High resistivity reservoirs (causes and effects): Sahara field, Murzuq Basin, Libya

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Abstract: High and low resistivity values is an alarming phenomenon that is usually associated with a very complicated reservoir history and worth looking into. Ordovician sandstone reservoirs are the primary oil producers in the Murzuq basin oil fields that is characterized with an average porosity of 14%, permeability range 410-10,760 md and clean quartz aranite composition. More than fifty wells were drilled in Sahara oil field, but only four of them were announced to have high resistivity values more than 100k ohm-m and ten others to be considered as low resistivity wells (below 50 ohm-m). Therefore, average deep resistivity was mapped in both water and oil legs using all available data set, and the top reservoir was employed as a trend map. They showed distinctive trends for low resistivity readings in oil-leg and confirmed the extreme deep resistivity nature for the wells (W7, W8, W9, and W10). Height above oil water contact and capillary pressure was also calculated for all the wells and revealed a high pressure (400 psi) at the location of the high resistivity wells. As a result, of higher capillary pressure in thicker reservoir area oil might have been able to displace water through geological time by benefitting of more considerable height above oil-water contact, higher connate pressure, and buoyancy forces support, which resulted in occupying all the larger pores and pushed the water into minor scattered pores leading to gradual alteration of reservoir wettability from water to oil-wet. Hence, the brine fluids will no longer be connected to each other inside the pore system. Therefore, they will lose their contribution to resistivity readings, and the resistivity tool will encounter a more resistant medium, which in turn will lead to underestimation of water saturation.

Keywords: High resistivity reservoirs, Upper Ordovician reservoirs, Murzuq basin, capillary pressure

INTRODUCTION

Glacial upper Ordovician sandstone formation is an excellent oil reservoir. It is located on the South Western side of the Murzuq Basin (Figure 1).

The overall reservoir thickness reaches about 400 meters. In Sahara field, extremely high resistivity intervals (more than 10,000 ohm-m) were encountered in four producing wells (W7, W8, W9 and W10) (Figure 2), while the highest resistivity recorded in the adjacent ten producing oil wells is 50 ohm-m and below. In this paper, we will attempt to investigate the causes of this event and employ it to simply and quickly uncover more complicated reservoir history, such as wettability that often needs more expensive and intense data analysis.

A reasonable core analysis program was designed by the operator to achieve a comprehensive reservoir rock characterisation. The program includes routine core analysis, special core analysis, and two wettability tests of the reservoir rocks. However, this analysis did not accurately resolve the issue of high deep resistivity variation of producing oil wells and only stated that

"high resistivity due to blocky clean sandstone that might be "oil-wet". As a result, a petrophysical analysis was carried on using an average saturation exponent

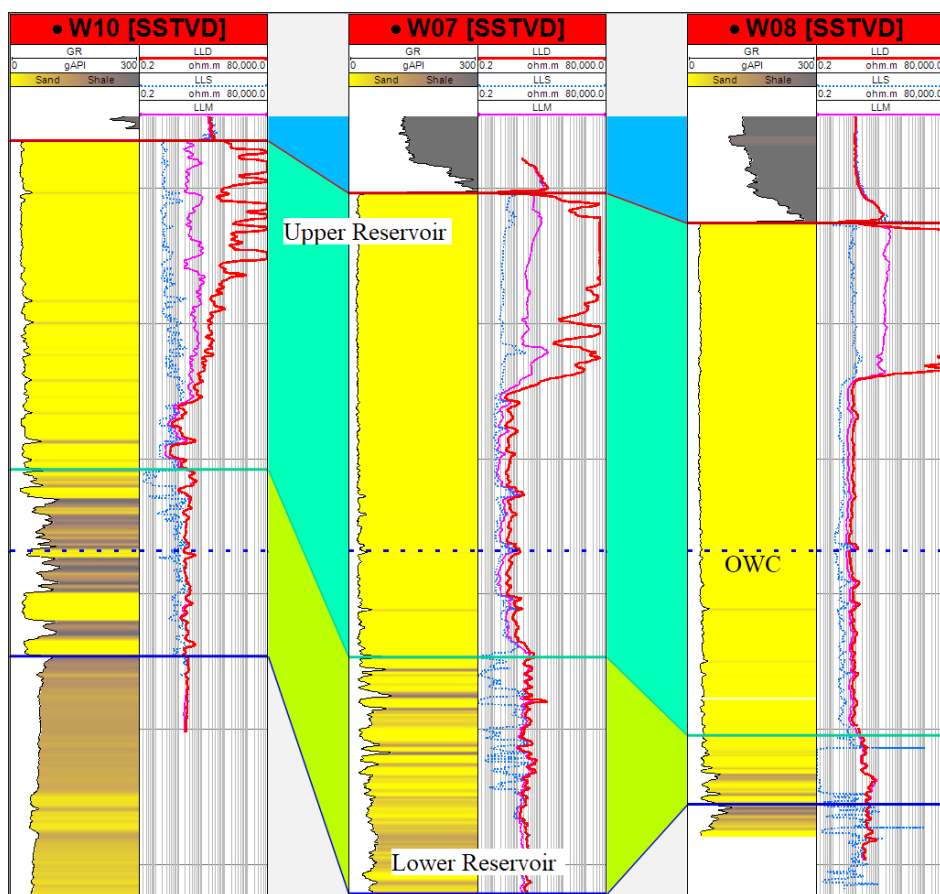**Figure 1:** Location of the studied wells.

Figure 2: The main three wells with extremely high deep resistivity readings.

(n) =1.96 for all the wells, which has not been a recommended practice when dealing with an oil-wet reservoir. Where "the (n) values are found to be higher significantly than in water-wet systems" (Rust, 1957; Morgan & Pirson, 1964; Raza *et al*., 1968; Anderson, 1986a; Donaldson & Siddiqui, 1989; Gladkikh *et al*., 2005; Feng *et al*., 2016). Few years ago, Toumelin & Torres-Verdin (2005) stated that identification of reservoir wettability is made routinely on core plugs. However, there are not many published petrophysical models that practically differentiate between oil-wet and water-wet fractions of reservoir zones using commonly available log suites. Therefore, in this paper, we will be focusing on how to recognise and separate reservoir wettability fraction effects based on deep Resistivity log response and special core analysis results (SCAL).

Reservoir characterization

The reservoir rock characterization is aimed to describe the two significant elements of reservoir rock; the grains and the pore network. The measured reservoir rock parameters are primarily influenced by nature and composition of solid parts as well as the distribution of pore network. Helium porosity, horizontal and vertical gas permeability and grain density were measured using
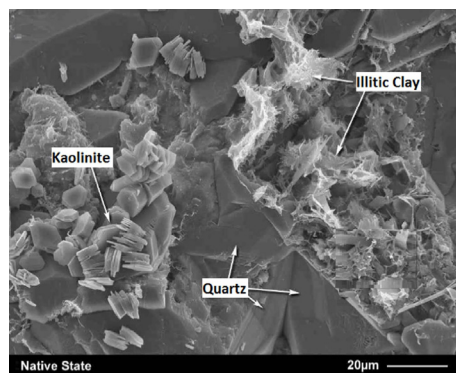

Figure 3: Main minerals identified in W7 as observed in some plugs.

core plug samples (Figure 3). The porosity ranges from 11-21 % with an average of 15 %. The horizontal core permeability ranges between 410-190k mD.

Some samples were selected for petrographic description such as in Figure 3, and it concludes that the rock is mainly quartz arenite with well-sorted grain ranging in their size from 0.177-0.250 mm. The rock is mineralogically mature, dickite and kaolinite are the dominant clay mineral phase while the K-feldspar is the minor (Figure 4).
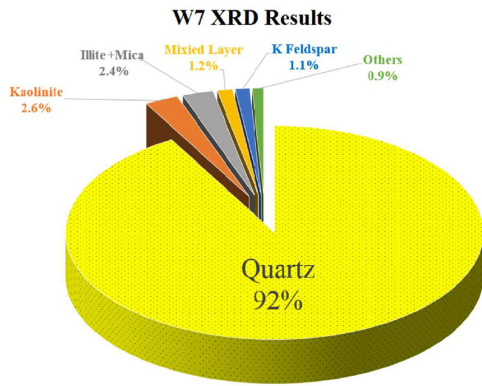
Figure 4: The main minerals identified in W7 using XRD analysis.

Wettability

Wettability is defined as the tendency of one fluid to spread on or adhere to a solid surface in the presence of other immiscible fluids (Gladkikh *et al*., 2005). The importance of wettability in reservoir rocks is that it controls the distribution of fluids within the pore network. The reservoir rocks were fully saturated with water when the rocks had been deposited. At initial conditions, the migrated oil displaced water from large pores. After the oil had been accumulated in the reservoir rocks, the water is filled small pores and form a continuous film coating the pore network. The described water saturation will render the reservoir rocks to be water-wet. Through time, if the wettability has changed to be oil-wet, the grains will be coated with oil and the water is accumulated as disconnected droplets in the centre of large pores.

Meanwhile, the small pores remain fully saturated with water. Two samples were chosen for wettability measurements. Amott method, including the static and dynamic displacement, was used to determine the wettability tendency of the reservoir rock. However, only stated neutral wet at W7 well, which is not enough.

METHODOLOGY

A detailed investigation is exclusively applied to deep resistivity data. Starting with data quality check and environmental correction using Schlumberger atlas to make sure that there was no technical error for deep resistivity readings. Then the correlation was established between high resistivity wells and normal ones to develop a notion of how the resistivity values respond to vertical, lateral lithology, and facies changes within the oil field (Figure 2).

Deep resistivity modelling (water and oil legs)

A detailed, careful mapping process for average deep resistivity has been performed in all available wells (oil-leg and water-leg) by using the top reservoir map as trend map during the modelling process (Figure 5), then a simple grid was created for the top and bottom reservoir.
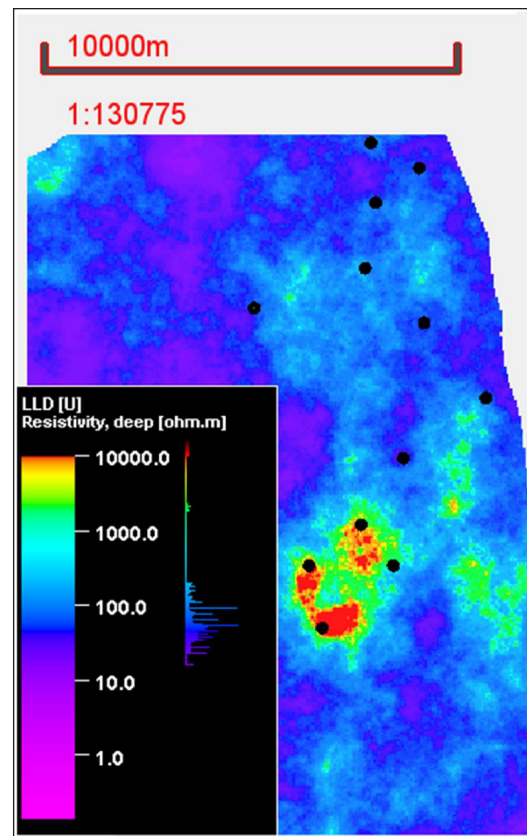

Figure 5: Deep resistivity map for the oil leg within the field for height above free water level estimation.

After that, the average resistivity were populated using Random Gaussian distribution (Figure 5). Similarly, the analysis were repeated in the water-leg.

Height above free water level

Once all the resistivity maps were modelled in the reservoir, it is very crucial to understand the reservoir pressure and fluid densities and distribution. In doing so, the density of oil, water and fluid contacts were obtained from repeated formation test (RFT) data provided by Operator Company, and then height above free water level has been determined by applying the following equations to both logs and core data.

$$H=SSD\text{-}OWC\,(ssd)\dots\dots\dots\dots\dots\dots\dots\dots\,(1)$$

Where, (H) is height above oil-water contact, (SSD) subsea depth and (OWC) oil-water contact (Figure 6).

Reservoir capillary pressure determination:

$$P_c=(H/144)*(\rho_w\text{-}\rho_o)\dots\dots\dots\dots\dots\dots\dots\dots\,(2)$$

For converting laboratory reservoir capillary pressure to reservoir conditions

$$P_{c,r}=P_c\,(\Delta\rho)*26/76=P_c\,(\Delta\rho)*0.361\dots\dots\dots\dots\,(3)$$

Then calibrate the estimated capillary pressure to a height above the free water level in the reservoir conditions, by:

$$H=P_{c,r}/P_c(\Delta\rho)=P_{c,r}/(0.44-0.33)\ldots\ldots...................(4)$$

Where, $(P_{c,r})$ capillary at reservoir conditions, $(\Delta\rho)$ difference between water and oil densities, 0.44 psi/ft. water gradient at reservoir initial condition, and 0.33 psi/ft. oil gradient at reservoir initial condition.

RESULTS AND DISCUSSION

The resistivity map exhibited a typical resistivity value for brine filled sandstone reservoirs; the highest deep resistivity value is 35 ohm-m, scattered along the eastern boundary of the oil field, while the lowest resistivity readings can be seen in the south-west and the middle part of the oil field (Figure 5).

The oil-leg highest resistivity values recorded is more than 10,000 ohm-m and scattered near the south-west boundary of the oil field; also some lower connected and disconnected low resistivity zones (10-50 ohm-m) can be outlined, especially, in both middle and southern parts (Figure 6).

Figure 7 shows S-NW cross-section view at the location of high resistivity wells (W07 and W08), where the high resistivity anomalies above 10,000 om-m are scattered within the top upper reservoir unit known as "clean Mamuniyat" reservoir and confirming the upper oil-water contact reservoir at this closure. However away from the closure centre resistivity values decays until it gets back to a normal one.

Figure 6: A cross-section of resistivity distribution in the location of high resistivity wells after the correction and modelling.

In the other wells such as W04 and W03, the resistivity of the same reservoir unit is below 100 om-m and even lower in the remaining wells (Figure7). This might be a result to thinner "clean Mamuniyat" reservoir in these wells than in the wells with high resistivity readings.

Similarly to the above deep resistivity map, the estimated height above water level and capillary pressure have their highest values in the exact areas where extreme deep resistivity readings were recorded, around 120 ft. Moreover, 4000 psi respectively (Figure 8).

Due to substantial capillary pressure in the areas with a higher hydrocarbon columns, oil might have been able to enter smaller pores and replace water. Through benefitting from high connate pressure and buoyancy forces support, occupying all the minor pores and forced the water into larger scattered pores leading to a gradual local alteration of reservoir wettability.

Hence, the brine fluids will no longer be connected to each other inside the pore system and they will lose their contribution to resistivity readings. When the resistivity readings are conducted in such clean and highly permeable oil-wet sandstone reservoirs, it is very likely that the resistivity current tends to follow the passes where the conductive mineral or fluid exist (Anderson, 1986a, 1986b; Donaldson & Siddiqui, 1989; Toumelin & Torres-Verdin, 2005; Feng *et al*., 2016). The absence of the conductive connected brine fluid and the existence of mostly resistant clean quartz aranite (with a resistivity of more than 500 k ohm-m) (Anderson, 1986b), resistivity current will have to flow either through oil since it is the connected wetting phase or through the rock composition itself or both. Although the latter two observation yet to be accurately proved by conducting more analysis about the things that might cause an increase of origin rock resistivity that isn't applied to current cases, such as lack of pore fluid fill, lower salinity, compaction and lithification (Anderson, 1986b; Donaldson & Siddiqui, 1989).

The distribution of high resistivity zones is largely controlled by the clean reservoir facies association (FA3 and FA5) that is composed of clean medium blocky sandstone and clean coarse sandstone (Figure 9).
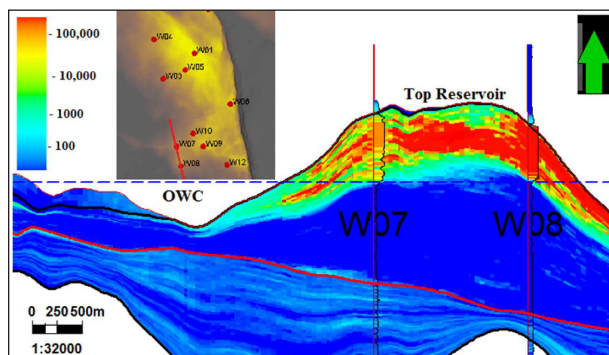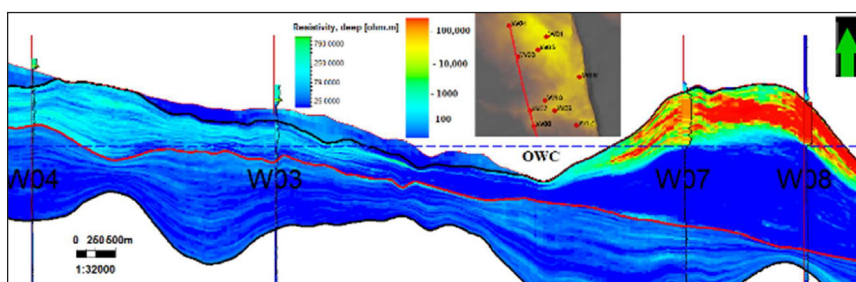

Figure 7: S-W cross-section of resistivity trend in the location of high and standard resistivity wells.

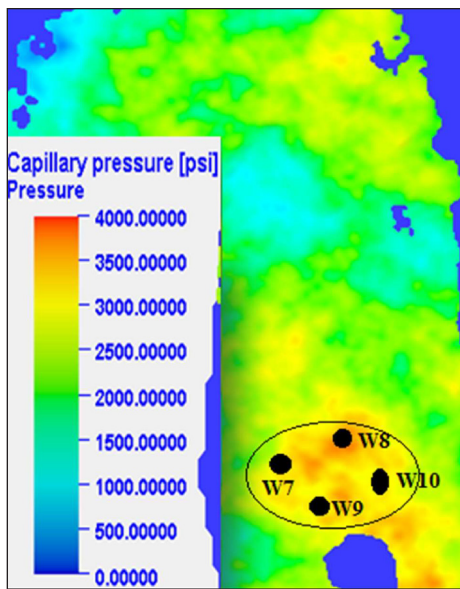ABUBAKER ALANSARI, AHMED SALIM, ABDUL HADI BIN ABD RAHMAN, NURI FELLO, HAMMAD JANJUJAH

Figure 8: The estimated capillary pressure map for the reservoir within the Sahara field.

CONCLUSION

The type of reservoir facies, height above free water level and the pressure of hydrocarbon occupying the connected pore system significantly control the distribution of high resistivity layers for the Upper Ordovician reservoir.

Finally, it is believed that by applying this simple, quick and cheap methods in similar cases will help enrich exploration and production activities choices. By considering different scenarios for calculating sensitive reservoir properties such as fluid saturation and carefully plan the field development injection wells for the wet oil system rather than just injecting water into the reservoir which is often effective in water-wet reservoirs system. Thus, an early highly possible water breakthrough can be avoided.
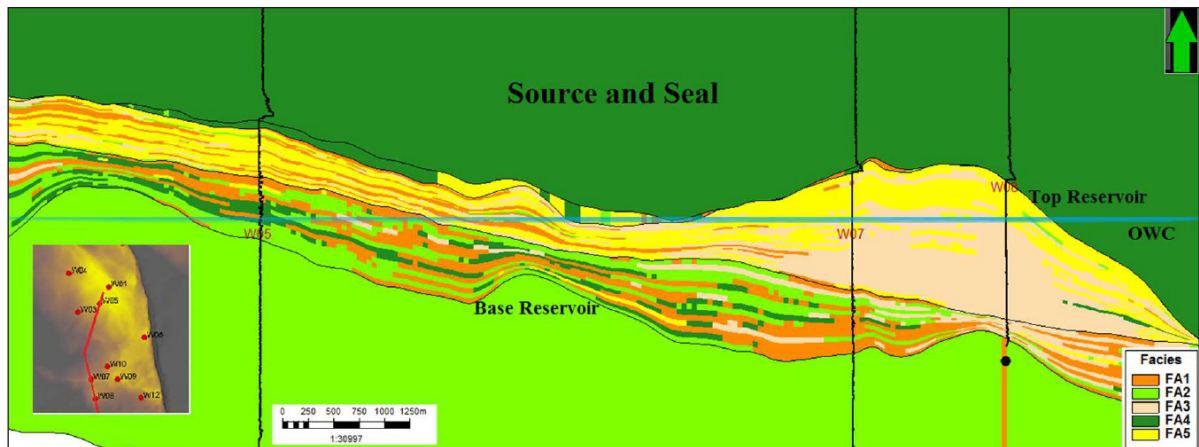
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Figure 9: S-W cross-section of resistivity trend in the location of high and standard resistivity wells.

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