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Fault seal evaluation of lower sands of Lower Goru Formation by using seismic and well data: A case study of Jherruck block, Lower Indus Basin, Pakistan

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Abstract

The Jherruck block is located in Lower Indus Basin in district Thatta, Pakistan. The area is bounded in east by Indian Kutch Basin, in the west by Kirthar Fold Belt, in south by Arabian Sea and in north by Sindh monocline. Twenty seismic lines and four well logs have been used for subsurface structural interpretation and identification. Lower Sands which include Middle Sand, Upper Basal Sand and Lower Basal Sand have reservoir potential and have been interpreted on seismic sections to generate time and depth surface maps. Surface maps recognized that Jamali Deep-1 well was drilled at appropriate crestal location of the structure. Using depth surface maps Allan diagram have been constructed for fault seal analysis. Results revealed that the middle sand was juxtaposed against hanging wall of D-Sand and hydrocarbons moved up dip towards D-Sand. Crestal location of Upper Basal Sand on footwall was juxtaposed against hanging wall of middle sand which acts as conduit lithology for hydrocarbons movement. Despite being complete petroleum play the well was unsuccessful to produce because of these sands juxtaposition.

Keywords: Lower Indus Basin, Jherruck block, Fault seal analysis, Allan diagram, Lower Goru, Juxtaposition, D sand.

1. Introduction

Seismic data has been utilised in identification, evaluation, pressure studies and sealing analysis (Lindsey et al., 1993). A fault can be transmitter or can act as a barrier for hydrocarbon accumulation (Yielding et al., 1997). Categorizing fault between these extremes can have drastic effect in risk reduction (Knipe, 1997). Allan diagram has been widely used in fault categorization and analysing lithological juxtaposition. These diagrams demonstrate the juxtaposition relationships along the fault plane thus indicating petroleum leak points (Allan, 1989).

The research area is located at latitude 24 ° 41' to 25 ° 10 ' N and longitude 68 ° 10 ' to 68 ° 26 ' E in Thatta district, Sindh Province (Fig.1). Tectonically the region is located in the south-eastern boundary of Lower Indus Basin, where normal faulting and strike-slip tectonic are present, and no imprints of deformation exist on earth surface (Kazmi and Jan, 1997; Kadri, 1995). The subsurface structural style of Jherruck block contributed to the accumulation of hydrocarbons but failure of Jherruck B-1, and Jamali deep-1 well in this hydrocarbon proven area are mainly due to the sand-sand juxtaposition. Lower Indus Basin is underlain by infra-Cambrian to Recent clastics and carbonates. It was passive margin up to the Late Cretaceous, it is sutured between the Indian Plate and the Afghan Block. The stratigraphic thickness varies in east-west direction (Shah, 2009; Tahirkheli, 1979). Precambrian basement rocks have been exposed in the southeast corner of the basin. Stratigraphically, Lower Indus Basin is composed of exposed Triassic to recent rock sequence (Shah, 2009; Raza et al., 1989). Stratigraphy of area is given below (Fig. 2). The problem has been addressed by performing the preliminary seismic interpretation on 2D seismic profiles and construction of Allan diagram. For structural interpretation of subsurface horizons, the geophysical and geological data that has been incorporated are as follows:

- Base map (Fig. 3)
- Well tops and velocity of Jamali Deep-1 well (Table 1)
- Seismic dip line 07-BDN-03 (Fig. 5)

The present study will identify the nature, geometry and distribution of the faults in the subsurface. Furthermore, sealing assessment of faults by using Allan diagram will help in identification of any juxtaposed sand result in hydrocarbon leakage.

2. Material and methods

In seismic interpretation, seismic reflection data is converted into a geological image after applying different processing and interpretation tools. Following methodology has been adopted for interpretation:

3. Seismic interpretation

The interpretation mainly relies on the reflections identification and placing them at their true positions (depth) in the seismic section, geometry of the structure (style and trend), identification of potential prospect, and correlating the interpretation with already drilled well data for validation and enhancing interpretation procedure.

Synthetic seismogram is used for correlation of surface seismic and well data. It is generated in Petrel software by using sonic and density logs of Jamali deep-1 well (Fig. 4) and used to correlate well data in depth domain with seismic time sections. The objective of synthetic seismogram is to confirmation of horizons marking on seismic section. By using the synthetic seismogram and stratigraphic column prominent horizons marked on seismic section given in (Table 2).

Different normal faults of variable throw marked on seismic section dipping in SW direction while some are dipping in NE direction (Fig. 5)

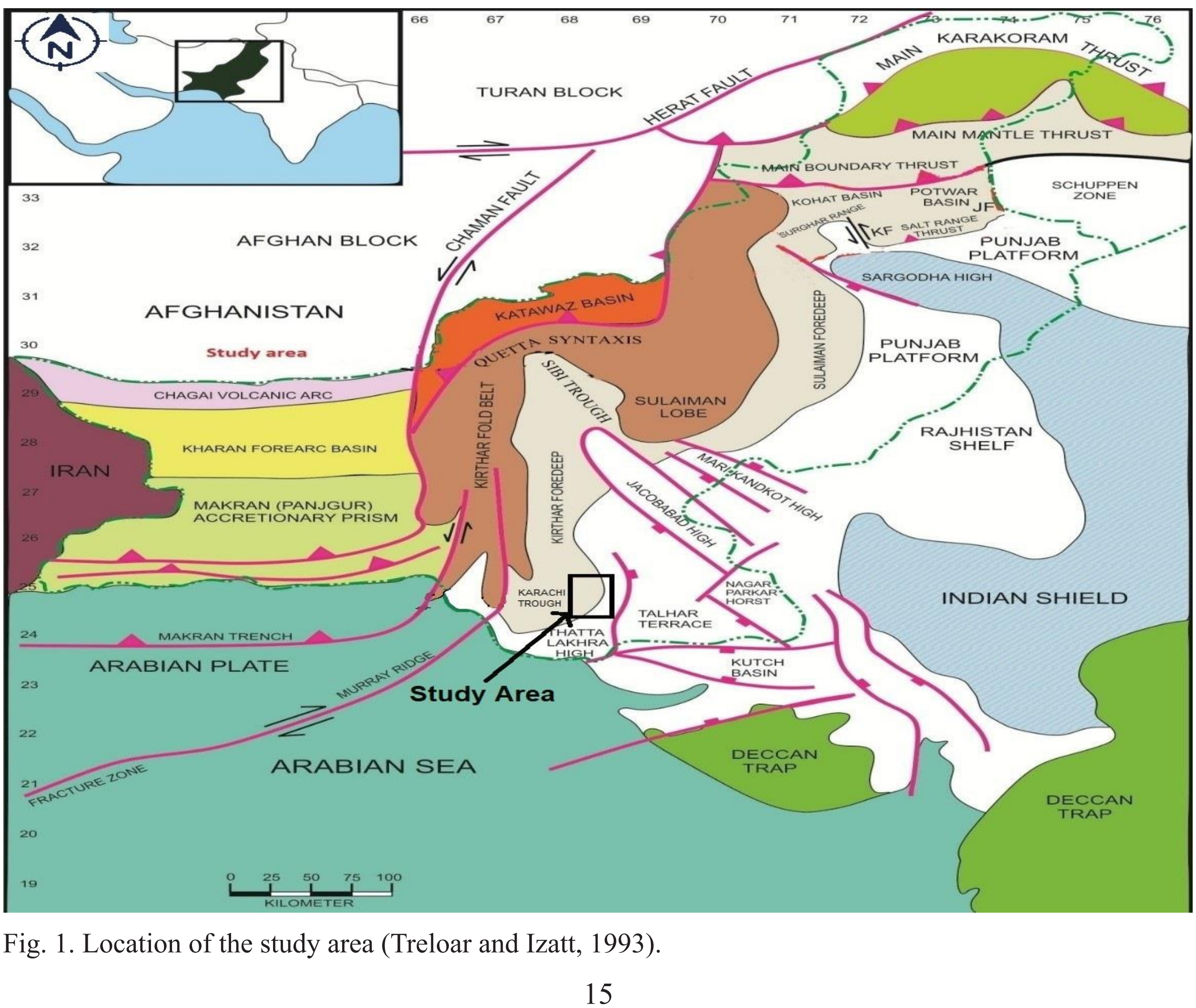

Fig. 1. Location of the study area (Treloar and Izatt, 1993).

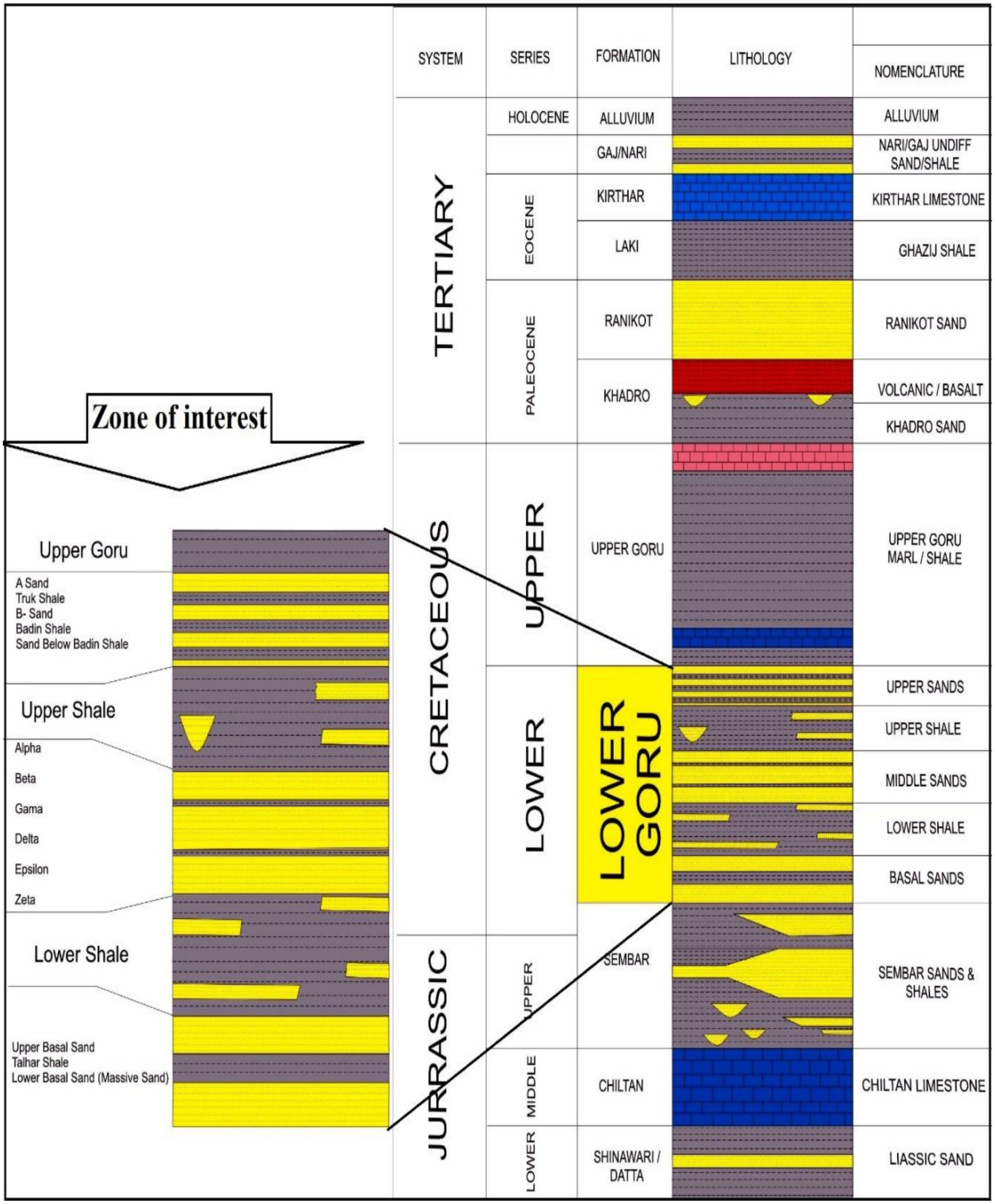

Fig. 2. Generalized Stratigraphic column of Lower Indus Basin, Pakistan (modified after, Shah, 2009; Kazmi and Abbasi, 1997).

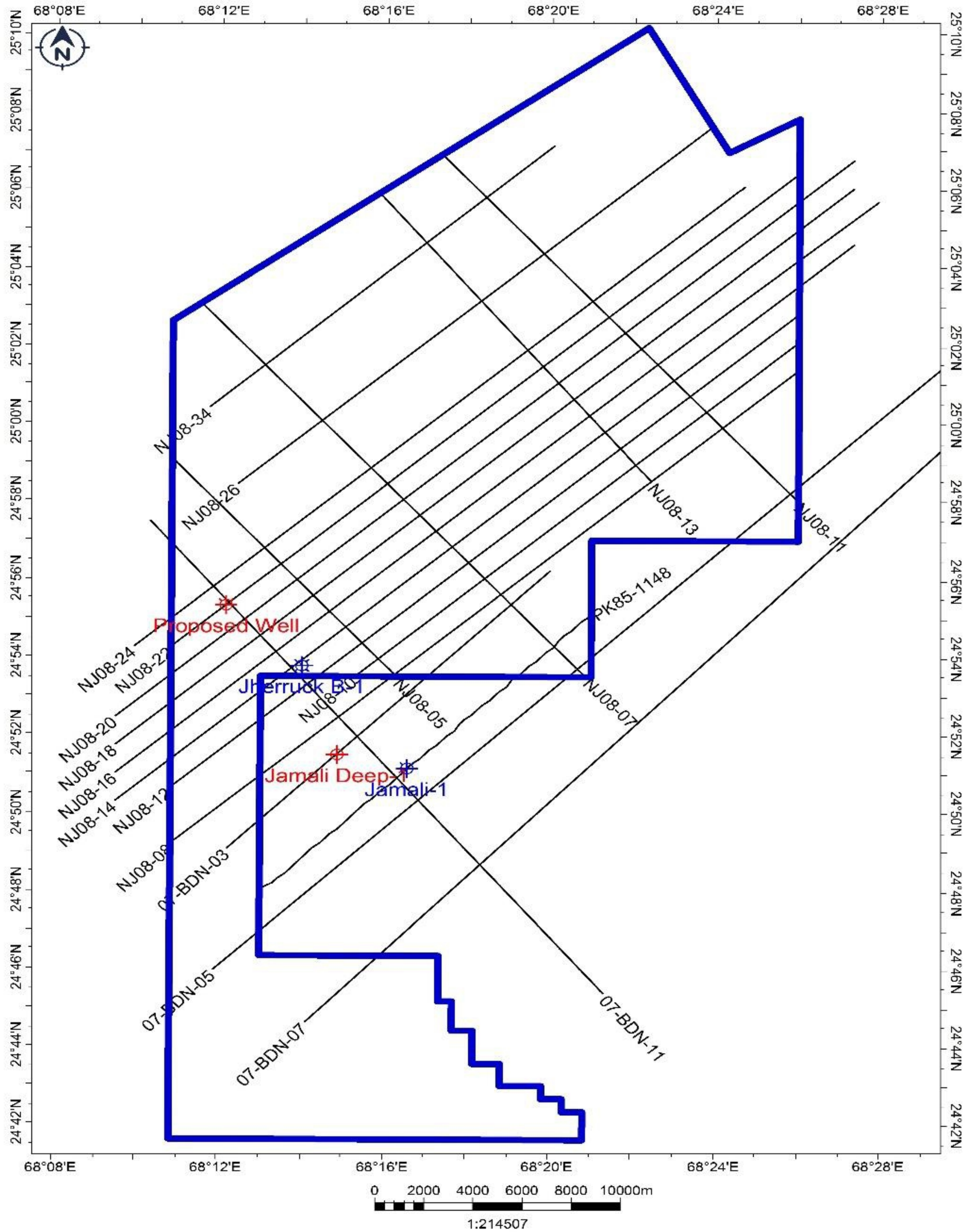

Fig. 3. Base map of study area displaying seismic dip and strike lines along with drilled wells.

Table 1. Jamali Deep-1 well descriptions.

Formation Top	**TWT (ms)**	**Depth KB (m)**	**Formation Thickness (m)**	**Average Velocity (m/s)**
Ranikot	45	67	514	1806
Khadro	522	581	231	2125
Upper Goru	654	812	1745	2401
TLG (A-Sand)	1694	2557	40	2987
Turk Shale	1711	2597	108	3004
B-Sand	1759	2705	26	3045
Badin Shale	1772	2731	36	3053
Upper Shale	1792	2767	323	3059
Middle Sand	1963	3090	38	3122
Lower Shale	1980	3128	322	3133
Upper Basal Sand	2133	3450	35	3209
Talhar Shale	2148	3485	52	3220
Lower Basal Sand	2172	3537	259	3232
Sembar	2283	3796	-	3302

Table 2. Colour legend of interpreted horizons.

Horizons	Interpretation Color	Horizons	Interpretation Color
Khadro		Middle Sand	
Parh		Upper Basal Sand	
A-Sand / TLG		Lower Basal Sand	
B-Sand		Sembar	
C-Sand		Chiltan	
D-Sand			

4. Time and depth surface maps

Time contour maps are generated in Petrel software by using interpreted horizons on seismic section in time domain and converted into depth surface maps by using velocity data given in Table 1.

5. Allan diagram

Allan diagram is a fundamental step in assessing fault behaviour and its sealing properties (Allan, 1989). In this diagram, all horizons of hanging and footwall are superimposed on fault plane. Hydrocarbon pathway can easily be highlighted where both porous and permeable lithology superimposed on each other. Interpreted horizons and their corresponding depth surfaces used to generate Allan diagram. A fault will act as a conduit entity if reservoir quality sand bodies of foot wall will juxtapose against hanging wall. Fluid will migrate through porous and permeable media instead of trapping there in fault bounded geological structure (Knipe, 1997).

6. Results and discussion

The interpreted seismic section is a dip line (07-BDN-03) on which Jamali Deep-1 well drilled (Fig. 5), by using well to seismic tie the targeted horizons were interpreted, the dip lines in this block are perpendicular to the major structures present in the subsurface of this block and are considered most suitable for geological interpretation. Jamali Deep-1 was drilled in 2009 to target the Lower Sands i.e., Middle Sand, Upper Basal Sand and Lower Basal Sand and drilled up-to the total depth of 3862 m. It drilled both hanging and footwall of Lower Goru Formation (Fig. 5), due to which complete package of C-Sand, Jhole shale and D-Sand while some part of Badin shale and Upper shale faulted out and not encountered during well drilling. Lower Sand makes structural closure on footwall of fault-1 which is moderately dipping having large fault throw. Different horizons interpreted on seismic section from top to bottom as mention in Table 2.

7. Time and depth surface maps

Using the velocity given in Table 1, time surface maps were converted into depth surface maps. D-Sand, Middle Sand, Upper Basal Sand and Lower Basal Sand were generated (Fig. 6.1-6.4) to mark the crestal location of these Sands and to prepare Allan diagram (Fig. 7) for fault seal analysis. The figures revealed that pattern of depth contour surface maps are similar for all the sands and generally all surfaces dip towards Northwest direction. Contours are closed across fault-1 and make a valid drillable prospect (Fig. 6.2-6.4). Crestal location of Middle Sand, Upper Basal Sand and Lower Basal Sand in depth surface maps (Fig. 6.2-6.4) confirms the location of Jamali Deep-1 well on seismic line 07-BDN-03. This well was unsuccessful because of sands juxtaposition which is shown in Allan diagram (Fig. 7). Interpreted faults on seismic lines are dipping towards SW direction while some are dipping towards NE. Fault-1 is a major fault appeared on all seismic lines which cuts all interpreted horizons with significant throw from Top Lower Goru (TLG) to Chiltan limestone level while Some faults die out towards southern portion of study area (Fig. 5).

Although the well was drilled at appropriate structural location shown in depth surface maps (Fig. 6.2 - 6.4) but well was unable to flow because lower Sands of hanging wall act as a conduit for hydrocarbons migration due to sands juxtaposition, analysed in Allan diagram (Fig. 7). There were no other structural prospects present for lower sands in Jherruck block.

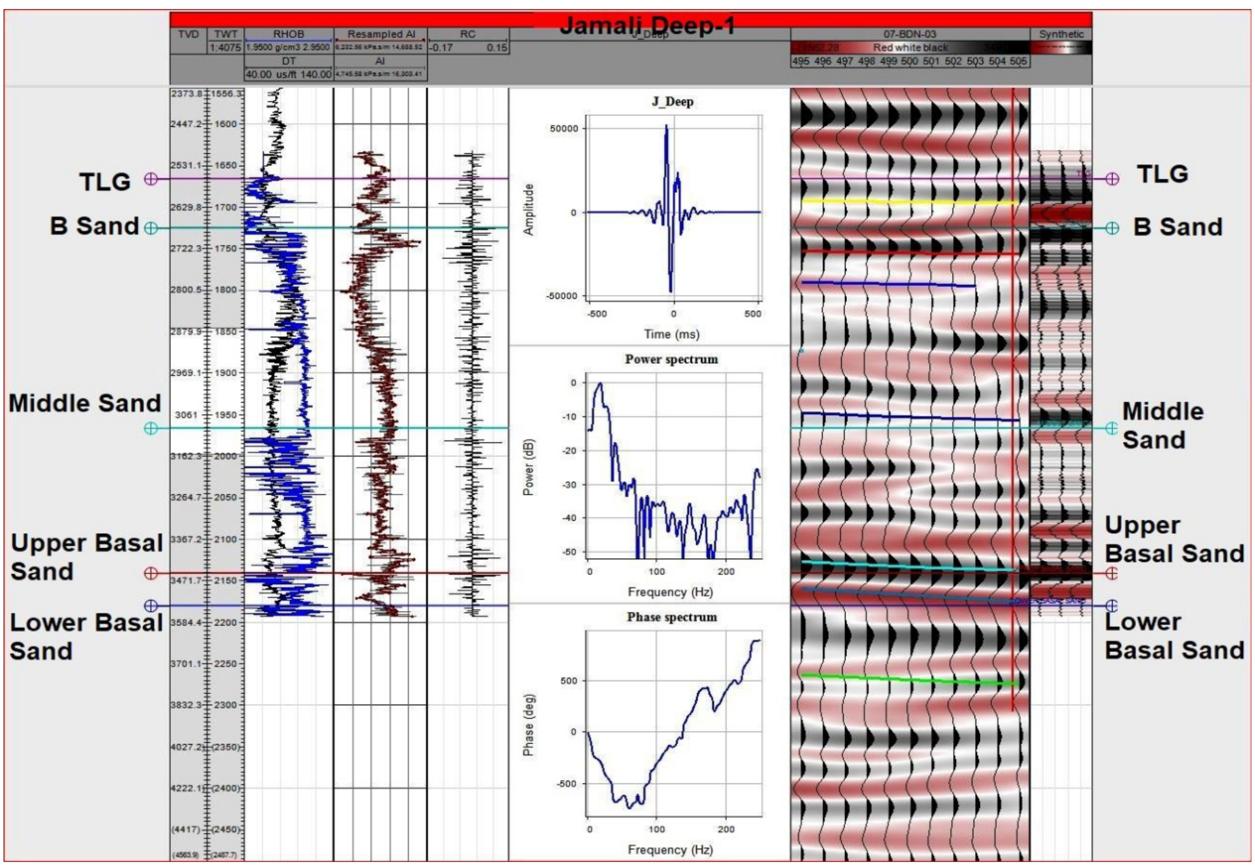

Fig. 4. Synthetic seismogram of Jamali Deep-1 well

8. Allan diagram

Fault-1 is Southwest dipping fault having large fault throw and gentle dip (Fig. 5). Jamali Deep-1 well drilled on the structure and targeted the lower sands (Middle sand, Upper Basal Sand and Lower Basal Sand) which was bounded across fault-1. Contours makes closure on seismic line 07-BDN-03 associated with fault-1 but Allan diagram (Fig. 7) shows that all lower sands for which Jamali Deep-1 well was drilled are juxtaposed as follows:

- Middle sand is juxtaposed against hanging wall of D-Sand and hydrocarbons moved updip direction in D-Sand.
- Crestal location of Upper Basal Sand on footwall juxtaposed against hanging wall of middle sand which act as conduit lithology for hydrocarbons movement. While middle sand of hanging wall further updip in opposite direction to fault-1.
- Lower Basal Sand is also juxtaposed against hanging wall of middle sand.

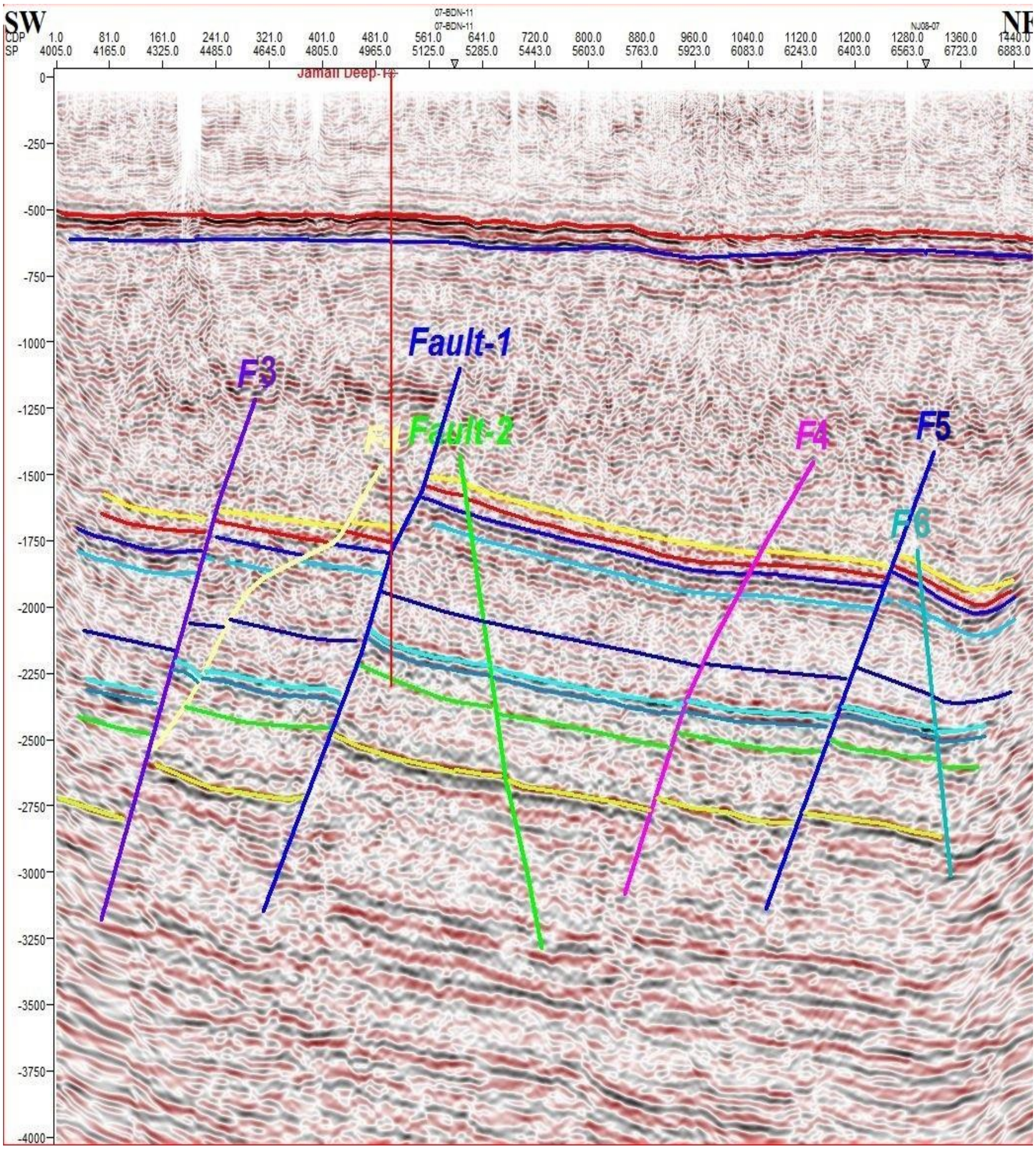

Fig. 5. Interpreted seismic section of 07-BDN-03.

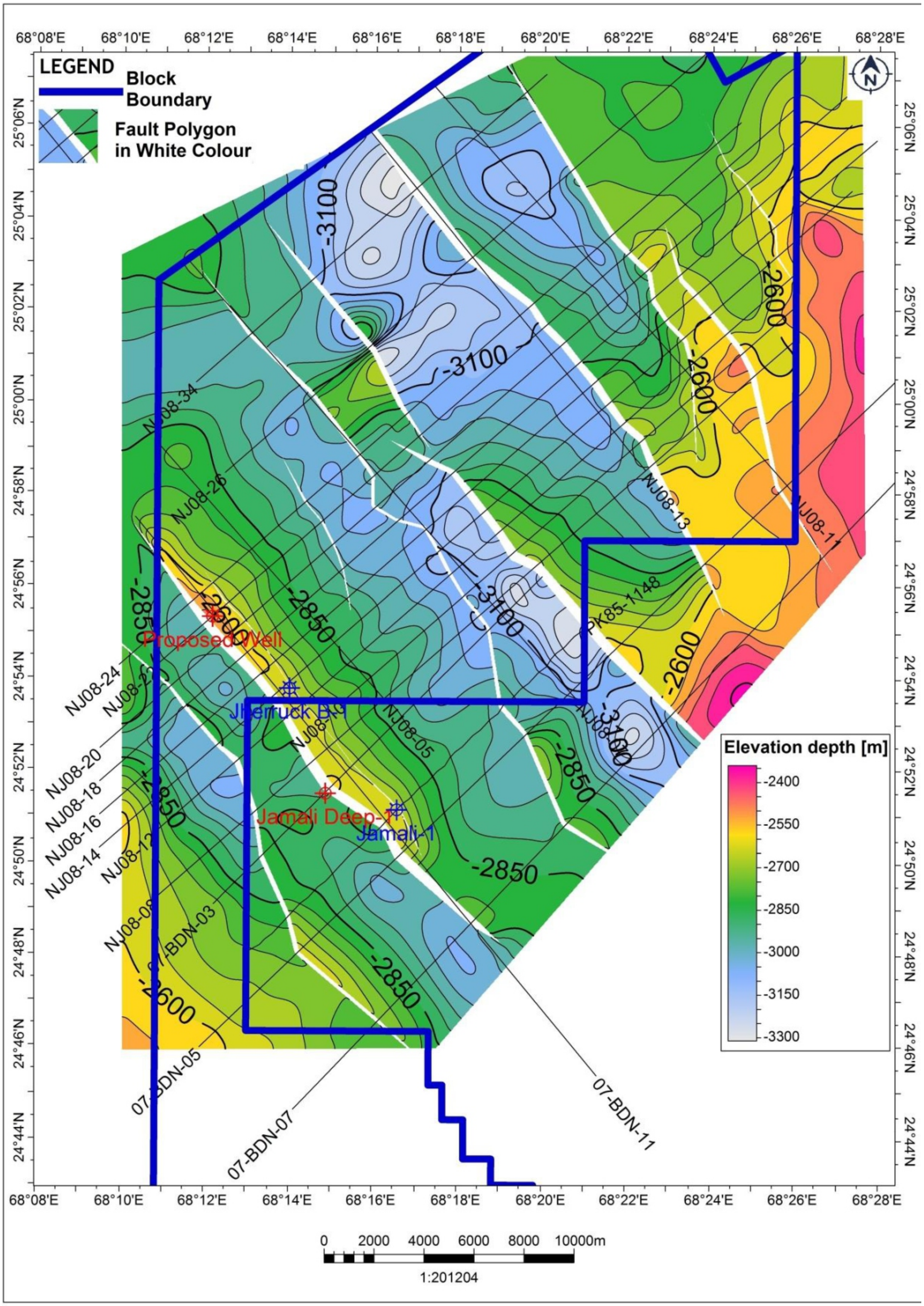

Fig. 6.1. Depth surface map of D-Sand.

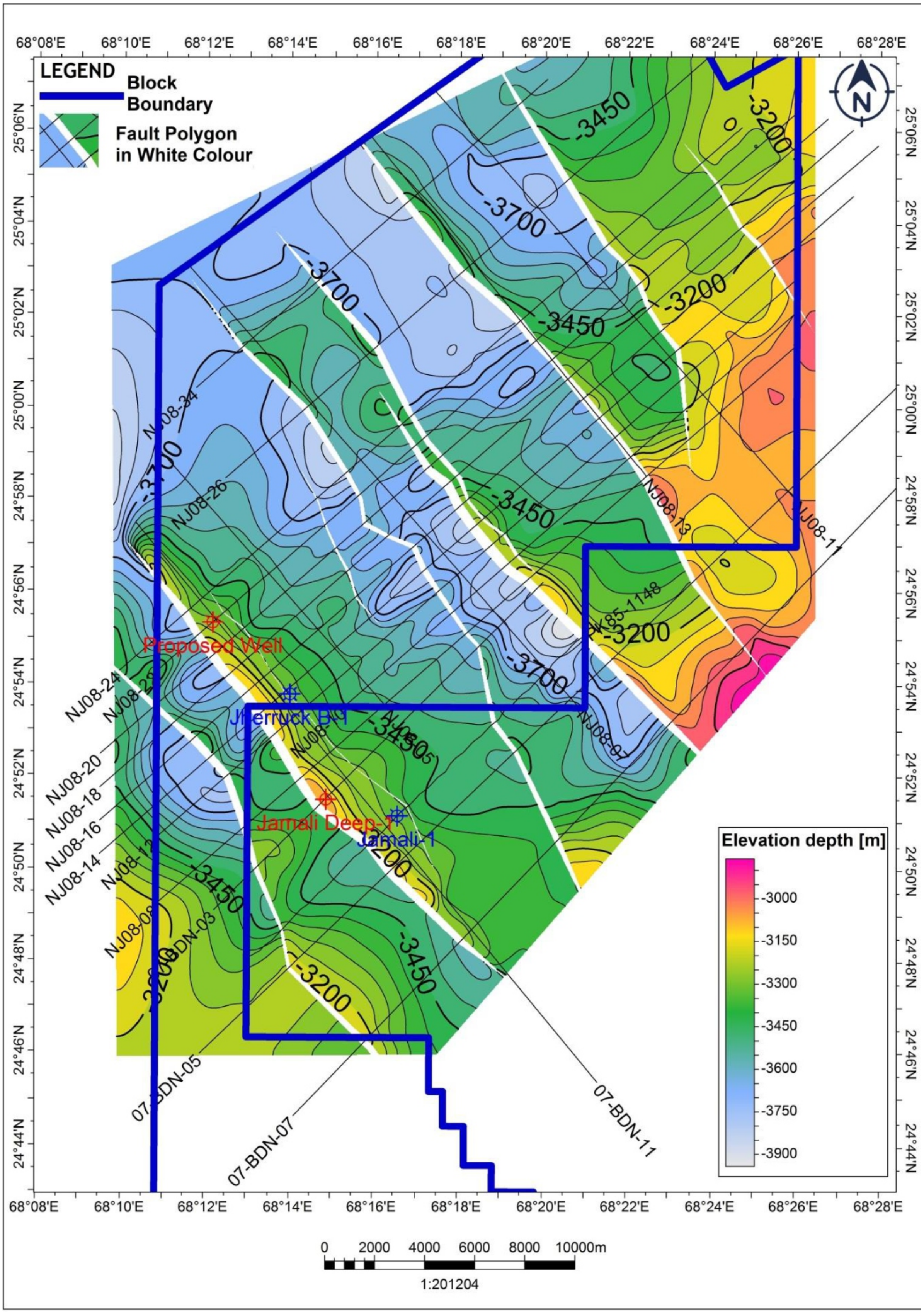

Fig. 6.2. Depth surface map of Middle Sand.

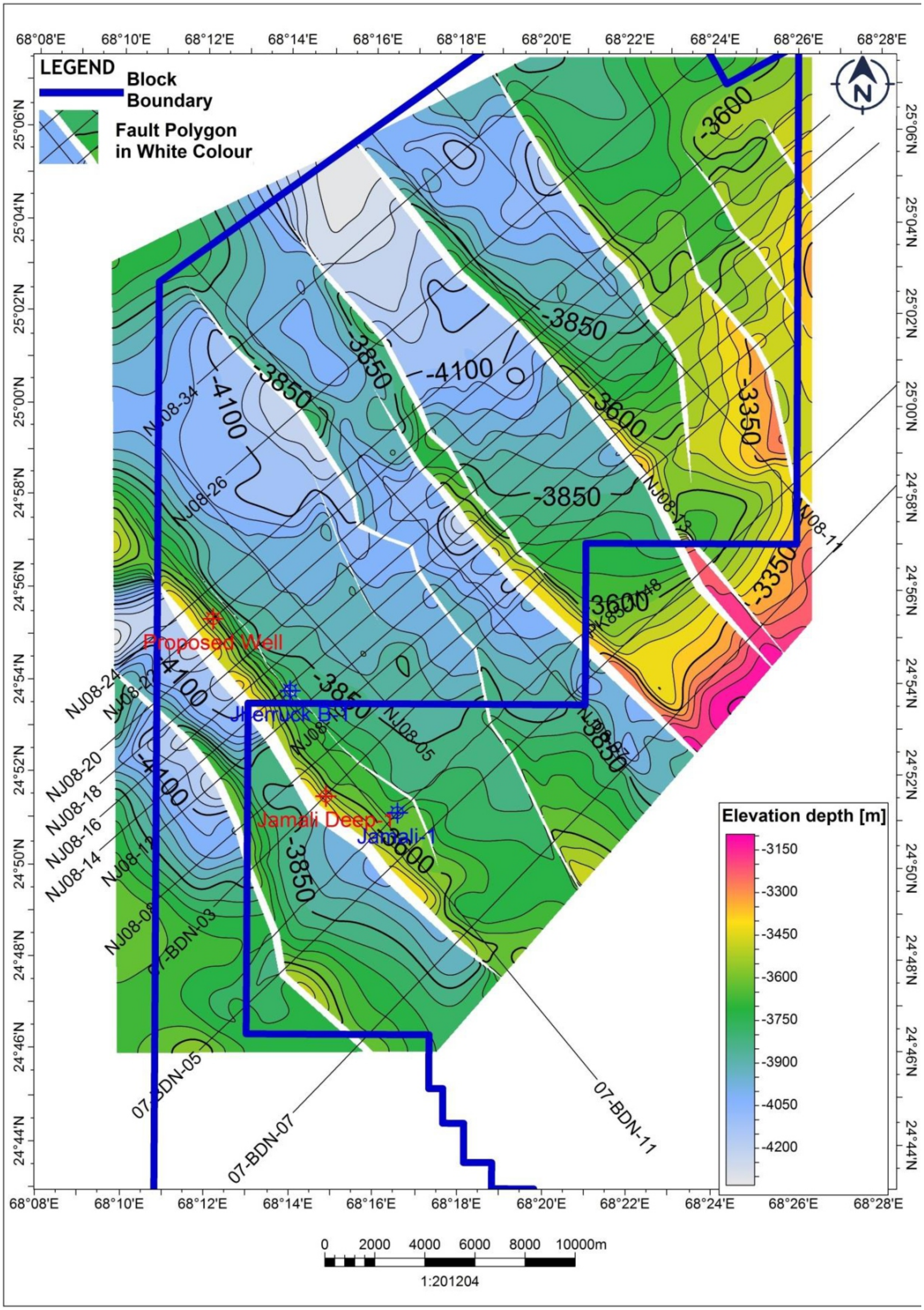

Fig. 6.3. Depth surface map of Upper Basal Sand.

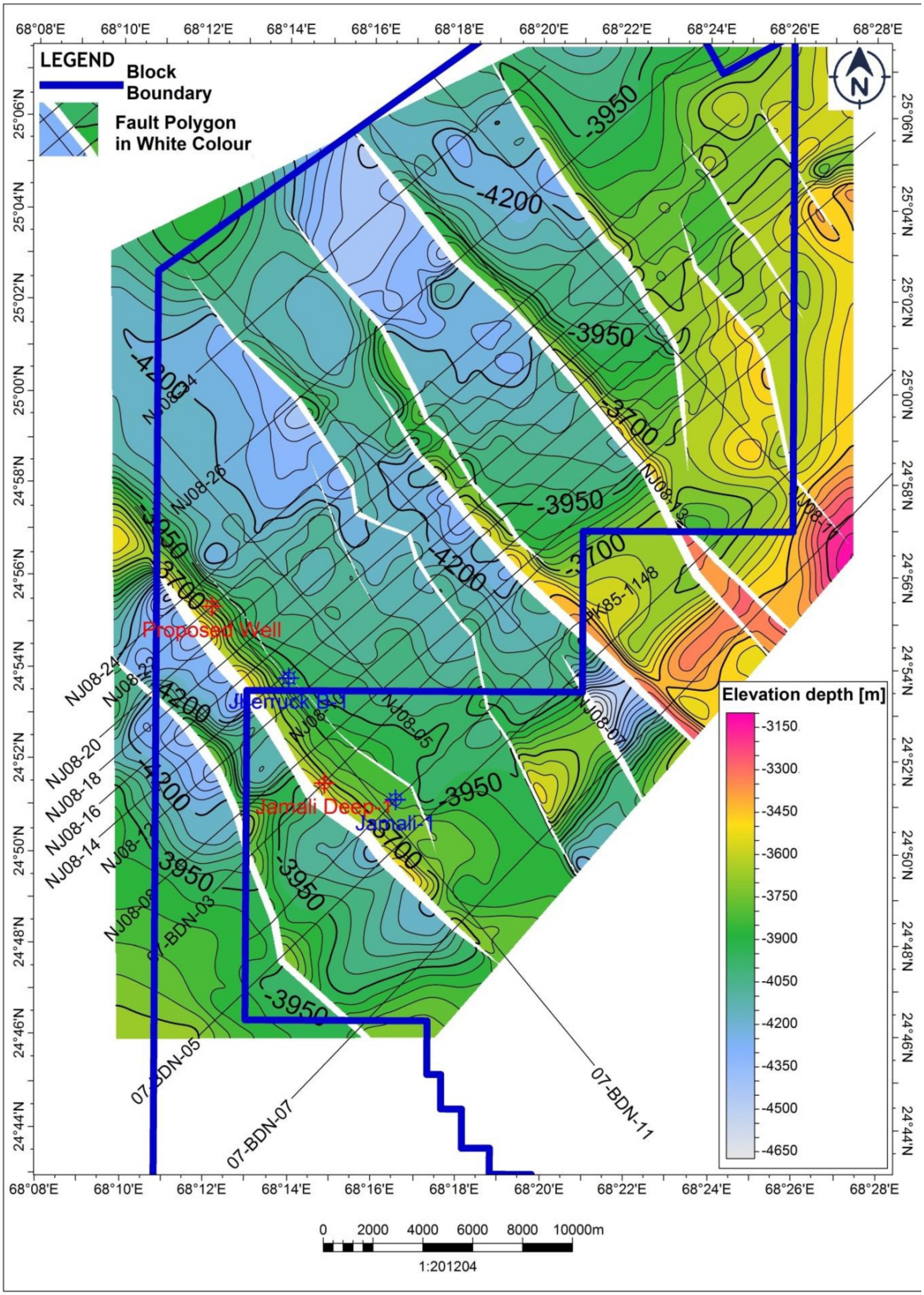

Fig. 6.4. Depth surface map of Lower Basal Sand.

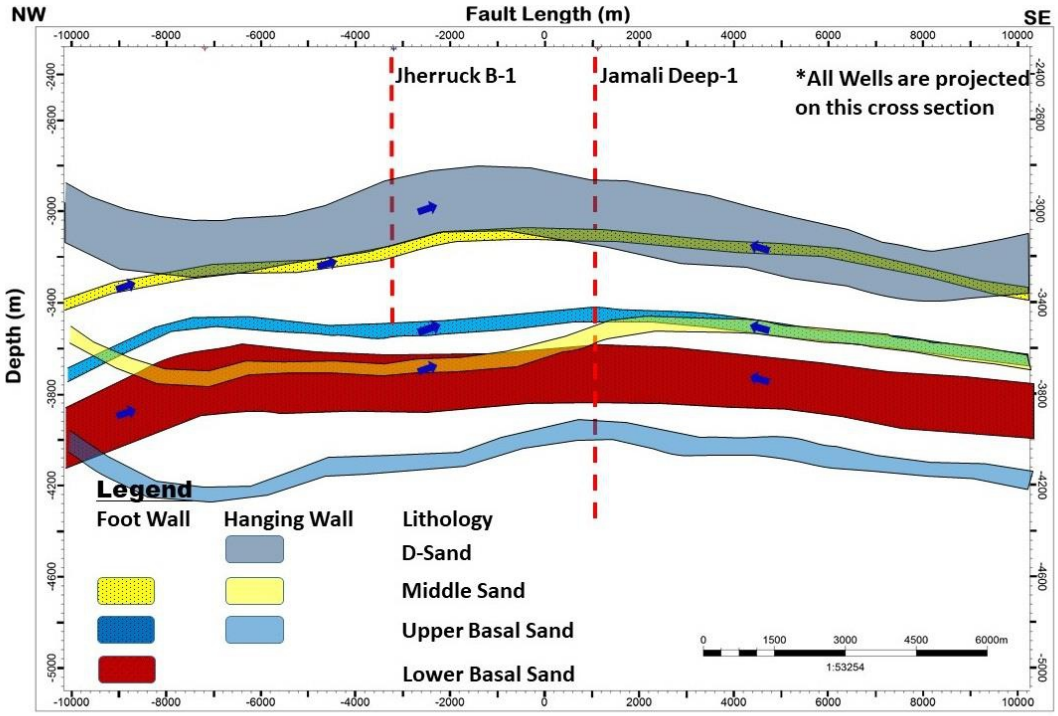

Fig. 7. Allan Diagram of lower sands (Middle Sand, Upper Basal Sand and Lower Basal Sand) across fault-1.

9. Conclusions

Estimation of sealing potential of fault, plays a vital role in structural and stratigraphic traps. The present study has revealed that integration of seismic and well logs data is expedient tool in addressing such problems.

The depth maps revealed bookshelf geometry associated with extensional regime. Fault-1 was selected and is the main prospective fault of the research area because contours make closures along this fault attributed to fault bounded structure. Additionally, this fault is present on all the seismic sections. Fault-1 has large amount of throw and Jamali Deep-1 well drilled at crest of fault bounded closure for lower sands but still it failed to produce hydrocarbons. The fault seal analysis indicated that Middle sand is juxtaposed against hanging wall of D-Sand and hydrocarbons moved up-dip direction in D-Sand. Crestal location of Upper Basal Sand on footwall juxtaposed against hanging wall of Middle Sand which act as conduit lithology for hydrocarbons movement. On the other hand, Middle Sand of hanging wall further up-dip in opposite direction to fault-1. Lower Basal Sand is also juxtaposed against hanging wall of Middle Sand in NW direction of the fault. The juxtaposition of different sand packages indicated that hydrocarbons moved towards up dip location.

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Authors' Contribution

Mudassar Nawaz, Developed the theory, was involved in writing and conceived the presented idea. Muhammad Rustam Khan Supervised the overall project, Muhammad Farooq supervised the findings of the project. Jabir Nazir provided the software and geological support. Umair Bin Nisar was involved in writing and correlation of results and is also corresponding author.

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