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# Seismic Interpretation and hydrocarbon Prospects for the post-Miocene sequence in Tao Field, offshore North Sinai, Egypt

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## Abstract

This study is concerned with the Neogene-Quaternary subsurface sedimentary succession of Tao Field in the Offshore North Sinai, Nile Delta Basin. The integration of the stratigraphy, the seismic data and the tectonics would help us to produce an overall view of the study area. The interpretation of all available seismic data using the PETREL-software enables to make basin prospect or field-scale 2D seismic interpretation and mapping in order to draw an integral view for the proposed aim of the work. The seismic analysis of available data allows the investigated succession to be divided into two mega-sequences: the Pre- and Post-Messinian Mega-sequences. The Miocene rock units are included in the Pre-Messinian Mega-sequence, whereas the targeted rock units are included in the Post-Messinian Mega-sequence. Different structural features are identified in the study area, including Slides, Slumps, Growth faults and collapse structures as shallow structures. Also, listric faults, roll-over fold and salt diapir are identified as deep structural features. The major structural trend is oriented NW-SE.

***Keywords:*** *Seismic interpretation, Neogene-Quaternary, Tao field, Offshore North Sinai concession, Kafr ElSheikh Formation, ElWastani Formation, Nile Delta Basin.*

## Abbreviations

Nile Delta basin **NBD**, offshore North Sinai **ONS,** Formation **Fm,** Neogene-Quaternary **NQ**

## Introduction

The Nile Delta is one of the most world's important deltaic systems; the inverted Greek letter Δ was used to describe its triangular shape (Sarhan, 2021). The Nile Delta Basin (NDB) is a large passive margin that extends onshore and offshore (Sestini, 1989). It developed through thermal subsidence as a result of Jurassic - Early Cretaceous rifting of the Tethyan margin (Dolson et al., 2005).
The NDB is best defined as a massive gas province of considerable interest holding

trillions of cubic feet of proven reserves and undiscovered potentials (Boucher, 2004**).** Recent studies have examined a number of gas discoveries from varying stratigraphic levels, from the Oligocene to the Quaternary (Leila et al., 2017). The Nile delta's gas fields were formed by the Neogene deltaic sequence of thermally mature source rocks (Vandre et al., 2007). The majority of delta gas production emerges from the Miocene and Pliocene reservoirs (Niazi et al., 2004).

The study area covers the Tao Field, which extends for 143 km$^2$ and lies between latitudes: 31° 30' – 32° 00' N and longitudes 32° 30' – 33° 00'E at offshore North Sinai (ONS) Concession (Fig. 1). The ONS Concession lies at the eastern part of the Nile Delta in the eastern Mediterranean region. It comprises a total area of 383 km$^2$ approximately; and encompasses three separate fields.

The current work aims to interpret the Neogene-Quaternary (NQ) subsurface succession at Tao Field in the ONS Concession at the eastern part of the NDB. The investigated succession's tectonic setting is examined by mapping the most distinguishable seismic horizons. This interpretation will aid in understanding the stratigraphic and tectonic setting of the study area. Furthermore, based on these geologic interpretations, this work emphasizes the hydrocarbon potentials in the NQ section.

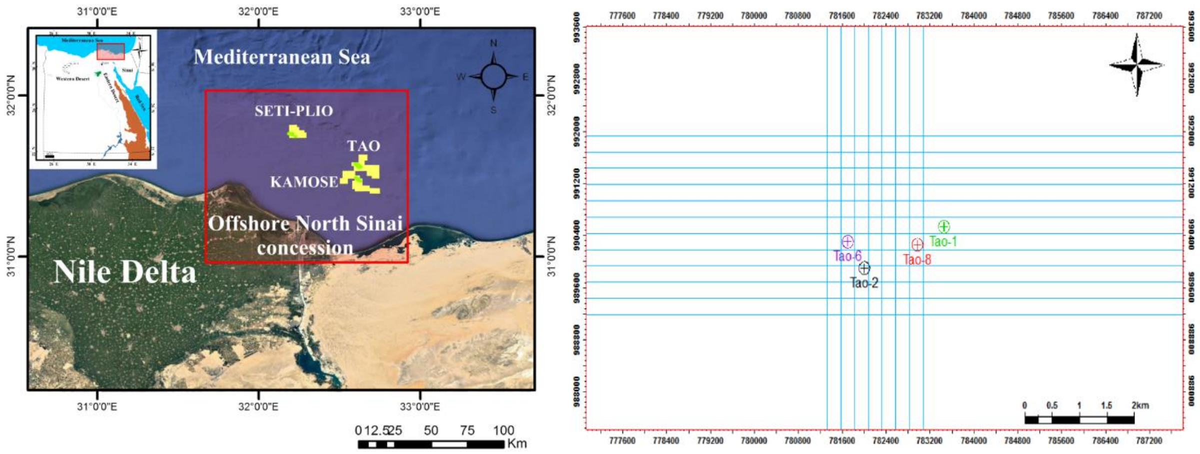


Fig. (1): Seismic lines location map at Tao field, ONS.

## Geological setting

The subsurface NQ succession of the NDB comprises more than six kilometers in thickness. It is bounded from the south by the E-W rifted zone, which is known as the Hinge Zone (Harms and Wary, 1990). The principal structural trends that directly affect the offshore areas are major faults that run parallel to the NW-SE fault trend of the Gulf of Suez, the NNE-SSW fault trend of the Gulf of Aqaba, and the WNW, E-W, and ENE fault trends of the Hinge Zone's northern margin (Sarhan and Hemdan 1994).

The study area lies in the northeastern part of the NDB, which is affected by NW-SE normal faults related to the Bardawil fault trend. Also, some E-W reactivated faults, have an impact on the area. The Red Sea–Gulf of Suez Rift, which propagate to the NW and directly affected the Upper Miocene section lying under the Nile Delta region, had an impact on the north-central portion of the NDB (Sarhan et al., 2014).

The sea level fall occurred during the Messinian due to the separation between the Atlantic Ocean and the Mediterranean. It is the major reason that resulted in the formation of large paleo-canyons in the Mediterranean (Harms and Wary 1990; Dolson et al. 2002). A phase of marine flooding occurred during the Pliocene age, which resulted from the Atlantic Ocean and the Mediterranean re-connection (Ruggieri and Sprovieri 1976; Lourens et al. 1996).

The NQ succession in the NDB is a post-rift mega-sequence, which was deposited in River Nile distal fluvial system active progradational phase (Sarhan et al., 2014; El-Fawal et al. 2016; Sarhan and Safa 2019). The Pliocene succession comprises the Kafr ElSheikh Fm, ElWastani Fm and Mit Ghamr Fm and the Quaternary is represented by Bilqas Fm (EGPC 1994) (Fig. 2).

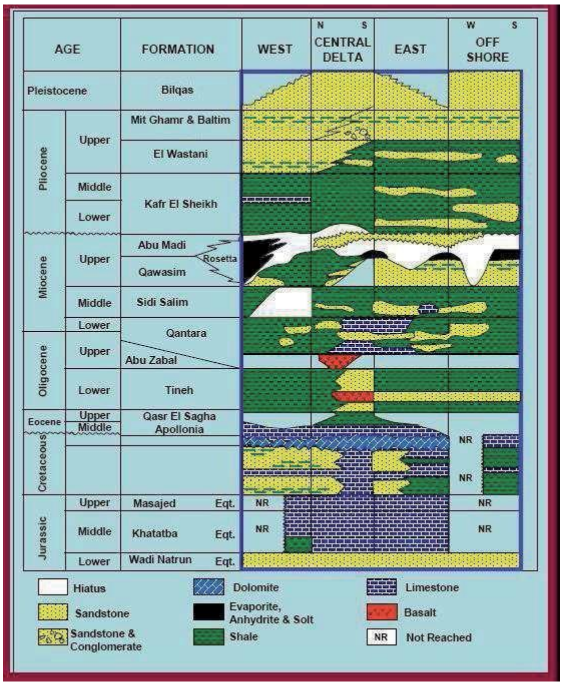


Fig. (2): The NDB Lithostratigraphic column (after EGPC, 1994).

## Available seismic data and methods

The seismic data are acquired as twenty offshore 2D seismic lines in the SEGY format covering Tao Field. The shooting of the acquired lines indicates that these lines contain 10 Xlines trending N-S and 10 Inlines trending E-W (Fig. 1). These seismic data were acquired in March, 2005. Composite logs for four offshore wells: Tao-1, Tao-2, Tao-6, and Tao-8 are also available.

The seismic interpretation of the NQ succession in the study area using available check shot data. It was carried out by selecting and tying the clearest seismic horizons and the major normal faults affecting those horizons over the available 2D seismic data grid. The selected horizons and faults were meticulously mapped across a grid of 2D seismic lines. The interpreted structures in the resulting maps were investigated in terms of the regional tectonic history that influenced the northeastern part of the NDB during the NQ period.

## Identification of seismic reflectors

The process of reflectors identification begins with the identification of the continuous prominent, high amplitude reflector by picking using the PETREL software. The picked reflectors were then tied and correlated using well-log data (composite and velocity logs). The well logs can help to have a useful geological overview and also to show the probably expected areas with strong reflections. Finally, the whole survey-picking process should be tied together to make sure that ‘all intersections of the seismic lines are considered’ by using a closed loop (Badely, 1985).

The seismic reflectors would be identified based on their acoustic characters (Omran, 1990). These characters comprise the continuity of seismic reflectors, geometry, attenuation, spacing, arrangement, and the relation between structural and sedimentary features.

Using these criteria as well as the seismic interpretation technique on the seismic data enabled us to identify four major reflectors. These four regional prominent medium to strong continuous reflectors were identified through the study area named and arranged from old to young as M, C, B and A reflectors. The quality of the pre-Messinian data is poor; consequently, it is difficult to interpret this section.

The following is a full description of the seismic characters for the four encountered reflectors arranged chronologically from the oldest to the youngest. The four main reflectors were identified through Tao-1 well passing through XL6080 seismic line at shot point 1041 and Il1695 seismic line between shot points 1261 and 1441 (Figs. 3&4).

*Reflector "M":*

According to the distributed wells in the study area, the M reflector can be dated to the Messinian (top Miocene). It is a very strong erosional surface of the Messinian evaporites. It is regarded as the most significant and regional key stratigraphic marker reflector for the geology of the Mediterranean in the study area (Stanley, 1977; Omran and Fathy, 1998; Omran, 2004).

The major characters used to identify reflector M as follow: a strong continuous planer reflector due to the high velocity of the evaporate; with high amplitude, high frequency, crinkled to wavy reflectors in some places, due to the effect of evaporite flow beneath it, it is broken by several normal faults, it is affected by shale diaprism, it appears in many places as double reflector on the top package of high amplitude reflectors, the sequence above M reflector is affected by the nearby tectonics such as collapse structures and growth faults and the Pliocene faults soles out against this surface, surrounded by chaotic facies of slumped materials and finally in some place it forms triangular shape due to the evaporite upward flow (Omran and Fathy 1998; Omran, 2004).

*Reflector "C":*

Reflector C has a strong amplitude. It is a discontinuous reflector. It is cross-cutting, Sub-horizontal, with moderate spacing between reflectors. Correlation of this reflector, using the well log data, suggested that this boundary represents the lower- Middle Pliocene part of Kafr El Sheikh Fm. Reflector C has a strong amplitude and is cut by different faults and can be picked at depth of 1875 (TVD) in most parts.

*Reflector "B":*

Reflector B represents the upper top sequence which can be picked with confidence. It was picked at 1200 (TVD). This reflector can be easily picked for all the lines in the study area. They are characterized by strong to medium amplitude, strong to medium frequency and continuous to discontinuous reflectors, parallel to the sub-parallel arrangement, sub-horizontal, cross-cutting reflector geometry with moderate reflector spacing and overstep sedimentary facies. The Correlation of this reflector with logging data suggests that it represents the Middle to upper Pliocene sediment or Kafr El Sheikh Fm.

*Reflector "A":*

This reflector is the youngest identified reflector picked at the study area. It was picked at 344 (TVD). This reflector is the late Pliocene in age. Reflector A is medium amplitude. This reflector is continuous to discontinuous and may be affected by growth faults. It also forms a sheet of slide materials as the previous reflector and in some places, it is overlain by parallel to subparallel reflectors.

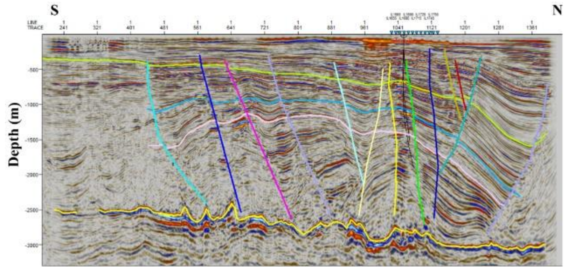


Fig. (3): Interpretations of the XL6080 seismic line.

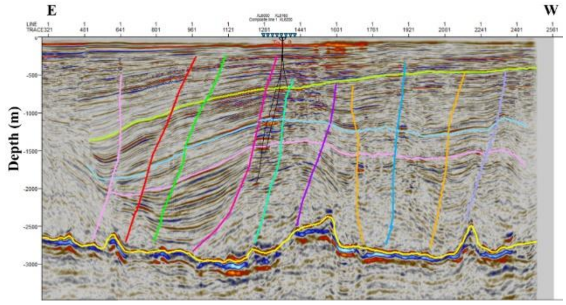


Fig. (4): Interpretations of the Il 1695 seismic line.

## Mapping of identified reflectors

The mapping of reflectors is primarily determined by the acoustic impedance contrast, and thus their reflectivity. The picked true vertical depths of the seismic reflectors along each section were used to map the depths of these reflectors. These data were then transferred to the base map, in order to produce a structural contour map.

The picked depth values and locations of fault segments are displayed on a map in order to construct four structural depth contour maps by using the average depth values. These maps represent, that the four horizons are affected by major normal faults trending especially in the NW–SE direction that is related to the Temsah trend, which is the main fault of the area.

*Mapping reflector M*

The Reflector M is the most widely recognized reflector in the Mediterranean, forming the surface of the Messinian evapoites formed as a result of the Messinian Salinity Crisis; reflector M is considered to be the most important and regional reflector in the study area. The depths to the M reflector is constructed by the direct planning of the picked depth value on the seismic records and automatically contoured and shown in Fig. (5).

The depth map of the M reflector is drawn with a contour interval 50 meters. The contour values of this map range from 2500 meters to 3050 meters. The minimum depth value obtained is 2500meters which occurs in the south part of the map and increases gradually toward the northeastern corner of the study area, where the maximum value of the depth obtained is about 3050 meters. Several negative anomalies are represented by the closed contour lines in the depth contour map of the M reflector in the study area.

*Mapping reflector C*

The depth map of this reflector is shown in Fig. (5). The map is drawn with a contour interval of 250m. The values of contours in the depth map are between 2250 m to 1500 m. The shallowest depth value obtained is 1500m; it is recorded at the southwestern part of the map. The depth values increase gradually at the northern and northeastern parts of the study area whereas the deepest or largest depth value obtained was 2250m. The longest fault is 6000 m and the shortest one is 1000 m trending NW-SE. This reflector is affected by many growth and syndeposition faults as a result of sediments overload and sliding along the slope in the seawards.

*Mapping reflector B*

The depth map of the top zone B reflector was drawn with a contour interval of 50m as shown in Fig. (5). The contour values range from 1950 m to 950 m in the depth map. The minimum depth value obtained is 950 m recorded at the southwestern part of the map. The depth values increase gradually to the north and northeastern parts of the study area where the maximum values obtained were about 1950m in the depth map. The longest fault is 6000 m and the shortest one is 900 m trending NW-SE. This reflector is affected by many growth and syndeposition faults as a result of sediments overload and sliding along the slope in the seawards.

*Mapping reflector A*

The Top Zone A reflector is the youngest picked reflector in the study area. The depth map of this reflector is shown in Fig. (5), it is drawn with a contour interval of 50m. The contour values range from 1100 m to 500 m in the depth map. The minimum depth value obtained is 500 m and occurs at the southwestern part of the map. The values increase gradually to the northern and northeastern parts of the study area where the maximum values obtained were about 1100m in the depth map. The longest fault is 5000 m and the shortest one is 900 m trending NW-SE. This reflector is affected by many growth and syndeposition faults as a result of sediments overload and sliding along the slope in the seawards.

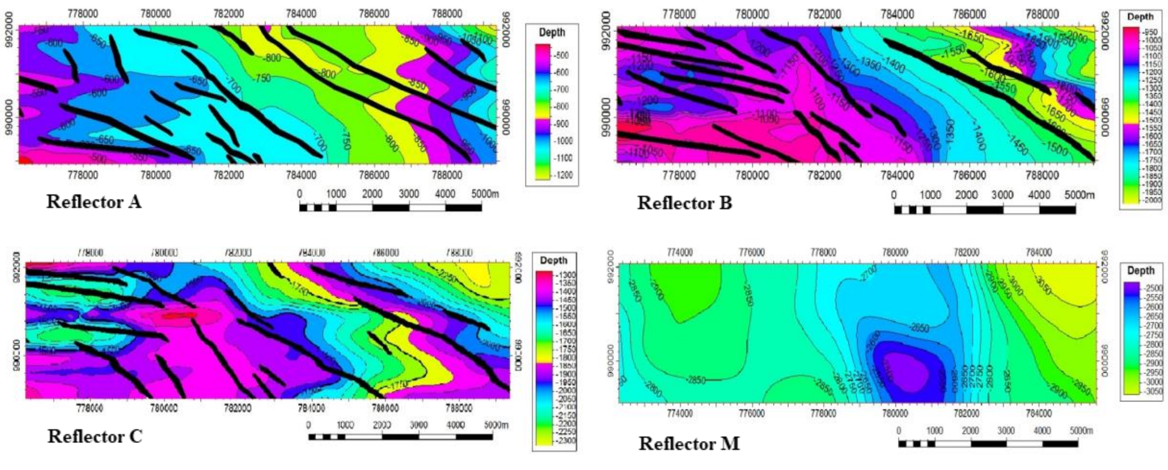


Fig. (5): Structural depth contour map of reflectors A, B , C and M.

## Discussion

The current study was carried out to shed more light on the geologic history and the depositional evolution of the Neogene – Quaternary subsurface sediments along the eastern flank of the Nile Delta. This study identified the structural and petrophysical characteristics of the Tao field in the offshore North Sinai area. The seismic interpretation of a grid of seismic profiles, led to the identification of four prominent regional reflectors.

These four regional prominent reflectors have medium to strong continuous appearance named and arranged from old to young as; top Miocene Messinian (M), Middle Pliocene (C), Middle to upper Pliocene (B) and Early Pliocene (A) reflectors. The quality of the pre-Messinian data is poor; consequently it is difficult to interpret this section. The A reflector is the youngest reflector picked at the study area. It was picked at 344 m as correlated with well log data. Reflector "B" represents the upper top sequence which can be picked with confidence at nearly 1200 m. Reflector C has strong amplitude appearance and cut by different faults and can be picked at depth of 1875 m in most parts of the study area.

Reflector M is considered as the most significant and regional key stratigraphic marker reflector for the geology of the Mediterranean (Ryan et al., 1970; Stanley, 1978; Omran and Fathy, 1998; Omran, 2001). It represents the top of the Messinian (Top of the Messinian Salinity Crises), as tied to the drilled wells. It is a very strong erosional surface of the Messinian evaporites, that was observed by many authors in the whole Mediterranean margin and the Levanent basin (Rayan 1970, Omran 1998 & 2001 and Albulushi, 2016).

## Conclusion

The present study was carried out to discuss the structural characteristic of the ONS. Through the interpretation of a grid of seismic profiles, four regional reflectors A, B, C and M have been identified. Also, according to the seismic interpretation of seismic profiles and structural maps, a number of structural features were able to be identified as following:

A-shallow structural features

Slides that include all down slope mass movements with displacement along the recognized surfaces. Slumped sediments are widely distributed in the study area on the shallow shelf areas. Slumped strata show a high degree of deformation with the absence of any internal reflectors. They are commonly identified by contorted to hummocky, chaotic seismic facies. It is worth mentioning that the causes of slumps were referred to gravity transport processes.

Growth faults are syndepositional faults, with listric geometries, flatten with depth and are associated with synthetic and antithetic faults. Most of the growth faults observed in the study area are extensional normal faults with throws ranging between a few meters to a few tens of meters. They sole out in the Messinian evaporite layer.

Many examples of collapse structures are recorded with in the study area. They form a negative flower structure at shot point 961. They usually form as the overlying formations tend to collapse, due to a slow subsidence rate.

B-deep structural features

Listric faults Most of the listric faults soles out basin wards and in the evaporates layer of the Messinian. Roll-over fold lies at the hanging wall of the major listric normal fault. It appears at shot point 1201 and 1281 as in Xl 6080.

Salt diaprism is observed beneath the continental shelf, they disturbed the continuity of the strata. They usually have cap on their top. These diapirs are separated by triangular evaporite diaprism and cause slumping of the surrounding strata. Salt diaprism appears to form at middle or upper Miocene sediments.

Structurally, the Tao field is affected by different sets of faults. The normal faults are the most predominant and mainly trend NW-SE wards.

In light of the occurrence of growth fault families and their associated rollover structures, the structures and depositional environmental conditions in the study area are suitable for hydrocarbon entrapment. The complex structural patterns promote hydrocarbon migration and accumulation in the downthrown sides or closures against the faults in the hanging walls, and listiric fault soles in the Messinian evaporite could aid in trap formation in the downthrown side of these expansion faults. The hydrocarbon traps are mostly rollovers in the growth faults' foot walls. The best reservoir consists primarily of sands found in the footwalls of growth faults.

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## الملخص العربي

### عنوان البحث: تفسير البيانات السيزمية واحتمالية تواجد الهيدروكربون لتتابع ما بعد الميوسين في حقل تاو ، شمال سيناء البحرى، مصر

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تعنى هذه الدراسة بالتعاقب الرسوبي التحت سطحي للنيوجين-الرباعي لحقل تاو في البحر شمال سيناء البحرى , حوض دلتا النيل. سيساعدنا تكامل طبقات الأرض والبيانات السيزمية والتكتونية في إنتاج رؤية شاملة لمنطقة الدراسة. يتيح تفسير جميع البيانات السيزمية المتاحة باستخدام برنامج PETREL إمكانية تفسير ورسم خرائط ثنائية الأبعاد أو تنقيب عن الأحواض على نطاق ميداني من أجل رسم رؤية متكاملة للهدف المقترح للعمل. يسمح التحليل الزلزالي للبيانات المتاحة بتقسيم التتابع المدروس إلى تسلسلين ضخمين: التتابع الضخم لما قبل وما بعد الميسيني. يتم تضمين وحدات الصخور الميوسينية في تسلسل ما قبل ميسينيان ، في حين يتم تضمين وحدات الصخور المستهدفة في تتابع ما بعد الميسيني. تم تحديد الملامح التركيبية المختلفة في منطقة الدراسة ، بما في ذلك الانزلاقات ، والانهيارات ، وفوالق النمو ، وتراكيب الانهيار كتراكيب ضحلة. أيضًا ، تم تحديد الفوالق القائمة ، والطيات الرول اوفرية ، ديابيرات الملحية على أنها تراكيب عميقة. الاتجاه التركيبي الرئيسي موجه نحو .NW-SE.