SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)
ISSN (Print) 1813-1743, ISSN (online) 2791-0547
Vol. 55:02 (2023).
Doi: https://doi.org/ 10.26692/surj-ss.v55i02.6636

Reservoir Characterization of Lower Goru Formation Using Seismic and Well Logs Data, Mubarak Gas Field, Lower Indus Basin, Pakistan

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Cite this:
Wahid, B., Alam, S., Salam, A., Halepoto, A. A., Jalal, S. (2023). Reservoir Characterization of Lower Goru Formation Using Seismic and Well Logs Data, Mubarak Gas Field, Lower Indus Basin, Pakistan. Sindh Uni. Res. J. (SS) 55:02.

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ABSTRACT

This research focuses on reservoir characterization of sand bodies of Lower Goru Formation in the Mubarak Gas Field, Lower Indus Basin, Pakistan. Mubarak Gas Field is located in Indus Platform, where Mesozoic extensional structures are concealed beneath Paleogene sequences. These extensional normal faults host largest hydrocarbon reserves of Pakistan. Source rock potential exist in Lower Cretaceous Sembar and Goru Formation, whereas Jurassic Chiltan limestone and Cretaceous Goru Formations are potential reservoir rock, sealed by shales of Upper Goru Formation. The study integrates seismic data and well logs to enhance understanding of the subsurface reservoir properties. Seismic interpretation indicate normal fault in subsurface, which host hydrocarbon reserves of Mubarak Gas Field. Other studies suggest that these faults are produced during rifting of Indian Plate during Mesozoic. Well log data suggest reservoir potential in Lower Goru B-sands and C-sands. The study will contribute to understanding of reservoir quality and future exploration strategies in the sand bodies of Goru Formation.

Keywords: Reservoir characterization, Goru Formation, Seismic interpretation, Wireline log analysis, Mubarak Gas Field, Lower Indus Basin, Pakistan

INTRODUCTION

Exploration and production of natural resources plays a vital role in the economic development of a country especially with the growing global energy demands. The seismic exploration technique in geophysics is mainly applied to search hydrocarbons initially started in 1920s. Three dimensional seismic surveying arouse in 1970s, and in the middle 1980s it had emerged as beneficial method for onshore and offshore imaging (Chopra & Marfurt, 2005). 3D seismic data provides most suitable and complete 3D image of subsurface which leads to more reliable interpretation (Yilmaz, 2001). Wireline logs are one of the most important data type in reservoir characterization for geoscientists. They provide borehole measurements in the form of continuous record which is further used to interpret the geological environment, fluid distribution and parameters calculated from petrophysics in the reservoir. Study area lies in Ghotki district

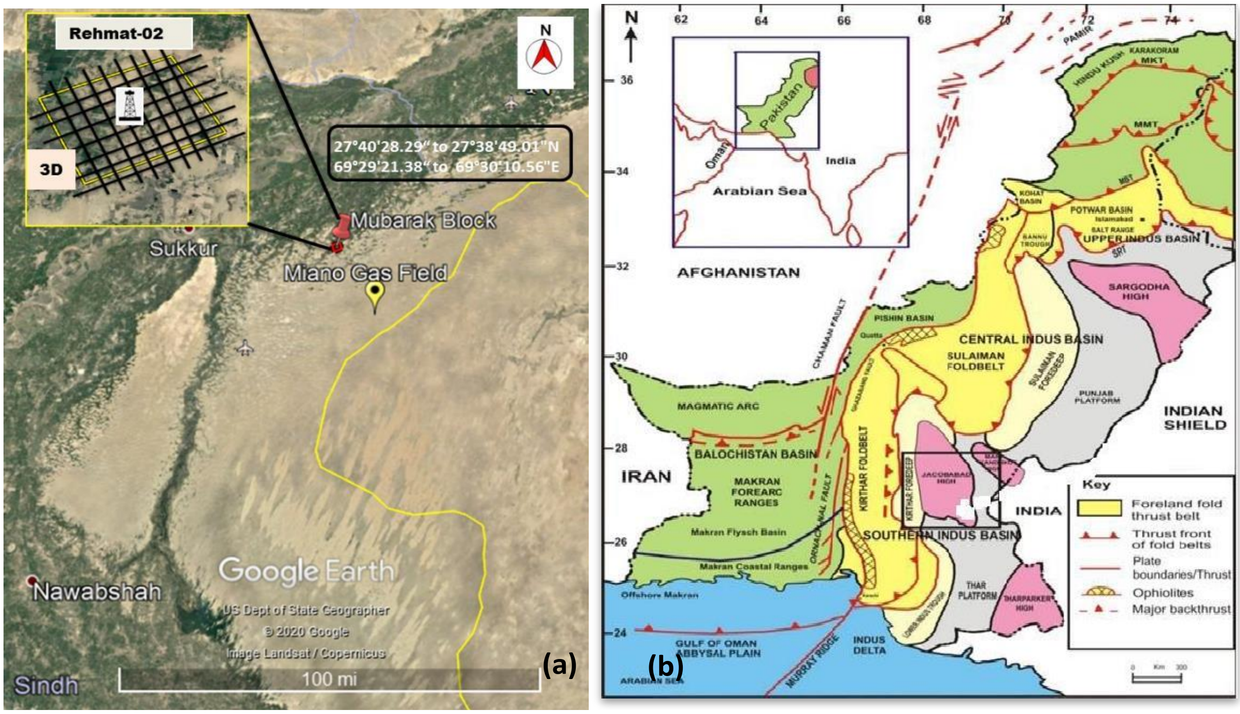

Figure 1: (a) Google Earth Imagery showing location of study area; (b) Regional tectonic map of Pakistan showing location of study area (after Aziz & Khan, 2003).

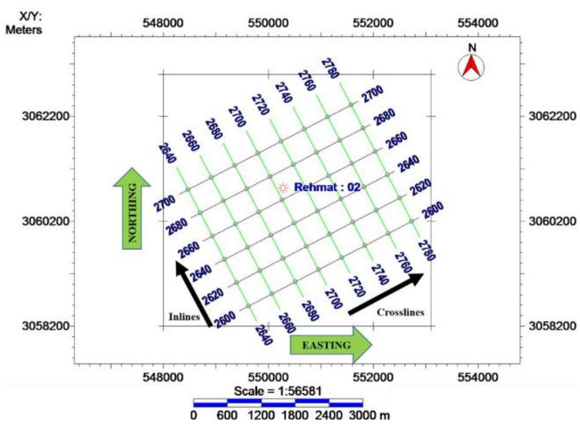

Figure 2: Base map of the study area, showing location of 3D seismic lines grid and well location.

of Sindh province, Pakistan (Figure 1). Mubarak is a gas producing field. Data acquisition of Mubarak block project was first awarded to PCPL (Petronas Carigali Pakistan Limited) in 1999. 3D seismic survey of about 550 square kilometers was carried out by PCPL in 2004. Spatial distribution and orientation of seismic lines, well location, shot points and other relevant information is shown in figure 2. This study shows that Lower Goru Formation possess unique characteristics which can act as potential reservoir. Previous and current studies of inversion integrated with multi attribute analysis reveal that sand reservoirs have good thickness can produce economical hydrocarbon. Identification and characterization of sand reservoirs and deposited channels would contribute to future production.

Petroleum System of study area

Sembar Formation of early Cretaceous age is the most prominent source rock in Lower Indus basin. Shale units of Lower Goru Formation has a unique character to act as source rock, especially Talhar shale and lower shale. Sember formation has TOC values greater than 1.5 wt. % (Wandrey et al., 2004). Fractured limestone of Jurassic Chiltan Formation is one of potential reservoir in Lower Indus basin (Quadri & Shuaib, 1986; Kadri, 1995; Asim et al., 2015). Porosity and permeability data of various fields depicts that Lower Goru sands has excellent production potential and its sand-prone sequences are prospective (Quadri & Shuaib, 1986; Kadri, 1995; Abbasi et al., 2015a). Sembar shale act as seal for underlying Chiltan Formation. Upper Goru shales act as seal for Lower Goru Formation. Shales of Ghazij and Ranikot Groups has the capability to act as seal rock for underlying formations (Raza et al., 1990: Halepoto et al., 2022) . The hydrocarbon trapping mechanism in Indus Platform area of Lower Indus basin is provided by both structural and stratigraphic traps (Ahmad et al., 2004; Abbasi et al., 2015a, 2015b, 2016; Ahmed et al., 2018; Halepoto et al., 2023a, 2023b). Rifting of Indian

Plate from other Pangean fragments during Mesozoic produced normal faults in Lower Indus Basin. Major hydrocarbon reserves are trapped in these faults traps (Ahmad et al., 2004; Abbasi et al., 2015a, 2015b, 2016; Naeem et al., 2016; Ahmed et al., 2018). Generalized stratigraphy of petroleum system in study area is shown in figure 3.

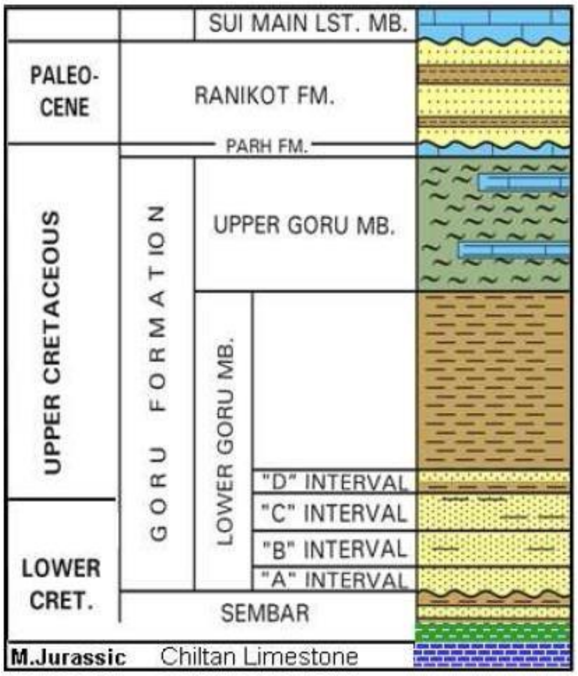

Figure 3: Generalized stratigraphy of Petroleum System in the study area (Ahmad et al., 2004).

MATERIALS AND METHODS

Generalized workflow adopted for dissertation is shown in the figure 4. Synthetic seismogram is generated at the well location of Rehmat-02 using well log data in order to identify various horizons of interest also to tie well with seismic data. Various horizons and faults are interpreted at reservoir level in given 3D seismic data. For regional extension and propagation of fault marked on various seismic inlines, fault polygons are generated and grid are created for contouring of interpreted horizons on whole seismic cube. Petro physical analysis is performed for quantification of pay zone by evaluating reservoir pore volume, shale volume, water saturation and hydrocarbon saturation in sand reservoir. Seismic attributes are applied to identify sand channel geometry, amplitude response and its lateral and temporal resolution at dominant frequency of seismic data. LMR cross plot are generated to discriminate fluid and lithology with in reservoir as well as for seismic inversion feasibility. Seismic inversion techniques are applied to map the spatial extent of petro physical properties and interpolation of well log information on seismic scale. Geostatistical techniques are applied for mapping spatial distribution of porosity by integrating well data with inverted impedance and seismic attributes. Estimation of S_w and V_{sh} volumes to observe spatial distribution of HC in reservoir.

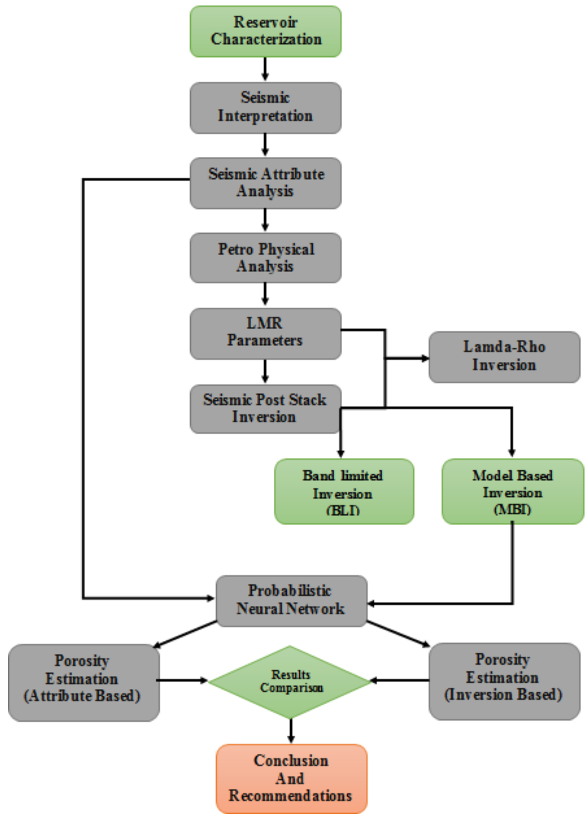

Figure 4: Workflow of present research.

RESULTS AND DISCUSSION

Synthetic Seismogram

Synthetic seismogram is the artificial reflection trace obtained by using well logs information also known as 1D forward model. Both density and sonic log product gives acoustic impedance which then transformed to reflection coefficient using empirical relation. Convolution of source wavelet with reflectivity series gives us synthetic trace. Both synthetic and real seismic data is compared through a correlation coefficient (Dobrin & Savit, 1960; Kearey et al., 2002). Synthetic seismic trace generated at well location of Rehmat-02 is shown in figure 5.

Seismic Interpretation

Stratigraphic units and faults are surfaces that discriminate the different lithologie by different

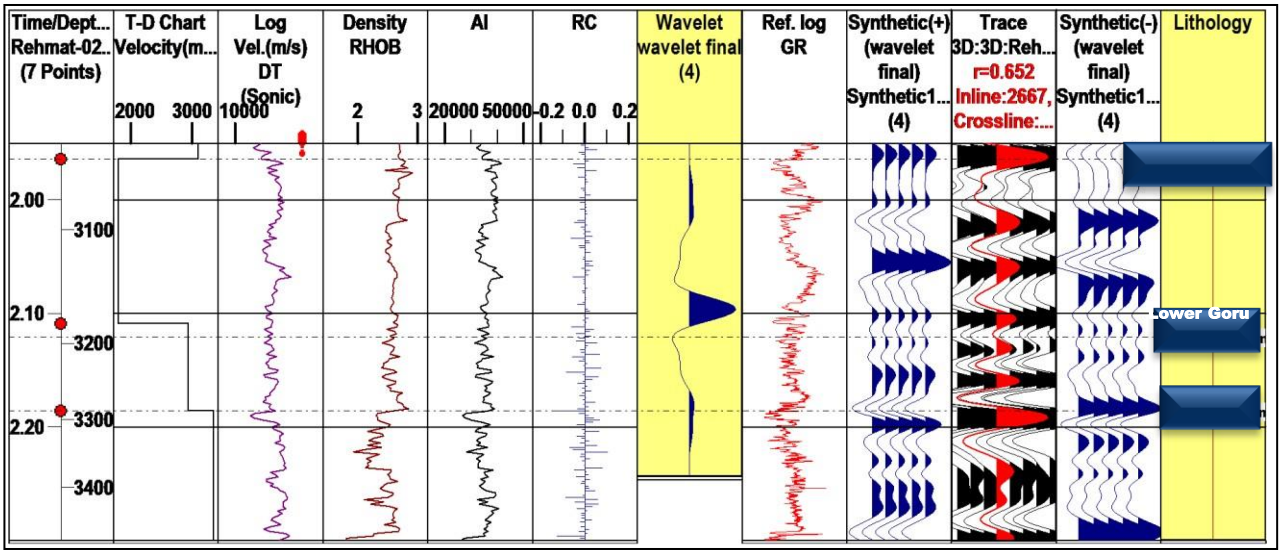

Figure 5: Synthetic seismogram of well Rehmat-02.

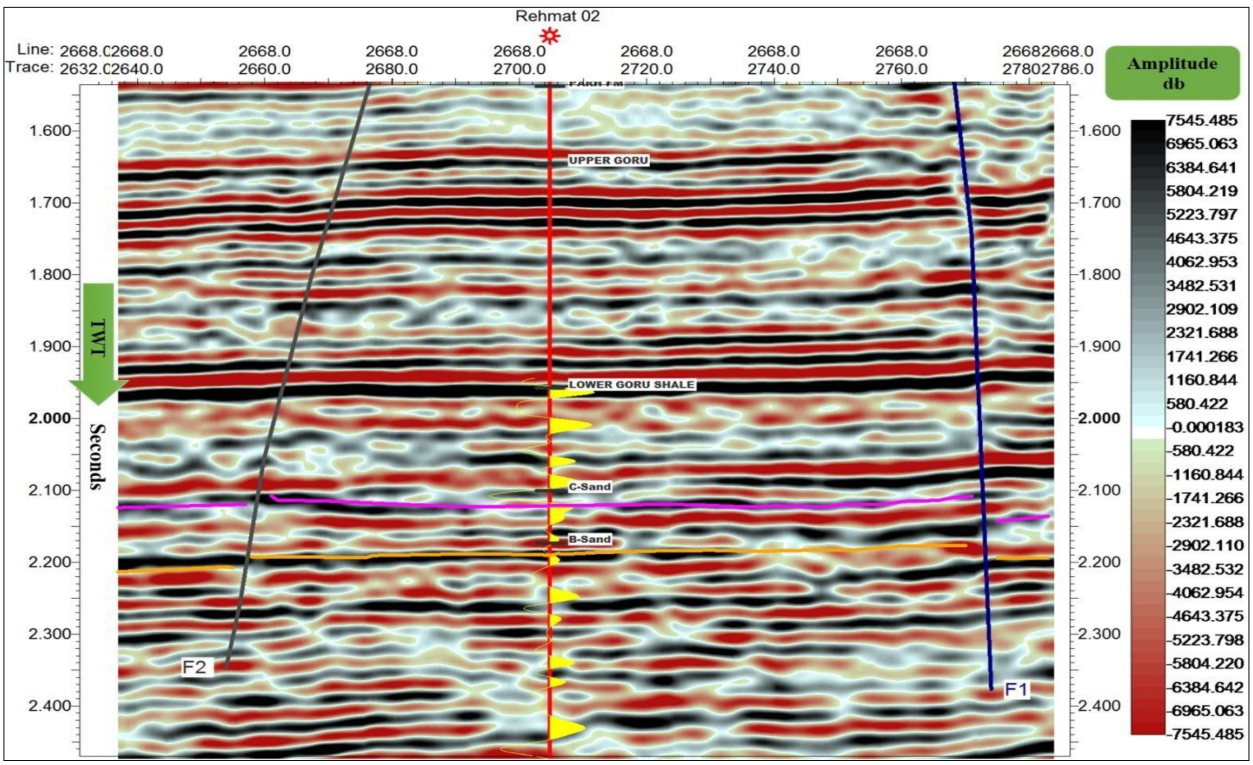

Figure 6: Interpreted horizons on Inline 2668 with well location.

reflection patterns. Horizon of interest can be marked on seismic data in the presence of formation tops obtained from well data. Using synthetic trace generated, various horizons are marked at their respective time and normal faults are interpreted on section. Horizons of interest in Lower Goru Formation are marked on the seismic section including B-interval and C-interval, using synthetic seismogram generated from well Rehmat-02. Inline 2668 and 2706 cross-line interpreted to analyze the regional structural trend. Rehmat-02 well is displayed on the section on inline 2668 along with its formation tops. Two horizons such as Lower Goru B and C-interval are picked with different color whereas two normal faults named as F1 and F2 are the marked in the section inline 2668. The seismic amplitude values vary in decibel (db) (Figure

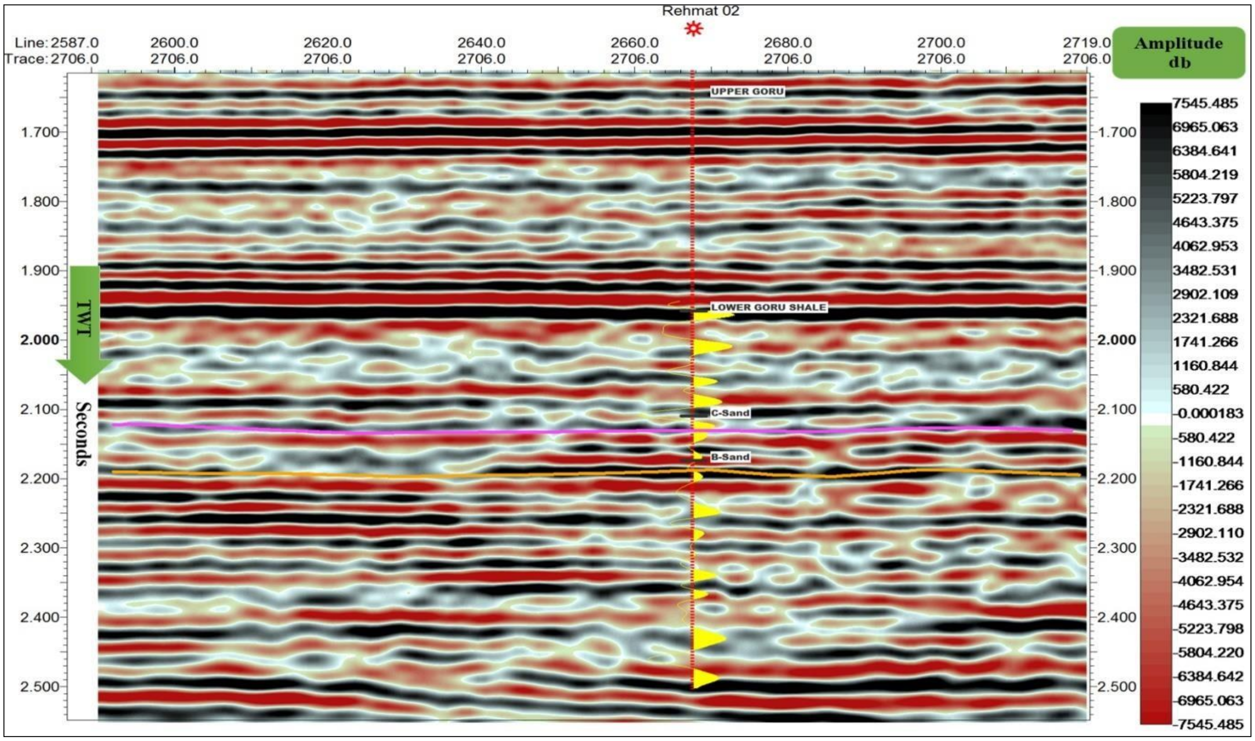

Figure 5: Interpreted horizons on cross-line 2668 with well location.

6). Cross-lines are parallel to strike, hence along these line the section does not show any structural variations. Interpreted seismic section of cross-line 2706 is shown in figure 7.

Contour Mapping

Contours are the lines formed by joining the point of same physical property in space and time. Time and depth contour maps of B and C-intervals show the position of horizon in time and depth domain and the type of structures formed at these horizons.

Time contour map shows the subsurface variation of reflecting horizons. Time of Lower Goru B-interval varies from 2.176 to 2.207 seconds and the depth varies from 3332 to 3380 meters in contour maps. Contour maps show well spudded on shallower depth (horst) of B-interval reservoir which is encountered at 3353 meters. Contour interval is of 0.8 milliseconds and 2 meters respectively for time and depth contour maps as shown in figure 8 and 9. Contour interval for time contour maps of C-interval is 1 millisecond and for depth map it is 2 meters are shown in figure 10 and 11 respectively.

Seismic Attributes Analysis

Any information that is extracted directly from seismic data or indirectly by logic-based information and experience is called seismic attributes (Asim et al., 2015; Abbasi et al., 2016). The information about physical parameters of seismic wave like impedance of earth layers, reflection and absorption coefficients, velocity etc. is provided by amplitude content of seismic data. Whereas the phase content gives insight into the reflections geometries and configurations. Hundreds of attributes are categorized into various depending upon the type of information extracted (Yilmaz, 2001; Asim et al., 2015; Naseer et al., 2015; Abbasi et al., 2016; Solangi et al., 2016).

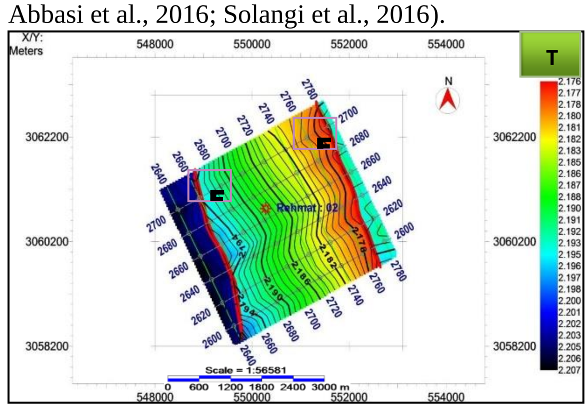

Figure 6: Time contour map of Lower Goru B-sand interval.

RMS Amplitude attributes

RMS, a post stacked attribute which is extracted from the seismic trace, is square root of sum of squared amplitudes divided by “N” number of samples with in a defined window. It is regarded as amplitude accentuating attribute, as its values are squared first and averaged later. Higher values of amplitude RMS attribute is principally found sensitive for detection of channel morphologies because it differentiates zone of high acoustic impedance contrast which also indicate lithological variation such as porosity, fluid content and lateral variation in volume of sand and shale in siliclastic environment. (Hu & Zhu, 2013). Applied RMS amplitude is validated by p- impedance highlighting low impedance response on zone of interest shown in figure 12. High magnitude of RMS attribute is observed at well qualitatively, because larger amplitude would have attenuated at b-interval probably due to high acoustic impedance contrast. In order to observe spatial amplitude response across the survey extracted RMS amplitude attribute sliced at B-interval indicate higher amplitude at well location and highlighting probable sand channel shown in figure 13.

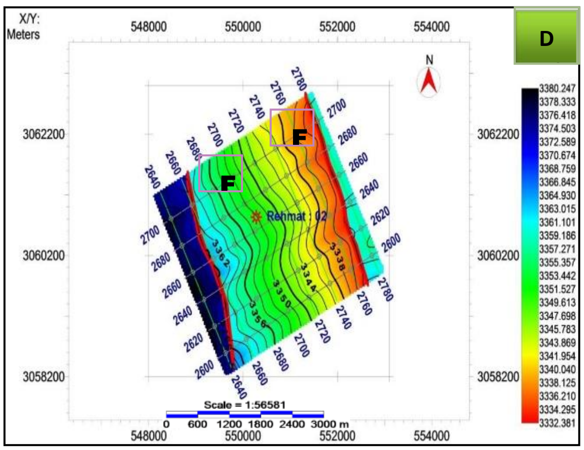

Figure 7: Depth contour map of Lower Goru B-sand interval.

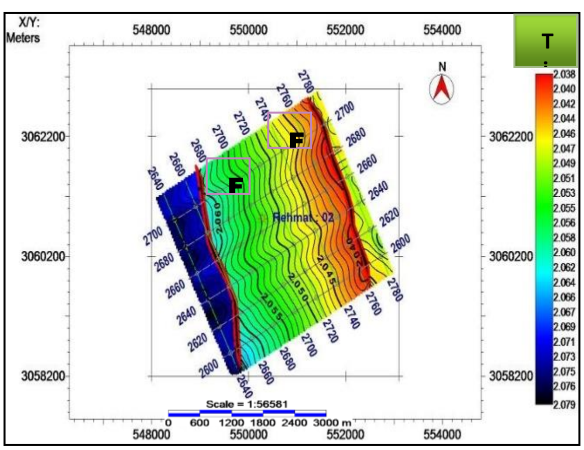

Figure 8: Time contour map of Lower Goru C-sand interval.

Sweetness attributes

Sweetness attribute is composite of two complex trace attributes. Mathematically it is calculated by dividing instantaneous amplitude (reflection strength) by square root of instantaneous frequency (Taner et al., 1994). It works well in geological settings where there are sand (hydrocarbon or brine filled) and shale layering of fluvial systems, for the visualization of isolated sand bodies because of their stronger reflection than the interbedded shales (Hart, 2008).

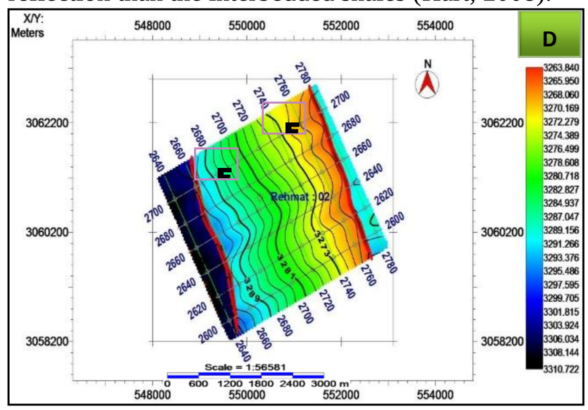

Figure 9: Depth contour map of Lower Goru C-sand interval.

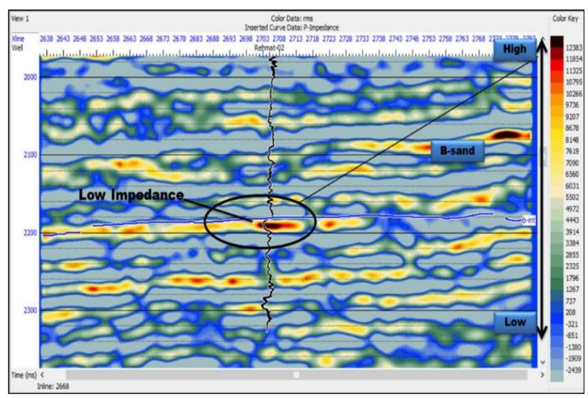

Figure 10: RMS amplitude attribute validation by inserting P-impedance log at inline section.

Sweetness is a tool that enhances the visualization of intervals of sand bodies and identify oil/gas prone zones known as sweet spots and very effective for the identification of sand channels and another stratigraphic feature (Hart, 2008). Sweetness attribute is validated by p-impedance highlighting low impedance response on zone of interest shown in figure 14. Sweetness slice extracted at the horizons of B-interval showing the higher magnitude of sweetness and well location also indicating probable sand channel signature shown in figure 15. Interval of shales are characterized by low magnitude of sweetness because it has low amplitude (low acoustic impedance contrast) and having higher frequency, on the other side sandy intervals such as channel fills tend to higher magnitude of sweetness because of higher amplitude (higher acoustic impedance contrast with shales) and low frequencies showing broad reflections (Radovich & Oliveros, 1998).

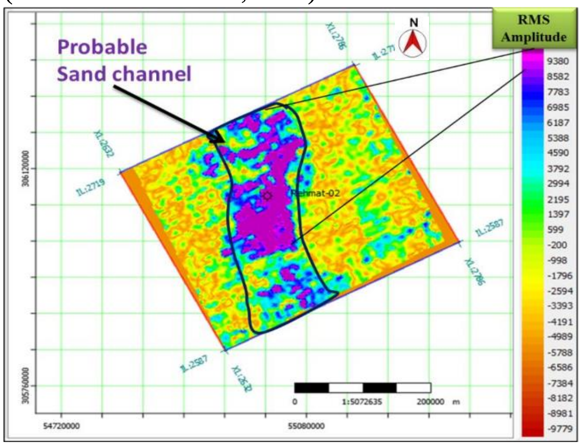

Figure 11: RMS amplitude attribute sliced at B-sand interval.

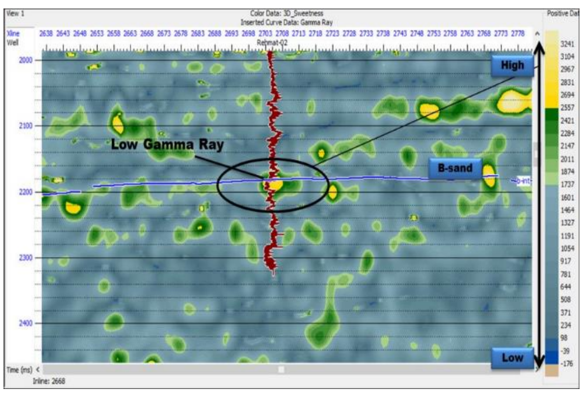

Figure 12: Sweetness attribute validation by GR log at inline section.

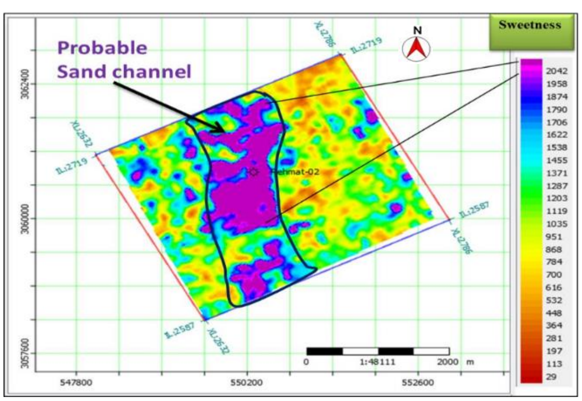

Figure 13: Sweetness attribute sliced at B-sand interval.

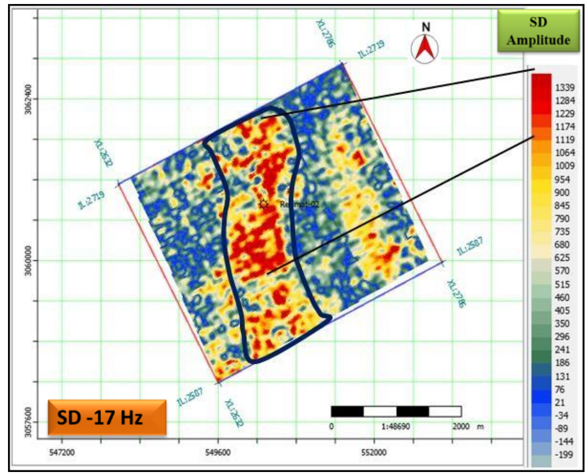

Figure 14: SD attribute applied on 17 Hz sliced at B-sand interval.

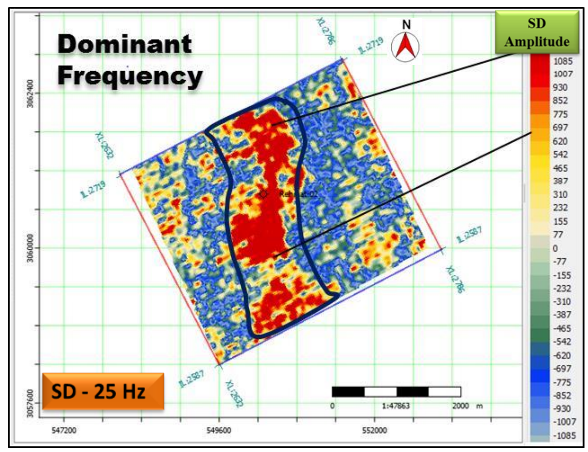

Figure 15: SD attribute applied on 29 Hz sliced at B-sand interval.

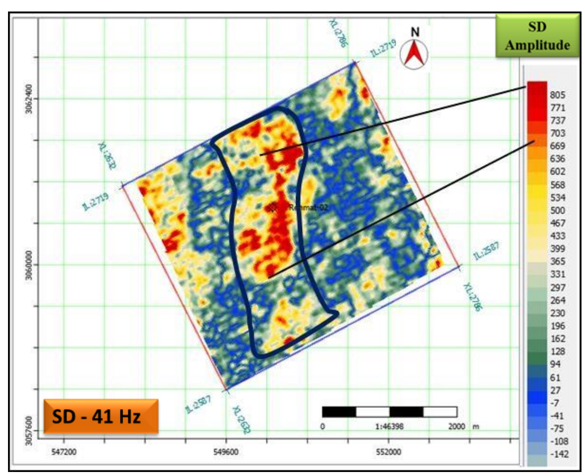

Figure 16: SD attribute applied on 41 Hz sliced at B-sand interval.

Spectral Decomposition

Reservoir facies and their temporal as well as lateral distribution pattern which are not easily resolvable using conventional seismic attributes. Spectral decomposition is time-frequency analysis. It is a robust technique which aid seismic interpretation and mapping bed thickness variation on different band of frequency (Partyka et al., 1999). Spectral decomposition is very effective for delineation of stratigraphic features (Marfurt & Kirlin, 2001). This technique, through mathematical methods i.e. continuous wavelet transformation (CWT) and other, decomposes seismic data into frequency domain. As frequency is related to vertical resolution of feature, rather than observing whole band of frequencies which carry much information may tend to mislead interpretation that is why we should observer decomposed bands of frequency with in survey amplitude spectrum. Higher the frequencies more it shall delineate thin bed and improve resolution and lower the frequency thicker formation is resolved. Prior to the application of CWT-SD amplitude spectrum of seismic data is analyzed and dominant frequency of seismic survey is observed at 25 HZ as observed in figure 17. Sand Channel frequency may be less or greater than the observed dominant frequency. Seismic 3D data was decomposed at different bands of frequencies i.e. 17 Hz, 25 Hz and 41 Hz to resolve sand channel temporal resolution and thickness. Band width helps to remove unwanted information and made the section easy to understand and interpret with clear appearance (Partyka et al., 1999). Spectral decomposition attribute is validated by p-impedance, highlighting low impedance and high amplitude response on zone of interest at 25 Hz frequency applied on inline, shown in figure 17. Therefore, at computed dominant frequency of 25 Hz sand channels temporal variation is resolved qualitatively aid seismic interpretation. Spectral decomposition slices extracted at B-interval horizon, over different frequency bands to observe at which frequency sand body is better resolved in term of frequency, are shown in figures 16-18.

Petrophysical Analysis

Petrophysical analysis is performed in exploration industry for the fluid and rock matrix characterization. It identifies and separates the zone of pore network from the non-porous zone, hydrocarbon bearing and water bearing zone and permeability (Cannon, 2015).

Petrophyical parameters, such as shale rock volume, porous rock matrix, water saturated rock matrix and hydrocarbons saturation are determined by using the well logs curves. Well logs used in petrophysical interpretation are generally classified into following:

- Lithological logs
- Porosity logs
- Resistivity logs

Petrophysical interpretation workflow, of well Rehmat-02 for quantification of pay zone, is shown in figure 19.

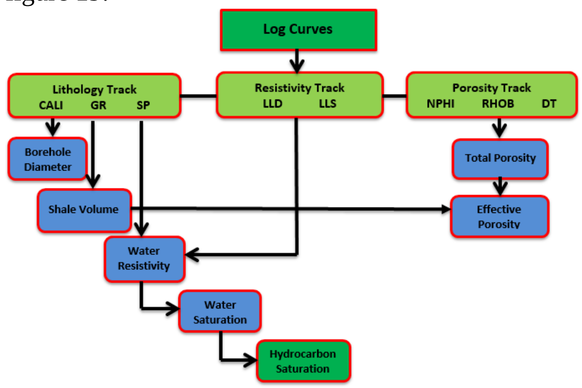

Figure 17: Petrophysical workflow of present work.

Table 1: Petrophysical parameters calculated for this zone.

S. No.	Petrophysical Parameters	Units
1	Shale Volume (V_{Sh})	22%
2	Total Porosity ($Ø_T$)	17%
3	Pay Zone Thickness	14m
4	Effective Porosity ($Ø_E$)	14%
5	Water Saturation (S_w)	22%
6	Hydrocarbon Saturation (S_h)	78%

Petrophysical Results for B-Sand Interval

Petrophysical analysis for B-sands was carried at the depth ranges from 3350-3400 m (table 1) Petrophysical analysis reveals that B-sand interval to be the best zone in terms of hydrocarbon potential the log responses are observed in B-sand interval. The crossover between resistivity logs is prominent marked zone which indicates that the hydrocarbons are present in this zone. The presence of potential hydrocarbons is best discriminated and confirmed by the crossover of neutron porosity and density log i.e. the density is decreased. The shale volume log also shows less percentage of shaly content in this zone due to which the water saturation also decreased because hydrocarbons replace it. The effective porosity is also very high as compared to its values in the other related zones (Figure 20).

CONCLUSION

Following conclusions are drawn from the study:

- The seismic structural interpretation confirms the presence of normal faulting in study area, which

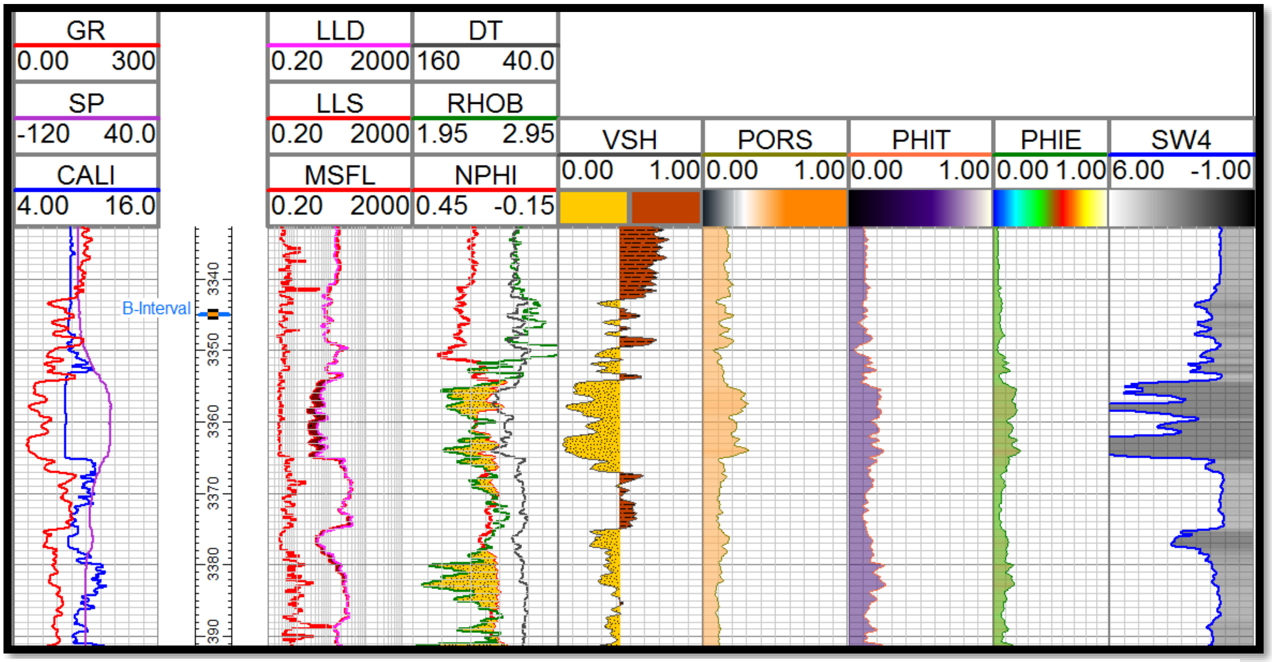

Figure 18: Petrophysical Analysis for B-sand Interval.

produced during Mesozoic extensional tectonic regime

- Petroophysical analysis quantifies that B-sand interval of Lower Goru Formation has porosity in 12-14% ranges and 70-80% of hydrocarbons saturation present in pay zone
- Petrophysical results confirm that Lower Goru Formation has significant potential to produce economic quantity of hydrocarbons

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