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Petrophysical Evaluation of the Devonian Tahara Formation in NC7A Concession, Ghadames Basin, Libya

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Abstract: The Devonian sandstones of the Tahara Formation represent the foremost hydrocarbon-bearing intervals in NC7A concession, Gullebi Field, Ghadames basin, Libya. The current work aims to determine the petrophysical parameters and assign the hydrocarbon-bearing intervals of the Tahara Formation. A quality controlled and environmentally corrected borehole data, in LAS format, was obtained. The deduced petrophysical parameters obtained using Interactive Petrophysics (IP-2018) software customized for a sandstone dominant lithological nature. These shale-poor sandstones are composed of fine to coarse-grained sediments. The Tahara Formation is assigned as gas-bearing intervals of excellent reservoir characteristics. The sandstone reservoir of the Tahara Formation was discriminated into four zones: A, B, C, and D. The pay zones characteristics show that zone A and zone B were assigned as hydrocarbon-bearing zones, gas accumulation, with excellent and very good reservoir quality. On the other hand, zones C and D are characterized by shale-rich sandstone interval with dispersed shale distribution. This reduces the effective porosity <0.12 and increased the irreducible water saturation content.

Keywords: Litho-saturation cross-plot –Tahara Formation – NC7A concession Gullebi Field - Ghadames Basin – Libya.

1. Introduction

The Ghadames Basin is considered the most important hydrocarbon province in Libya. The Paleozoic sandstone reservoirs, particularly the Devonian Tahara sandstones, represent the main target for petroleum exploration. Since the discovery of the giant Edjeleh field in Algeria, the Ghadames basin was considered as a frontier basin and several concessions were granted for exploration in Libya (Hallet, 2002). The Gullebi oil field (the Libyan share portion of the well-known Gazeil oil field) was discovered in 1960 by the Oasis Oil Company. The exploratory well A1-26, NC7A concession, represents the first oil and gas discovery from Tahara sandstone intervals. An additional southeast well characterized by water-bearing reservoirs is abandoned. Subsequently, gas-bearing reservoirs from different stratigraphic intervals (Tahara, Aouinet Ouenine, and Ouan Kasa formations) were discovered northeast of the A1-26 well. Gas associated with oil accumulations in the Tahara Formation as well as oil in the Aouinet Ouenine Formation had been reported in A5-26 well. The National Oil Company (NOC) performed a widespread exploration and drilling program at Gullebi oil field from 1975 to 1977, that led to drilling a total of 11 wells. In 1988, the HH1-NC7A well located northwards of the A13-NC7A well produced gas from the Devonian Tahara Formation (Teknica, 1997).

The aims of the present study are to petrophysical evaluate the hydrocarbon potentiality of the Tahara Formation, identify the dominant lithological nature, determine the reservoir characterizations, recognize the hydrocarbon phase, and assess the NC7A concession, Ghadames Basin, Libya. This optimizes new well locations and reduces uncertainty and risks for further development.

The Tahara deposits exhibited fluviatile to fluviomarine deltaic environment (Ali, 1977). It is a storm dominated siliciclastic shelf shoreface sequence deposited on the eastern margin of the intracratonic Hamada Basin (Hassi 1993). The series was oriented at an angle to the shoreline. It is thought to reflect a transition to an increasingly offshore distal position (Hassi 1993).

2. Area of investigation

The Gullebi oil field is located in the southern central portion of the Ghadames basin. The NC7A concession positioned between latitudes 29° 30’ to 30º 00’ N and longitudes 11° 30’ to 11º 87’ E (Fig. 1). The Gullebi oil field has a northeast-southwest trend with a total length of 48 km and a width of 5 km.

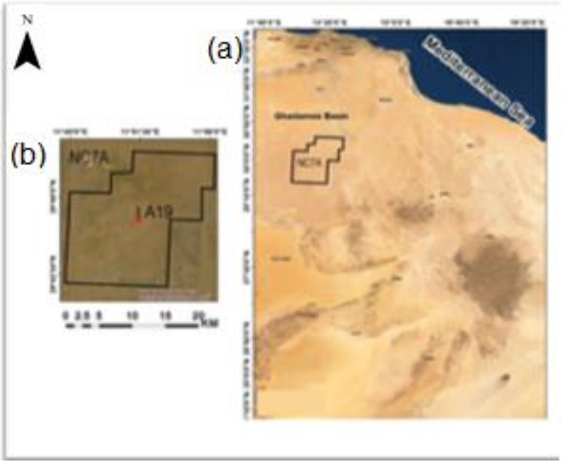

Figure 1 :(a) Index map showing the location of the Ghadames basin relative to the entire country of Libya. **(b)** Enlarged map displays the Gullebi oil field, NC7A Concession.

3. Tectonic Framework

The Ghadames Basin extends into southern Tunisia and eastern Algeria whereas the Libyan share portion (so-called Hamada basin) is located in north-western Libya (Fig. 2). The basin is bounded structurally by the Nefusa and Gargaf uplifts to the south and the north, respectively. Whereas the Tripoli-Assuda Arch located at the east and the northern extension of the Thempoka Arch surrounded the western part. The Ghadames Basin was influenced by Caledonian Orogeny (Cambrian – Early Devonian) which formed Al Gargaf Arch whereas the northern part was uplifted by the Hercynian folding during the Early Devonian - Early Triassic (Buroelet 1960). By the advent of the Early Mesozoic, the basin was subsided. The Late Cretaceous uplift was accompanied by Northwest-southeast fault trends. The northern Jifarah old highs and the southern Al Gargaf were rejuvenated during Late Cretaceous - Early Paleocene period (Jordi and Lonfat, 1963). The intra-cratonic sag Ghadames basin is mainly composed of a thick clastic sedimentary section. The Paleozoic succession is unconformably superimposed by Mesozoic and Tertiary successions (Belhaj, 2000). The basin comprised 21,000 ft. of basin-fill sediments in Algeria compared to 18,000 ft in Libya (Hallett and Clark-Lowes, 2016).

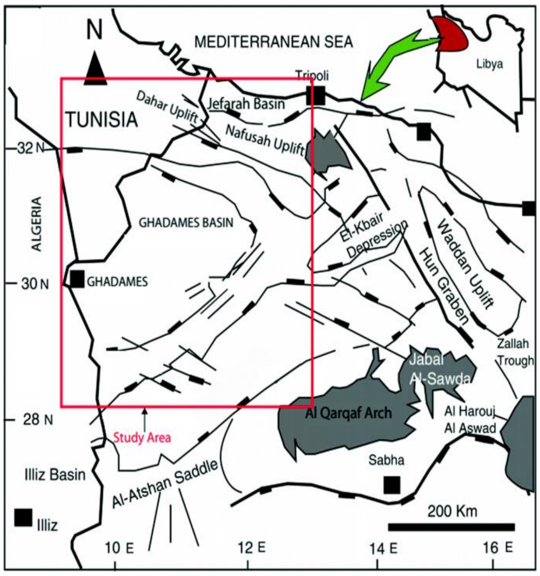

Figure2: The tectonic framework of Libya and structural features that bounded the Ghadames basin (modified after Echikh, 1998; Elruemi, 2003).

4. Stratigraphy

The intra-cratonic Ghadames basin is composed of thick clastic sequence deposited in non-marine environments that prevailed during the Paleozoic (Fig. 3).

This sedimentary sequence was settled through three stages as follow:

1. Non-marine to shallow marine deposits, forming the basal transgressive, deltaic-fluviatile sandstones of the Ordovician Memuniyat Formation.
2. Marine transgressive forming the Tanezzuft shale.
3. Regressive sediments of the Acacus-Tadrart sandstones.

The principal stratigraphic nomenclature in Libya (Burollet 1960), followed by other geologists (Compagnies Pétrolieres, 1964; Tawadros, 2011) shows that the stratigraphic nomenclature of some of the Libyan formations differs from those equivalents utilized in other countries (Belhaj, 2000).

The Cambrian – Carboniferous succession in Ghadames basin is characterized by five regional unconformities. These unconformities are related to tectonic and sea level changes during the development of the Ghadames basin. These unconformities could be timed as follows:

1- Early Cambrian (Pan-African)

2- Late Ordovician (Taconian)

3- Late Silurian-Early Devonian (Caledonian)

4- Late Devonian- Early Carboniferous (Acadian)

5- Late Carboniferous (Hercynian).

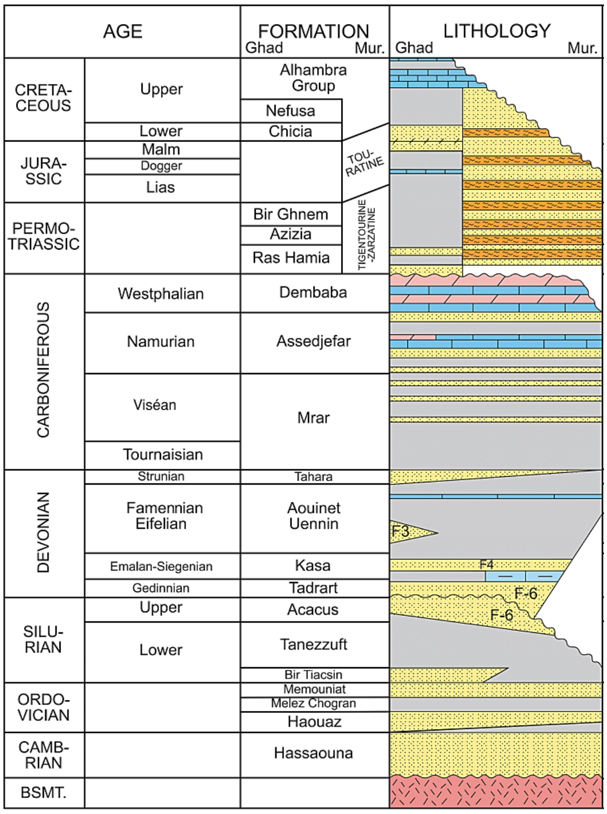

Figure3: The Generalized stratigraphic column of the Ghadames basin (Rusk, 2001).

The Tahara Formation (Massa, et. al. 1974) is mainly composed of sandstone and siltstone intercalated with micaceous shales. The formation is unconformably overlain by the Early Carboniferous Mrar Formation (Banerjee, 1980). The sandstones are fine grained, white to light grey, with siliceous or kaolinitic cement, graded to siltstones with an occasional glauconitic content (Beicip, 1973). The Tahara Formation had been subdivided into three levels from base to top (Beicip 1973):

- The sandstones unit
- The shales grading upwards sandstones
- The sandstones grading from shales

5. Well Logging Approach

A litho-saturation cross-plot associated with several cross-plots was used to evaluate the dominant lithological nature, shale content, shale distribution mode, total porosity, effective porosity, water (wetting phase) saturation and type of water (irreducible and free water). Wireline log readings are significant tools for characterizing the reservoir intervals, determining the petrophysical properties of the hydrocarbon-bearing zones, identifying the lithological nature of the penetrated sequence, and testing the fluids connectivity. The petrophysical assessment based on wireline readings represents consistent approach that determines the reservoir characteristics and its hydrocarbon potentiality (Schlumberger, 1974).

6. Results and discussions

The available data is provided in digital LAS file format due to its simplicity. A complete data set for a single well location in the Gullebi Field, A19-NC7A well, Ghadames Basin has been presented. The data sets (Fig. 4) include natural gamma-ray (trace GR, API), self-potential (trace SP, MV), caliper (trace CALI ,IN), Resistivity logs (trace Shallow, RILL, Rdeep, and Rmud ,OHMM), density trace RHOB (g/cm^3), sandstone-corrected neutron (trace NPHIss, dec), sonic (trace ΔT, µsec/ft), photoelectric effect (trace PEF), and gamma ray spectrometry trace Th, K, and U.

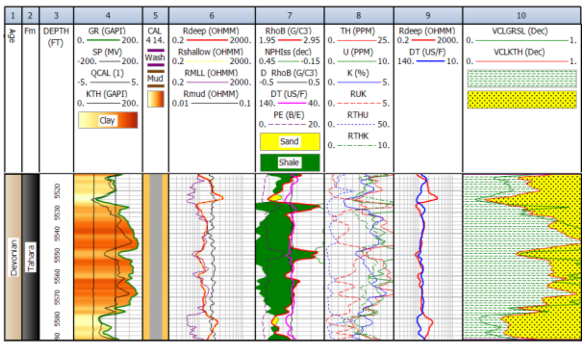

Figure 4: The litho-saturation cross-plot shows the readings and deduced petrophysical analysis of the A19-NC7A well**.**

The dataset was inspected to confirm that the entire log readings are depth-matched. Moreover, recognize missing or detached readings and appropriately fix such errors. The database is numerically processed using the Interactive Petrophysics (IP-2018) software. The qualitative and quantitative analysis of the log readings permits the evaluation of the Devonian Tahara Formation. Careful values were utilized (effective porosity, PhiE >0.09, shale content, v.sh < 0.33, water saturation, Sw<0.75) for the sandstone reservoir and pay zone intervals. The sandstone reservoir was discriminated into four zones: A, B, C, and D.

The density-neutron cross-plot (Fig. 5) shows that the data points are clustered around the sandstone line (zone A). This indicates that the dominant composition of the Tahara Formation is sandstone. The southeast scattering of the data points and shifting to the denser limestone is attributed to the presence of siderite and shale contents.

This outcome agrees with the previous findings (Massa et al., 1974). This supports sandstone and siltstone sediments intercalated with micaceous shale.

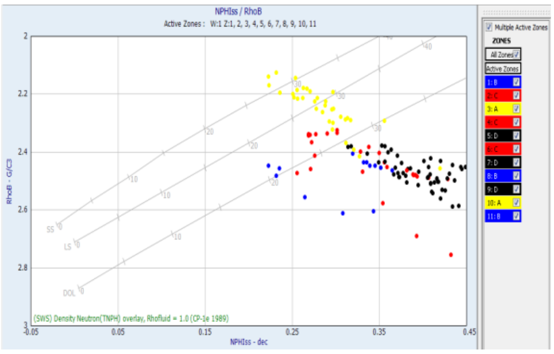

Figure 5: Neutron (NPHIss) -Density (RhoB) Cross -plot in “A19-NC7A” Well.

The mineral identification (M-N) cross-plot (Fig. 6), shows that the data points clustered at quartz region. (zone A) and scattered in the shale region. (Zones B, C, and D). This plot supports the previous findings (Hassi 1993). and confirms the dominant siliclastic sandstone shelf shoreface sequence

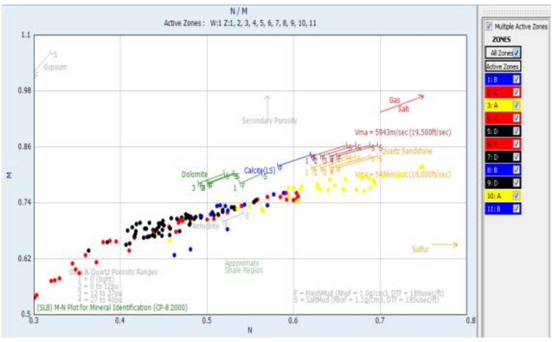

Figure 6: N-M Cross-plot in “A19-NC7A” Well.

Figure 7 demonstrates that the Tahara Formation is composed of sandstone. However, some points (zones B, C, and D) are shifted toward the limestone line due to their high grain density value. Thus the Tahara Formation is mainly composed of sandstone with variable shale content.

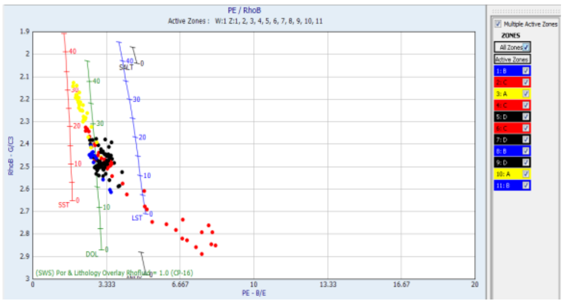

Figure 7: Photoelectric Factor (PE) - Bulk Density (RhoB) cross-plot in “A19-NC7A” Well.

The Tahara formation is characterized by relatively moderate to high potassium and thorium content (mostly less than 1-4%, and 12-32 ppm, respectively. The thorium - potassium cross-plot (Fig. 8) shows dominance of the mixed clay layer – micaceous clay as a main composition of the existing clay content. This finding differs from the previous outcome (Beicip, 1973) that documented a kaolinite cement graded to siltstone with glauconite content. This may be attributed to changing in depositional setting (Ali, 1977) from fluvial to fluviomarine deltatic environments.

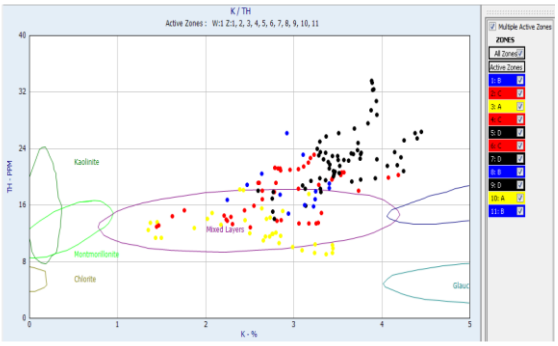

Figure 8: The Thorium (TH)–potassium (K %) crossplot in “A19-NC7A” Well.

The formation water resistivity Rw, cementation factor m and saturation exponent n were determined employing the Pickett’s plot (Fig 9). It provides a graphical solution to Archie’s equation (Archie, 1942) to calculate reservoir water saturation by plotting deep resistivity versus effective porosity on a log-log scale. The calculated parameters are: Rw (0.111 Ω), cementation exponent m (1.74), saturation exponent n (1.65) and tortuosity factor a (1). The m value is greater than n value, indicating an Archie water wet reservoir.

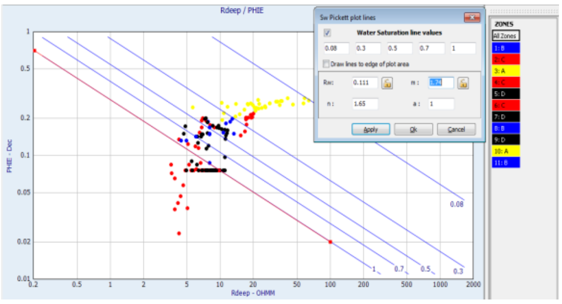

Figure 9: Resistivity (Rdeep) - Effective Porosity (PHIE) cross-plot (Pickett's Plot, 1966) in "A19-NC7A" Well.

The Buckle's plot shows the relatively low bulk volume of water (BVW= PhiE*SW = 0.04, Fig 10), indicating medium grained sandstone intervals.

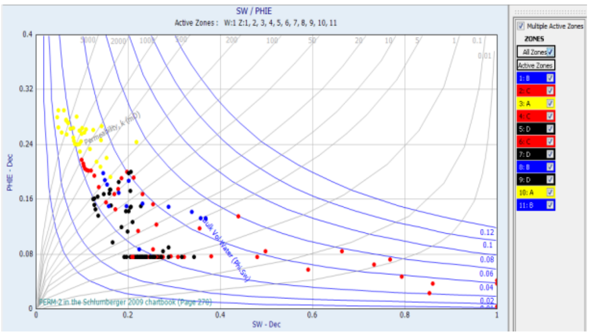

Figure 10: Water Saturation (SW) - Effective Porosity (PHIE) Buckle's plot in "A19-NC7A"Well.

The water –wet reservoir interval is close to irreducible water saturation (Swirr 0.10-0.58). This means that the production of hydrocarbons will be associated with low water content.

The litho-saturation cross-plot of A19-NC7A well (Fig 11) shows the vertical distribution of sandstone dominated lithology with dispersed shale volume (less than 33%). The dominated siliclastic sequence (Hassi 1993) with mixed layer micaceous clay reflects the transition from fluvial to fluviomarine deltatic environments.

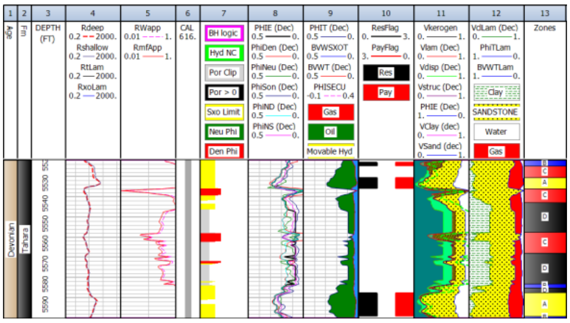

Figure 11: Tahara Formation reservoir with estimated water saturation, volume of shale, porosities and present fluid types in A19-NC7A Well.

Zone A exhibits an excellent gas-bearing reservoir dominated by clean sandstone framework (shale-poor) with low laminated shale distribution (0.23) and excellent effective porosity 0.26. On the other hand, zone D is characterized by shale-rich sandstone interval with dispersed shale distribution up to 0.33. This reduces the effective porosity <0.12 and increased the irreducible water saturation content (Swirr 0.58).

The net-pay zones characteristics show that zone A and zone B were assigned as hydrocarbon-bearing zones, gas accumulation, with excellent and very good reservoir quality. The high effective porosity values (0.15-0.26), relatively low shale contents (0.23-0.28), and low water saturation values <0.20 improved the hydrocarbon potentiality of the Tahara Formation. The deduced petrophysical parameters are shown in Table (1).

Table 1: The average petrophysical parameters of the Tahara Formation showing the different pay zones assigned from the petrophysical evaluation

Zones	Top (ft.)	Bottom (ft.)	Gross (ft.)	Net-pay (ft.)	N/G	Av PHI	Av SW	Av VSh	PHI*H	Phis*H
B	5512	5515	3.00	1.50	0.500	0.150	0.206	0.28	0.23	0.18
C	5515	5519	4.00	---	---	---	---	---	---	---
A	5519	5526	7.00	5.00	0.714	0.267	0.072	0.23	1.34	1.24
C	5526	5533	7.00	---	---	---	---	---	---	---
D	5533	5547.5	14.5	---	---	---	---	---	---	---
C	5547.5	5558	10.5	---	---	---	---	---	---	---
D	5558	5573	15.0	---	---	---	---	---	---	---
B	5573	5575	2.00	---	---	---	---	---	---	---
D	5575	5577	2.00	---	---	---	---	---	---	---
A	5577	5588.5	11.50	10.75	0.935	0.252	0.083	0.23	2.71	2.48
B	5588.5	5590	1.50	0.25	0.167	0.207	0.121	0.32	0.05	0.05

7 .C onclusions

The well log data and the obtained parameters were presented vertically against depth in a litho-saturation plot for A19-NC7A well using the IP2018 software. It shows a dominated siliciclastic sandstone lithological nature of the Tahara Formation with mixed layer to micaceous shale content of laminated- dispersed distribution. The clay-poor sandstone intervals (zone A) intercalated with mixed layer shale (zones B, C, and D) enriched with siderite. This may reflect a transition to an increasingly offshore distal positional non-marine regressive sediments. The Tahara Formation is subdivided into four reservoir zones (A-D) with different reservoir quality. Zone A represents the best reservoir characteristics with minimum laminated shale distribution and excellent effective porosity saturated with low water saturation close to irreducible water saturation. The relatively low bulk volume of water 'BVW' (0.04) indicates that the reservoir will produce hydrocarbons with fairly low water content. The reservoir zone A is considered as the most prospective zone in the Tahara Formation in A19-NC7A Well at depth interval (5512-5590 ft.). It is also indicated that zone B is considered as the second prospective zone with good effective porosity, relatively low water saturation, and relatively low shale volume.

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