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Seismic Data Interpretation and Fault Mapping in Badin Area, Sindh, Pakistan

A. MUNIR, S. ASIM++, S. A. BABLANI*, A. A. ASIF**

Department of Earth Sciences, Quaid-i-Azam University, Islamabad, Pakistan

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Abstract: The purpose of this research is to study structural variations of subsurface using seismic and well log data of Badin area. 2D seismic reflection data of ten lines after correlation with five wells of the area reveal that extensive structural and depositional changes have occurred as a result of major & minor tectonic events. Seismic interpretation confirms Horst & Graben geometry in the studied area. Grabens are main areas for generation of hydrocarbons. Primary structuring is defined by structural style at Middle Sand level. Compensating faults are increased at shallower level (Top Lower Goru) due to variation in rock mechanics and applied forces. The variable throw at different levels describes structural evolution through the geological time. Contour maps in two way time and depth domain show faults having northwest to southeast trend in the studied area.

Seismic and well data is used to establish stratigraphic correlations of different wells in Lower Indus Basin and also to elucidate the source of sediments and depositional centers during different geological time periods. Structuring in the area provides basic elements of requirements of petroleum system as proven by number of oil and gas discoveries in the area. Faults act as conduits providing migration pathway from source to reservoir rock and seals in trapping mechanism for hydrocarbons.

Keywords: Seismic Interpretation, Fault Mapping, Badin.

1. INTRODUCTION

Study area is located in East of Badin district in Sindh province of Pakistan. The district is placed between 24° 5'N to 25° 25'N Latitude and 68° 21' E to 69° 20' E Longitude and is bounded on the North by Hyderabad district, on the South by Arabian Sea & Rann of Kutch, on the East by Mirpurkhas & Tharparkar districts and on the West by Thatta and Hyderabad districts **(Fig.1)**.

Exploration History

Exploration in the Lower Indus Basin started in 1939 by Burmah Oil Company (BOC) near Karachi. In 1948 second well was drilled on the Lakhra structure by BOC. Aeromagnetic surveys were conducted by Standard Vacuum Oil Company (SVOC) in 1955 and by Oil & Gas Development Company (OGDC) in 1962-63. Gravity surveys were carried out by SVOC in 1954-56, Sun Oil Company (SOC) in 1957-59, Pakistan Petroleum Ltd (PPL) in 1949 and 1956-60, Pak Hunt Petroleum Ltd in 1957-59, Tide Water Oil Company in 1959-60, OGDC in 1966-75 and Pakistan Texas Gulf in 1975. In May 1981, a joint venture of Union Texas Pakistan, Occidental of Pakistan Inc., and OGDC discovered oil at Khaskeli within the Badin Block. With this discovery, the Lower Indus Basin became the second largest oil producing sub basin of Pakistan, after Potwar (Afzal, 1996).

2. MATERIAL AND METHODS

2D seismic reflection & well data is obtained from Landmark Resources (LMKR) by permission of Directorate General Petroleum Concessions (DGPC) of Pakistan. Seismic data comprises of ten lines : PK85-0935 (Strike), PK92-1685 (Strike), PK85-0960 (Dip), PK85-KH04 (Dip), PK85-KH06 (Dip), PK86-1200 (Dip), PK86-1202 (Dip), PK92-1678 (Dip), PK92-1680 (Dip), PK92-1682 (Dip). Well top data of five wells : Nur-01, Rajo-01, Jabo-01, Jabo-05 & Doti-01 is also incorporated to endorse seismic interpretation. Base Map shows location and orientation of ten seismic lines **(Fig. 2).**

Structural Setting and Tectonic History

During Cretaceous, there was a period of tectonic instability. The spreading rate was high, ~20 - 30 cm/ a in 80 - 53 Ma (Gnos *et al.*, 1997; Mahoney, 1988; Farah *et al.*, 1984).

Badin Rift Basin is located in Thar platform area of Lower Indus Basin. It is the Sargodha High in fact which is considered to be a divide for Upper Indus Basin & Lower Indus Basin (Kadri, 1995). The Badin Rift is characterized by a series of horst and graben structures present below the base Tertiary unconformity within Cretaceous and older strata. These horst and graben structures were formed as a result of rifting

++Corresponding Author: Email: Shazia@qau.edu.pk, Cell: + 92 300 950 5000
* NREM, University of Kurdistan, Hewler, Iraq (s.bablani@ukh.ac).
**Oil & Gas Development Corporation Limited, Pakistan.

between India and Seychelles during the Late Cretaceous (Alam, 2002). The most significant styles seen are rifting, overprinted by shear modification and subsequently modified by doming. The major periods can be characterized as: Distal rift during the Late Jurassic & Early Cretaceous. Reactivation of Shear Modification during Middle Cretaceous. Inversion in Late Tertiary (Uplift and Doming).

Badin area was distal to main deformation locations in all three cases, and exhibits a provisional degree of deformation across the Badin. As a result the degree of deformation is relatively low, and progressively increases from East to West. The extensional tectonics during Cretaceous time created tilted fault blocks over a wide area of eastern Lower Indus sub-basin. Seismic reflectors, representing Cretaceous and older layers, are broken by a system of faults with normal dip separation. The Cretaceous faults generally strike between N 30^{o} W and N 50^{o} W (Kemal *et al.*, 1991). Commonly, faults are arranged in en-echelon sets, aligned in zones that trend almost north-south. The tilted fault block traps were in existence at time of hydrocarbon generation. Fault associated structural closures are responsible for trapping oil and gas in Lower Goru sandstone in Badin block. The under filling of structures can be attributed to upward leakage across extensive structures and redistributed hydrocarbon (Kemal *et al.*, 1991). Stratigraphy of Badin area is given in **Fig 2**. Numerous plays and prospects of hydrocarbon are associated with the Cretaceous system, consequently the Indus basin is attractive to petroleum exploration companies in Pakistan (Sheikh and Naseem, 1999).

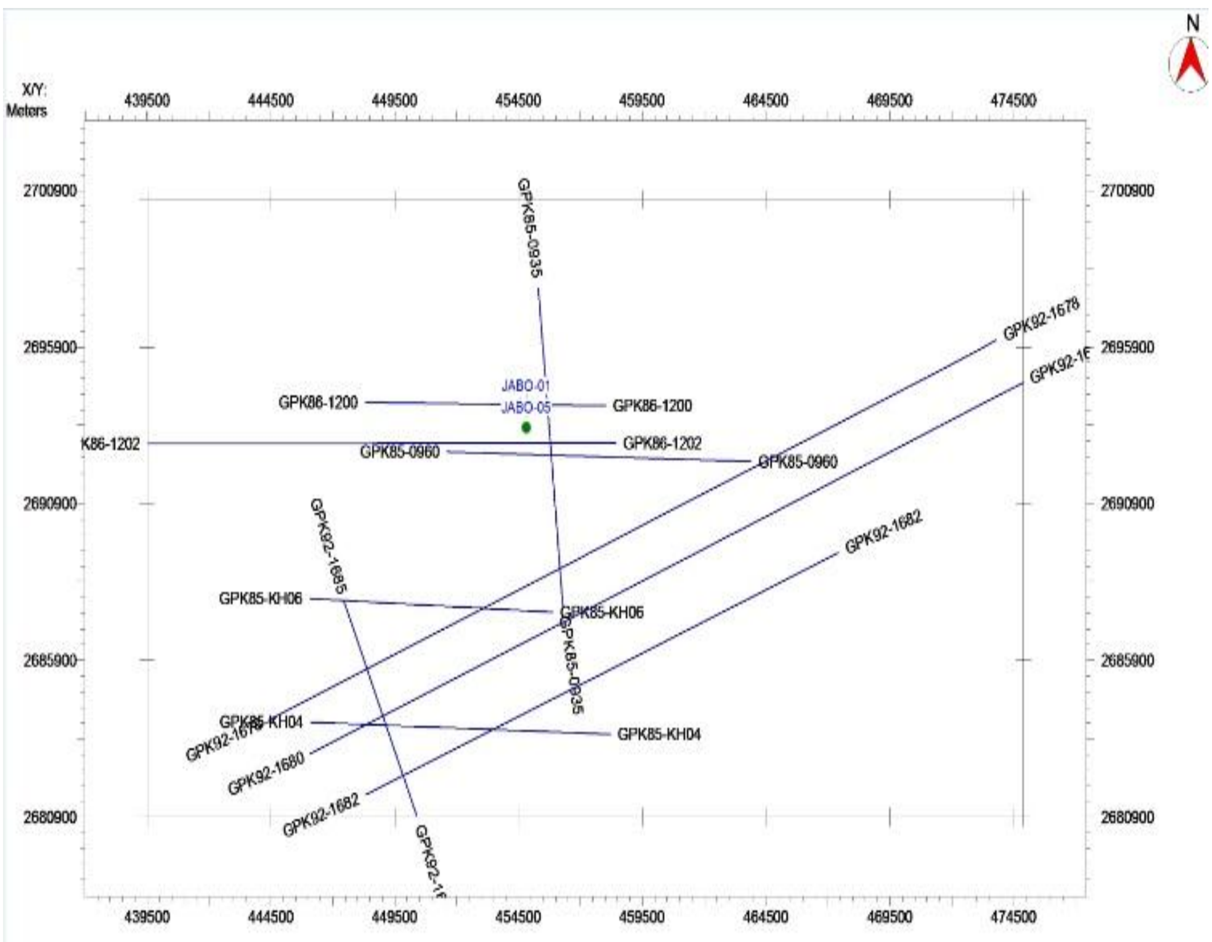

Fig. 1: Base Map of the Area, showing location & orientation of seismic lines

Well Correlation

In many basins, interpretation of well log data is primary method for development of a stratigraphic framework which can be used for mapping and prediction of reservoir intervals. Well log data is used to establish stratigraphic correlations of different wells in Lower Indus Basin and also to elucidate the source of sediments and depositional centers during different geological time periods. This helps in identifying the maximum thickness of zones of prospective formations in Lower Indus Basin and direction of sediments flow in Lower Indus Basin during different geological periods.

In Badin area, major cause of thickness variation is faulting. There are horst and graben structures in the area. The thickness variation in the lower Goru is mainly due to existence of faulting. Lateral facies change and differential erosion at the top lower Goru unconformity also contribute to strata thickness variation (Alam, 2002). It is clear from wells correlation **(Fig.4)** that thickness of cretaceous is increasing from Southeast to Northwest.

Structural Interpretation

Seismic is correlated with formation tops penetrated in wells using well velocities. Major faults were picked on dip lines and mapped to study structures throughout the area. Misties analysis is conducted on all four horizons: Khadro, Top Lower Goru (TLG), B Sand and Middle Sand. Misties are < 5 ms. Two way time maps are generated using fault polygons in order to define structural trends at different levels. Generally normal faults are extending in the NW-SE direction reflecting the extensional tectonics of the area **(Fig.5).** Comparing all maps horst and graben geometry is confirmed in study area **(Figs. 6-9).**

In defining the petroleum system of the area horst and graben geometry in dip lines is of primary importance. For generation of hydrocarbons, grabens are mainly kitchen area. High temperature gradient in graben also provides proper temperature for maturation of hydrocarbon. For generation of hydrocarbon, overburden in access as a result of subsidence providing sufficient pressure is required. The tilted fault blocks like a bookshelf as result of extensional forces facilitate petroleum system by providing migration pathway for hydrocarbons and Cross-faults seals to provide trapping mechanisms for hydrocarbon. For accumulation of hydrocarbon, horsts in this area are mainly providing traps. These traps are three way dip closures, two way dip closure against a main fault in center of a horst and kink door structures or Crotch traps (combination of one way dip and a small fault joining the main fault). The variable throw at different levels describes the structural evolution through geological time and smaller faults associated with main fault on dip lines (**Figs.6-9).** Primary structuring is defined by structural style at Middle Sand level. Compensating faults are increased at shallower level (TLG) due to variation in rock mechanics and applied forces. During deposition of Upper Goru, tectonic activity was active and Upper Goru deposition was being controlled by faulting as well. At the end of Upper Goru Tectonic activity was reduced remarkably. Moving from North to South, following features can be observed on dip lines related to horst and its bounding faults. Throw of main Dark Green & Purple Faults is greater at Middle Sand level as compared to Top of Lower Goru Level. This indicates that either fault movement was continued during time of deposition above Middle Sand level or faults were generated at early stage and were reactivated at a later stage due to subsidence because of overburden or a tectonic event at a later stage.

Looking below the Middle Sand level on all dip lines, it seems like a big roll-over which indicates some sort of transpression which is not reflected in faults. This might be a result of earlier inversion. It is very hard to describe this kind of geometry below level of Middle Sand on a regional scale in correlation with tectonic history of the area due to short length of seismic lines, and limited data.

Khadro and shallow portion have no indication of faults representing that tectonic event at the time of deposition of Khadro Formation or a later stage slowed down. Some minor faults are not visible on seismic, generated by later tectonic, which may be below seismic resolution. There is variation in dip of faults while crossing different lithologies. Dip angle of faults is mainly defined by competency of lithologies and force applied. Variation in dip angles on dip lines helps in understanding vertical & lateral variation in the lithology.

Deposition at all levels is believed to be from Southeast to Northwest direction. Best tool to determine direction of deposition is to flatten seismic section at a particular level observing thinning and thickening of strata under study. Flattening at Khadro Level indicates: Upper Goru level is thickening towards West indicating that Upper Goru has filled up accommodating surface in West which was created by basement high in East. Khadro is a regional geological event which has isolated effect of early tectonic activity from recent one. After deposition of Khadro, episodes of basin tilt are recorded. Main source of sediments is from East to West, but due to local tectonic events, depocenter kept on shifting in causing asynchronous thickening of Eocene formation as, Khadro is thick in West above Goru.

There is not only thickening of strata in West side but also there is uplifting of strata. As described earlier, Lower Goru and its sand units are deepening in West contrary to Khadro which is deepening in East. This is a major indication of change in basin tilt at a later stage after deposition of Khadro.

3. RESULTS AND DISCUSSION

Two Ways Time (TWT) & Depth maps are generated at Middle Sand Level **(Fig.10-15)** are generally deepening from East to West. Shallowest Contour Value is at Time 1.7 Second and at Depth 2320 meters whereas Deepest Contour Value is at Time 2.2 Second and Depth of 2340 meters. At B Sand Level contours are also deepening from East to West with Shallowest Contour Value of Time 1.4 Second and Depth 1842 meters. The Deepest Contour Value is having Time 1.9 Second and Depth of 2653 meters. Top Lower Goru (TLG) Level is deepening from East to West with shallowest Contour Value of Time 1.15 Second at Depth of 1480.4 meters and Deepest Contour Value of Time 1.67 Second at Depth 2199 meters.

4. CONCLUSIONS

Seismic data reveals that as a result of major & minor tectonic events, the study area has gone through extensive structural and depositional changes forming horst and graben structures at Lower Goru level (Cretaceous) whereas Khadro Formation (Eocene) is unaffected.

Structuring in the area provides basic elements of petroleum system. Grabens are main areas for generation of hydrocarbons while faults are providing migration pathway for hydrocarbons from source rock to reservoir rocks. Faults are also providing trapping mechanism for hydrocarbons. The main constituents of petroleum system are present as proven by number oil and gas discoveries in the area.

5. ACKNOWLEDGEMENT

Authors are thankful to Landmark Resources (LMKR) and Directorate General Petroleum oncessions (DGPC) for providing seismic data of the area.

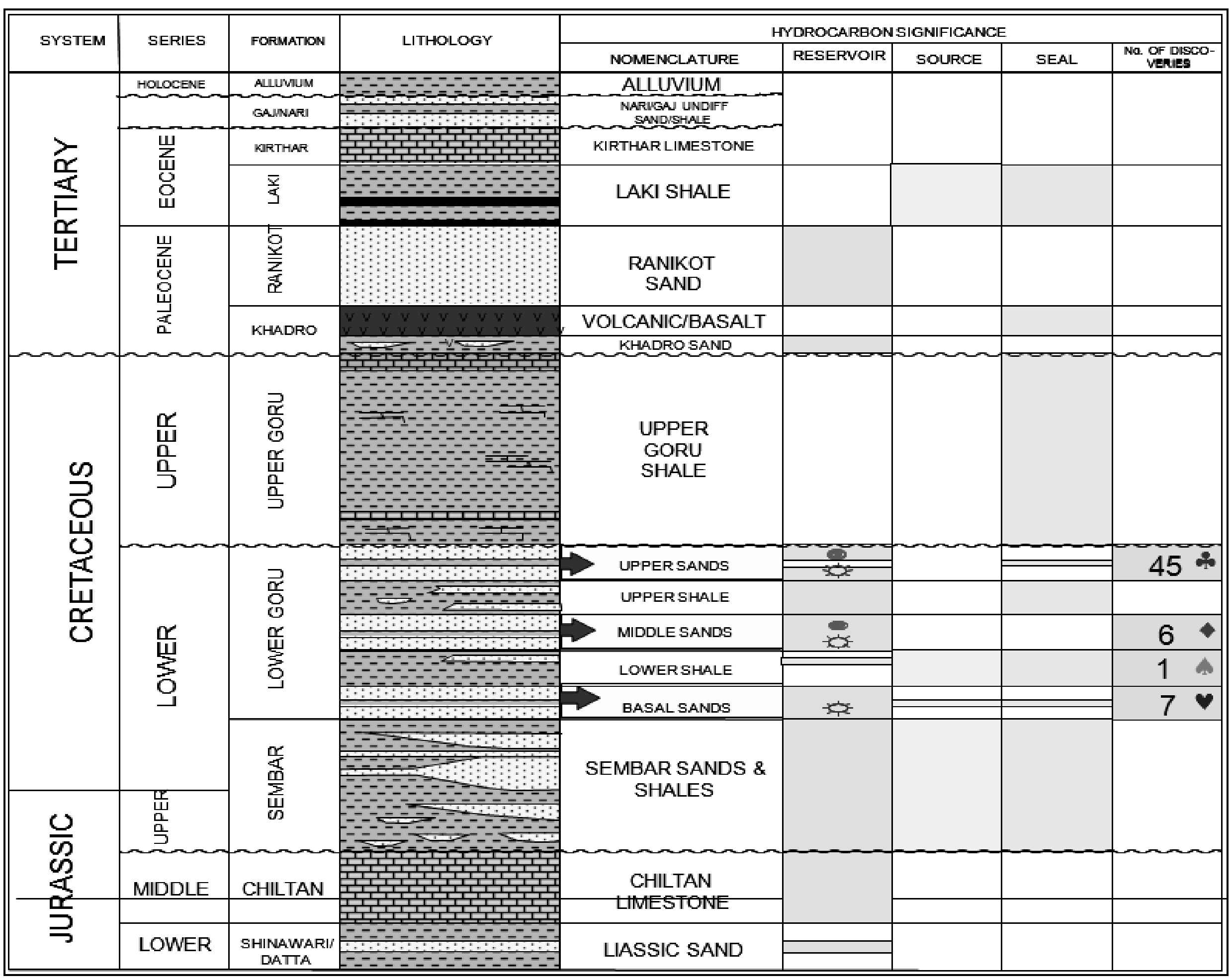

Fig.2: Generalized Stratigraphic Column and Petroleum System of Badin area (Courtesy GPXP).

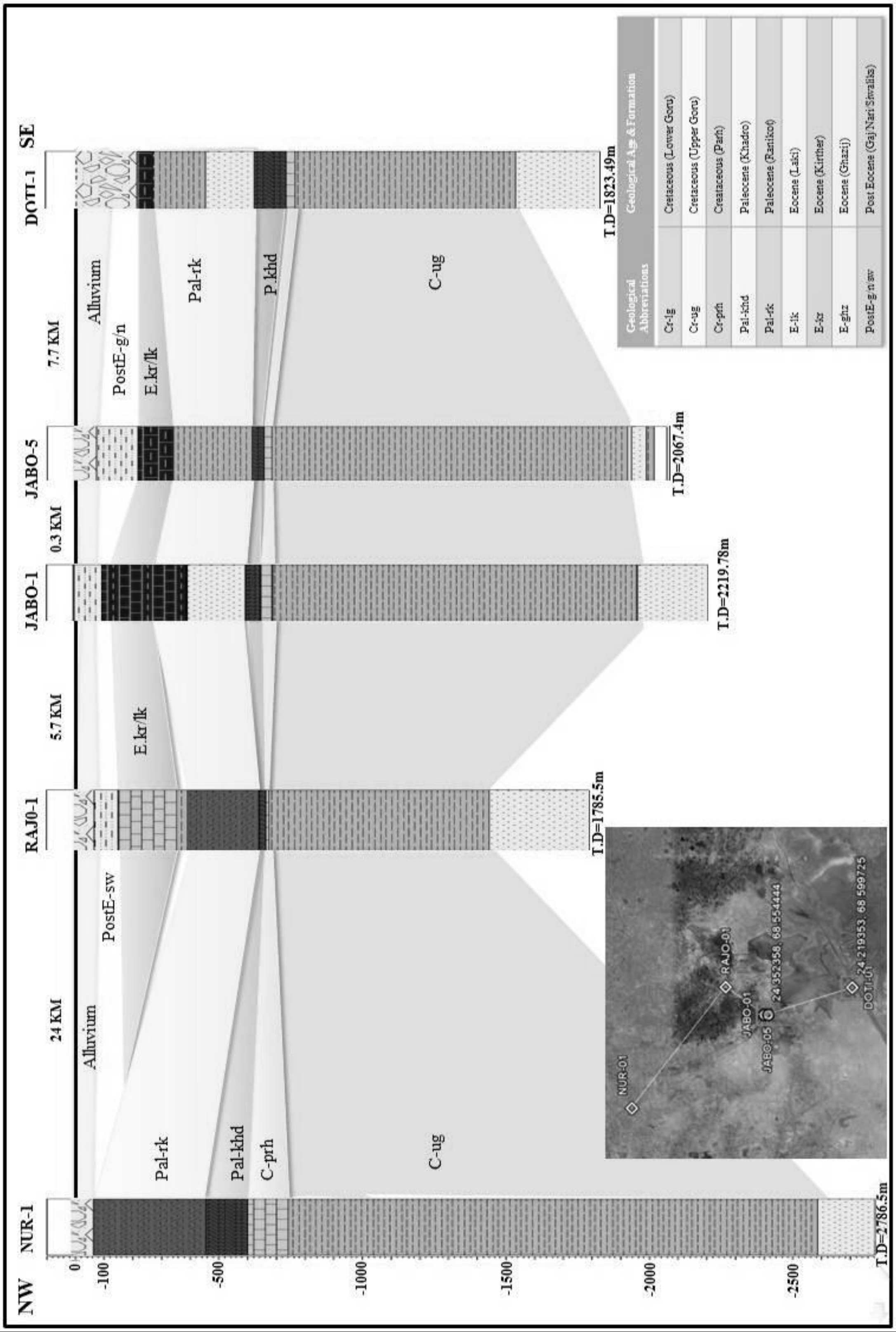

Fig. 3: Correlation of five wells in study area. It is clear that thickness of Cretaceous is increasing from Southeast to Northwest.

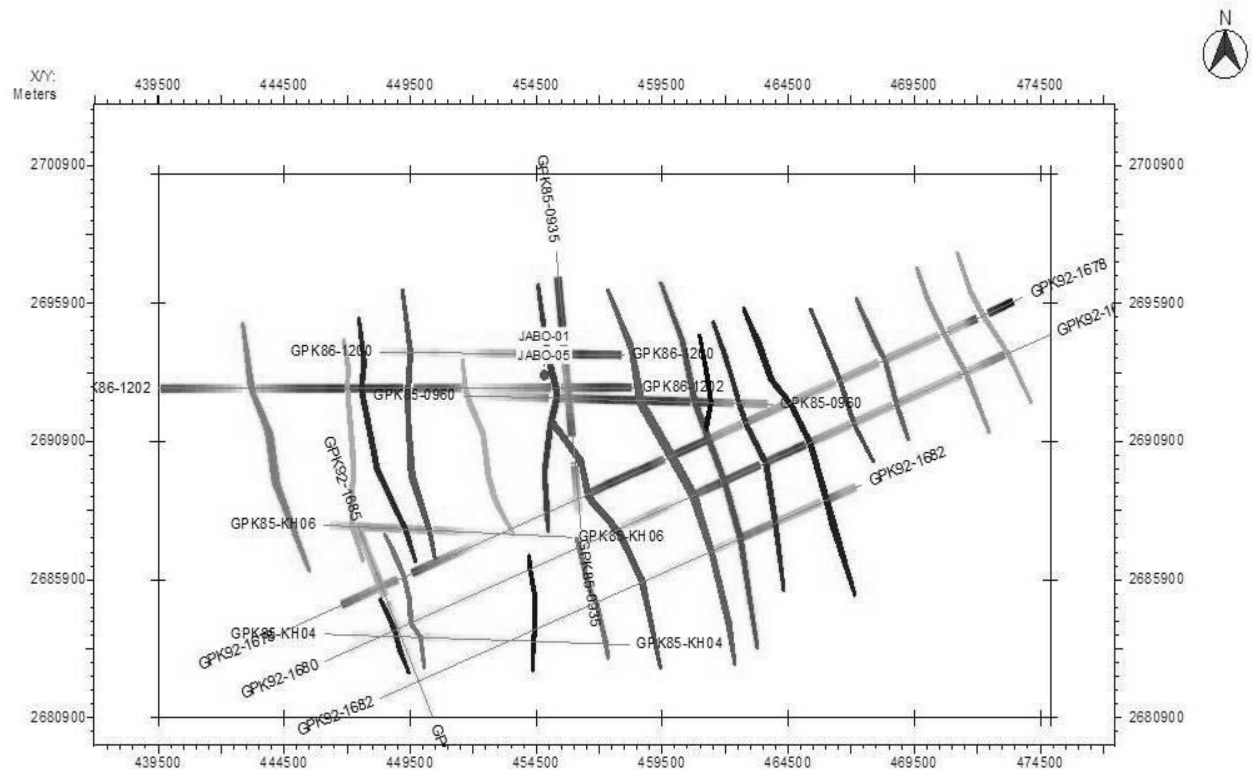

Fig. 4: Faults orientation in the area. Generally normal faults are extending in Northwest-Southeast direction.

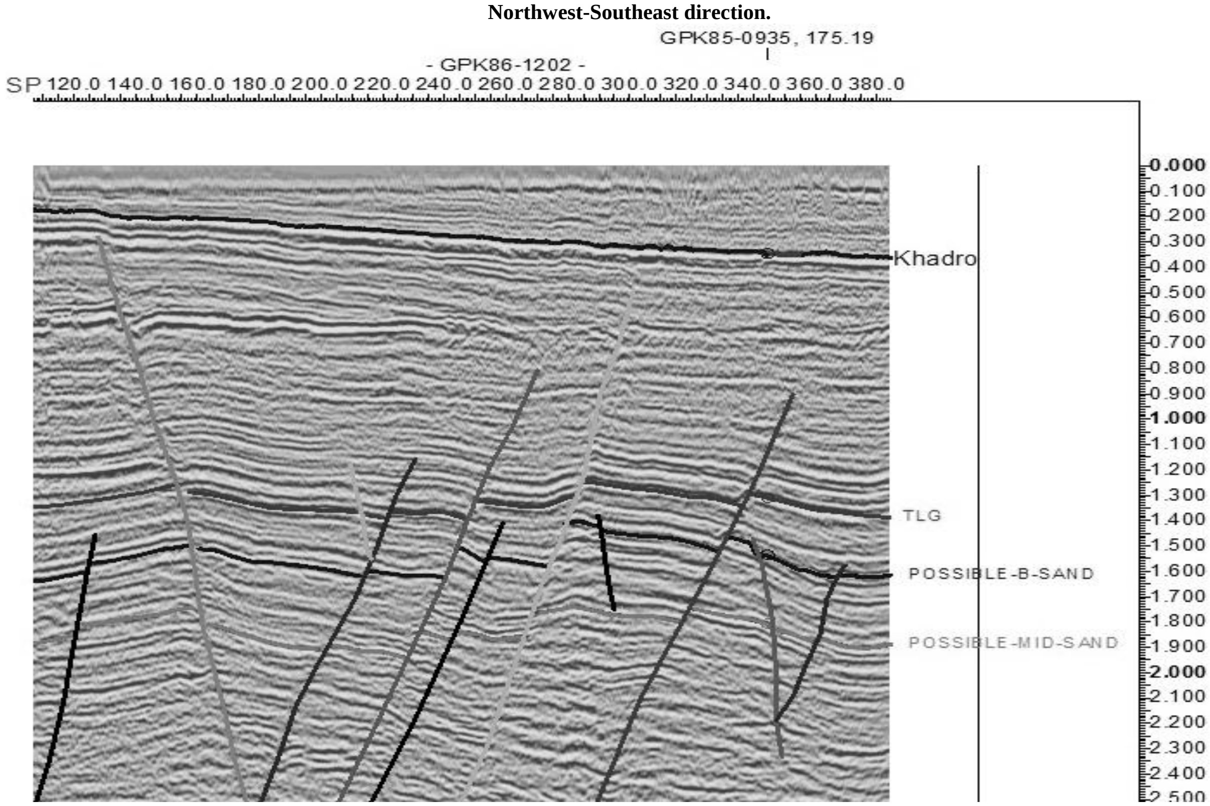

Fig. 5: Interpreted Seismic Line PK86-1202. Horst & Graben geometry is confirmed in the area.

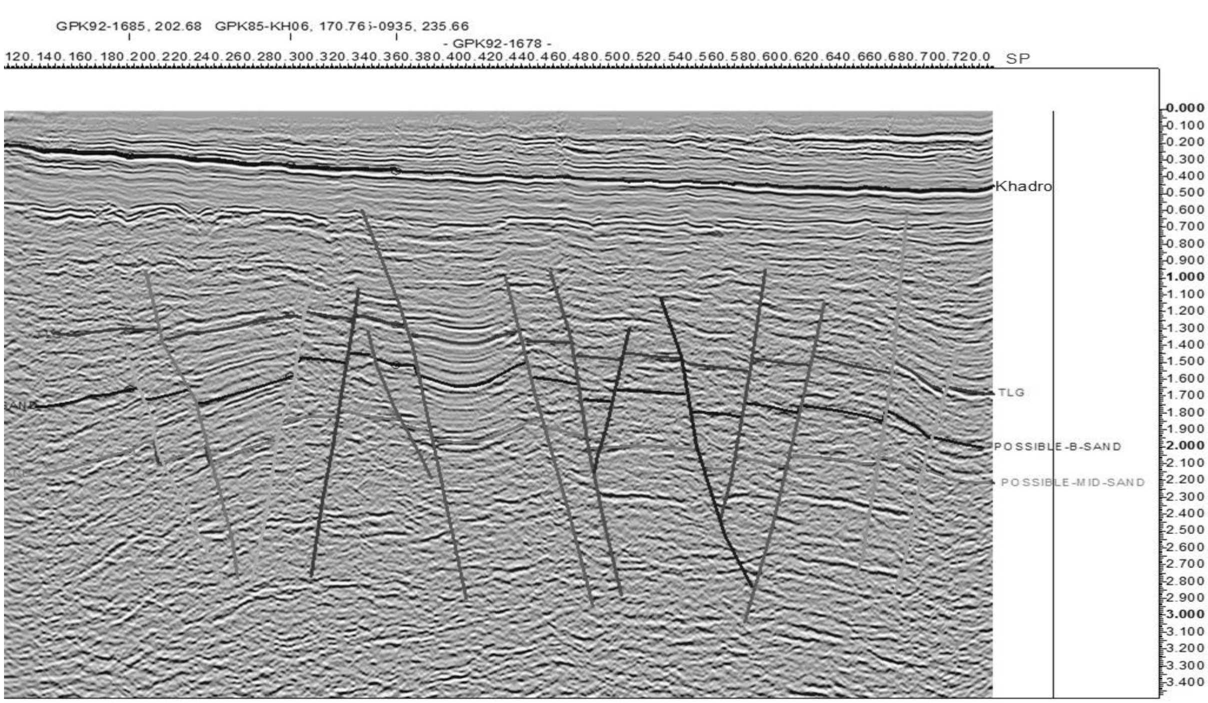

Fig.

Fig. 6: Interpreted Seismic Line Pk92-1678. Horst & Graben geometry is confirmed in the area.

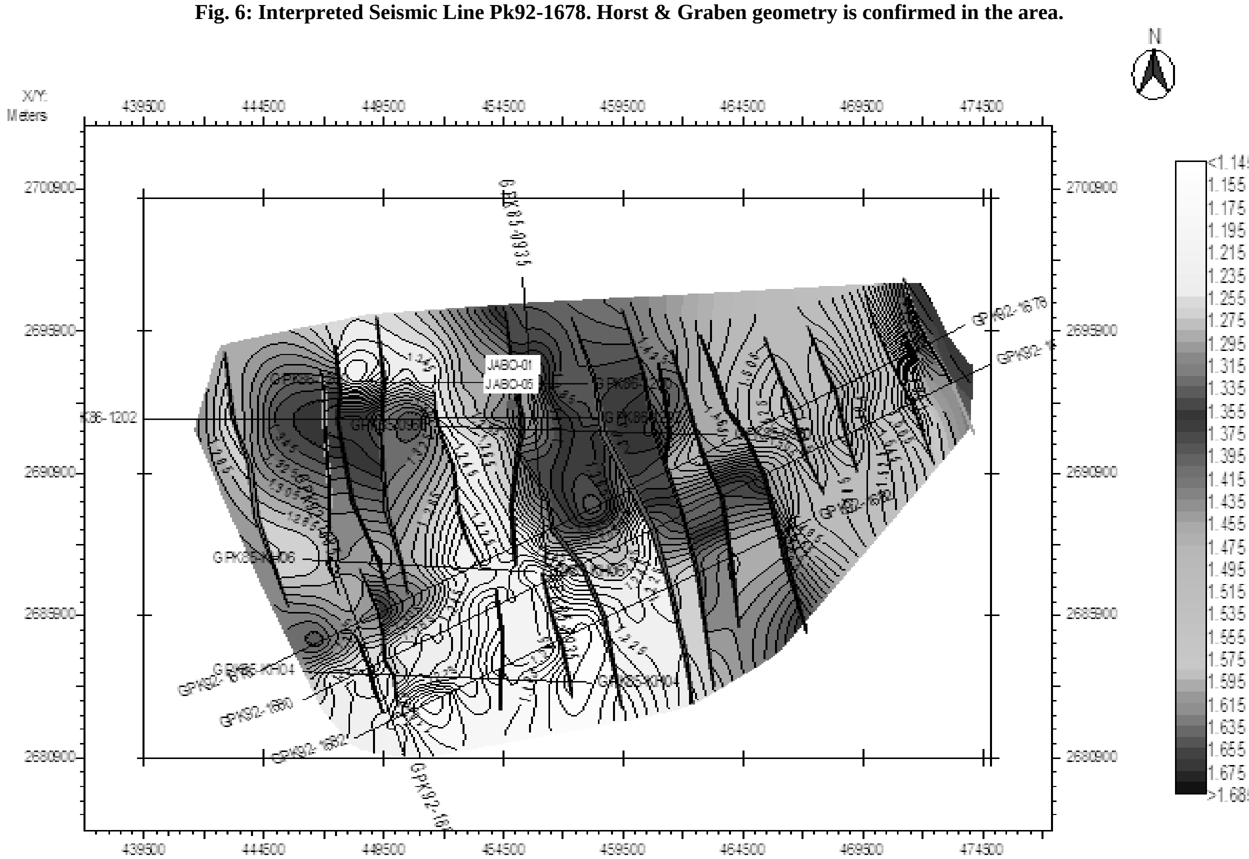

Fig.7: Contour Map (Two Way Time in second) of Top Lower Goru, generally deepening from East to West.

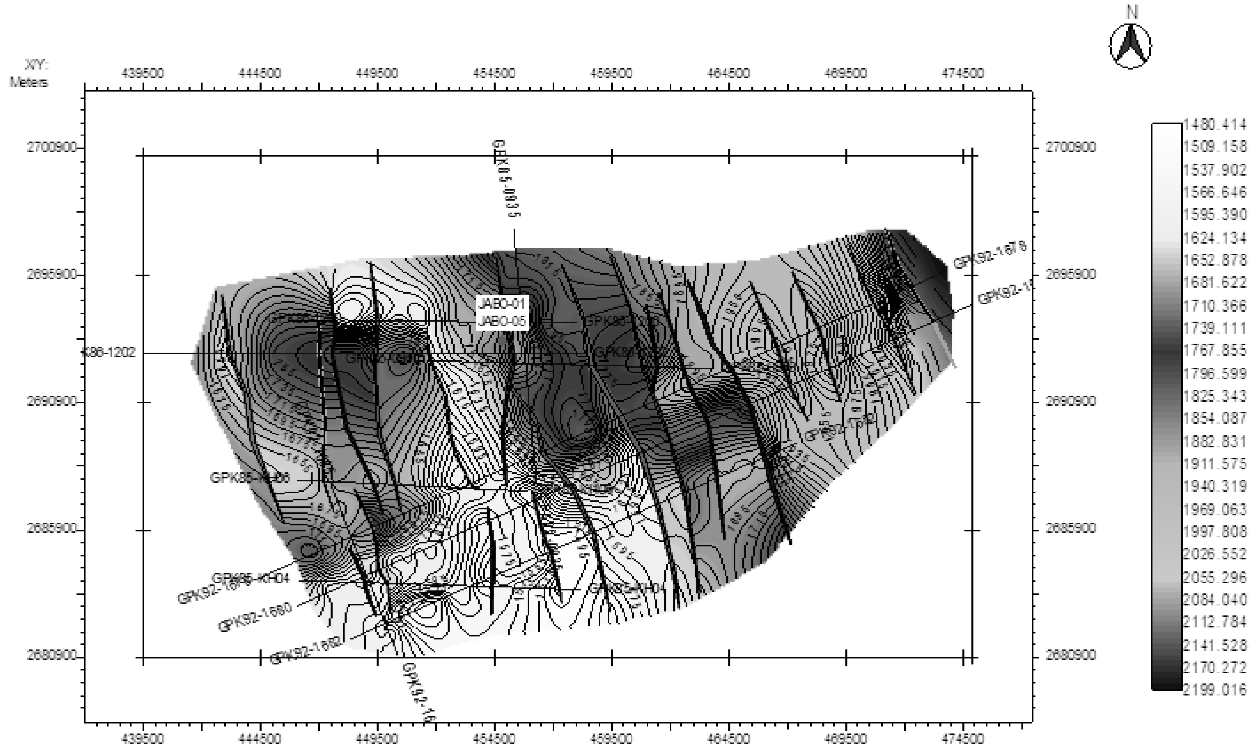

Fig.8: Contour Map (Depth in m) of Top Lower Goru, generally deepening from East to West.

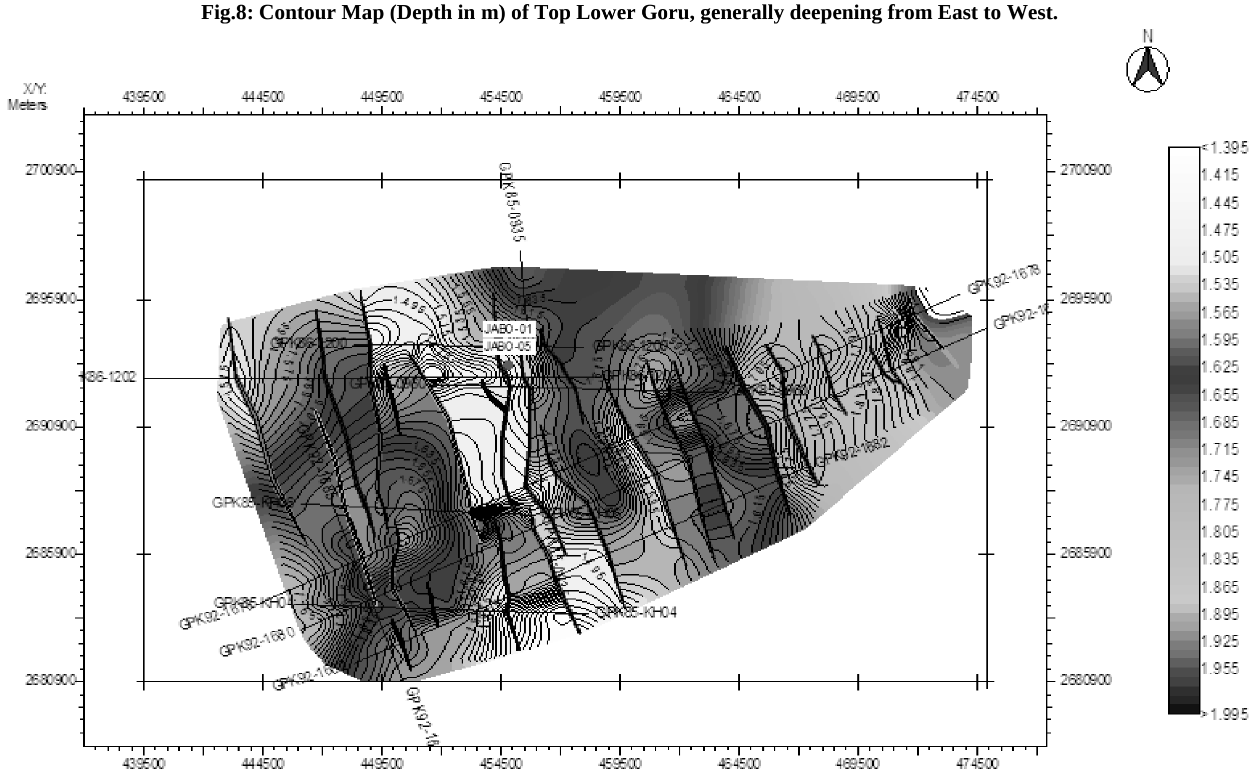

Fig.9: Contour Map (Two Way Time in second) of B Sand, generally deepening from East to West.

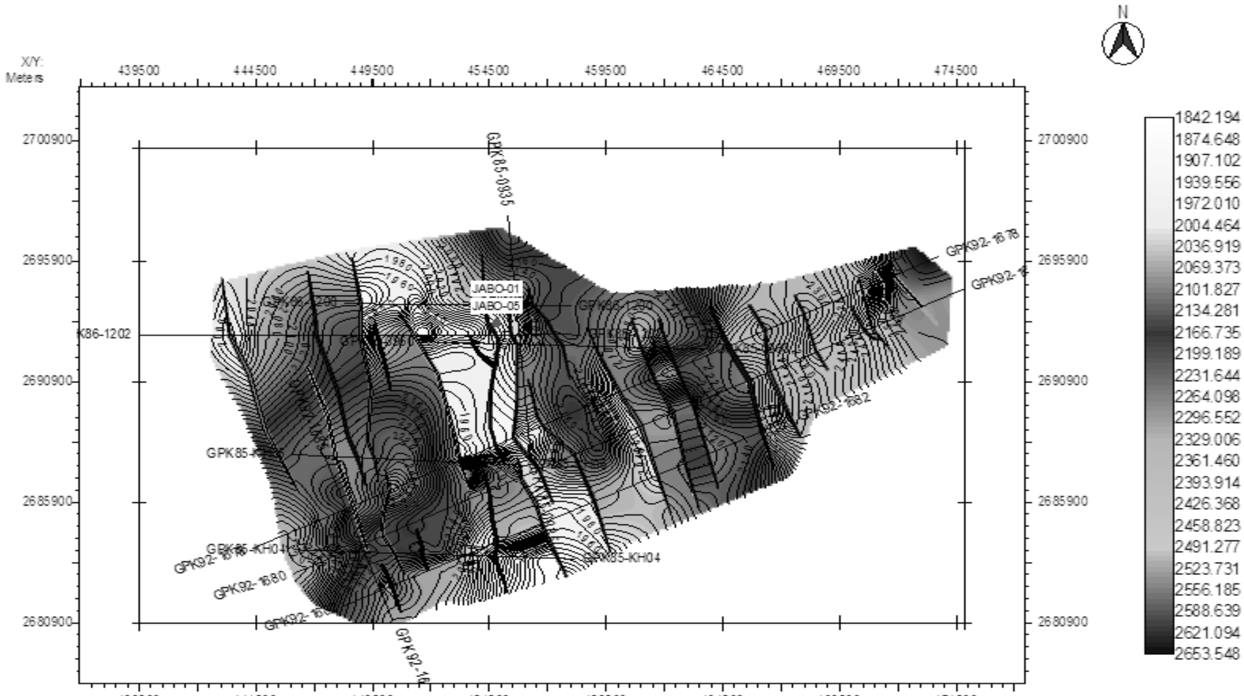

Fig.10: Contour Map (Depth in m) of B Sand, generally deepening from East to West.

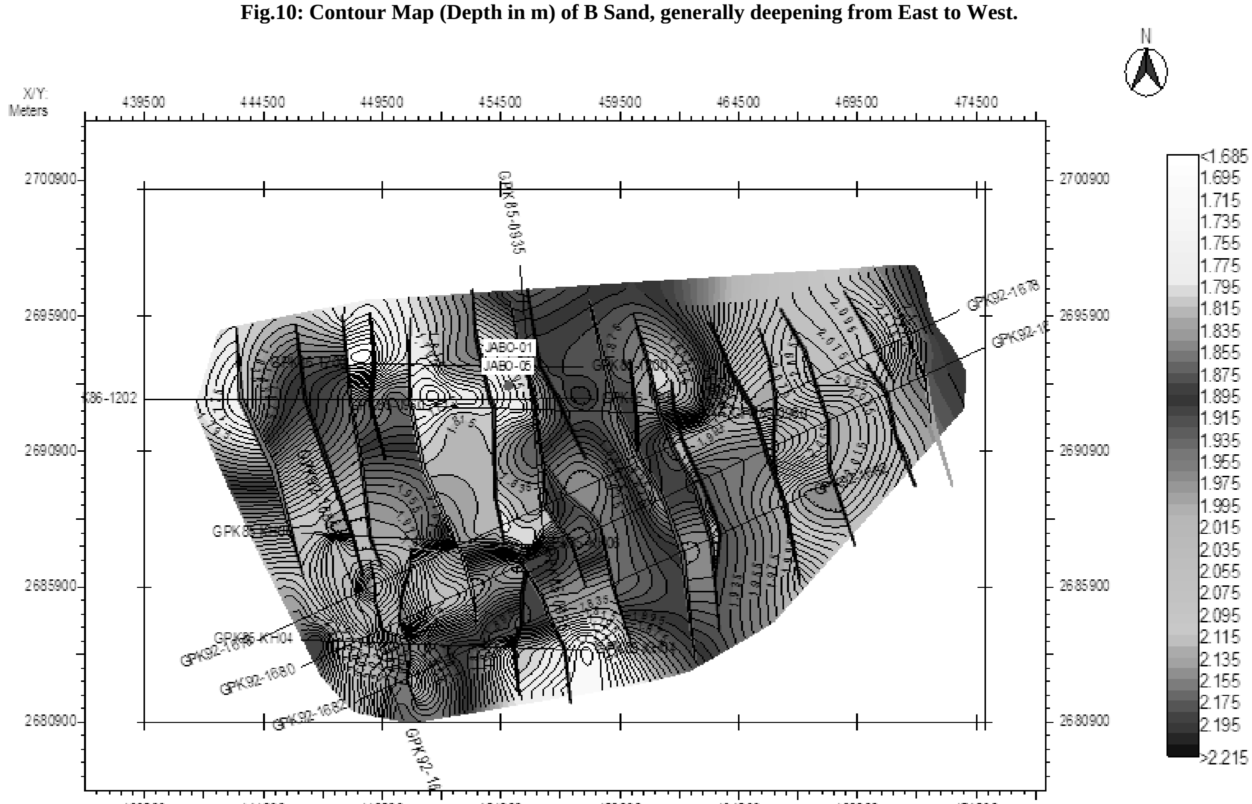

Fig.11: Contour Map (Two Way Time in second) of Middle Sand, generally deepening from East to West.

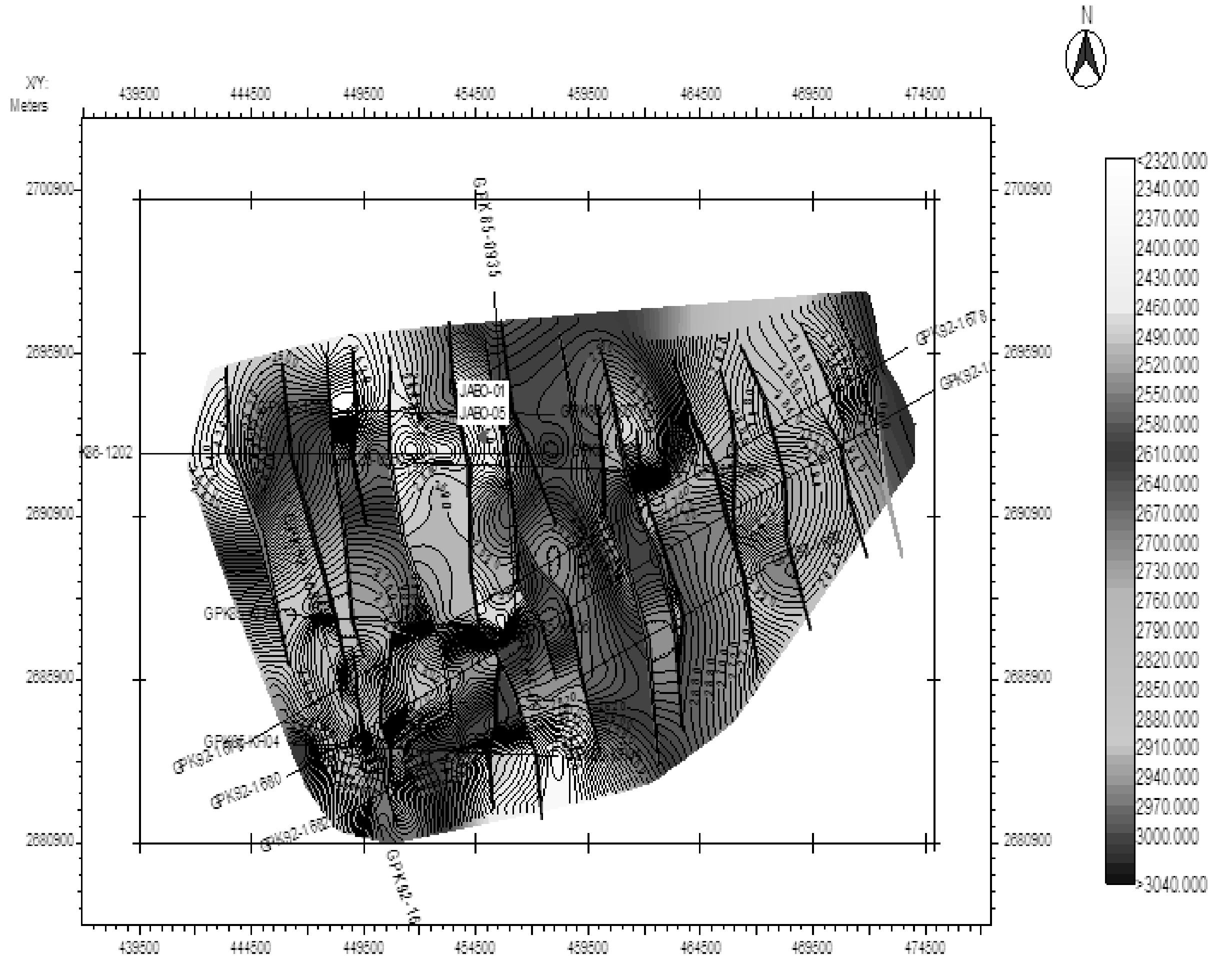

Fig.12: Contour Map (Depth in m) of Middle Sand, generally deepening from East to West.

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