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Thermal Maturity and Hydrocarbon Potential of Jurassic Sediments, Northeastern Sinai, Egypt

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Abstract: Thermal maturation of organic matter, present in the source rocks of Jurassic sediments in some wells (Jb 91/3, Ja 90/2, Misri-1, El-Khabra-1 and Mango-1 wells) in Northeastern Sinai, is performed by different techniques. Some of these are based on the physico-chemical conditions such as rock eval pyrolysis data for identification of the nature and type of organic matter; as well as the burial history results, such as time-temperature index TTI, which helps in the definition of the time of onest, peak and end of oil generation. Several cross-plots have been constructed, using the different parameters of geochemical analysis to describe the organic richness and thermal maturity level. Moreover, the study of kerogen type is determined using pyrolysis process. The present study reveals that, the Jurassic sediments may be considered as fair to very good organic content rock potential of a marine or lacustrine supply of organic matter and is marginally mature to mature source rocks for the generation of significant amounts of oil and gas occurrences.

Key words: Burial history · Thermal maturity · Source rocks · Kerogen types

INTRODUCTION

The principal objectives of basin analysis are to reconstruct the thermal and burial histories of the studied basin and to understand the processes and mechanisms by which the basin had been formed. Moreover, it leads to following the time evolution of a sedimentary basin, in order to make quantitative predictions of the geological phenomena leading to hydrocarbon accumulations. Basin modeling techniques, combined with organic geochemistry, can be used to tell us about how and when various types of kerogen are converted to hydrocarbons and whether a basin has hydrocarbons in commercial quantities and whether they are likely to be oil, natural gas, or both.

The evaluation of sedimentary rocks as effective source rocks of petroleum affinity requires the determination of the amount and type of organic matter and the degree of conversion of the organic matter to petroleum hydrocarbons. The results provide information about the quality and quantity of organic matter source rock potential and level of thermal maturity, as discussed by numerous authors, such as Lopatin [1], Barker [2], Waples [3], Espitalie *et al.* [4], Leckie *et al*. [5], Shaheen [6], Tammam [7], Waples [8], Rahman and Kinghorn [9], Hunt [10], Roberts *et al*. [11] and Fowler [12] and others.

The determination of thermal maturity of a source rock, based on vitrinite reflectance, is an important factor for evaluating its hydrocarbon potential. As shown by Espitalie *et al*. [13], the temperature of maximum pyrolytic hydrocarbon generation (T_{max}) increases with increasinf the thermal maturity of organic matter. Hence, the T_{max} value is used here to determine the thermal maturity of the investigated samples. Tissot and Welte [14] reported that, the T_{max} value is considered to be among the most reliable factors for characterizing the thermal maturity, particularly in case of marine or lacustrine environments where vitrinite is often scarce or absent.

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The study area lies in the northeastern corner of Sinai and bounded by longitudes 33° 39` and 34° 15` E and latitudes 30° 55` and 31° 30` N (Fig. 1). Five wells are scattered across the study area and selected for organic formation evaluation in the present work. These are Jb 91/3, Ja 90/2, Misri-1, El-Khabra-1 and Mango-1 wells. The first four wells are onshore, while the last one is offshore well. The maximum recorded Jurassic thicknesses are 1747 m at Misri-1 well and 1735 m at Jb 91/3 well.

The identification of the total organic contents (ORG) of the source rocks in the subsurface, their types and levels of maturity, are very important motive in the field of petroleum exploration. So, this work can be considered as a trial to provide information about the local subsurface geology of this area, as well as to characterize the hydrocarbon source potential of the Jurassic sediments in the area of interest.

GEOLOGIC SETTING

The lithostratigraphic units of the Northeastern Sinai district have been defined from examination of the measured sections and subsurface cores, electric logs, tied to microfaunal and palynological studies of ditch samples and thin sections by many workers, such as: Shata, [15]; Said, [16, 17]; Neev, [18]; Beyth, [19]; Jenkins *et al*. [20, 21]; El-Badry and Abd El-Rahman, [22]; Ayyad and Ibrahim, [23]; Armmar and Afifi, [24]; Zaghloul and Khidr, [25]; Abd El-Shafy and Sallam, [26]; Abdel-Shafy *et. al*. [27] and others. On the other hand, the study area was the site of intensive surface and subsurface geological and geophysical investigations during the hydrocarbon prospecting and exploration. Among these studies are those by Al Far [28], El Shazly *et al*. [29], Moustafa and Khalil [30], Said [17], May [31], Abd El Aal *et al*. [32] and Abd El Aal and Lelek [33] and others.

Jurassic rocks in Northeastern Sinai are that of Jebel Maghara, where they reache to almost 2000 m [28] and is used in this study as a reference section. The Maghara Group is subdivided into the following formations, in ascending order: Mashaba; Rajabiah; Shusha; Bir Maghara; Safa; and Masajid Formations. The only few wells, that penetrated the Jurassic succession in Northeastern Sinai are El-Khabra-1, Misri-1, Jb 91-3, Ja 90-2 and Mango-1 wells. This succession is predominantly made up of shallow and marginal marine to continental fluvial clastic sediments, represented by limestone, shale and siltstone, intercalated with sandstones.

The 2D and 3D depth contour map representations on top the Jurassic sediments sequence (Fig. 3) reflect an asymmetric closure running NW-SE, with general dip northwestward.

Identification of Clay Minerals: Clay minerals are identified by XRD and interpreted through wireline logs, such as natural gamma-ray spectroscopy (NGS), litho-density tool (LDT) and photoelectric absorption index (Pe). To identify the types of clay minerals in the Jurassic sediments, the log values were plotted on crossplots, which distinguish clay mineral species. Figure (3) is the thorium-potassium concentration crossplot, on which the data are composed of a mixture of kaolinite and montmorillonite-mixed layer clay minerals.

HYDROCARBON POTENTIAL

The presence of sufficient organic matter is a necessary pre-condition for hydrocarbon generation. The quantity of organic matter is proportional to the organic-carbon content of the respective sediments (Hunt, [34]). Hence, the total organic-carbon content, expressed in weight percent (Wt. %) in the whole rock, is employed to evaluate the organic richness of the analyzed samples.

Organic Richness: The organic richness of the samples analyzed by Gondwana [35] was evaluated through the determination of total organic carbon (TOC) content in terms of weight percent (wt. %) in the whole rock. A threshold value for the organic richness was taken as 0.5 wt. % TOC (Welte, [36]). Peters, [37], rated a content of 0.5 wt. % TOC as poor, 0.5-1.0 fair, 1.0-2.0 good and >2.0 very good. This rating is used in the present work for assessing the organic richness of the samples analyzed. Figure (6) shows an organic geochemical evaluation log for the Jurassic sediments in the study area. The TOC contents of the samples analyzed from these sediments range between 0.12 and 2.64 wt. %, reflecting fair to very good organic contents.

Type of Organic Matter: The type and amount of hydrocarbons produced from a particular kerogen depend on its characteristics, which in turn depend on the type of the organic source material and the digenetic history of the kerogen concerned. In the present study, the kerogen type was determined using pyrolysis data, by plotting the hydrogen index (HI) versus the oxygen index (OI) on a Van Krevelen diagram (Fig. 4). The position of the samples in this diagram shows that, the Jurassic sediments are generally characterized by kerogen type II, indicative of marine or lacustrine supply of organic matter. It has a great capacity to generate liquid hydrocarbons.

THERMAL MATURITY

The determination of thermal maturity of a source rock organic matter represents an important factor for evaluating its hydrocarbon potential. As shown by Espitalie *et al*. [4], the temperature of maximum pyrolytic hydrocarbon generation (T_{max}) increases with increasing thermal maturity of organic matter. Hence, the T_{max} value is used here to determine the thermal maturity of the investigated samples. Tissot and Welte [14] reported that, the T_{max} value is considered to be among the most reliable factors for characterizing thermal maturation, particularly in the case of marine or lacustrine kerogens (type I and II), where vitrinite is often scarce or absent. They also added that, the T_{max} value is influenced by the type of organic matter during the diagenesis stage and the beginning of the catagenesis. It is lower in the terrestrial type III kerogen and higher in the marine or lacustrine types I and II kerogens.

The relationship between (HI) and T_{max} shown in Fig. (5), reflects that, most of the studied samples derived from Jb 91/3, Misri-1 and Mango-1 wells are mainly composed of vitrinite-inertinite macerals, as their HI are ranged from <300 to >150. This reveals gas and oil producing organic matter, in combination with gas-prone macerals of HI < 150. Structured lipid-rich vitrinites are mostly of terrigenous origin and have the potential to generate oil and gas deposits in an euxinic environment (Tissot and Welte, [14]).

Throughout the whole sequence analyzed, the amount of organic carbon was low, with the highest TOC value being 2.64 % and the highest potential yield (S_2) values being 3.63 mg Hc/g rock (Fig.6). The average values for these parameters are 0.83 % and 3.21 mg Hc/g rock, respectively. These quantities are considered to be fair in terms of source potential. The quality of organic material is fair, indicating a type II kerogen, as consistent with marine or lacustrine organic matter.

The hydrocarbon indications in Fig. (6) reveal high values (pyrolysis S1 yield, 2.08 to 3.58 mg HC/g) and the production index (PI) ranges from 0.06 to 0.76. This may indicate the presence of migrated hydrocarbon. The free (S1) hydrocarbons could have impregnated the vitrinite particles and consequently the vitrinite has acquired a fluorescing perhydrous nature. The combination between the maximum temperature (T_{max}) and the production index (PI) shows that, the organic matter in the studied samples are marginally mature to mature (Reached to the oil window) (Fig. 7).

According to Espitalie *et al.* [4], T_{max} value with less than 430°C indicates immature organic matter, while the end of oil generation (beginning of wet gas and condensate) is indicated by T_{max} value of approximately 450 - 455°C for type II kerogen and 465°C for type III kerogen. End of wet gas and condensate generation is at T_{max} value of 520°C and values greater indicating the dry gas zones. The T_{max} values of the analyzed samples from the Jurassic sediments of the study area are ranging between 432°C and 446°C, reflecting marginally mature to mature kerogens. A plot of the T_{max} versus depth for these samples (Fig. 6) reveals that, the T_{max} values show an irregular increase with depth, which may indicate a low geothermal gradient in the study area. Based on the estimated T_{max} values, the Jurassic sediments represent a marginally mature to mature level (T_{max}: 432°C - 446°C).

Modeling of Thermal Maturity: Thermal maturity, if indigenous organic matter, provides a direct measure of the time-temperature history of the host rocks, which in turn constrain the thermal burial history of strata. This measurement is generally valid, regardless of the age or lithology of the enclosing rocks.

Burial History Modeling: Based on Lopatin's method [1] and Waple's modification [38], thermal maturation of organic material is a process controlled by both temperature and time. To construct the geologic history of a rock unit using its organic maturity, the thermal and burial history of an area has to be known. This method gives an estimate of the present organic maturity of the stratigraphic section. The Lopatin's method assumes that, the rate of chemical maturation of organic material approximately doubles with each 10 degree centigrade increase in temperature. It is, therefore, possible to extrapolate up and down the temperature scale by a factor of two to identify a temperature weighting factor for each 10 degree centigrade interval. The time-temperature index (TTI) of a given unit is defined as the sum of the products of weighting factors and residence time of the unit for every degree centigrade interval.

Burial history modeling for three wells in the study area was constructed to determine the depths of oil window (onset and end of oil generation) and the area extent in the basin, below which a peak generation of hydrocarbon might have occurred.

Timing of Hydrocarbon Generation and Migration: In order to determine when a particular source rock began to generate hydrocarbon, it is necessary to calculate the maturity level. This is done by calculating the depth of burial needed to initiate oil generation through the burial history of the study area; assuming no change in the geothermal gradient during the recent geological past.

Based on the time-depth curves for the encountered sedimentary units, the timing of entry into different phases of the oil window is calculated by interpolation or plotting. From burial history study of these wells (Figs. 8, 9 and 10), the Jurassic sediments reached to the top of oil window at depths of 2984, 2587 and 3270 m in Jb 91/3, Misri-1 and Mango-1 wells, respectively. The bottom of oil window is detected in Mango-1 well only.

CONCLUSIONS

The study of thermal maturation of organic matter present in the source rocks of the Jurassic in Northeastern Sinai reflects that the, the studied Jurassic sections are lithologically very close to Gabal Al Maghara type section, with occasional slight variations in thicknesses and lithologies. The depositional environments prevailing during the Jurassic were deeper northwards. Organic carbon richness (TOC), according to the TOC measurements, the Jurassic sediments are considered as fair source rock quality and are marginally mature to mature. The clay minerals composed of a mixture of kaolinite and montmorillonite-mixed layer. The low levels of maturity are such to preclude any large scale gas generation from the sediments analyses. One dimensional basin modeling of the studied wells indicated that, the Jurassic interval is within the oil window.

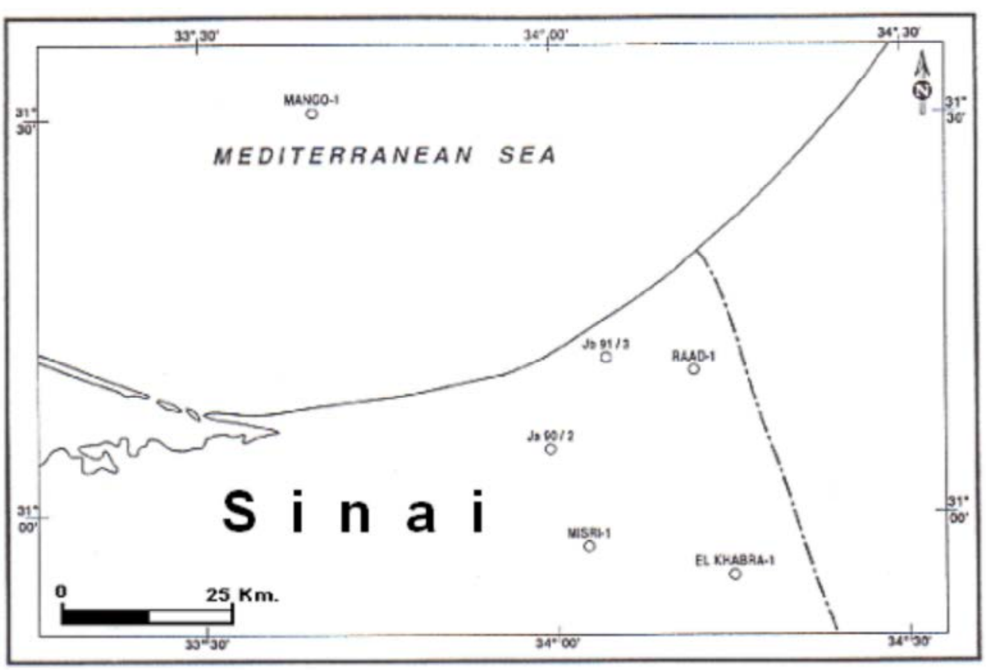

Fig. 1: Location map of study area

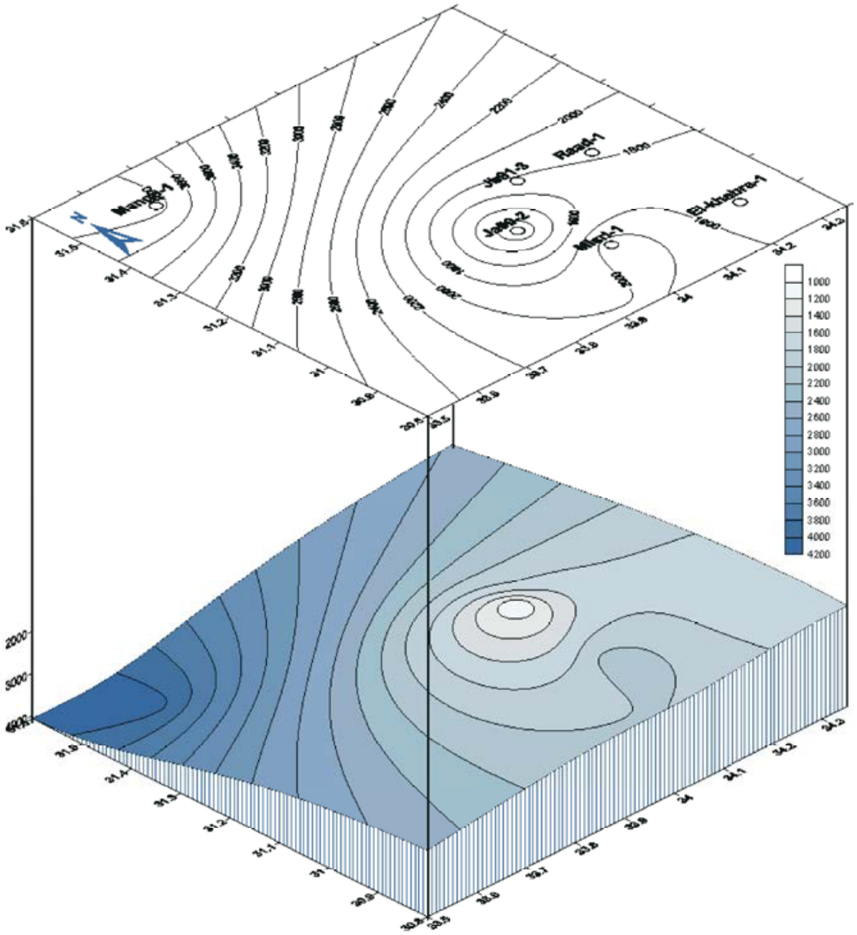

Fig. 2: 2D and 3D representation of the depth contour map on top Jurassic sediments, Northeastern Sinai, Egypt. (C.I. =200 m.)

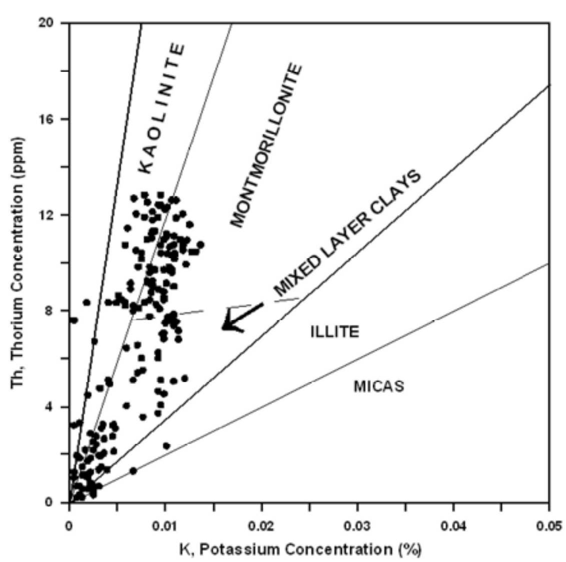

Fig. 3: Crossplot of thorium against potassium over the Jurassic sediments, Northeastern Sinai, Egypt

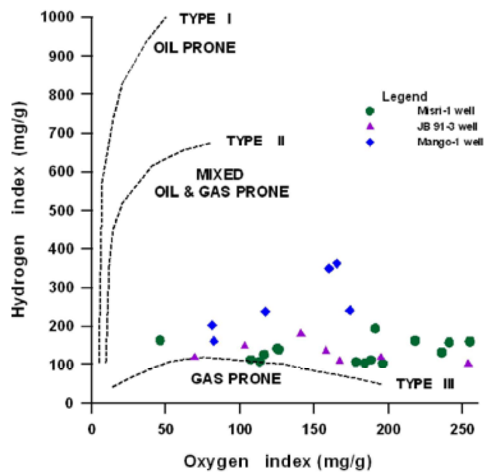

Fig. 4: Hydrocarbon index versus oxygen index, showing the Kerogen types, as illustrated by Van Krevelen diagram.

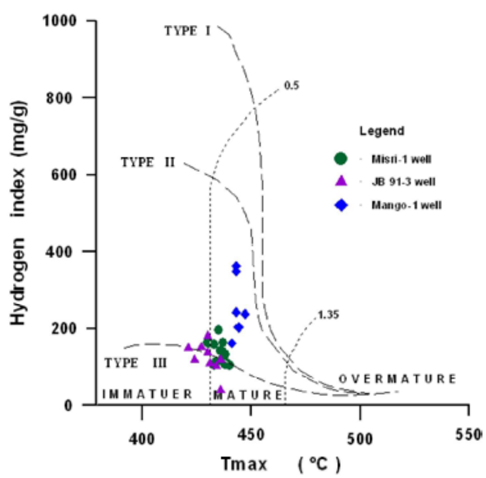

Fig. 5: Tmax vesus hydrogen index showing the type of organic matter and the level of maturity.

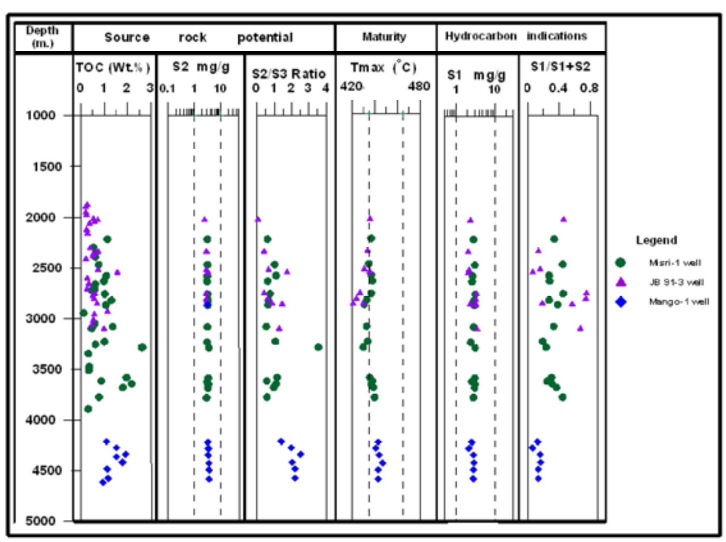

Fig. 6: Source rock evaluation of the Jurassic sediments in the Misri-1, JB 91-3 and Mango-1 wells. Key of abbreviations: TOC= Total organic carbon, S2= Oil potential, S2/S3= Hydrocarbons generated to trapped CO2, Tmax= Temperature of maximum rate, S1= Free hydrocarbon, S1/S2+S3= Production index or transformation ratio.

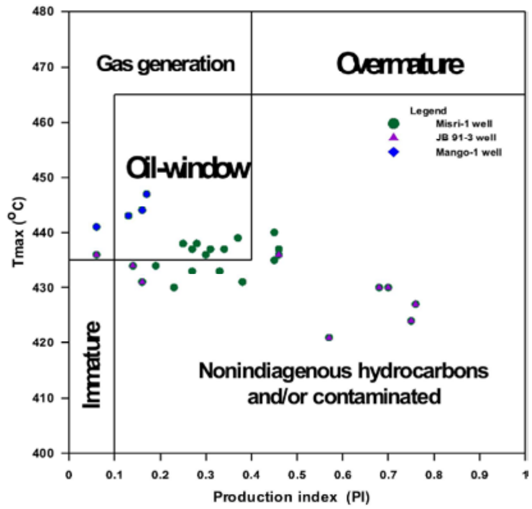

Fig. 7: Tmsx (°C) - PI diagram of the investigated samples

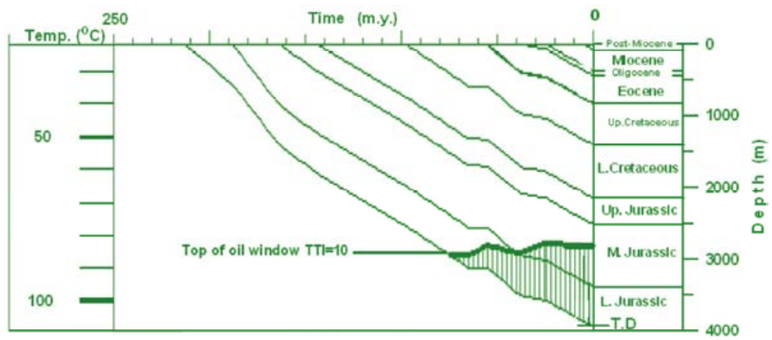

Fig. 8: Burial history, timing of hydrocarbon generation and maturity modeling of Mango-1 well

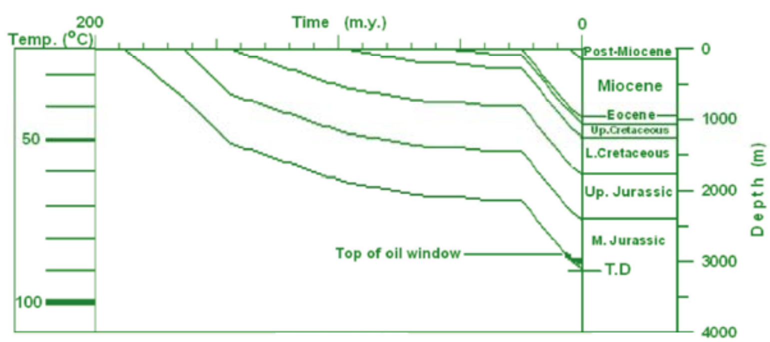

Fig. 9: Burial history, timing of hydrocarbon generation and maturity modeling of Jb91-3 well.

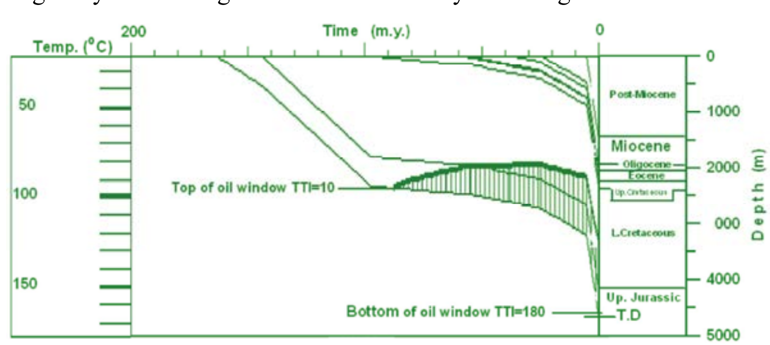

Fig. 10: Burial history, timing of hydrocarbon generation and maturity modeling of Misri-1 well

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