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Gas detection technique in low resistivity pays of Lower Acacus reservoir, concession NC7A, Ghadames Basin, NW Libya

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Highlights

- **Low Resistivity Pay represents the main challenge in the shaly-sand Lower Acacus reservoir in Ghadames Basin. Up to date, no real procedure has been found to define the hydrocarbon in this type of reservoir.**
- **In this study, we were able to define gas reservoir by applying a specific feature in Techlog software named "Pallete-Spectrum" of the sonic log. However, this is not applicable on oil reservoir.**
- **The advantage of this procedure is that, it does not need any extra measurement or calculation. In addition, it has been applied on different gas wells in Ghadames Basin, which shows a good result.**

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ABSTRACT

Lower Acacus Member is one of the main reservoirs in the Ghadames Basin and it is composed of alternation sandstone and shale facies. It is characterized by low resistivity multiple stacked pays, making the hydrocarbon detection task difficult. To date, no real procedure has been found to correctly define the hydrocarbon in low resistivity intervals. Gas layers as an example could be defined using density and neutron cross-over, but in shaly sand reservoirs as in this case, the shale effect on the neutron log measurement is opposite to the gas effect making the detection of the gas zone by cross-over not valid. On the other hand, the sonic log is affected by the gas by decreasing the rock density, which leads to overestimation of porosity. This phenomenon shall help diagnose the gas presence in low resistivity reservoir. Using color editor of petrophysical software enables the subdivision of log curves into horizontal intervals with specific color or shade based on certain values. Intervals with DT (90-100 msec/ft), which corresponding to 25-36% porosity unit, are shaded red. Comparing production test results with high porosity zones (red shaded on logs) proved that they are gas producers. The advantage of this procedure is that it does not need any extra measurement or calculation; it is only a way of displaying the logs. It has been applied to different gas wells in Ghadames Basin, and it shows a good result. However, this procedure is not applicable to oil pays.

1. Introduction

The present study is based on the need for generating a new approach aimed to delineate gas intervals within Lower Acacus reservoir, which characterized by Low Resistivity Pay (LRP) phenomena.

1.1 Location of the Study Area

The study area (Fig. 1) (Arabian Gulf Oil Company, 2007) is located in the south-central part of Ghadames Basin, with three wells (Well-1, Well-2, and Well-3) under the supervision of Arabian Gulf Oil Company (AGOCO). The study area (Concession NC7A) is located about 100 km to the East of Dirj City.

1.2 Regional Tectonic Setting

The Ghadames Basin is a large intracratonic basin on the North African platform. Formed during the early Paleozoic era, it covers an area of 350,000 km^2 and straddles the borders of Libya, Tunisia, and Algeria. The Libyan portion represents the eastern flank of the basin and covers an area of about 183,000 km^2. It is an important hydrocarbon province since the 1950s (Echikh, 1998). The main tectonic elements bounding the Ghadames Basin are the Dahar–Nafusa uplift to the north, the Qarqaf arch to the south, partially bounded by the extension of Tihemboka uplift to the west, and the western flank of the younger Sirt Basin to the east (Fig. 2).

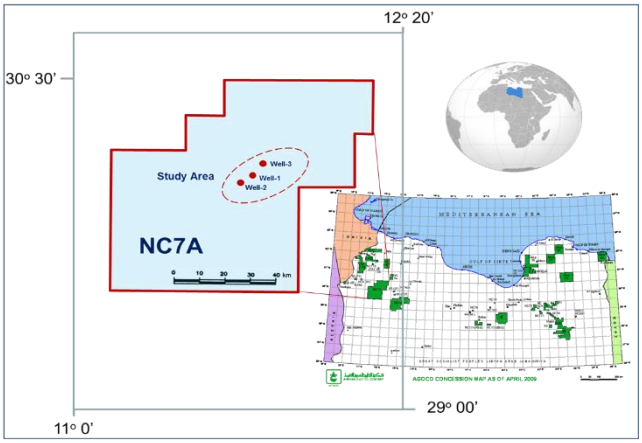

Fig. 1. Location of the study area in Ghadames Basin (Arabian Gulf Oil Company, 2007)

Many of these structural features were initiated in the late Precambrian Pan-African orogeny, with repeated reactivation of older structures occurring throughout the Phanerozoic. The basin contains up to 5,200 m [~17,000 ft] of Paleozoic and Mesozoic sediments, the Paleozoic section being separated from the Mesozoic deposits by a major regional unconformity of the Hercynian(Devonian-Carboniferous) age (Figs. 2&3).

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This Hercynian unconformity is represented as the most conspicuous feature of the basin as Paleozoic sequence is overlain by Mesozoic succession with a markedly different basin configuration. Erosion patterns and the topography that developed on the surface of this regional unconformity have had a direct influence on the petroleum systems within the basin. (Hallett, 2002).

1.3 Regional Geological Setting

The Ghadames Basin comprises four major tectonic cycles. The oldest one, that represents the Cambro-Ordovician cycle, ended by the Early Caledonian tectonism; the second one of Silurian age ended by the Late Caledonian epeirogeny and the third one of Devonian–Carboniferous age terminated by the Hercynian epeirogeny. The Alpine Orogeny, represented by Mesozoic sedimentary cycle, has increased the northern extension of the basin and changed it into a marginal sag basin (Hallett, 2002). Paleozoic deposits are dominated by non-marine and marine clastics: conglomerates, sands, silts and shales that comprise more than 95% of the total section. There are much more carbonates and evaporates in Mesozoic deposits, while the Cenozoic deposits consist of limestone and shale. The depositional setting in Paleozoic is an interior, cratonic regime of subsidence characterized by shallow marine and non-marine environments. The depositional setting of marginal platform regime dominates during Mesozoic time.

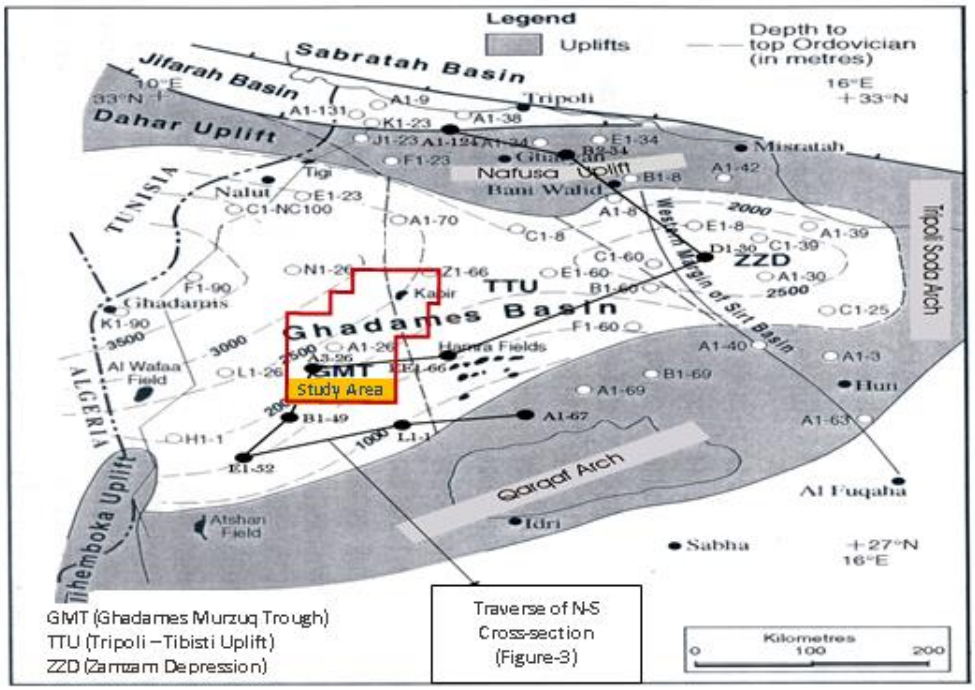

Fig. 2. Tectonic elements of Ghadames Basin (Hallett, 2002)

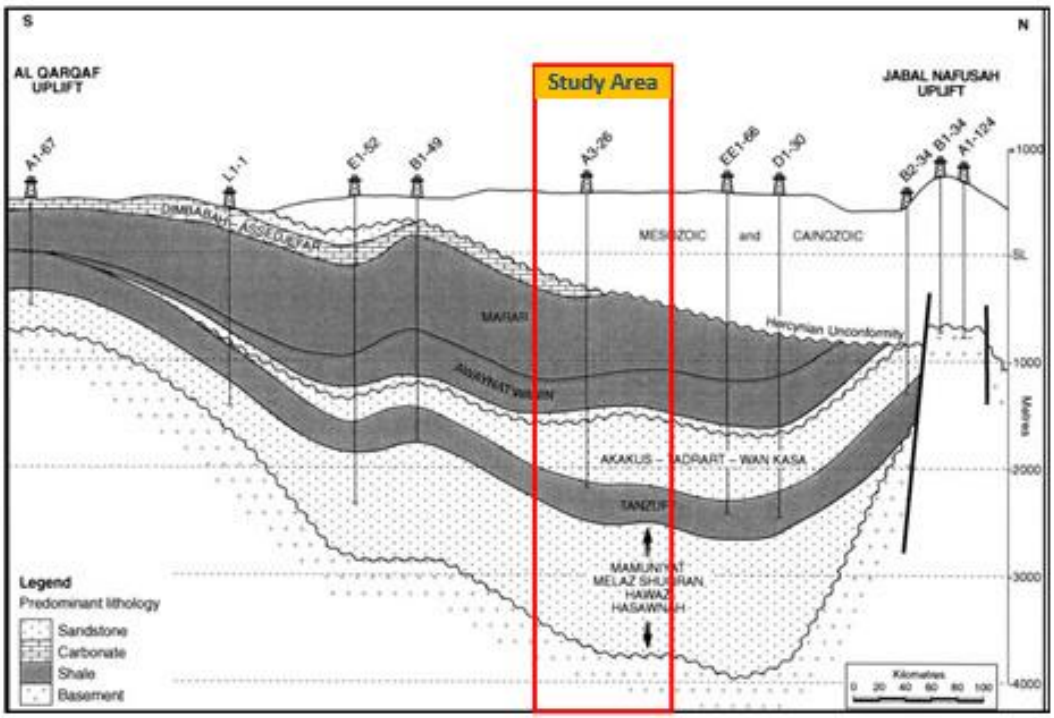

Fig. 3. N-S cross-section line of Ghadames Basin (Hallet, 2002).

In general, development of the Lower Acacus reservoir coincides with a high stand system tract during Late Silurian time, which leads to the development of prograding delta complex. The inter-fingering of the delta front sandstones with adjacent prodelta mudstone provides the multi-pay reservoirs. This reservoir represents the main targets for oil exploration and production and it is characterized by the low resistivity phenomena, making the hydrocarbon detection from well logs a very difficult task.

1.4 Objectives

The main aim of this study is to introduce a new, best-fit reservoir determination approach between sonic log analysis and production tests data on three wells with multi-pay intervals. It could also indicate additional reservoir intervals as bypassed pays.

2. Methodology

The method is based on the best display of sonic log in order to indicate the gas-bearing reservoir. In Techlog (Schlumberger software), they develop a type of color-fill known as (Palette) instead of using only vertical base-line to separate between the log measurements. In the Palette editor, you can divide any type of logs to the number of intervals horizontally and define the intervals by a specific type of lithology (shale or sand). In order to indicate the gas zone, sonic log was divided into six intervals from 40 up to 100 msec/ft (Fig. 4). Every interval is represented by a specific color, for example, green color (value ranges 60-80 msec/ft) represents normal sandstone units with no gas presence, while the values between (90-100 msec/ft) shaded red to indicate gas-bearing reservoir in the study area.

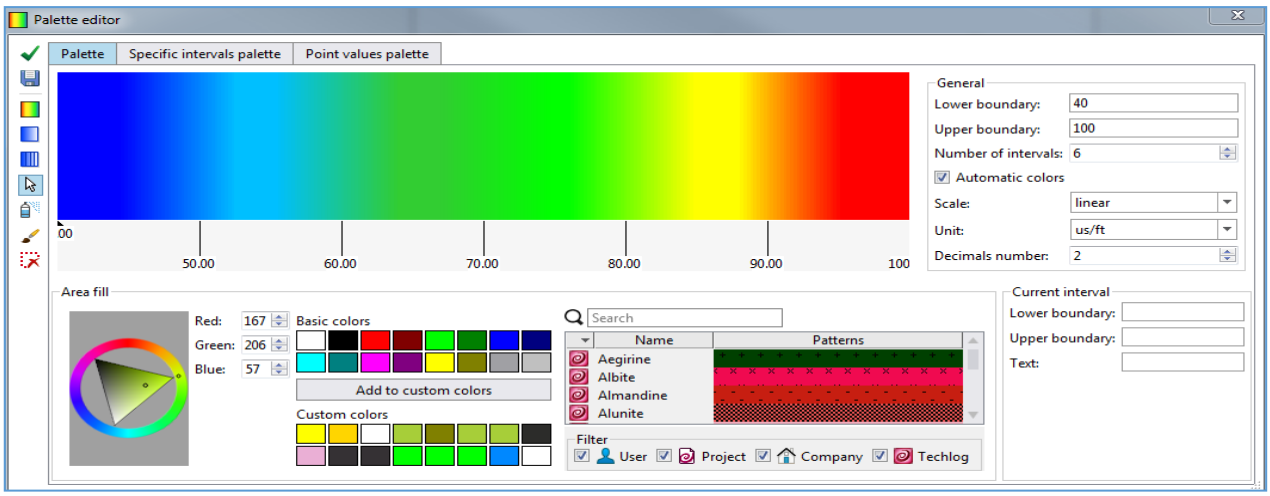

Fig. 4. The Palette editor in Techlog Software shows the six intervals used in this study with the selected colors, in which red color indicates values of gas formation.

The red color should be corresponding to a high concentration of gas molecules illustrating high sonic log reading. This range is actually equal to (26-33 %) porosity unit, which is not common to develop in sandstone reservoirs at deeper sections unless unconsolidated sand is detected. The loose sand could be detected when a wash-out zone occurs in sand layers and it could be excluded by applying the (bad hole flag) between bit size and caliper log giving a value equal to 0.3 inch. As a result, every time caliper log reads 0.3 inch higher than bit size in the sandstone intervals will indicate the unconsolidated aspects and hence, the interval should be further tested to confirm the gas accumulation in the sandstone reservoir intervals.

3. Results and discussions

In order to see the impact of this technique on the gas bearing intervals, two gas wells (Well-1, and Well-3) and one dry well (Well-2) are used in this study. Table 1 represents the top and bottom of Lower Acacus reservoir and the total gross thickness of the formation.

Table 1

Lower Acacus Formation tops and gross thickness among the studied wells.

	Well-1	Well-2	Well-3
Top	9025	9126	9046
Bottom	9730	9820	9786
Thickness	705	694	740

Presentation Summary Track:

Table 2 represents the well-log plot summary tracks (from left to right).

Table 2

Well-log plot summary tracks

Track#1	GR log with lithology Pallete of Sandstone (0-75 API), Silt (75-100 API), and Shale (100-200 API)
Track#2	Measured depth with vertical scale in feet (1:200)
Track#3	Density and Neutron logs with Sand-Shale zone shaded
Track#4	Deep Resistivity
Track#5	Sonic log with gas indication Pallete, and Bad Hole Flag indicated red color

Well-1:

The test results of the well indicate a tremendous amount of gas, and accordingly additional well (Well-2) was drilled to appraise the discovered structure. In the normal reservoir, gas zones could be defined when high resistivity values come across low neutron log reading and low-density log measurement (known as density-neutron crossover). Nevertheless, it can be seen that density-neutron crossover is not pointing to the gas bearing intervals in Lower Acacus shaly-sand reservoir due to the shale effect on the log measurement. Moreover, deep resistivity measurement should read high at gas intervals but this is not the case in the low resistivity pay of Lower Acacus reservoir. Comparing that to the sonic log analysis, in which the log response in the gas zone is more reliable. An increase in the sonic log porosity is clearly seen in gas reservoir interval, which actually was confirmed by production test intervals. In this procedure, gas intervals appear as red color while other sandstone units look green in color. Fig. 5 and Fig. 6 show the result of DT_Facies_Pallete and how correlatable to the production test data. Furthermore, a new zone was identified as bypassed zone (Fig. 7) which might express the advantage of this technique.

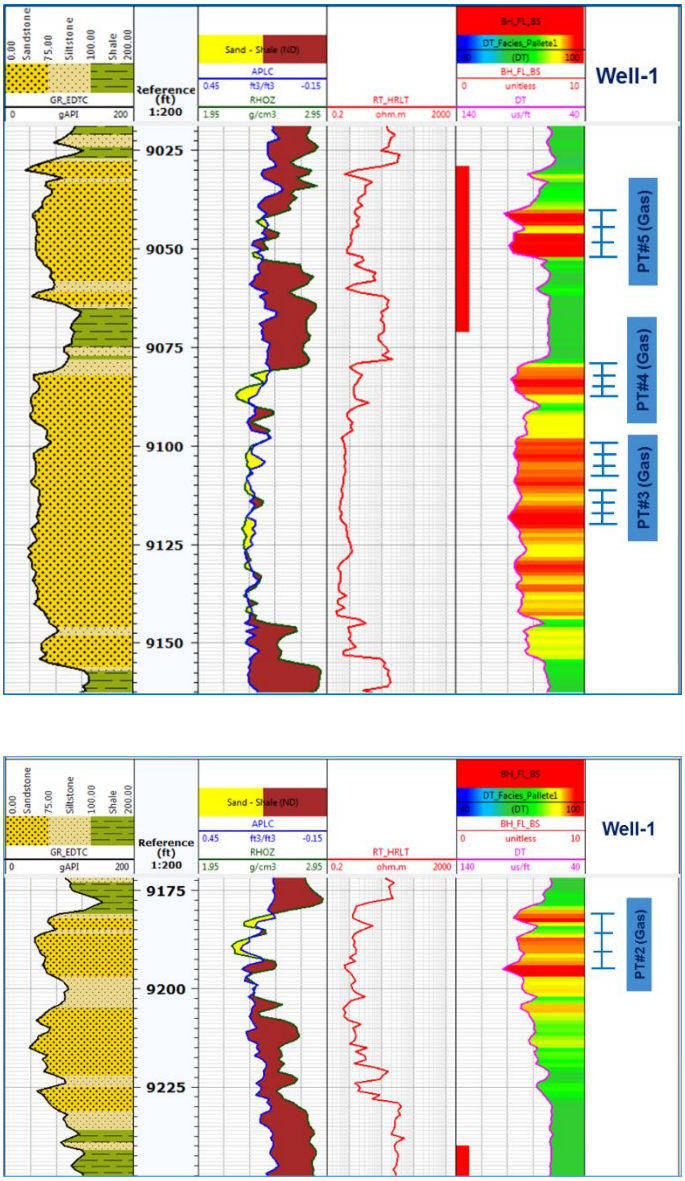

Fig. 5. (A) and **(B)** production test near the top part of Lower Acacus reservoir shows a good fit between gas intervals and DT_Facies_Palette.

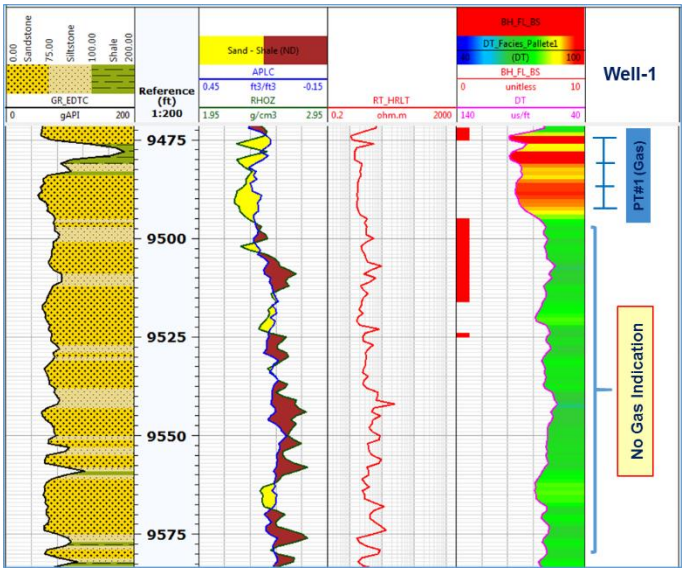

Fig. 6. Thick sandstone unit with gas accumulation at the top of the unit.

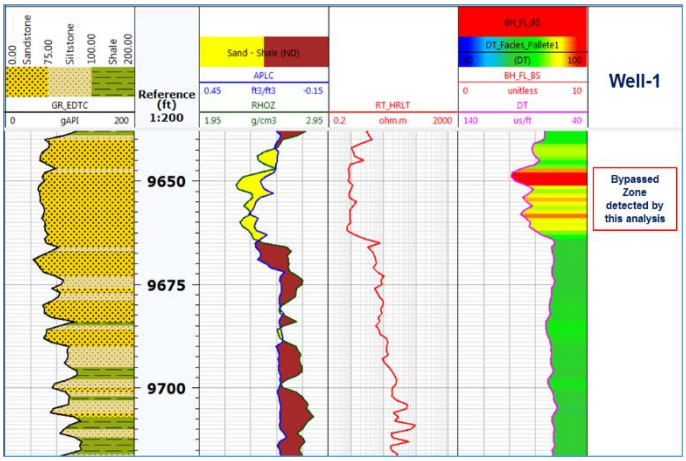

Fig. 7. A new zone was defined at the deeper part of Lower Acacus reservoir, which actually was not tested previously.

Well-2:

The well is aimed to appraise the discovery that was made by Well-1. Regarding the structural status of the well, the DT analysis shows that no gas zones could be defined in the reservoir intervals and the production tests confirm the DT evaluation on the well. Fig. 8 shows that water-producing intervals shall appear in different colors corresponding to values less than that of gas bearing formation.

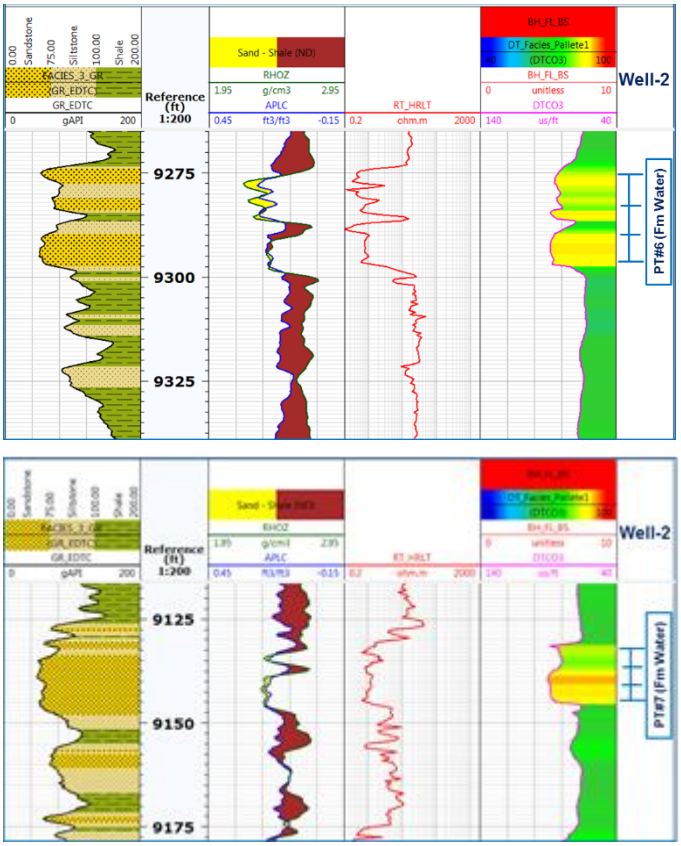

Fig. 8. (A) and (B) production test near the top part of Lower Accus reservoir shows a good fit between water intervals and DT_Facies_Pallete.

Well-3:

In order to confirm the gas presence in the area another well was drilled NE of Well-1 targeting the Lower Acacus shaley-sand reservoir. In a similar way of evaluation of Well-1, different reservoir intervals were recommended for production tests and only one test is contradictory to flowed gas. This gas interval is clearly defined by DT-Pallete analysis confirming the formation production test and delineating the gas-bearing interval (Fig. 9).

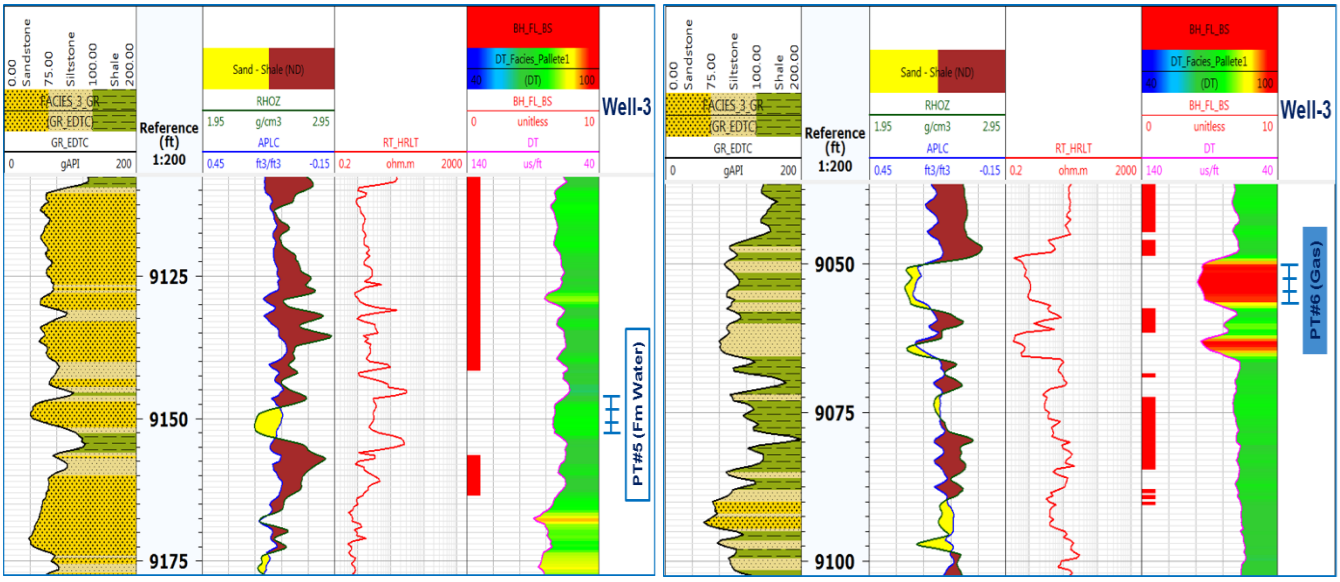

Fig. 9. (A) Production test near the top part of Lower Acacus reservoir shows a good fit between water interval in PT#5 and **(B)** Gas interval in PT#6 with DT_Facies_Palette.

4. Cross Section:

In order to better display the result of the studied well horizontally, a stratigraphic cross section was generated among the area of interest to the upper part of Lower Acacus reservoir in order see the reservoir lateral continuity as well as to simply observe the gas intervals (Fig. 10). Flattening the top of Lower Acacus reservoir, Well-1 comprise of the thickest sandstone intervals with lateral continuity in both directions. However, it is seen that neither density-neutron crossover nor resistivity log is a good indicator to the gas presence in Lower Acacus reservoir. On the other hand, sonic log supported by the DT-Pallete analysis is more reliable to detect gas intervals in the targeted reservoir.

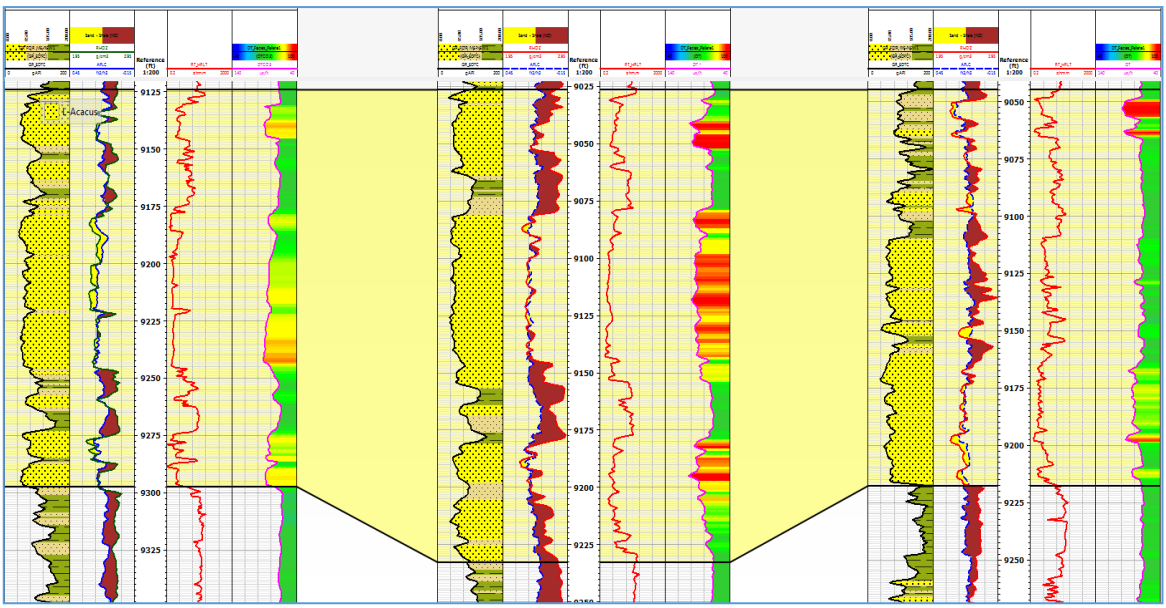

Fig. 10. Stratigraphic cross section of the upper part of Lower Acacus reservoir among the studied wells.

5. Conclusions

In the shaley-sand reservoir, neither density-neutron crossover, nor resistivity log is a good indicator of the gas bearing formation as in the case of Lower Acacus reservoir. On the contrary, Pallete-spectrum of the sonic log could be used to support other analysis (for example; gas measurement in the field, and/or petrophysical analysis) to delineate gas intervals in Lower Acacus reservoir. In DT-Palletegas zones appear red colored indicating a high concentration of gas molecules, while other sandstone units appear green showing no presence of gas in the sandstone reservoirs. Therefore, the DT values need to be calibrated in other fields to be set in the samerange of color. These calibrations allow DT-Pallete to be correctly displayed and acceptably indicate gas-bearing reservoir.

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