Integration of seismic interpretation and petrophysical studies on Hawaz Formation in J-field NC-186 concession, Northwest Murzuq basin, Libya

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Abstract This study has been carried out by the integration of seismic interpretations and the well-logging analysis of ten wells distributed in J-field of concession NC-186, Murzuq basin, Libya. Twenty (3D) seismic lines and ten wells have been analyzed. The results of this study indicated that, the main reservoir in this concession is Hawaz Formation. Hawaz has been split into 8 units with a subdivision of Hawaz H4 into three subunits with the objective of better characterization of the three general fine upward intervals. The lower interval of H4 zone presents the better reservoir properties. The depth of reflector H4 ranges from 4100 ft in the northwestern part of the study area and increases to 4600 ft in the southeastern part of the study area. In this study, the outline of the Hawaz paleohighs which is NC-186 Field “J” is generally trending in the NW-SE direction. The well logging analysis particularly quick look interpretation indicates that Hawaz Formation in the studied wells is mainly oil-bearing with some water-bearing sand levels at the horizons from H4 to and H6 which are potentially the main reservoirs. The water bearing zones are beyond these horizons starting from the sub-horizon H6c and the oil water contact is probably at depth 4495 ft. The crossplot of porosity-saturation for H5 and H6b indicates firmly that these horizons are indeed at irreducible state and will produce mainly oil as indicated in J4-NC186 well, while the crossplot of H8 shows wide scattering of points which is the main characteristic for water producing horizon.
1. Introduction

The Murzuq basin located on SW Libya is one of the most important basins on the North African Platform. The structural fabric imparted to the North African continental lithosphere during the Late Proterozoic, Pan-African event has played an important role in controlling the structural and stratigraphic evolution of the basin. During Early Paleozoic tectonism, a series of NNW-SSW trending arches and sub-basins across the North Africa, and shallow marine deposits and transgressive open marine facies are created. The Early Paleozoic tectonism effectively controlled the distribution of Late Ordovician reservoirs and distribution of Silurian “Hot Shale” which onlap early formed fault blocks (Klitzsch, 2000; Fello et al., 2006).

Four main sedimentary basins are present in Libya, and the Murzuq basin is one of them. Three of these basins are assigned to the Paleozoic while the fourth is assigned to the Mesozoic (Fig. 1). It has a roughly triangular shape, narrowing toward the south from Libya into Niger. It is characterized by an erosional remnant of a much larger Paleozoic sedimentary basin which originally covered most of North Africa (Fig. 1).

The Paleozoic and some Mesozoic and Cenozoic sedimentary sequences are overlying the Pre-Cambrian crystalline basement. In the central part of the basin the total sedimentary thickness exceeds 3500 m (Thomas, 1995).

The north-south ridge of the Ghat/Tikiumit Arch separated the Murzuq basin from the Illizi Basin, Algeria, to the west and it is located between three tectonic elements: El Qarqaf uplift in the north, the Tibesti/Haruj uplift in the east and the Pre-Cambrian Hogger on the west which extends into Algeria and Niger (Conant and Goudarzi, 1967; Bennacef et al., 1971).

The whole sedimentary succession is well exposed along much of the edge of the basin, as well as on the southern flank of the Qarqaf Arch. The full sedimentary succession is present in only a few outcrop areas connected with the Caledonian and Hercynian orogenies, and other lesser unconformities affecting all formations. In the core of the Qarqaf arch the crystalline basement outcrops in relatively small areas (Selley, 1997).

Figure 1  Location map of Libya showing the main sedimentary basins.
Figure 2  Location of the NC-186 concession including J oil field.

Figure 3  Generalized tectonic map of Libya showing major structural features and the main sedimentary basins (Hallet, 2002).
Figure 4  Shot points location map including the 3D seismic lines and the location of ten wells drilled in the study area.

Figure 5  Composed interpreted seismic section showing the identified main reflectors in the NC-186 concession, NW Murzuq basin.
Figure 6  Selective example of the log curves for well J1-NC186.
The NC-186 concession is situated north of NC-115 in the southwest of Libya in the Sahara desert near the village of Ubari, some 720 km from the Mediterranean Sea. The concession area is 4295 km² and it is situated between latitudes 26° 40' and 27° 00' and longitudes 12° 00' and 13° 10' (Fig. 2).

In November 2000 Repsol YPF (Madrid) announced an oil discovery in well A1-NC186 in the exploration block NC-186 of the Murzuq basin. The well A1-NC186, has found a significant oil column in the sandstone of the Hawaz Formation.

The Hawaz Formation was studied first by Massa and Collomb (1960) and named after Jabal Hawaz (West of Jabal Qarqaf). Pierobon (1991) described it as "typically consisting of cross-bedded, quartzitic sandstone in part kaolinitic, with thin shaley intercalations. Tgililites-bioturbated levels and ripple marks are conspicuous". Melez Shuqran Formation conformally overlain Hawaz Formation. Clark-Lowes (1985) describes a similar type section in the Ghat region. Hawaz Formation thickness ranges from 50 m (Dor Al Qussah) to 280 m (Al Qarqaf) in outcrops, and 30 m to 170 m in the subsurface.

Pierobon (1991) speculated that, Hawaz Formation was a Middle Ordovician (Llanvirnian-Llandeilian) age for the whole succession of the Hawaz Formation, based on palynological data from Braspetro type well C1-NC58. It also showed a probable transition to a shallow marine depositional setting (foreshore to shoreface), with the offshore tidal sands (shoal massifs) of the continental shelves of northern Brazil, the North Sea and China's Yellow Sea as possible modern depositional analogues.

This paper is carried out to analyze the petrophysical characteristics to evaluate the hydrocarbon potentialities of Hawaz Formation in J oil field. The hydrocarbon potentialities of the studied formation have been studied through the implementation of (20) 3D seismic sections, and well logging, in order to deduce the petrophysical parameters to assign the depth to the reservoir from the interpreted seismic sections. The well-logging data comprise shallow and deep resistivity, sonic, neutron, density, spontaneous potential, caliper, gamma ray logs, whereas the geologic data are represented by composite logs.

2. Geologic setting

During the Ordovician, the North African part of West Gondwana constituted a passive margin and was covered by a wide, shallow-water marine platform (Sutcliffe et al., 2000; Kuhn and Barnes, 2005). Most sedimentary units forming the stratigraphic column of the basin are widespread and have good correlation in the subsurface and outcrop. The Murzuq basin has a relatively structure and simple stratigraphy, and it contains sedimentary rocks ranging in age from Cambrian to Tertiary-Quaternary. The maximum thickness in the Murzuq basin centre (Awbari Trough) is about 3500 m. The structure of the Murzuq basin is quite simple (Fig. 3) where the subhorizontal or gently dipping strata are faulted and the faults are most frequently parallel to the axis. Tectonic movements affected the basin to a greater or lesser degree from middle Paleozoic (Caledonian) to Post-Oligocene (Alpine) times (Bellini and Massa, 1980).

Pierobon (1991) indicated that, during the Paleozoic time the sedimentary fill of the Murzuq basin is a typical section of cratonic Paleozoic basins in other parts of the world and the marine incursions came from the northwest. The depositional history of Murzuq basin is relatively uncomplicated with some conspicuous characteristic facies patterns. The major sedimentary deposits defined in the Ghadames basin in

![Figure 7](image)

Figure 7 Selective example of the log curves for well J4-NC186.

The NC-186 concession is situated north of NC-115 in the southwest of Libya in the Sahara desert near the village of Ubari, some 720 km from the Mediterranean Sea. The
subsurface areas and on the outcrops are also found more to the south in the Murzuq basin.

The structure of the classic Hawaz Paleo-high is created during the erosional event of Hawaz. The Hot Shale member of basal Tanezzuft is the main source rock in the area, whereas, the main regional seal is the Silurian shale formation.

3. Methods of the study

The available data used in NC-186 concession consist of 20 (3D) seismic sections and ten wells that penetrated the study area (Fig. 4). These wells located on or near the selected seismic lines. These wells are used as guide points to tying...
our seismic sections to the geology of the investigated area. The seismic lines available in the present study are distributed along the J field of NC-186 concession. They are variegated into dip (xlines) and strike (inlines) lines. These seismic data were acquired and processed by seismic crews and centers to get rid the extraneous factors affecting the seismic wave propagation in the subsurface section of the studied area.

Several specific analysis steps are employed in the well logging data in the study area for interpretation process: (1) filtering the raw log response data to remove and correct anomalous data points, (2) correct neutron, sonic, density and resistivity logs for environmental conditions, and (3) plotting the well logging data after correction as a function of depth. The processing and interpretation of data depend mainly on the quick look view of log responses, and then displaying the data using interactive petrophysics program, and plotting the petrophysical parameters in the form of cross plots.

4. Results and interpretations

After analysis and interpretation of many seismic sections in this area, many seismic horizons are interpreted and identified on basis of their acoustic characters. These characteristics include continuity, geometry, spacing, arrangement and the relation between these reflectors and tectonic sedimentary features. After applying these characters on these seismic sections, many reflectors can be identified. Some of these reflectors are prominent in the area of Murzuq basin such as Tanezzuft and Hawaz. These reflectors are arranged from the top to the bottom as follows: Marar, Awaynat Wanin, top Tanezzuft and hot shale base Tanezzuft, upper Hawaz, Achebyat, Hasaaouna and finally basement surface. Only, two surfaces of them Tanezzuft and top Hawaz Formations are interpreted and mapped as two way time. The top of the studied surface is converted to the depth map by using the average velocity.

Through Hawaz Formation, there are a number of identified reflectors arranged from H1 to H8. On many seismic sections H4, H5 and H6 are characterized by high amplitudes (Fig. 5). These horizons are the productive reservoir in the study area when they are compared to H1, H2 and H3 horizons, where they have the poor petrophysical parameters.

The preliminary investigation of the well logging data response is of prime importance after doing environmental corrections (Mohamed et al., 2013). The quick Look technique of log records is well known and used, as an alternative to quantitative comprehensive formation evaluation of Hawaz reservoir (Mohamed, 2016), to describe many petrophysical characteristics such as the nature of the reservoir in the form of the prevailing lithology, shaliness, porosity, and the possible presence of movable hydrocarbons. Also connate water resistivity (Rw) can be quickly estimated when the reservoir is homogeneous clean with intergranular porosity fully saturated with water. Since J field is only oil bearing zone with no gas, the prolific oil zones of good reservoir quality are clearly seen between horizons H4-H6 in that field but it differs from well to well. Fig. 6 is selective example of J4-NC186 well. Here the positive resistivity separation between Rxo and Rt is picked in the interval (from 4114 to 4231 ft) representing the oil bearing horizons from H4 to H6 in that well. The extremely
high Rt value (>2000 $\Omega$ m) is distinctive in these zones and accordingly to this character, a movable oil is expected. The low gamma ray (GR) response reflects the clean nature of this interval and this is confirmed from the neutron and density curves with quick look porosity of 15%. The well logging response of J1-NC186 well is represented in Fig. 7 as another selective example. Hawaz Formation in J1-NC186 well extends from depths 4405 to 4762 ft and represents only horizons from

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**Figure 12** Interpreted seismic section of inline 2845 showing the internal reflectors H4, H5 and H6 is characterized by high amplitudes (bright spot) due to the hydrocarbon importance. This also indicates the basement surface is characterized by high amplitudes and its continuity. Pinch out of Tanezzuft against Hawaz Formation that is characterized by paleo-high topography.

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**Figure 13** Interpreted seismic section of xline 5601 showing the Hawaz surface is the classic paleo-high surface created during the post Hawaz erosional event and unconformably underlies Tanezzuft formation.
H5 to H8. This formation is overlain by Horizon H1 of Mamuniyat Formation of good reservoir quality. The positive separation of resistivity curves is very clear over H1 of Mamuniyat Formation and H5 and H6b of Hawaz Formation. Also, GR log reads very low values opposite to H5, H6b and H6c horizons indicating clean formation. Horizon H6a has high GR response with coincidence of neutron and density curves representing shale streak separating H5 from H6b. The shale indicator calculated from gamma ray log for Hawaz Formation as a whole has maximum value of 11.8% at well J14 (Fig. 8). The corresponding (Vsh) is 5.35%. This means that the sandstone reservoir for Hawaz Formation in the studied wells is definitely clean.

The disappearance of resistivity separation and reduction of resistivity values with depth suggests the possible location of water below H6b at the inflection point at depth 4495 ft. Applying Archie and Humble equations, in the absence of core data, yields Rw value. The oil and water zones have the same clean matrix (sandstone) and porosity (12%). At water zone of depth 4495 ft (lower H6b), the true resistivity equals the formation water resistivity (RT = Ro = 15 Ω m). Formation resistivity factor F is 43 (~ 0.62 \( \sqrt{\text{TWT}} \)) then Rw equals 0.35 Ω m (Ro = FRw). Also, water saturation can be calculated for oil zones. For example, H5 which has Rt = 700 Ω m (deep resistivity reading) contains 15% water saturation (Sw = \( \sqrt{\frac{Rt}{Ro}} \)). This indicates potentially oil zone. Rw is also calculated to the lower part of H8, which has been selected since the best fully saturated water zone can be picked clearly at 4820 ft with the lowest resistivity value of Ro equals 6 ohm m and porosity 18% as given in the following:

\[
F = \frac{0.62}{0.18\sqrt{\text{TWT}}} = 24.7 \quad RW = \frac{Ro}{F} = \frac{6}{24.7} = 0.24 \Omega m
\]

This value of 0.24 ohm m is the same as that obtained for H-NC186 field (Selim et al., 2015) indicating the reservoir in the two fields is related dispositionally. The information obtained from Repsol oil operation of this well gives Rw value of 0.3 ohm m, which is very close with that mentioned above.

Porosity-Saturation have been plotted in the form of Buckle crossplot (Figs. 9 and 10) for H5 and H6b. They indicate firmly that these horizons are indeed at irreducible state and produce mainly oil as the plotted points track exactly BVW curve of 0.02. Horizon H8, which is well known water bearing throughout Hawaz Formation in J Field, when plotted on Buckle plot (Fig. 11) shows wide scattering of points as characteristic for water producing horizon.

5. Mapping top of Hawaz (Hz)

Top Hawaz Formation is the main target in this study and it is overlain principally by Tanezzuft surface and unconformably overlies Hawaz (Middle Ordovician age). It is characterized by a medium to low amplitudes and discontinuous due to the uplift of this surface. It can be classified into eight (8) reflectors (Fig. 12). The structure is the classic paleo-high formed during the post Hawaz erosional event (Figs. 13 and 14). This top Hawaz surface is traced at 540 ms (TWT) in the northeastern part of the study area and increases to 855 ms (TWT) in the southwestern part of the study area (Fig. 15). This surface indicates the outline of the Hawaz paleo-highs in NC-186. “J” field is generally trending from northwest to southeast direction. The main reservoir (Middle Ordovician) in NC-186 concession especially is in the western part of J-field.

The depth structure contour map of top Hawaz in this study has been generated by using the “average velocity”
method. The average velocity map was constructed for the Hawaz horizon. This map includes the 10 wells of J-field NC186 where, the average velocity in J-NC186 field ranges between 9410 ft/s in J5 and J1N-186 in the eastern part of this field. The average velocity of this field increases to the northern part of this field to 9650 ft/s in J13-Nc-186 (Fig. 16).

Depth structural contour map of the top Hawaz surface indicates the depth of Hawaz surface ranges between 4109 ft in the northwestern in J4 field and increases to more than 4500 ft in J11 field in northwestern parts of the study area (Fig. 17). J-field depths gradually decrease again toward the south to 4195 ft in J5 field in southeastern and finally increase to more than 400 ft in J14 well in the southeastern parts of this area.

Hawaz Formation is overlain unconformably by the main source in this concession (Tanezzuft Formation). This reflector can be picked up all over the study area. It is mainly composed of dark greyish to black color, graptolitic shales with intercalation of siltstone and very fine-grained sandstones, often forming rhythmic alternations (Pierobon, 1991). It is a medium to high amplitude and high frequency and is characterized by its continuity (Figs. 12 and 13). This reflector is picked at 3500 ft in the northern part of the study area and increases to 3800 ft in the southeastern and northeastern parts of the study area (Fig. 18). This reflector is widely known as one of the important reflectors identified in the NC-186 concession in Murzuq basin. Three interpreted horizons H4, H5 and H6 are characterized by very high amplitudes on seismic sections, and they are represented as depth and thickness maps of “J” field in NC-186 concession.

5.1. Mapping of H4, H5, and H6 units

Horizon H4 is the one of the most important reflectors interpreted from this study. This horizon is characterized on seismic section by its continuity with little irregularities and characterized by high amplitude (Fig. 5). Depth structure contour map of H4 NC-186 indicates the depth of this horizon ranges from 4100 ft in the southwestern part of the J-field especially in J2 well in the southeastern and increases to more than 4500 ft in the southeastern part of this field at J14 NC-186 and J13 NC-186 wells (Fig. 19). The thickness of this formation ranges from 5 ft in the northwestern part of this field especially in J4 and increases to more than 60 ft in the central western part of this field in J1 and J8 wells in NC-186 concession (Fig. 20).

The second surface mapped from Hawaz package is Horizon H5. It is characterized by parallel reflector and closely spaced to Horizon H4 on seismic section (Fig. 5). The mapping of this horizon indicates that the depth of this surface ranges between 4200 ft and 4450 ft (Fig. 21). The lowest depth is located in the northwestern part of j-field especially in J12 and J4 fields and increases to the highest value at J14 well in the southeastern part of this field. The thickness of this formation (Fig. 22) ranges from 40 ft in the northern part of this field at J13 NC-186 well and increases to more than 72 ft in the southeastern part of this field and in the southeastern part of J field at J2 NC-186.

Horizon H6 is the third reflector in Hawaz Formation mapped by this interpretation. It is characterized on seismic section by high amplitudes, parallel reflector and closely spaced to Horizon H5 (Figs. 12 and 13). The depth contour map of horizon H6 (Fig. 23) indicates, the depth of this surface ranges between 4300 ft and 4600 ft. The highest depth is located in the southeastern part at J14 well and J11 well in the central part and decreases to the lowest value at J12 and J4 wells in the northwestern part of this field, respectively. The thickness H6 unit (Fig. 24) ranges from 62 ft in the northern part of this field especially at J12, J4 and J6 fields and increases to more than 165 ft in the southeastern part of this field and in the southeastern part of J field at J14 NC-186.

The basement surface is located at the base of the sedimentary succession in Murzuq basin and marked by strong, high amplitude (Figs. 12 and 13). This reflector, which locally shows a polarity reversal from a negative (trough) to a positive (peak), is onlapped by more continuous overlying reflectors. This surface is unpenetrated by the drilled wells in the north Murzuq basin.
Figure 16  Average velocity contour map of Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 10 ft/ms.

Figure 17  Depth contour map of Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 20 ft.
Figure 18  Depth contour map of Tanezzuft formation of J field in the NC-186 concession, NW Murzuq basin. CI = 20 ft.

Figure 19  Depth contour map of H4 surface in Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 20 ft.
Figure 20  Thickness contour map of H4 unit in Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 0.5 ft.

Figure 21  Depth contour map of H5 surface in Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 20 ft.
Figure 22  Thickness contour map of H5 unit in Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 2 ft.

Figure 23  Depth contour map of H6 surface in Hawaz Formation of J field in the NC-186 concession, NW Murzuq basin. CI = 20 ft.
6. Conclusion

This research has been carried out using integrated 3D seismic and petrophysical studies of Hawaz Formation in J-field NC-186 concession, Murzuq basin, Libya. 3D seismic data have been processed and interpreted by Petrel software (2013). The petrophysical properties have been evaluated through the analysis of well-logging data using quick look interpretation technique and plotting crossplots. The results can be concluded in the following items:

1. The main reservoir in this concession is Hawaz Formation (Middle Ordovician). Hawaz Formation is a paleo-high structure generally trending in the NE-SW direction.

2. Hawaz Formation is subdivided into 8 units from H8 to H1. The Main productive reservoir comprises from H4 to H6. The upper units H3 to H1 present poor reservoir characteristics.

3. Top Hawaz surface ranges between 4109 ft in the northwestern in J4 field and increases to more than 4500 ft in J11 field in northwestern parts of the study area.

4. The base of the Hawaz Formation starts with a transgressive surface culminating in a maximum flooding surface represented by H7, the upper members H6 to H4 stand on a sequence boundary above which stacked fluvitotal channels are deposited in response to a forced regression representing the best reservoir facies.

5. The well logging data analysis illustrates that horizons from H4 to H6 are mainly oil bearing zones while horizons from H6c to H8 are mainly water bearing zones.

Generally, it can be recommended to focus on horizons from H4 to H6 for any future drilling and detailed study should be given to these units.

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