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Reservoir Rock Genetic Types Using Log Curve Shapes: Abu-Madi Formation, Offshore Nile Delta - Baltim Gas Field, Egypt

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Abstract. Recognizing of detail rock genetic types in Abu-Madi Formation using log curve shapes techniques is the main object of this research work. Abu-Madi Formation has been drilled in The Baltim gas field, offshore Nile Delta, and is deposited in a fluvio-marine environment which exhibits complex lithofacies. It is composed mainly of sandstone intercalated with siltstone and shale interbeds. The Abu Madi Formation is considered as the main gas producing reservoir rock in the Baltim gas field. Facies analysis and reconstruction of facies patterns for Abu-Madi Formation were performed using Log curve shapes interpretation. The constructed vertical profiles of three borehole logs data against lithologic intervals of the Abu-Madi Formation define the depositional history and the prevailing different rock genetic types. Two main rock genetic types were recognized indicating deltaic sedimentation. They are: 1. Distributary channel and 2. Stream Mouth bar deposits. They are exhibited either by a single unit of distributary channel or a complex superimposed on a stream mouth bar unit. Generally, they are representing lower deltaic plains and deltaic fringes sediments respectively. These rock genetic types are considered as the main gas producing zones in the Baltim field.

1. Introduction

Baltim area lies to the north of the Nile Delta between latitudes 31°37′25″ and 31°56′19″N and longitudes 31°1′12″ and 31°26′7″E, about 25 km of the Mediterranean sea shoreline. It covers an area of about 500 km2, with a length of 25 km and a width of 18.75 km ‘figure 1’. The Nile Delta off shore area is characterized by the presence of large number of gas fields that have a big amount of hydrocarbon reserves. The Baltim North Field is located in the offshore Nile Delta. Exploration of this field added an additional play concept for gas, condensate and oil prospecting in onshore Nile Delta area.

The main object of the present research work is to understanding the mutual relationship between gas chimneys and their direct impact on the Gas reservoirs characteristics. Recognizing the reservoir rock genetic types using log curve shapes give good ideas about the depositional history of the study area. It is integrated with quantitative borehole log data analysis in order to obtain true opportunities for tracking the channel sand systems and other reservoir rock types in the area for further exploration. After first paragraph, other paragraphs are indented as you can see in this paragraph. After Introduction, divide your article into clearly defined and numbered sections.
Baltim field is characterized by a thick sequence of Tertiary sediments ‘figures 2&3’, dominated by deepwater siliciclastics[1&2]. The Messinian Abu Madi Formation represents the sedimentary infill of a fluvial-dominated palaeo-valley which extends in the subsurface over a south-north distance of about 130 km and 30 km from east to west (2&3). It has an average thickness of 300 m and characterized by stacked fluvio-deltaic sandstones and shales on lapping southwards [4].

Petrographically, the Abu Madi sandstones comprise quartz to sublithic arenites, fine to medium grained and poorly to moderately sorted [4&5].
2. Methodology
The Abu Madi Formation as the main gas producing zone is studied in 4 boreholes drilled in the Baltim Field using log curve shapes. The Log curve shapes of Abu-Madi Formation are directly related to reservoir rock genetic types, its associated primary structures and history of deposition by observing both gamma ray and deep resistivity curves against it. Abu-Madi reservoir intervals are investigated to recognizing different reservoir rock genetic types in both vertical and areal distribution.

These technique has been early introduced and investigated by [6,7,8, 9; 10, 11&12], and applied in oil industry. It was found that sandstone intervals are characteristically distinguishable by gamma ray in combination with electrical resistivity curves to recognizing different genetic sand bodies especially in a deltaic environment.

Tech-log software is used as a powerful tool for computing Petrophysical analysis such as porosity and water saturation from digitized borehole log data of the four studied wells (BN-1, 2 & 4 and BNE-1), also for interpreting the different log curve shapes.

3. Results and Discussions
The vertical profiles of Gamma ray log in combination with electrical resistivity log curves facing the Abu-Madi Formation are used to investigate and categorize the reservoir rock genetic types according to log curve shapes [11, 13]. The main log curve shapes have been found are:

3.1 Distributary Channel (cylindrical shape)
It is obtained in Well-BN1 facing the upper part of Abu Madi Formation and representing a gradual upward decreasing in gamma ray value curve response. Electrical resistivity curve behave as mirror image to the gamma ray curve shape. In shallow marine settings, this trend reflects a change from shale-rich into sand-rich lithology and upward increase in depositional energy with shallowing-upward and coarsening of sand grains. In deep marine settings, this trend reflects an increase in the sand content of turbidite bodies. The cylindrical shaped gamma ray curve indicates massive, featureless, non-graded sand normally associated with channel fills as meandering fluvial and delta distributary channels rock genetic types ‘figure 4’ and indicating lower deltaic plain.
Figure 4. Abu-Madi formation log curve shapes (cylindrical) indicating Distributary channel deposits (Well-BN1)

3.2 Deltaic Fringes (Serrated Curve Shape)
It is founded in Well BN2 as distributary channel represented by cylindrical shape in the base of the Abu Madi Formation followed by stream point bar sand represented by a bell shape. In Well BN2, sand units are relatively fine grained and moderately sorted. These two units are repeated several times indicating deltaic fringe sand intercalated with shale deposits. However, curve shapes reflect a general coarsening upward in a highly serrated funnel type configuration. The serrated curve shapes probably arise from irregular downward movements due to growth faulting, which are common in a highly constructive delta, Figure 5.

Figure 5. Abu-Madi Formation log curve shapes (cylindrical followed by Funnel shape) indicating deltaic fringe deposits, Well BN2
3.3 Upper Deltaic Plain (Stream mouth bar- Distributary Channel Combination)
Well BN2 (Abu Madi main) exhibits log curve shapes representing superimposed distributary channel sand units overlain by stream mouth bar sands. This combination is indicating middle to upper deltaic plain ‘figure 6’.

![Figure 6. Distributary channel overlain by stream mouth bar deposits, BN2main](image)

| Well name | Abu-Madi Formation (Environ. of deposition) | Depth interval (m) | Kafr el sheikh Formation (Environ. of deposition) | Depth interval (m) |
|-----------|---------------------------------------------|-------------------|-----------------------------------------------|-------------------|
| BN-1      | Distributary channel Stream Mouth Bar       | 3730-3780         | Distributary channel                          | 3535-3555         |
|           | Distributary Channel mouth bars            | 3660-3700         | Distributary channel                          | 3345-3365         |
| BN-2      | Distributary Channel Stream alluvium        | 4165-4205         | Distributary channel                          | 3890-3920         |
| BN-2      | Distributary Channel Stream Mouth Bar       | 4060-4080         | Distributary channel Barrier Bar              | 3725-3740         |

3.4 Net-pay thickness contour map
The net pays thickness map of Lower Abu-Madi reservoir ‘figure 7’ shows that the net pays thickness ranges between (40-60m). The highlighted interpreted value indicates large sand pay thickness about 50 m net pay thickness of Abu-madi reservoir which gives good indication for reservoir parameter. The highest thickness is present around the BN-1 Well. Hydrocarbon potentiality increases with the net pay thickness increase.
3.5 Average porosity contour map
The porosity values were calculated from sonic logs of the studied boreholes in the Balim gas field. The average porosity map of Abu-Madi reservoir shows that it ranges between (0.12 -0.19). The highlighted values indicated average porosity values (Ø%) of an approximately 20% which characterizing a good reservoir quality ‘figure 9’.

3.6 Abu Madi Shale Volume Contour Map
The shale volume percentages increase where porosity decreases and vice versa ‘figure 9’. This behaviour is logic if the shale volume not reached up to 50%. The presence of decreases both reservoir flowing and storage capacity.
Figure 9. Abu Madi Shale Volume Map

3.7 Water saturation contour map
The water saturation (Sw) values were calculated from electrical resistivity logs using empirical equations for a, m, and n calculations and also derived from different cross plots. The average water saturation map of the Lower Abu-Madi reservoir ‘figure 10’ shows that water saturation values ranges between 0.35 and 0.60 which is relatively high. The highlighted values indicating water saturation (Sw) approximately of 35% gives a good reservoir quality. Baltim N-1 and BN-4 wells are considered as the most gas producing in the study area.

Figure 10 Abu-Madi Water Saturation Map

3.8 Hyderocarbon Reserve Estimation
Accurately estimating the reserves of hydrocarbons in the reservoir is extremely important. This calculation not only relies on computations from log data but also on the size and shape of a reservoir, and correlations of logs from many wells in the field. A useful quantity for hydrocarbon-in-place measurements is therefore the hydrocarbon pore volume, or HCPV, which is defined [14] as:

\[
HCPV = \phi (1 - Sw)
\]
Thus, at any depth in a well, if both porosity and saturation are deduced from logs the concentration of hydrocarbon in the reservoir at that depth can be estimated. In Baltim study area, if porosity is 16% and water saturation is 35%, then HCPV = 0.16 (1-0.35) = 0.104 or 10% of the bulk reservoir volume contains gas. At a neighboring point in the same well, the value of HCPV may be different. Thus, in order to sum the total hydrocarbon-in-place (HIP), an integration of HCPV with respect to depth and area is calculated as:

\[ \text{HIP} = \sum \phi (1 - S_w) h A = 2,500,000,000 \text{ m}^3 \]  

in case if we used the study area (A) = 500 km2 and the net reservoir thickness (h) = 50 m.

4. Conclusions
Two main rock genetic types recognized in the Abu Madi Formation are indicating the deltaic sedimentation. They are: a. Distributary channel and b. Stream Mouth bar deposits. The barrier bar rock genetic type is frequently present superimposed on the distributary channel indicating middle to upper part of the deltaic plain. The calculated average porosity is approximately 0.16, net reservoir thickness = 50m and average water saturation = 0.35, while the calculated gas reserve in-place for the study area(HIP) reaches to more than two trillions cubic meters.

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