RESERVOIR CHARACTERIZATION OF SIDI SALEM FORMATION IN AKHEN FIELD, OFFSHORE NILE DELTA, EGYPT

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ABATRACT

The Sidi Salem Formation of Middle–Late Miocene (Serravallian-Tortonian) age, attracted the attention for hydrocarbon exploration after oil had been encountered in its sands in Temsah field. The formation thus acquired a certain importance with regards to gas and condensates exploration, previously known as only gas province.

From four wells drilled in the Sidi Salem Formation in Akhen area were examined the petrographic and petrophysical features using core chips Also, electric logs and subsurface geologic data were evaluated to obtain information's about the main reservoir characteristics of the formation. The formation is divided into four sand channels Sand 1, Sand 2, Sand 3 and Sand 4 (from top to bottom). Also, the obtained data were utilized to assess the lateral variations (from NW to SE).

This study revealed that the Sidi Salem Formation Sand 2 and Sand 3 channels have better reservoir quality, than those of Sand 1 and Sand 4 channels. The quality of sandstone improved toward the southeast of the study area. There is lateral or/and vertical connectivity between all channels in the study area .this finding is in contrast with the previously assumption which was based on seismic stratigraphic interpretation.

***Keywords*:** Stratigraphy, Reservoir characterization, Akhen.

INTRUDOCTION

The study area is located in the southeastern Mediterranean basin covering the Nile Delta cone between the Herodotus abyssal plain in the west and the Levant basin in the east. The field lies at latitude 31° 54′ 54" N and longitude 31° 54′ 0.84" E (Fig. 1), about 45 km offshore the Nile Delta and water depth averaging 88 meter. This work focuses on the main lithological and petrophysical features of the Sidi Salem Formation (Serravallian- Tortonian). It is based on the study of subsurface geological data that were collected from four wells drilled in the study area (Akhen-1, W.Akhen-1, W.Akhen-2 and W.Akhen-4) (Fig. 2).

GENERALIZED GEOLOGIC SETTING

The Akhen field is located in a NW-SE trending antiform structure (Fig. 3) which involves Miocene and Pre-Miocene formations. It appears to have a flower-like shape which, as such, indicates a past history of strike-slip movements. The structure lies more or less along the Bardawil alignment. It is aligned with the NW Temsah, SE Temsah, Wakar and Port Fouad structures, which are antiforms of the same type although with a minor flower-like character. The alignment is actually not perfect, there being some little offset or slight obliquity of the single structures.

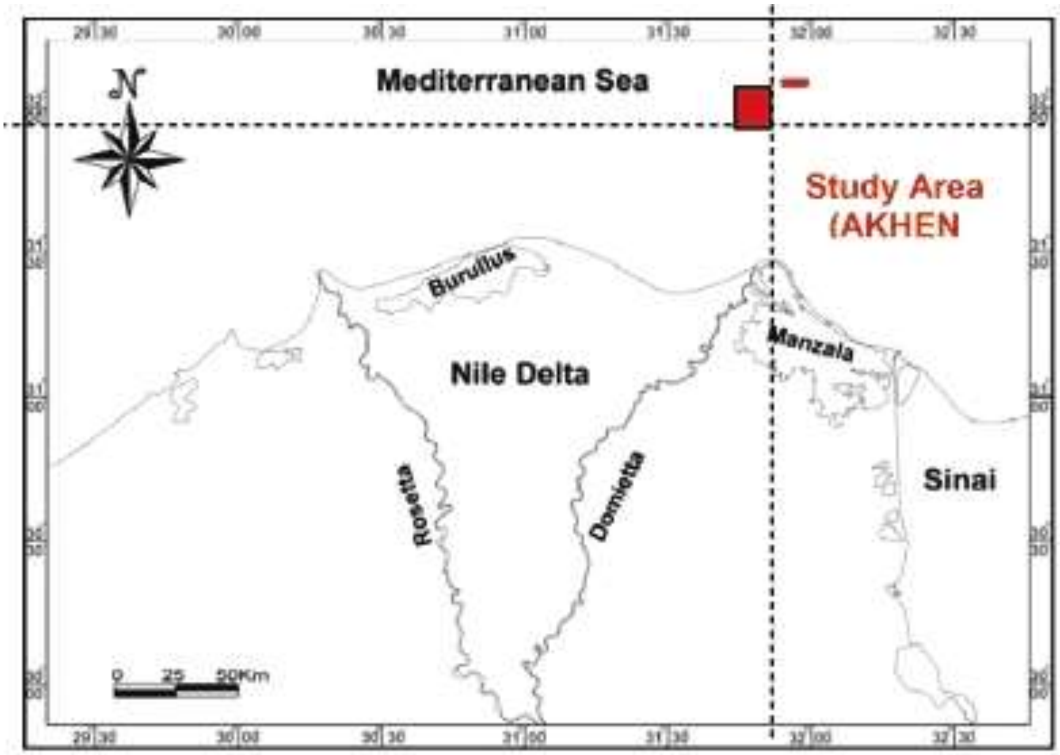


Fig. 1: Location map of the study area.

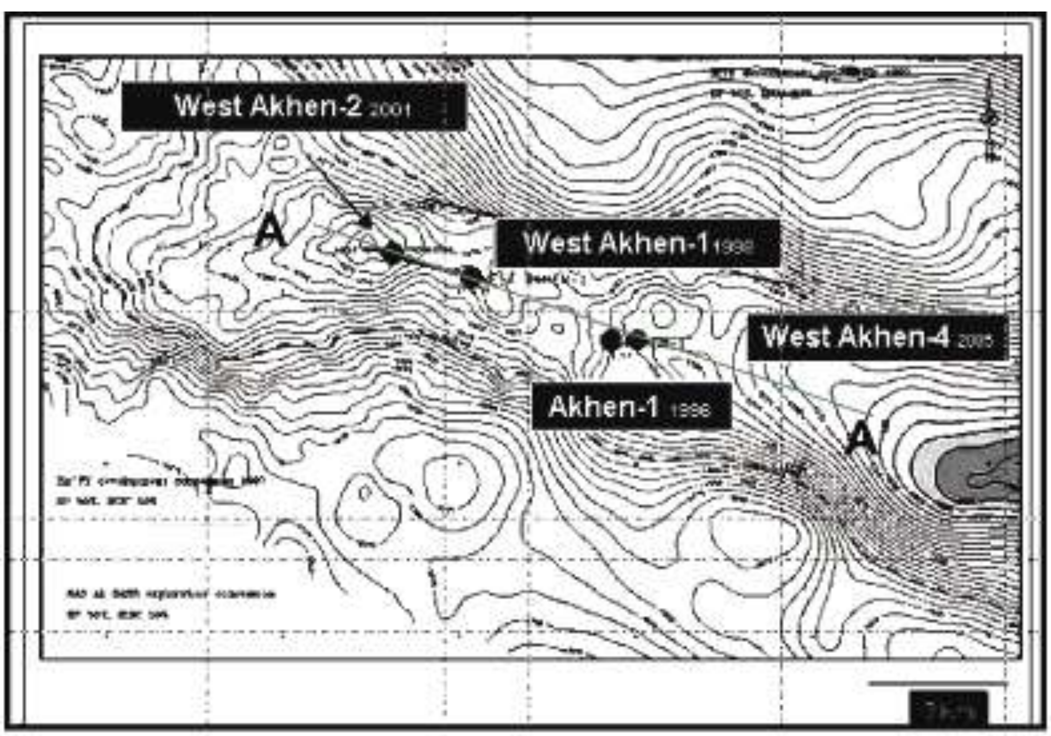


Fig. 2: Akhen field depth structure map for the maximum flooding surface directly above the Serravallian (Miocene) reservoir section (modified after BP, 2004).

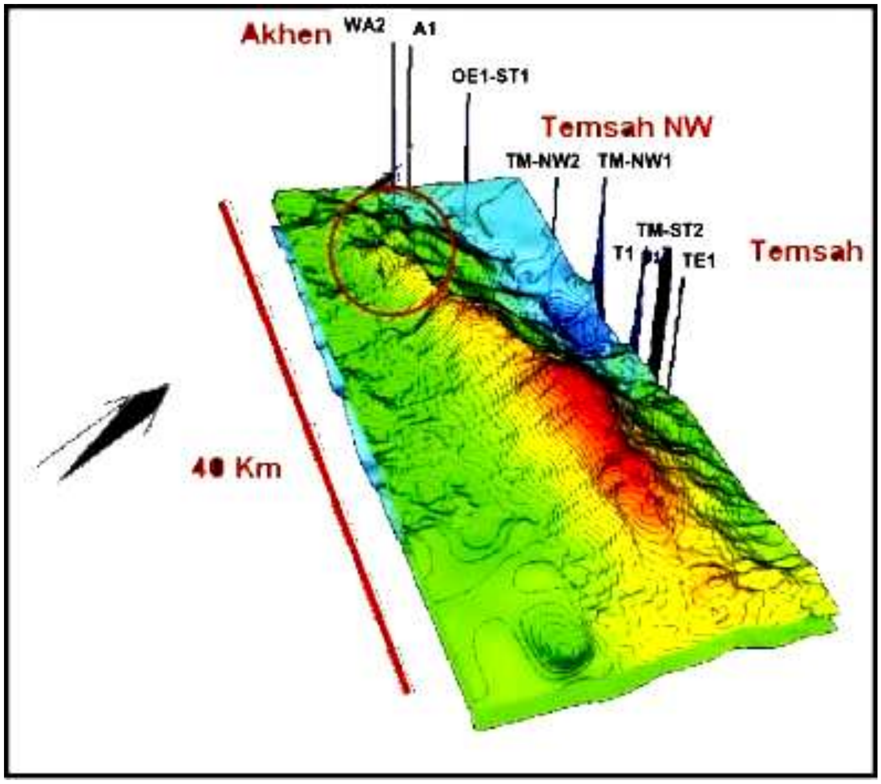


Fig. 3: 3D view of the structure showing NW-SE trending antiform structure along the Akhen and Temsah fields (after BP, 2004).

From the southeast to the northwest, the depth at which the top of these structures is encountered increases, in accordance with the increasing depth of the basinal area. The origin and timing of these structures are not yet well understood. During the Middle Miocene, the Bardawil line was subjected to shear displacement possibly induced by movements occurred along the major Qattara-Eratosthenes and Pelusium lines. This shear will appear to have led to the creation, along the line, of en-echelon faulted-folds. The final compression phase occurred during the Messinian early Pliocene.

Northwest of the study area, the Pliocene productive trend is represented by the Kafr El Sheikh Formation which encompasses the Denise-1, Denise South-1, Seth-1 and Ha'py-1 discoveries. It is predominantly developed on the downthrown side of expansion faults in the Ras EI Barr and Temsah concessions. This province is characterized by a complex growth faulting and rotation within the larger fault blocks, setting up structural rollover into the growth faults. The syndepositional nature of these growth faults caused relatively large amounts of sand to accumulate on their downthrown sides. Transgression during the Early Pliocene terminated the supply of coarse clastics from the south and, unsteady thick sequences of mud, silt, and localized thick sands were deposited forming the Kafr EI Sheikh Formation. The overlying Pleistocene section of the El Wastani and Mit Ghamr formations in this area is characterized by the marked dominance of sand with minor shales (Wigger et al., 1996). Southeast of the study area, the Miocene and pre-Miocene sections in the Temsah field structure represent the main producer Temsah-Akhen structures, which were associated with the Late Cretaceous to Early Tertiary Syrian Arc tectonic event (El Heiny and Enani, 1996 a, b).

Structurally, Akhen appears to be a fault-bounded four-way closure most of which is related to two faults that bound the northern and eastern limits of the Akhen sand reflective package. The study area discovery wells were drilled as a test of the deep Serravallian age potential of the western end of the greater Temsah-Akhen structure. The wells were positioned on the axis of the east-west oriented structure, just to the west of a local four way culmination (Fig. 4). The structure is fault-bounded on the north, south and east. It down-dip extent to the west has was mapped to the vicinity of the Ha'py-1 well location. A seismic cross section along A-A' line of the section (Fig. 5) displays normal contacts between the different formations from the surface to the total depths recorded in the four wells drilled in along study area from the northwest to the southeast (BP,2004).

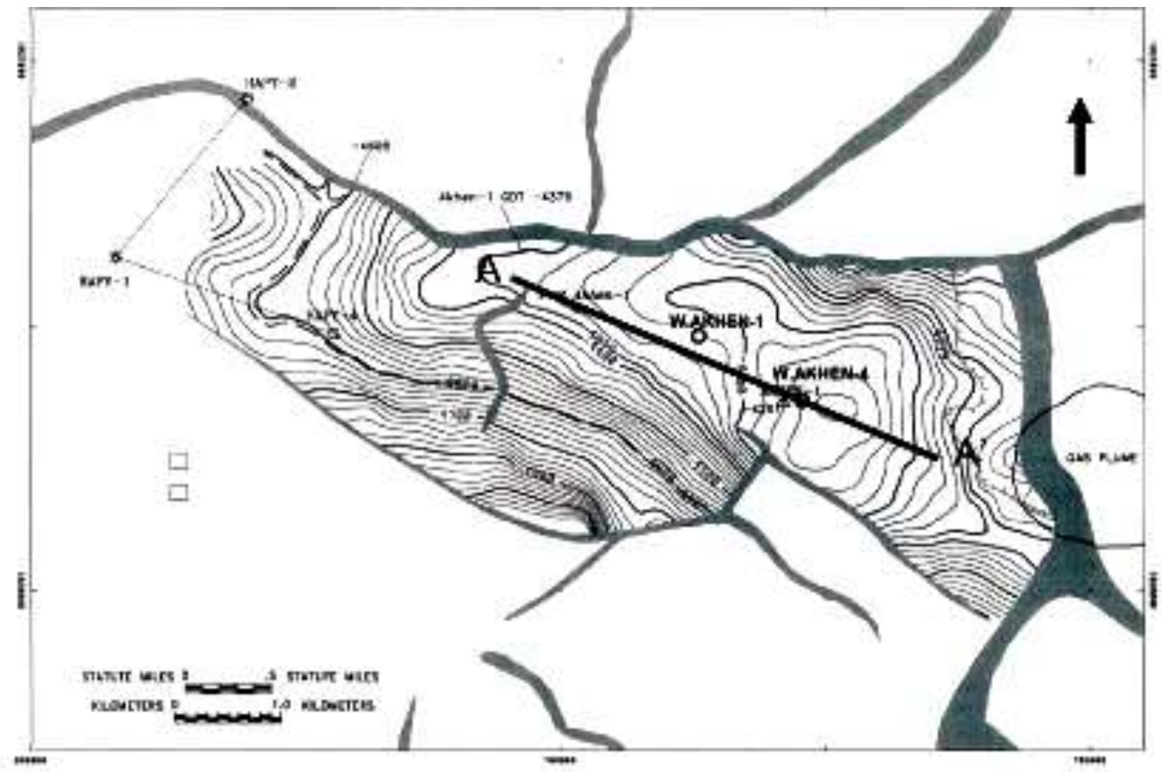


Fig. 4: Akhen field structure described as four way closure structures fault-bounded on the north, south and east (modified after GUPCO, 1998)

LITHOSTRATIGRAPHY

The Sidi Salem Formation ranges in age from Serravallian to Tortonian and consists of marine clays with a few intervals of dolomitic marls and rare interbedded sandstones and siltstones (Rizzini et al., 1978). The Abu Madi Formation belongs to the Late Miocene (Messinian) and is composed of sandstone intercalated with siltstone and shales. The fluvio-marine origin of this formation is indicated by the presence of brackish-water benthic forams in-situ marine dinoflagellate cysts associated with fresh water algae, and the great majority of land-derived plant pollens of Early Cretaceous age (EI Heiny et al., 1990). The base of Abu Madi Formation was deposited from braided rivers of low stand system tract. This was followed by a transgressive system tract and maximum flooding surface above which a high stand system tract (deltaic complex) was developed (El Sisi et al., 1996).

The stratigraphy of the study area was determined through a detailed examination of the four wells penetrating the Akhen structure. The Miocene, Pliocene, Pleistocene and Holocene sections are confirmed in Akhen-1, West Akhen-1, West Akhen-2 and West Akhen-4 wells. The basal section of the Sidi Salim Formation is recorded in all wells at the final total depths, except in W.Akhen-1 well which may penetrates the upper most zone of the Qantara Formation. The drilled Late Miocene-Recent sequence (Table 1) includes the formations from (top to base) Bilqas, Mit Ghamr, El Wastani, Kafr El Sheikh and Sidi Salem.

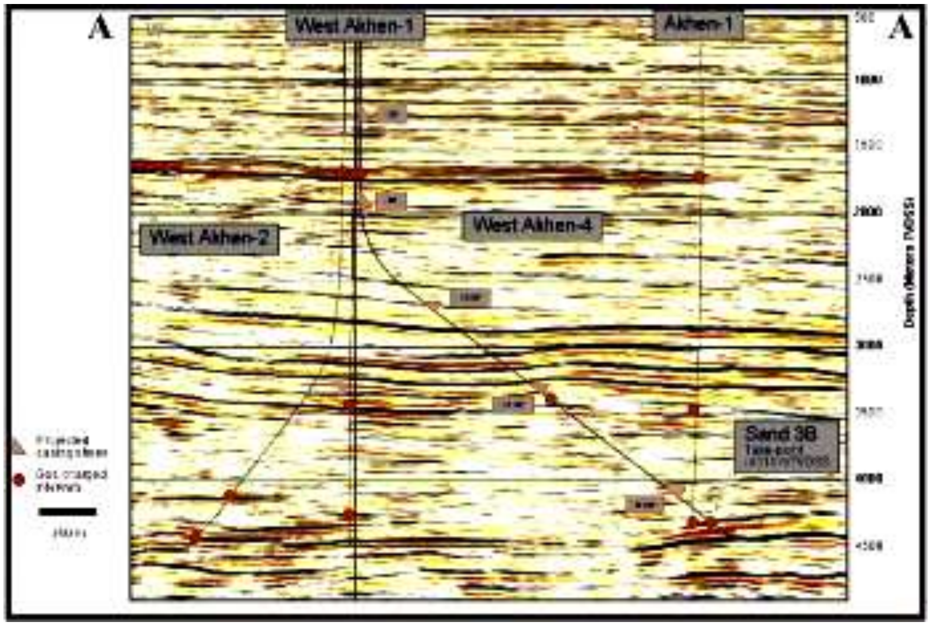


Fig. 5: Akhen field Seismic cross section along A-A' line of section (modified after BP, 2004).

DEPOSITIONAL ENVIRONMENTS

Serravallian gross depositional environment map (GDE) of the study area shows that the sandstone reservoir of Sidi Salem Formation was deposited as deep marine turbidite channels of continental slope depositional environment, draped over the Temsah-Akhen anticline. Identification of the main types of mass transport processes, in the study area is based on the results of examination of core photos from West Akhen-1 well and then correlation with reference photos. The main criteria of the various types of mass transport process occurred along the continental slope depositional environment reveled the following:

(i) Debris Flow

Debris flow structure of matrix supported clasts exhibit a random fabric throughout the bed or sub-parallel orientation especially at the base and top of the flow units. It occur as sheet to channel-shaped bodies ranging from centimeters to several 10's of meters thick, 100's to 1000's of meters long where as widths are variable (Cook et al., 1982).

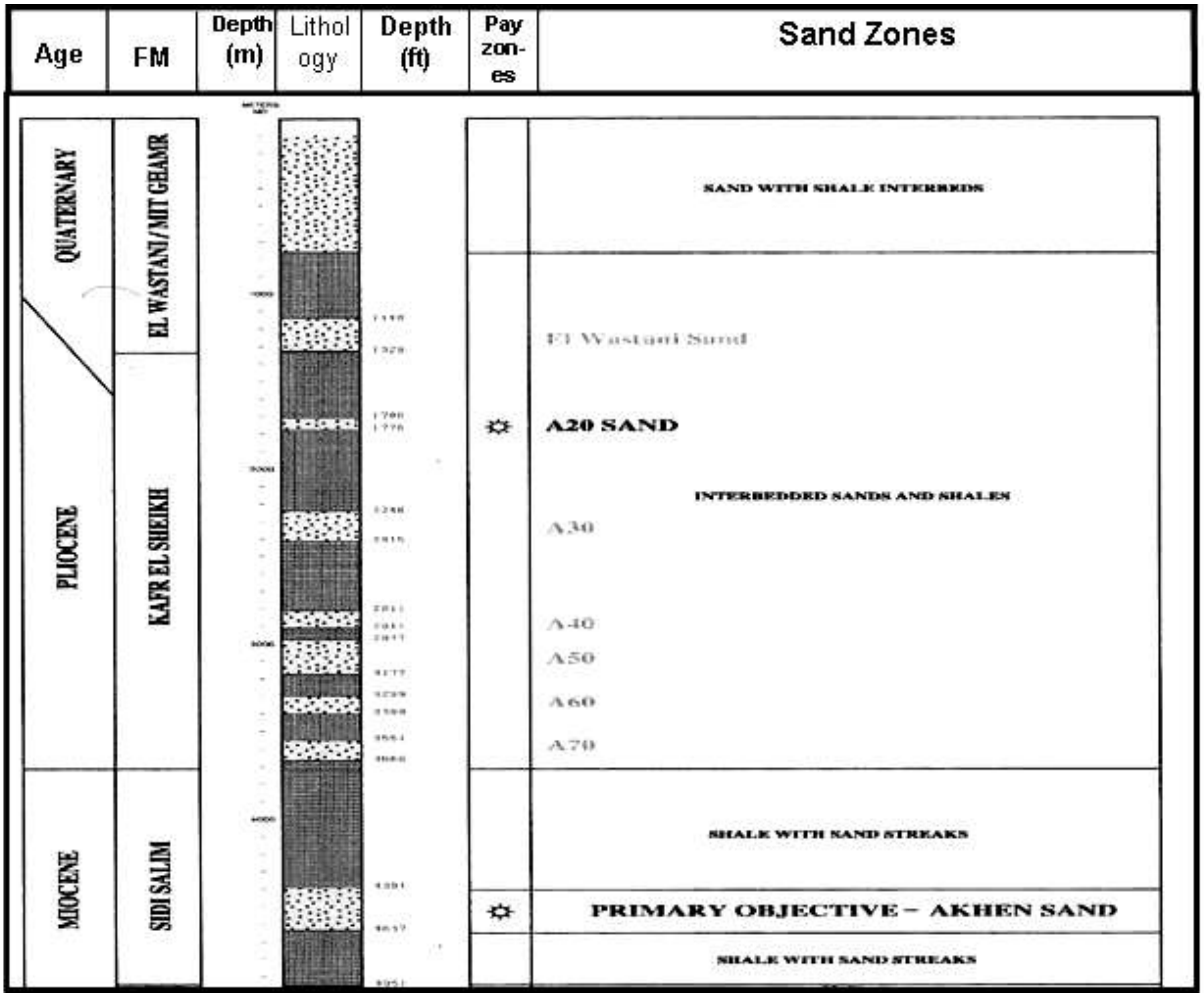
(ii) Turbidity Flow

Turbidity flow, liquefied flows and fluidized flows are considered to behave mainly as fluids (the sediment-water mixture has no internal strength). Turbidity flows sedimentary structure and bed geometry (described as Bouma sequences) are millimeters to several 10's of centimeters thick, 10's to 1000's of meters length, with variable widths.

(iii) Grain Flow

Grain flows behave either as plastic or fluid media. Hampton (1972, 1975), Middleton and Hampton (1976) and Lowe (1976a, b) gave detailed treatments of sediment gravity flow processes. Grain flow sedimentary structure and bed geometry are described as massive clast a-axis parallel to flow and imbricate up-stream, inverse grading may occur near base dewatering structures, sandstone dikes, flame and load structures, convolute bedding and homogenized sediment.

Table 1: Stratigraphic column of the Akhen field.



DEPOSITIONAL MODEL

The Miocene sediments that accumulated in the offshore east of the Nile Delta area typically share common characteristics being deposited as multi-layered reservoirs with varying thicknesses, and genetically consisting of complex geometries of channel-levee and sheet sand deposits (Sestini, 1989; Bertello et al., 1996; Dolson 2001, Sharaf et al., 2008). The absence of good analogs, the poor quality seismic data and the limited and discontinuous cored intervals are the main challenges in understanding the depositional environments of these turbidite deposits. The depositional patterns of the Middle Miocene reservoirs in Akhen area are part of the regional turbidite system that characterizes the offshore, east of the Nile Delta.

The depositional model of Akhen field refers to turbidite channels-levee and sheet complex (Fig. 6). The Akhen turbidite complex forms at least two of these complex systems that are connected at the same reservoir level, but are separated by inter-channel mudstone. Both systems consist of multi-layered channel-levee and sheet complex (Sharaf, in press). The channel geometries are variable, trending SE-NW, and show varying degrees of sinuosity. Lateral correlation of Akhen wells indicates that sand 1 and 3a reservoirs are only defined at the western side of the field and refer to channel-levee complex around West Akhen-2 well. Seismic mapping west of the West Akhen-2 well area shows a wide lateral extension of these reservoirs, which are most probably of channel-sheet complex origin.

The sand 2 reservoir unit is defined by more laterally extending channel-sheet and channel-levee complex. The channels and levees pinch out eastward and are more developed toward the west. Most channel-fill sediments are not seismically resolved; therefore, channel-channel relationship is not clear. However, the cores and logs of Sand 2 unit show that most described channels are amalgamated. The 3D seismic imaging indicates that the Akhen reservoirs are part of unclearly defined Miocene-Oligocene turbidite slope system. The channel-levee complexes are most probably of upper to middle slope setting. However, Sand 3 reservoir channel-levee system is more argillaceous, less amalgamated than Sand 2, and spreads out (fans out) at the well area. This sand package might have been deposited in deeper conditions, most probably upper to middle fan (Sharaf, in press).

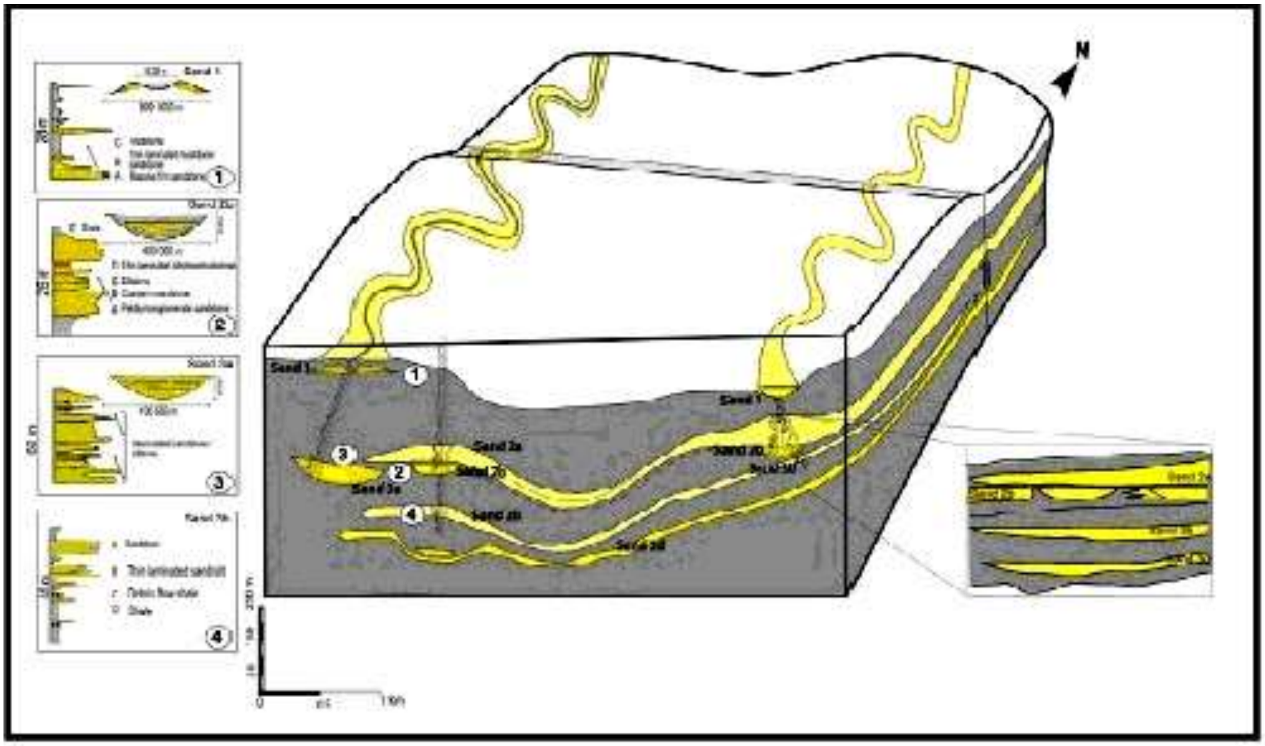


Fig. 6: Constructed depositional model from the Middle Miocene reservoirs in Akhen area. Adscription of the two main channel systems that is penetrated by wells is presented. The model shows the laterally -and vertically stacked-channels that form each system. The two channel systems are not completely isolated. (after Sharaf, in press).

MATERIALS AND METHODOLOGY

The recognition of the reservoir quality units in the Akhen Field is based on petrographic examination of ditch samples, and thin sections, X-ray diffraction analysis of the samples and then clay fractions compositions, scanning electron microscopy (SEM), and petrophysical evaluation of logs from the four Akhen wells. The permeability and porosity measurements of the core plugs were carried out using the Nitrogen permeameter and the Helium porocimeter devices respectively, at the COREX labs in Egypt.

PETROGRAPHY AND FACIES ANALYSIS

The Sidi Salem Formation in the study area, consist of vertically-stacked sequences of sandstones, shale and siltstone, it can be subdivide into four major lithofacies associations or channels. The following is a brief description of these facies (from top to base):-

(i) The Sidi Salem Formation Sand-1 Channel

The Sand 1 channel is represented by the upper part of the Sidi Salem Formation, which unconformably underlies the Kafr El Sheikh Formation. It consists mainly of sandstone with shale intercalations. The West Akhen-2 well exhibits maximum thickness in the study area around (50m), while the West Akhen-1 well has the least thickness (33m)**.**

Sample Depth 4392.5 m (zone-C)

This sample consist of moderately-sorted, coarse to medium grained sand size, pebbly and are sub rounded to rounded. Visual estimates of whole-rock composition are: 70% quartz, 25% clay minerals and 5% feldspars and calcareous cement. The photomicrograph in plate 1a highlights composite, pebble-sized quartz grains, while plate 1b shows calcareous cement and medium sand-sized grains.

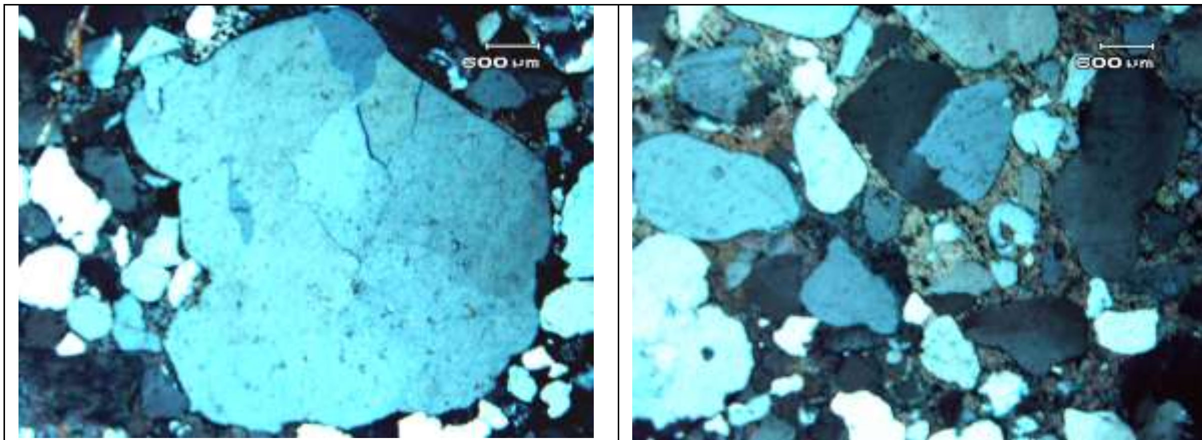
Sample Depth 4393.13 m (zone-C)

This sample is made up of Moderately-sorted, medium to fine sand-sized and subrounded to rounded grains. Visual estimates of whole-rock composition are: 75% quartz, 20% clay minerals and 5% feldspars (plagioclase), the visible porosity 10% -15%. The photomicrograph plate 2a highlights visible porosity ranges from 10% to 15%, while that in plate 2b shows the plagioclase.

Cross-plots of the core porosity against each of the horizontal permeability and vertical permeability (Fig. 7 a&b) indicate that Sand 1 channel the 15m cored interval (4380- to 4395 m) can be easily differentiated into three different zones (A, B and C). in **Zone-A** 4380.11 to 4388.17 m, both of horizontal permeability and vertical permeability directly proportion with core porosity, indicate homogeneous rock. In **Zone-B** cluster from 4388.17 m to 4392 m, both horizontal permeability and vertical permeability without increase in the core porosity (10%-12%). This may be attributed to the presence of minor fractures having no effect on porosity effect. These features indicate moderately/ homogeneous rocks. This is nicely correlated with core chips thin section description of sample 4391.5 m, which highlights poor sand quality. In **Zone-C** (4392 to 4394 m) both the horizontal and vertical permeability increase up to 100 mD, when core porosity increases up to 27 % (directly proportional). This matches with core slices thin section of samples 4392.5 m, which shows an increase in grain size and good sorting and 4393.13 m sample show good porosity. These directly proportional relationships between porosity and permeability are assumed to be attributed homogeneous rock characters, which reflects high reservoir quality.

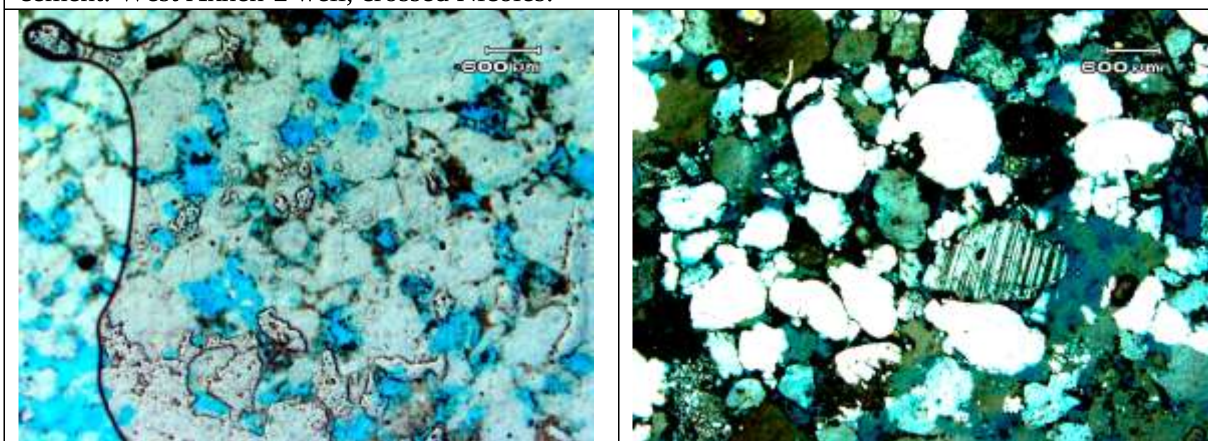
(ii) The Sidi Salem Formation Sand-2 Channel

It consists mainly of sandstone with shale intercalations. The West Akhen-1 well exhibit the maximum thickness (60m), while eastward in West Akhen-4 and Akhen-1 wells the average recorded thickness is 50 m. Westwards the unit was not encountered at West Akhen-1 well. There is no available core or ditch sample to describe the petrographic characters of Sand 2 channel. Sand 2 constitutes the main producing reservoir in the Akhen Field area. This sand unit is of Serravallian age based on nanno-plancktonic zones and seismic interpretation. It was cored at the base of the reservoir in W.Akhen-1 well. The sand is thicker and distributed over a relatively wider area than Sand 1, indicating a larger reservoir volume. The Sand 2 unit pinches out westward as it does not exist at West Akhen-2 well two distinct sand units (Sand 2a and 2b) could be delineated and mapped to the east of West Akhen-2 well (Sharaf, in press).



a	b

Plate 1: Photomicrograph of thin sections of core ships (sample grains 4392.5 m) (a) highlights Composite, pebble-size of quartz sections of; (b)medium sand- size of grains cemeted by calcareous cement. West Akhen-2 well, crossed Nicoles.



a	b

Plate 2: Photomicrograph of section of thin Core chips (sample 4393.13 m,) (a) highlights visible porosity 10% to 15%; (b) feldspars plagioclase type. West Akhen-2 well, Crossed Nicoles.

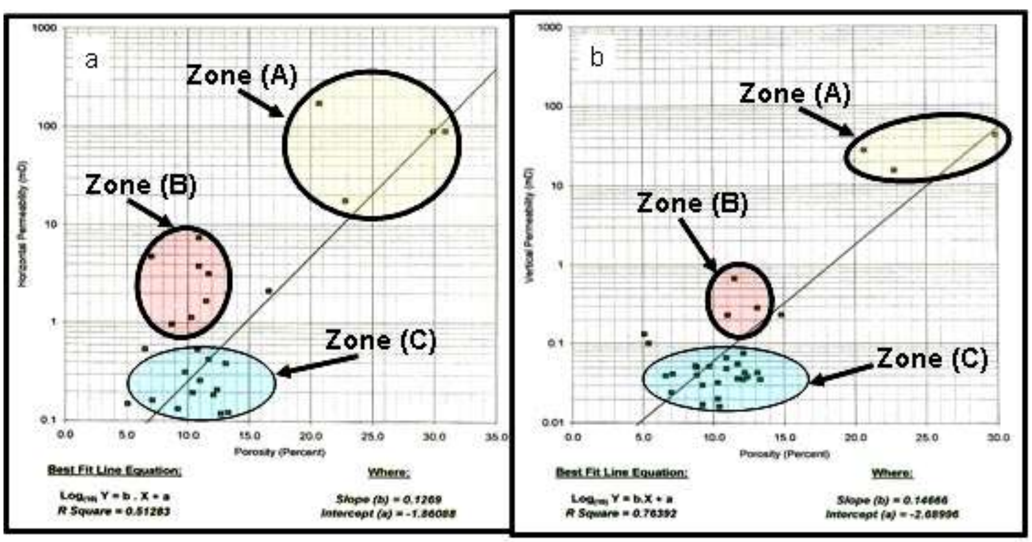


Fig. 7: Cross plots of porosity and permeability in cores from the West Akhen-2 well; horizontal permeability-porosity cross plot; and vertical permeability-porosity cross plot.

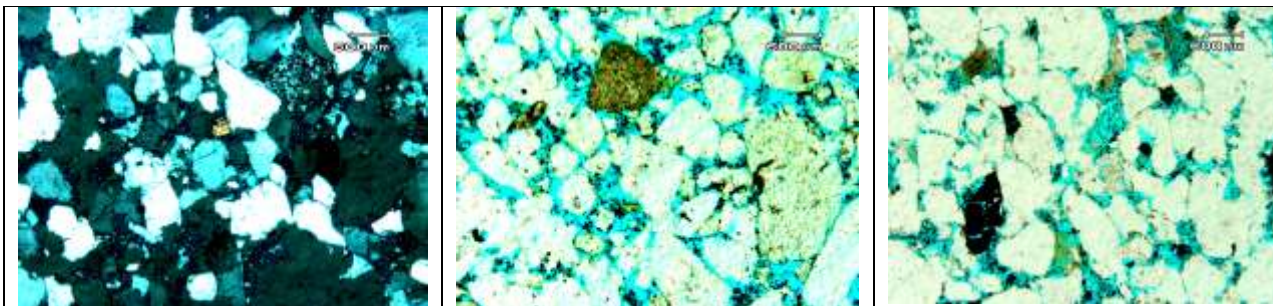
(iii) The Sidi Salem Formation Sand-3 Channel

It consists mainly of sandstone, siltstone and shale intercalations. The West Akhen-2 well exhibits the maximum thickness (100m) in the area while eastward at West Akhen-1, West Akhen-4 and Akhen-1 wells recorded the least thickness (25m-60m). The Sand 3 channel in study area, changes has to shale at the southeast in West Akhen-2. It is easily differentiated into two zones Sand 3a and Sand 3b, while there is a body of shale isolating the upper part (Sand 3a) from the lower part (Sand 3b).

Sample Depth 4382.2 m (zone-3b)

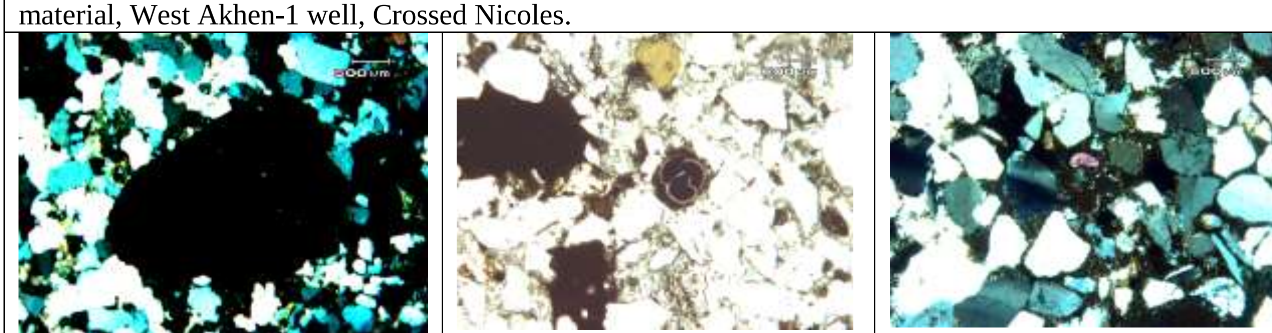
This sample consist of well-sorted, medium-fine sand size of quartz grains, rounded to sub rounded. Visual estimates of whole-rock composition are: 80% quartz, 15% clay minerals mainly illite, with a trace of organic material, feldspars microcline, mica flakes and heavy minerals traces. The zone displays a good porosity (up to 15%) reflecting good reservoir quality. The photomicrograph in plate 3a highlights microcline and heavy minerals, photomicrograph plate 3b indicates 12-15 % porosity, while photomicrograph Plate 3c shows traces of organic material.

Plotting of the grain size versus cumulative weight percentage for Sand 3 channel of core sample depth 4382.2m (Fig. 8 a&b), shows that the grains size ranges from 0.08 to 0.4 mm, fine to medium sand. It shows that 99% of the samples have an average size of medium sand, with unimodal grain size distribution. This indicates well sorting, medium sand sized grains.



a b c

Plate 3: Photomicrograph of thin sections prepared from core chips thin (sample 4377.7 m,) (a) highlights microcline and heavy minerals; (b) highlights 12-15 % porosity; (c) highlights traces of organic material, West Akhen-1 well, Crossed Nicoles.



a b c

Plate 4: Thin section of core chips(sample 4546 m,) (a) Micritic grains embedded in sandstone, (b) Remains of fossils shells, (c) Heavy minerals, West Akhen-1 well, Crossed Nicoles.

DIAMETER (mm)	SAMPLE WEIGHT (g)	SAMPLE WEIGHT (%)	CUMULATIVE SAMPLE WEIGHT	CUMULATIVE WEIGHT %
>1.00	0.10	0.17	0.1	0.17
1.00-0.50	1.20	2.00	1.3	2.17
0.50-0.40	4.40	7.34	5.7	9.50
0.40-0.25	25.30	42.19	31	51.69
0.25-0.20	13.70	22.84	44.7	74.54
0.20-0.16	8.00	13.34	52.7	87.88
0.16-0.080	7.00	11.67	59.7	99.55
0.08-0.063	0.20	0.33	59.9	99.88
<0.063	0.07	0.12	59.97	100.00

TOTAL SAMPLE WEIGHT = 59.97

a

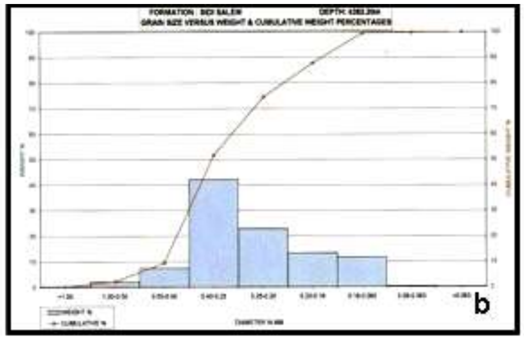


Fig. 8: Data of sample weight and diameter data in W.Akhen-1 well (core number 1 sample depth 4382.2m) sample weight and diameter analysis, (a).tabulated data; (b). grain size versus weight and cumulative weight percentages.

The grain size versus cumulative weight percentage plot for Sand 3 channel of core sample depth 4383.8m, (Fig. 9 a&b) shows that grain size ranging from 0.16 to 1 mm (fine and coarse sand). It shows that 90% of the samples have average size of 0.25 to 1 mm (medium to coarse sand) with bimodal grain size frequency distribution. This indicates moderately-sorted, medium to coarse sand- sized. It was observed that Sand 3 channel sediments display a coarsening upward trend from 4383.8 m to 4375 m, this indicates distributary channel facies, composed of moderately to well-sorted sands. It contains subangular to subrounded, medium -coarse grained quartz and feldspar grains with minor lithic fragments. The sedimentary structures are relatively less common, with massive to crudely-bedded. Glauconite grains are rare and bioclasts are locally distributed. The force-mentioned characteristics indicate a moderate-to high-energy traction current of deposition.

DIAMETER (mm)	SAMPLE WEIGHT (g)	SAMPLE WEIGHT (%)	CUMULATIVE SAMPLE WEIGHT	CUMULATIVE WEIGHT %
>1.00	37.80	38.43	37.80	38.43
1.00-0.50	22.00	22.37	59.80	60.80
0.50-0.40	9.10	9.25	68.90	70.05
0.40-0.25	17.70	18.00	86.60	88.04
0.25-0.20	5.70	5.80	92.30	93.84
0.20-0.16	3.10	3.15	95.40	96.99
0.16-0.080	2.80	2.85	98.20	99.84
0.08-0.063	0.10	0.10	98.30	99.94
<0.063	0.06	0.06	98.36	100.00

TOTAL SAMPLE WEIGHT = 98.36

a

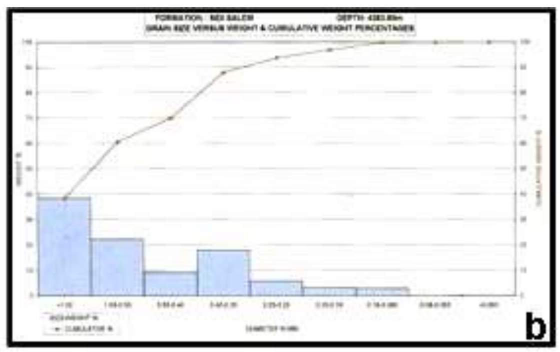


Fig. 9: Data of sample weight and diameter data in W.Akhen-1 well (core number 1 sample depth 4383.8m) (a). tabulated data; (b). grain size versus weight and cumulative weight percentages.

(iv) The Sidi Salem Formation Sand-4 Channel

This unit is represented by core No. 2 of West Akhen-1 well (interval 4537 to 4554.5m) with a recovered thickness of 17.5 m. This interval consists mainly of shale and thin lamina of pebbly sandstone. Core No. 2 data are not available for the present study and hence it depends only on description of thin sections.

Sample Depth 4546m (Sand-4)

This unit is made up of quartz arenite composed of moderately-sorted, medium to fine sand –sized, rounded to subrounded quartz grains. Visual estimates of whole-rock composition are: 80% quartz, 10% clay minerals (mainly illite), 10% feldspars, and traces of fossil remains, heavy minerals and it has an argiallaceous matrix and micritic cement. The porosity is poor to medium reflecting low reservoir quality. Photomicrograph Plate 4a highlights Micritic grains inbeded in sandstone and contain fossils traces, photomicrograph Plate 4b highlights Fossils remains or fossils shells, while photomicrograph Plate 4c with shows heavy minerals. These reflect poor reservoir quality due to the presence of calcareousareous micritic cement combined with poor sorting.

The petrographic analysis indicates that Sands 1 and 2 are characterized by a wide range of grain size, sorting, and porosity. The average sand size ranges from very fine in the lower part of the unit to very coarse in its upper part. Silt and pebble sizes are also common in Sand 2 unit. Grain sorting ranges from poor to good. The sands are loose to compact and range from subangular to subrounded. The units have varying porosity ranging from 15-30%. Both primary and secondary intergranular pores are present. Sand grains are dominantly quartz (more than 50% of the total volume) with a variable percent of feldspars (trace to 8%) and detrital clays. The feldspars are represented by orthoclase and microcline with subordinate proportion of plagioclase. The feldspars exhibit variable degrees of alteration. Silica overgrowth, carbonate and pyrite grains are also common in most of the studied samples (Sharaf, in press).

The Sidi Salem Formation sand channels in the study area accumulated in a continental slope environment. Each channel is composed of either individual or group of complete and/or incomplete fining upward lobes or cycles; this reflects a rapid rate of deposition, which is in accordance with the findings of El Sisi et al., (1996). They studied the source of clastic supply to the Sidi Salem and Abu Madi reservoirs of the Nile Delta and emphasized that the Sidi Salem reservoir clastics (Serravallian Tortonian) were inherited mainly from nearby exposures, with a significant contribution from the metamorphic rocks of the Red Sea hills. Also the Sidi Salem reservoirs can be recognized using electric logs, as they show low density and resistivity values when compared with the Messinian reservoirs.

PETROPHYSICAL EVALUATION

Correlation of sand units in Akhen wells is a challenge due to facies complexity, limited number of cores and lack of nearby analogs. Cores were taken from nonproductive and un equivalent stratigraphic intervals do not match the main reservoir sands. Several methods were used to correlate the different reservoir intervals and subunits in Akhen wells. Among these methods was the correlation of the various types of pressure data and fluid geochemistry of the reservoir interval to conclude the fluid pathways and lateral connectivity of the reservoir sands.

Based on petrophysical evaluations of Akhen wells, the reservoir quality indicates that Sand 2 unit has the best reservoir quality as compared to the other sand units. Sands 1 and 3 have lower reservoir quality than that of Sand 2. The core taken in the basal part of Sand 3b does not reflect the actual sand quality as it did not target the main Sand 3b body. Advanced methods to evaluate reservoir quality have focused on petrophysical measurements. One of these methods was developed during the 1970s by H. K. Winland of Amoco Oil Company. The Winland method Kolodzie, 1980 is based on the relationship between porosity, permeability and pore throat radii at a measurement of 35% mercury saturation in capillary pressure measurements. This method is generally reliable in rocks with only intergranular porosity (such as sandstone) where pore and pore throat geometry are related closely to the rock texture.

Winlad plot is a plot of porosity, core permeability measurements and inferred pore-throat size. The use of this plot indicates that there are three main rock types in Akhen sands (Fig. 10). These rock types are correlated with the litho-facies types encountered in each reservoir sand unit. Rock type 1 (RT1) is the highest quality sand with the highest porosity and permeability values. This rock type is limited to Sand 2 unit in West Akhen-1. Lateral correlations suggest its presence in West Akhen-4 and Akhen-1 wells. RT1 corresponds to the channel-fill sand facies which represents the main reservoir unit in the Akhen area. Rock type 2 (RT2) is not common in the Akhen field. It is characterized by moderate porosity and permeability values. This rock type is represented by data obtained from both W.Akhen-2 and West Akhen-1 cores and it is related to the thinly laminated beds that most probably represent the channel abandonment facies. Rock type 3 (RT3) is the lowest quality sand with the lowest porosity and permeability values. This rock type is represented by the data obtained from West Akhen-2 core and the lower core of W.Akhen-1 that was taken from the intercalated shale with mudstone beds at the base of Sand 3b. This rock type corresponds to the levee-type facies of Sand 1 at W.Akhen-2 and Sand 3b in W.Akhen-1 wells.

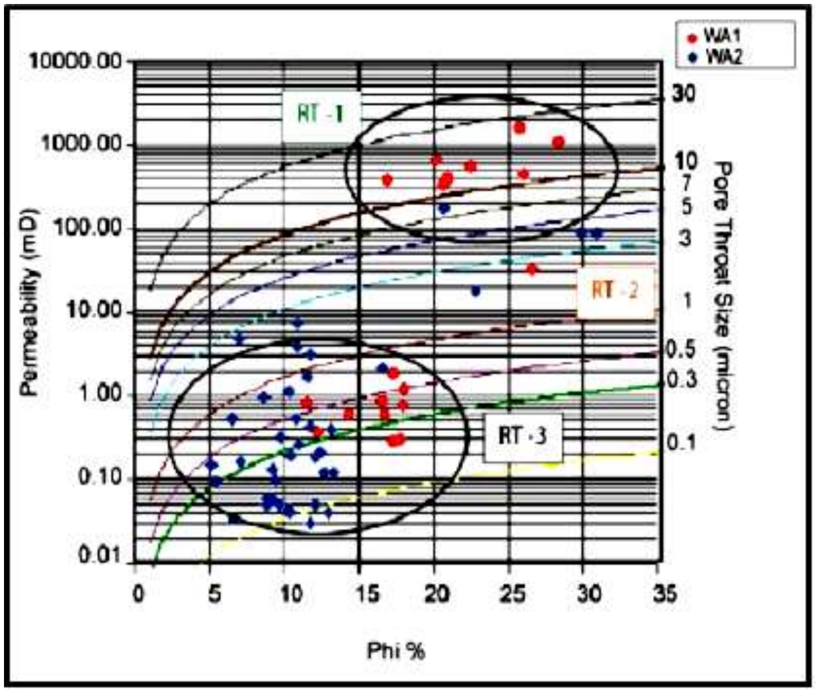


Fig. 10: Interpretation of porosity and permeability measurements from the cores based on the Winland plot. The plot shows the different rock types that constitute the Akhen reservoirs (modified after Sharaf, in press).

CONCLUSIONS

The Sidi Salem Formation sand channels in the study area, are assumed to have been deposited in a continental slope environment. A sediments transportation mechanism is either turbidity flow, debris flow or grains flow. Each channel is composed of either individual or a group of complete and/or un-complete lobes or cycles of fining-upward depositional regime. Reflecting a rapid rate of deposition, this is in accordance with the findings of El Sisi et al., (1996) who studied the source of clastic supply to Sidi Salem and Abu Madi reservoirs in the Nile Delta. They conclude that the Sidi Salem reservoir clastics (Serravallian-Tortonian) were driven mainly from nearby exposures, with a significant large contribution from the metamorphic rocks of the Red Sea hills.

The reservoir characterization of the Sidi Salem Formation sandstone channels in Akhen field reveled following three main reservoir facies:

(i) - Sand 2 channel in West Akhen-1 well corresponds to the channel fill sand facies. It has having the highest quality sand, with the highest porosity and permeability values. Lateral correlation suggests that its presence in West Akhen-4 and Akhen-1 wells. Sand 2 represents the main reservoir unit in the Akhen area, having homogeneous reservoir characters.

(ii) – Base of Sand 1 channel in West Akhen-2 and **Sand 3a channel** in West Akhen-1 wells consists mainly of thinly laminated sediments that most probably represent the channel abandonment facies. It is characterized by moderate porosity and permeability values.

(iii) - Top of Sand 1 channel in West Akhen-2 and **Sand 3b channel** in West Akhen-1 wells correspond to the levee-type facies the sands of the lowest quality in the Akhen area, with the lowest porosity and permeability values in the Akhen area, with heterogeneous reservoir characters.

The obtained petrographic data are nicely correlated with those of manual and computerized petrophysical formation evaluation. Integration of the result reveled that the Sidi Salem Formation in the study area can be considered to have good reservoir quality especially toward the central and southeast parts of the field. Pressure data and fluid geochemistry of the reservoir interval suggests that there is either lateral or vertical connectivity between the Sidi Salem reservoir sands.

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خصائص صخر المكمن لتكوين سيدي سالم في منطقة أخن بالجزء البحري لدلتا النيل, مصر.

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التكوين الصخري سيدى سالم جذب الانتباة لاستكشاف وإنتاج الهيدروكربونات بعد أن تأكد وجود كلا من المتكثفات والغازات بعد حفر أبار في حقل التمساح , حيث كان يفترض سابقا تشبعة بالغازات فقط. تم تقسيم عصر الميوسين (المبكر والاوسط) او تتابع سيدى سالم في منطقة الدراسة(حقل أخن البحري) إلى أربع تتابعات منتجة Producing channels تسمى رقم 1 (Sand 1) و رقم 2 (Sand 2) و رقم 3(Sand 3) و رقم 4(Sand 4). حيث تعتبر طبقات الحجر الرملى المترسبة في التكوين الصخري سيدي سالم هي المنتج الرئيسي في منطقة الدراسة.

اعتمدت هذة الدراسة على فحص وتحليل ووصف العينات الصخرية اللبية, القطاعات الرقيقة لعينات الصخور اللبية, البيانات السيزمية, البيانات تحت السطحية, الغازات المجمعة أثناء كلا من الحفر والإنتاج وتفسير التسجيلات الكهربائية لطبقات الحجر الرملي الأربع المترسبة في تكوين سيدي سالم المسجلة على امتداد الآبار المحفورة في منطقة الدراسة.

أوضحت الدراسة خصائص صخور الخزان البتروجرافية والبتروفيزيقية والجيوكيميائية لطبقات الحجر الرملي المنتجة في تكوين سيدى سالم, حيث أكدت أن خصائص الحجر الرملى لطبقة 2 و3 تكون أفضل جنوب شرق منطقة الدراسة بينما تتحسن الخصائص ويزداد سمك طبقة 1 كلما اتجهنا إلى الجزء الشمالي الغربي. أثبتت الدراسة وجود اتصال إما عرضي أو طولي بين طبقات الحجر الرملي الأربع المنتشرة على امتداد منطقة الدراسة.

الكلمات المرجعية : طبقات , خصائص الخزان , اخن.