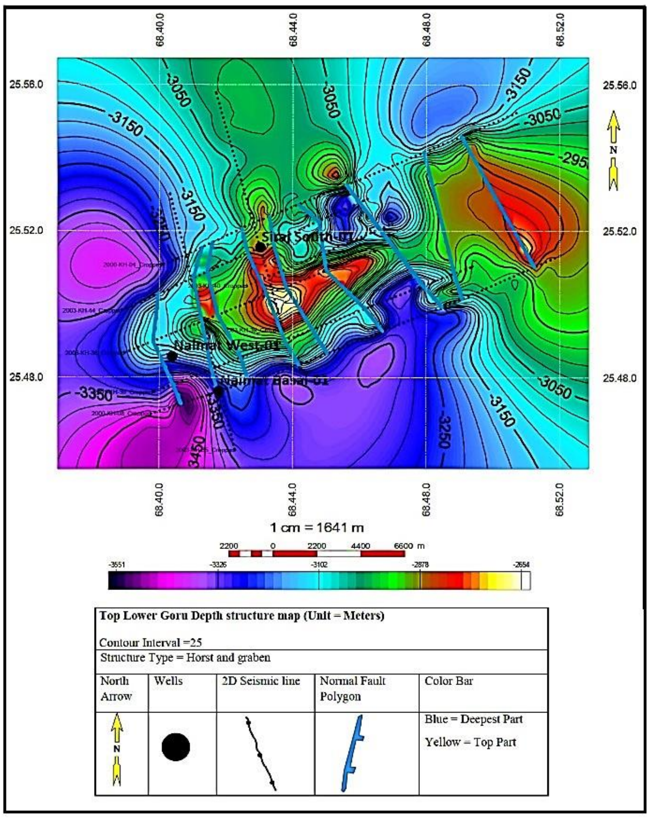


Fig. 14: Depth contour map of basal sands.

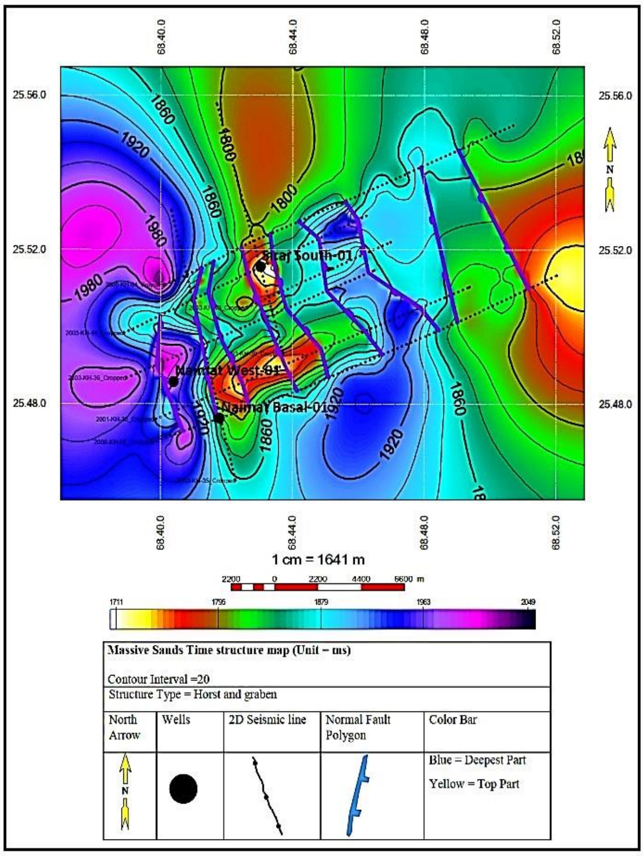


Fig. 15: Time contour map of massive sands.

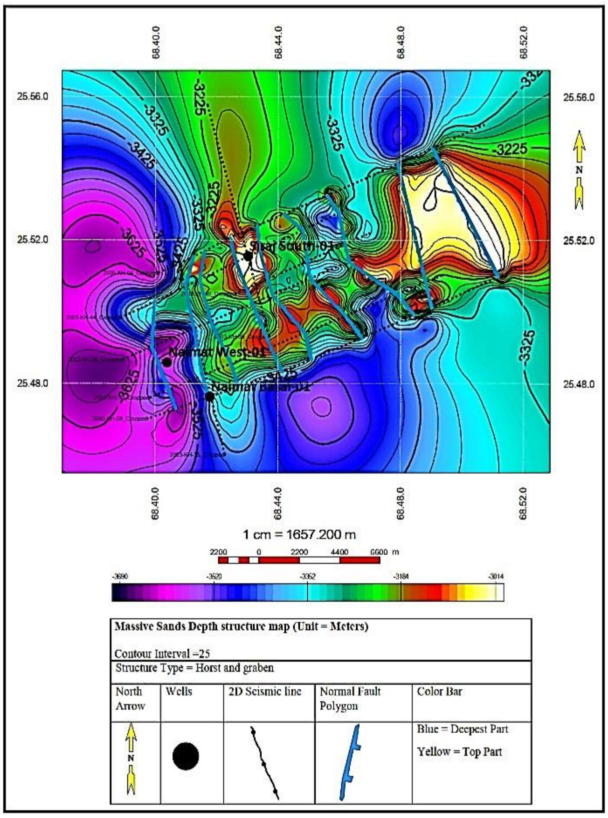


Fig. 16: Depth contour map of massive sands.

## *4.3 Well Logs Interpretation of Siraj South-01and Naimat Basal-01*

Petrophysical analysis has been performed for the both wells. One reservoir zone in each well has been marked within the Massive Sands of Lower Goru Formation. Based on log curve trends zones of interests are identified in reservoir sands. The low values of gamma ray log, separation between the MSFL and LLD resistivity curves and N-D crossover have been identified on different intervals which show the potential hydrocarbon bearing zones. The zone in the wells have been highlighted in Figs. 17a and 17b.

The zones have thicknesses of 4.8 m and 8.0 m in Siraj South-01 and Naimat Basal-0 wells, respectively. The basic Petrophysical properties which have been determined within the Massive Sands include the volume of shale, volume of clean (Sandstone), average porosity and effective porosity.

Table 1: Results of petrophysical interpretation.

| Zone | Naimat Basal-01 | Siraj South-01 |
|---|---|---|
| Top MD (m) | 3539 | 3115.2 |
| Base MD (m) | 3547 | 3120 |
| Thickness (m) | 8 | 4.8 |
| Avg. Vshl (%) | 8 | 8 to 10 |
| Avg. PHIE (%) | 12 to 15 | 10 to 16 |
| Avg. Sw (%) | 20 to 25 | 20 to 30 |
| Avg. Sh (%) | 75 to 80 | 70 to 80 |

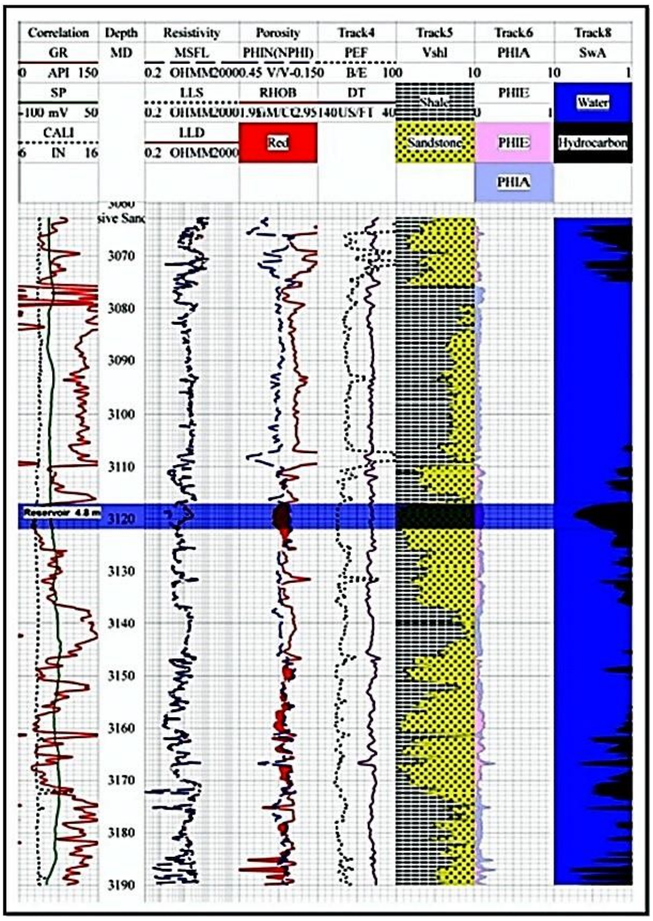


Fig. 17a: Well Log interpretation of Siraj South-01.

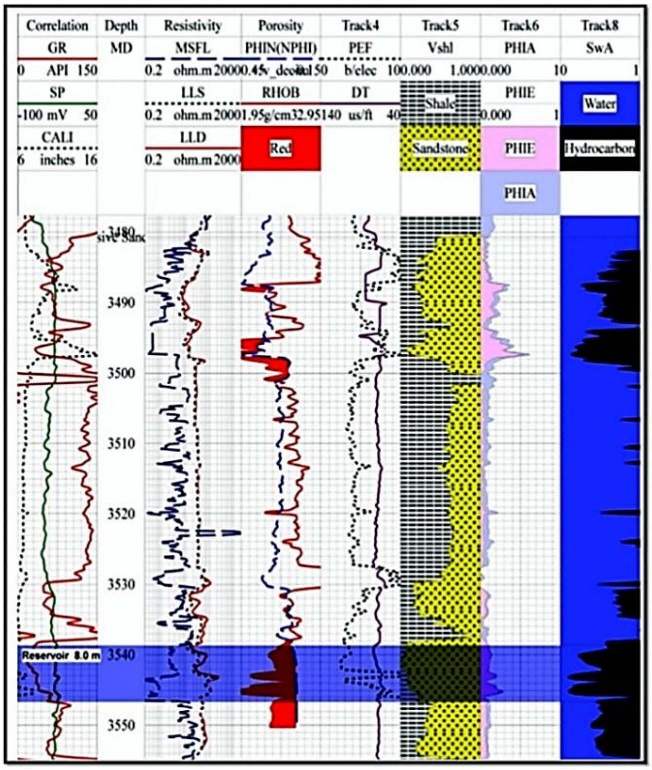


Fig. 17b: Well log interpretation of Naimat Basal-01.

Track 5 presents the calculated volume of shale; average and effective porosities are given in track 6, whereas track 8 gives the calculated results of fluid saturation within the reservoir interval of interest (Figs. 17a and 17b). In the Siraj South-01 well, the pay zone starts from 3115.2 m to 3120 m, where the average shale volume ranges from 8% to 10%. Whereas**,** this interval shows relatively good porosity values in the range of 10% to 16%. The high values of LLD and separation between LLD and LLS suggested that it bears good amount of hydrocarbon which ranges from 70% to 80% which make it a good reservoir zone (Table 1).

In the Naimat Basal-01 well, the net reservoir zone is 8m thick, starts from 3539 m to 3547 m. Here the average volume of shale is 8% and bears good porosity values in the range of 12% to 15%. The low values of water saturation suggested that it comprises of good quantity of hydrocarbons, which is confirmed through the amount of hydrocarbon saturations that ranges from 75% to 80%.

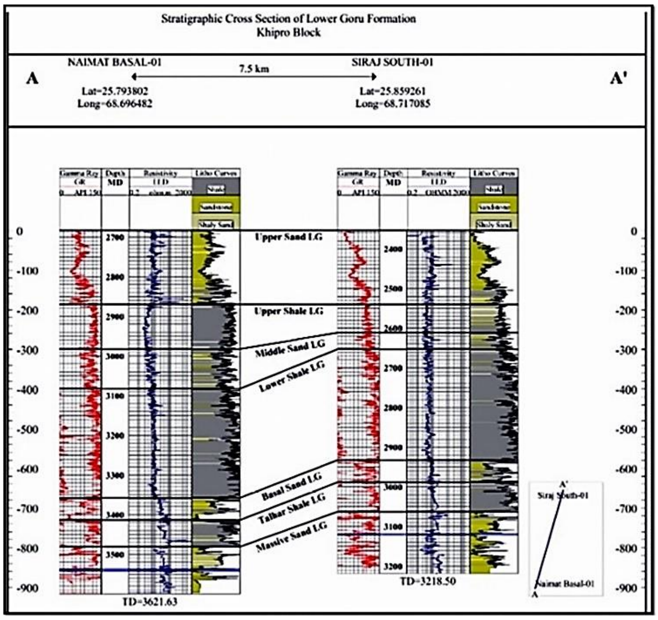


Fig. 18: Stratigraphic correlation of Khipro wells.

Stratigraphic correlation has been done between Siraj South-01 and Naimat Basal-01 wells. In the index map, it is clear that Naimat Basal-01well is lying on the southern side of the Siraj South-01 well. For stratigraphic correlation, wells have been hanged at the topmost shales of Lower Goru Formation. From the well correlation, it is observed that the formations are getting deeper in Naimat Basal-01 as compared to the Siraj South-01 (Fig. 18). Therefore, we can say that Naimat Basal-01 is lying distal ward (basin ward) while Siraj South-01 is closer to source area. Middle sand is thinning from south-west to north-east.

### 4.4 Isopach Mapping

Isopach map shows the variation in thickness of the different formations; these are calculated by subtracting the top formation from top of the next successive formation. Isopach map of Massive Sands were generated (Fig. 19). Isopach map of Basal Sands showed minimum thickness near the center. Contour interval was 50 m while minimum and maximum thickness was ranging from 150 m to 900 m. The map showed maximum thickness at south west, indicating that the depocenter was towards south west at the time of deposition.

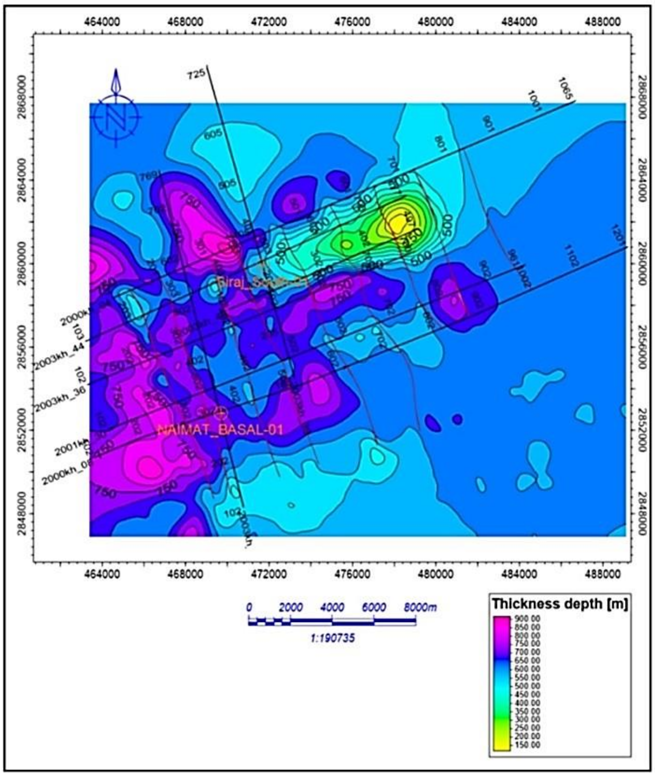


Fig. 19: Isopach map of massive sands.

### 4.5 Porosity and Net to Gross Map

The variation in sand thickness has great influence on the porosities. It can be clearly observed from porosity and net to gross ratio maps (Figs. 20a and 20b) that porosities are decreasing with the decrease in thickness. Porosity of the two wells at reservoir is calculated and then contoured. Porosity calculated at level of Massive Sand clearly depicted the increasing trend from north to south (Fig. 20a). Average porosity of reservoir sands at Naimat Basal-01 is 15%, while it is 10% at Siraj South-01. Net to Gross map was also generated (Fig. 20b); the amount of sands present in the reservoir is 30% in Naimat Basal-01 and 35% in Siraj South-01. Net to Gross ratio of pay thickness is increasing towards North.

### 4.6 3D Modeling of the Area

3D cross sectional views of Jurassic and Cretaceous horizons along with the faults orientations and their respective wells have been generated to understand the subsurface geometrical variations and are shown in Figs. 21a and 21b. In the generated models, the Cretaceous formations (yellow colour interval) were taken as a single unit and the horizontal plane of both, Cretaceous and Jurassic, were interpolated according to depth contour maps of the formations.

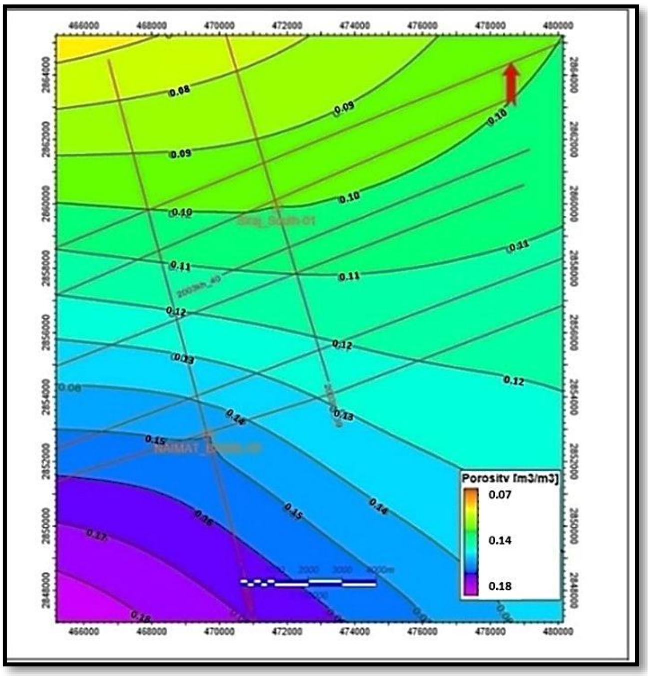


Fig. 20a: Porosity map of the area.

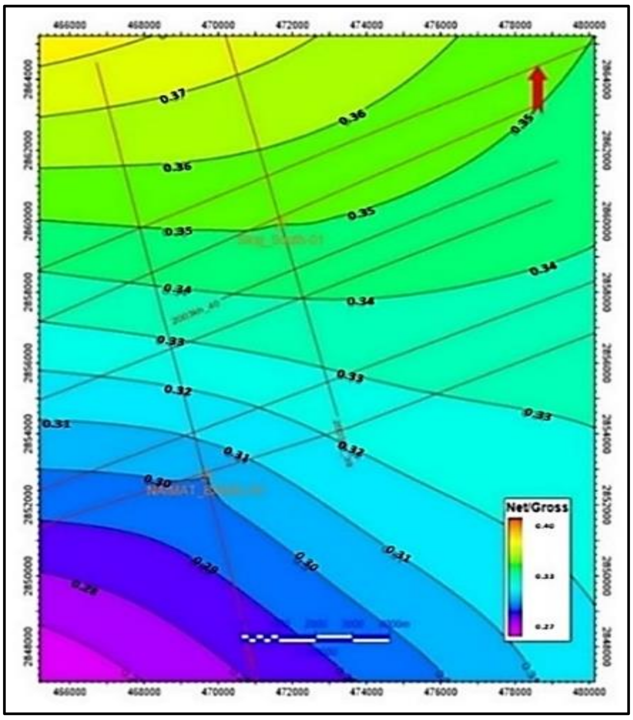


Fig. 20b: Net to gross thickness map of the area.

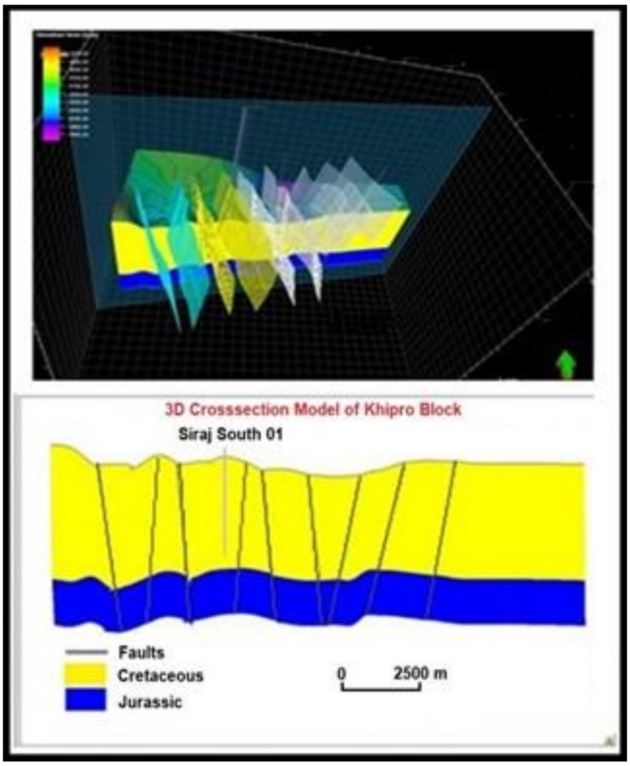


Fig. 21a: 3D cross section model showing Siraj South-01.

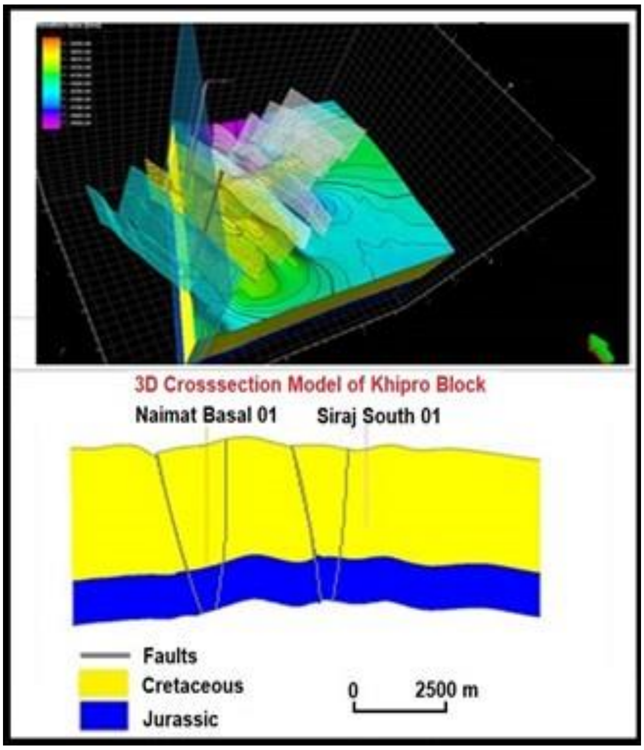


Fig. 21b: 3D cross section model showing Naimat Basal-01.

## 5. Results and Discussion

Khipro lies in the extensional regime having horst and graben structures. Shales of Sembar Formation act as source rock; whereas, Basal and Massive sands of Lower Goru Formation act as reservoirs. Shales and Marls of Upper Goru Formation act as seal rocks. Correlation of Naimat Basal-01 and Siraj South-01 showed that the thickness of the Cretaceous formations decreases towards north. There might be a chance that shales of Upper Goru Formation may not be acting as seals in the northern side of this region because of its decreased thickness. More thickness towards south-southwest also indicated that the depocenter lie towards south-southwest of this area during Cretaceous times. This depocenter shifted later towards north-northwest after Cretaceous time, as shown in the correlation of wells. The faults are younger than Lower Goru Formation, as appreciable disturbance can be observed above that level; which is quite evident through seismic interpretation. Therefore, the age of these normal faults can be estimated to be middle or late Paleocene.

In the Khipro area, minor seismic velocity variations are observed that indicate a relative homogeneous lithology with less structural variations. Time and depth contour maps confirmed the orientation of dips and areal extents of structures in the subsurface. Two distinctive compartments, north-northeast and south-southwest were quite evident through time and depth maps at Basal and Massive Sand levels. The north-northeast compartment resides at greater depths as compared to south-southwestern compartment.

The petrophysical analysis of Naimat Basal-01 well shows promising hydrocarbon potential zone at depths ranging from 3539 m to 3547 m along with the presence of porous sands that are indicated by neutron and density logs at these depths. Similarly, in Siraj South-01 well hydrocarbon bearing sands are present at depths ranging from 3115.2 m to 3120 m. Isopach maps at Massive Sands levels indicate that the sand thickness is increasing in south-southwest direction, signifying the presence of depocenter. Porosity at reservoir level is increasing towards north as demonstrated through the porosity map. Further validation is provided by the Net to gross thickness map which showed increase percentage of sands towards north direction. The trends of Cretaceous and Jurassic rocks, and the faults displacing these rocks were in conformance to the above statement, depicted through 3D modeling.

## 6. Conclusions

Stratigraphic correlation of Khipro wells show that the thickness of Upper Goru Formation is decreasing towards north and the thickness of Paleocene and recent formations is increasing in north direction. Time contour maps of Basal Sands and Massive Sands show that there are two compartments. The south-southwestern compartment is showing shallow time values and the north northeastern compartment is showing higher time values. The logs at sands show the presence of porous sands and indicate the presence of hydrocarbons. The porosity and Net to Gross ratio is increasing towards north. While 3D modeling of the area shows that the both wells, Naimat Basal-01 and Siraj South-01 are drilled on horst structures.

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