



Organic geochemical and petrographical characteristics of the lower part of Sarmord Formation, M-2 Well, Miran Oil Field, Kurdistan, NE Iraq: Implications for hydrocarbon generation potential and thermal maturation

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Abstract

The Lower Cretaceous Sarmord Formation (Hauterivian–Barremian) has been investigated in this study. The selected M-2 Well is one of the wells belonging to Miran block, Sulaimani Governorate, Kurdistan Region of Iraq. The area of interest is situated in the High Folded Zone, Western Zagros Fold-Thrust Belt, being approximately 30 km far from Sulaimani City towards the northwest direction. The selected samples were analyzed by Rock-Eval pyrolysis, infrared spectroscopy, and also studied microscopically to determine the quality and quantity of organic matter, the level of thermal maturity, as well as the hydrocarbon generation potentiality. Rock-Eval pyrolysis data show that the total organic carbon for Sarmord Formation is between 0.83 wt.% to 1.55 wt.%, with an average value of 1.27 wt.%. The average and range of S1, S2, and genetic potential (S1+S2) are: 0.76 (0.55–1.09) mg HC/g rock, 0.82 (0.65 – 1.28) mg HC/g rock, and 1.58 (1.21 -2.37) mg HC/g rock, respectively. The average value of pyrolysable carbon (PC) and residual carbon (RC) are of 0.23 wt.% and 1.04 wt.%, respectively. The hydrogen index (HI) is between 47 and 98, with an average value of 66. The obtained data indicate that the Sarmord Formation has a satisfiable range of total organic carbon content, but the organic matter by itself has poor potential to generate hydrocarbons because of low amount of S2, HI, and PC. The Rock-Eval maturity parameters (T_{max} and PI) are undependable in this study. Because they are out of the acceptable range. The cutting samples in this well have been contaminated by solid drilling additives, which were identified during the petrographical study by their structure and low reflectance values. The double peaks of S₂, solid drilling additives, are affected of disturbing maturity parameters of Rock-Eval data. The petrographic study proved that the samples mostly contain bituminite, which is disseminated predominantly within the clayey particles, with minor amounts of alginite. Additionally, weathered and degraded humic particles are interpreted as content of drilling mud. The kerogen types are mostly of Type II kerogen, because the *vitritine macerals* are absent and we have an indication of alginite; which is one of precursors of formation of bituminite. This result is controversial with the graphical presentation of kerogen type by Rock-Eval and infrared microscopy, as they are interpreted as Type III gas-prone kerogen. The equivalent vitritine reflectance for the studied section ranges between 0.73-0.81%, with the values close to 0.80% being more accurate as were measured in homogenous solid bitumens. The obtained values indicate maturation within the oil window. While based on infra red spectroscopy, maturation is between 0.80 to 1.10, suggesting to higher maturation level compared to vitritine reflectance values.

1. Introduction

In the last decade, the Kurdistan Region of Iraq hosted many international oil companies aiming for hydrocarbon exploration and upgrading oil and/or gas reserves. The entire region has been subdivided into

many blocks awarded to specialized oil companies. Miran block is one of them, it was awarded to Heritage oil company which received license to operate in 2007. In 2012 the company decided to sell its remaining interest (49%) to Genel Energy Company (Heritage Report, 2012).

Source rock assessment consists of addressing the hydrocarbon generating potential for rock unit by testing organic matter capacity for hydrocarbon generation, type of organic matter content, and level of thermal maturity, as well as addressing which type of hydrocarbon might be expelled. By regarding all the previously mentioned points, it is possible to answer questions about if, how much, what kind, and when hydrocarbon generation has occurred, as well as providing clues for the paleoenvironmental conditions (Hunt, 1996; Dembicki, 2009).

The most lower part of Sarmord Formation in the M-2 Well (Fig. 1) has been selected in this study to perform organic geochemical and petrographical characterization. The aim is to determine the organic geochemical properties of the selected samples, and to determine the quality, quantity and thermal maturity of the organic matter. Also, it aims to define the paleoenvironmental conditions through organic matter characterisation.

2. Geological Setting

2.1. Study area

The area of interest is located within the Zagros Fold Belt of the Iraqi Kurdistan. According to the tectonic subdivision of Iraq, the area is a part of the High Folded Zone (Fig. 1). This Zone is located between the Zakho area at the Turkish border in the northwest and the Darbendikhan-Halabja area near the Iranian border in the southeast (Ahmed, 2013). The studied M-2 well lies on latitude 35° 40' 19.177" N and longitude 45° 03' 13.695" E. It is belonging to Miran Field/Block (Fig.1), which is about 30 km far from Sulaimani City in the northwest direction. Miran Block occupies an area about 1050 km², elongated in the northwest-southeast direction (Fatah, 2014; Fatah and Mohialdeen, 2015).

Seismic exploration and field mapping upon the area led to the finding of the large anticlinorium, known as Miran Structures (Miran East and Miran West); both structures (anticlines) occur generally sub-parallel to each other. The structures are separated by the NNW-SSE trending Tasluja Ridge that is exposed on the surface, extended to the center of the block (Heritage Report, 2012). Miran East and Miran West anticlines have slight expressions on the surface (Al-Hakari, 2011). These anticlines have been covered by Quaternary deposits and have no surface exposure. There is no indication of a syncline between Miran West and Miran East, reflecting partial thrusting of the latter over the former (Heritage Report, 2012).

2.2 The general framework of the area

The Kurdistan Region is situated on the north and northeastern part of Iraq. The mountains of this area are trended in a general NW-SE direction, reflecting the Arabia-Eurasia collision. The rock units of Hauterivian-Albian age are cropped out in several localities within Kurdistan territory. These units (formations) have formed the shield and the core of the anticlines, such as Azmar, Piramagroon, Surdash, Rania (Kewa Rash), Korek, Handren, and Bekhme anticlines (Ahmed et al., 2016).

In this area, the thick sequences of marine and continental facies are present in the longitudinal zone trended NW-SE (Fig. 2), being deposited during the opening of the Neo-Tethys until the final phase of the Arabian-Eurasian collision (Ahmed et al., 2015).

The High Folded Zone of Iraq is characterized by the harmonic fold of Mesozoic limestone in their cores, and Palaeogene and Neogene limestone and clastics on their flanks. The effect of block movements in the High Folded Zone caused uplift of this area during Cretaceous and Palaeogene, and deformation during the Late Tertiary Period (Jassim and Buday, 2006). The study of Kubli (2013) more or less confirmed this tectonic model suggesting that the Miran structures were subjected to thick-skinned deformation before two million years ago. The deformation caused limited shortening, steep reverse faulting and tightening of preexisting anticlines, as well as uplifting of several anticlines in the area, among them Miran anticlines.

During Valanginian-Aptian age, the reefal platform of Qamchuqa Formation has been precipitated leading to the division of the basin of Iraq into two parts: (i) the shallow facies in the west and, (ii) the deep basinal facies of Balambo Formation in the east (Dunnington, 1958 and Fig. 3). This situation continued and extended

until Albian. Moreover, Ahmed et al. (2016) considered that during the Berriasian to Barremian, Kurdistan area was covered by the carbonates of the Balambo and Sarmord formations. In the east and southeast, the neritic Sarmord Formation gradationally and laterally passes to the basal facies of the Balambo Formation.

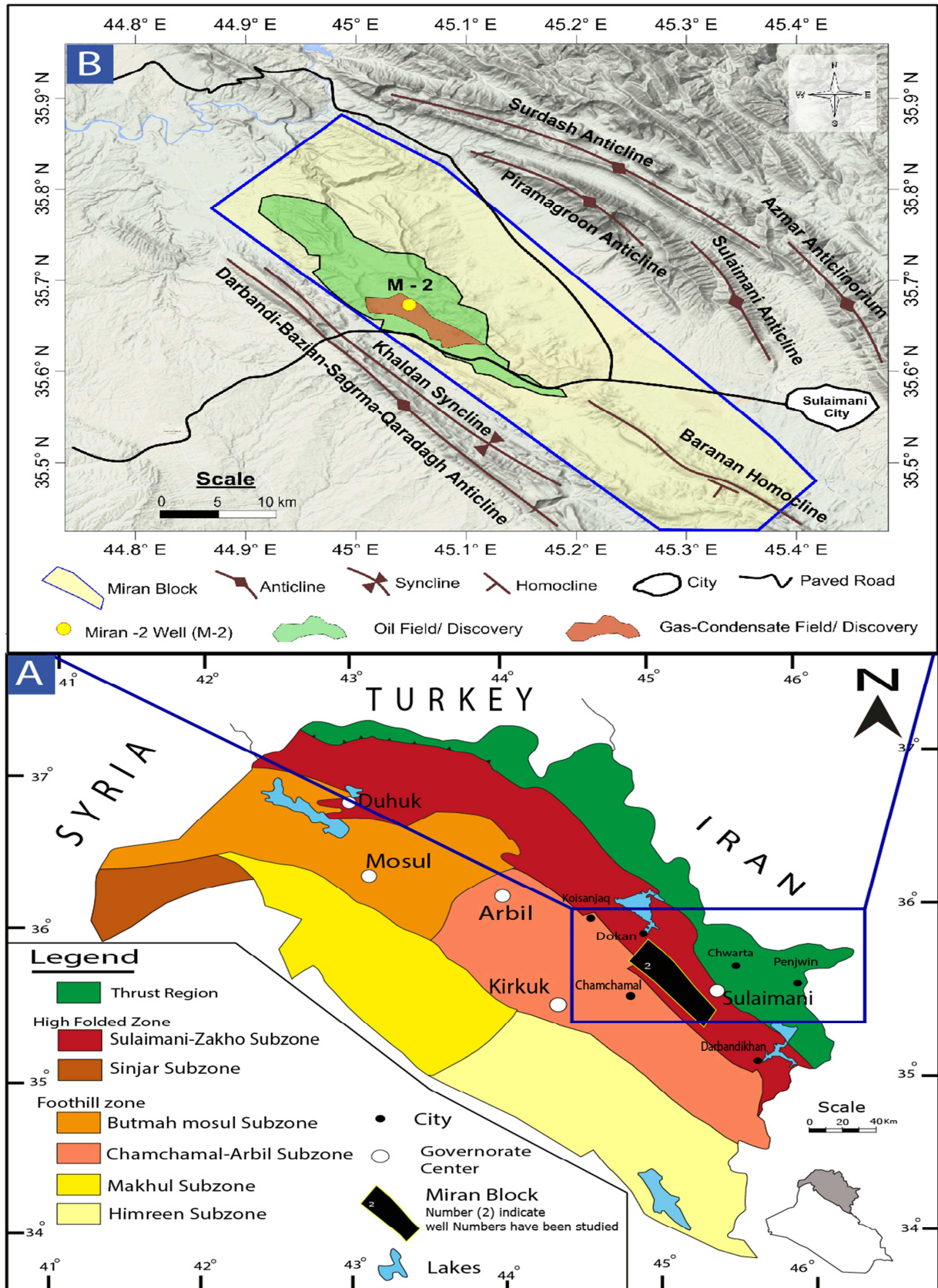


Fig. 1: Location map of the study area. A: simplified Tectonic Map of northern Iraq with an indication of Miran Block (after Fatah, 2014), B: Google terrain showing location map of M-2 Well within Miran Block (Google Terrain Map, 2012 and Western Zagros Map, 2013).

2.3 Sarmord Formation

For the first time, the Sarmord Formation (Hauterivian-Barremian) was defined by Wetzel (1950 in Bellen et al., 1959) in Surdash anticline of the High Folded Zone in the Sulaimani area NE Iraq. It composes of 544m of brown and bluish marl, buff weathering, with alternations of marly neritic limestone. The underlying and overlying formations are Balambo and Qamchuqa, respectively, with gradational and conformable contact (Bellen et al., 1959; Jassim and Goff, 2006).

The regional stratigraphic column (Fig. 4A) shows that the presence of thick Jurassic, Cretaceous, and Tertiary succession composed of sedimentary rocks (Al-Ameri et al., 2013). Based on the master log of M-2 Well, which was created by Heritage Oil Company, the thickness of Sarmord Formation in M-2 Well is 356.5m, from 1839m measured depth below rotary table (MDBRT) on top and 2195.5m MDBRT in base (part of Master log shown in Fig. 4B). In this well, Sarmord Formation is underlies by Chia Gara Formation and overlies by Qamchuqa Formation with conformable and gradational contact.

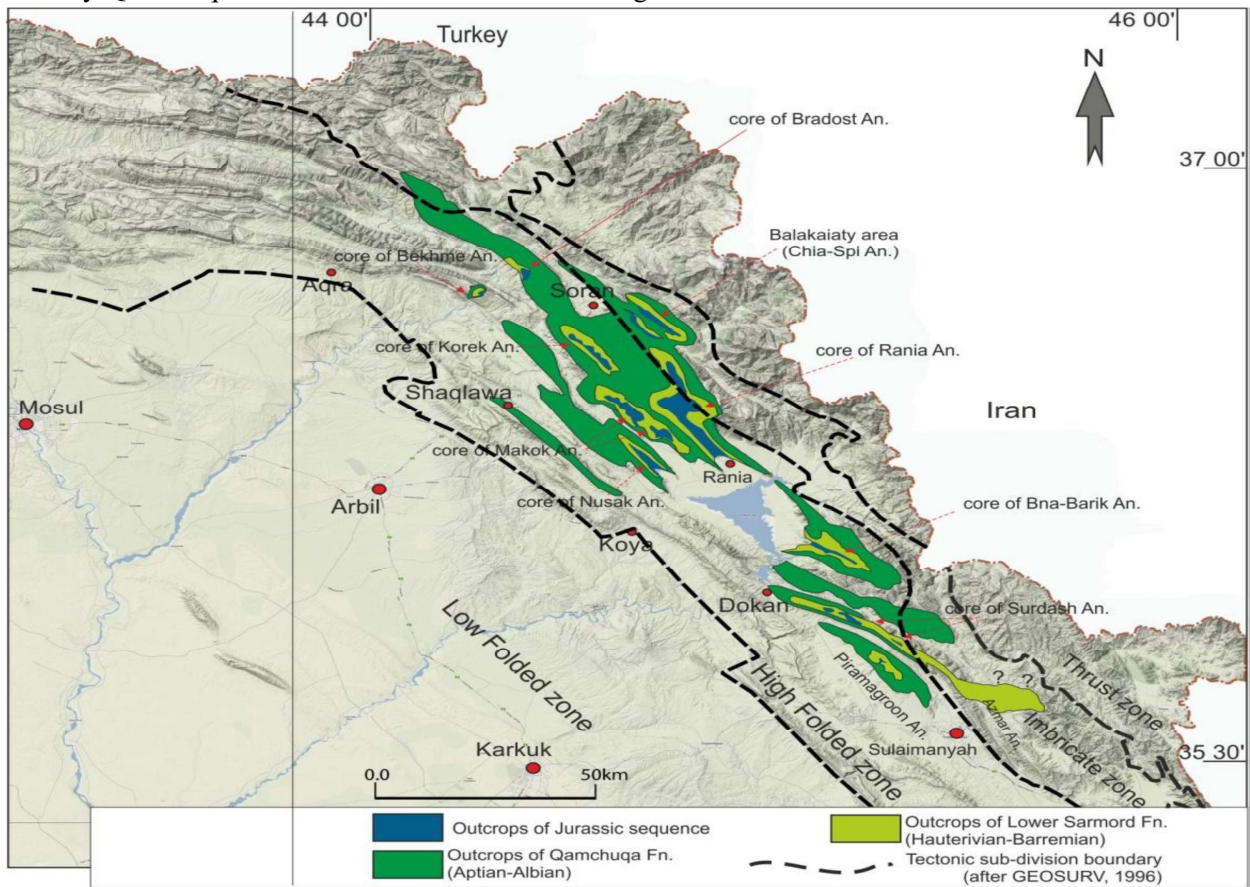


Fig. 2: Surface distribution of Qamchuqa and lower Sarmord Formations on the Kurdistan Terrain map (Ahmed et al., 2016).

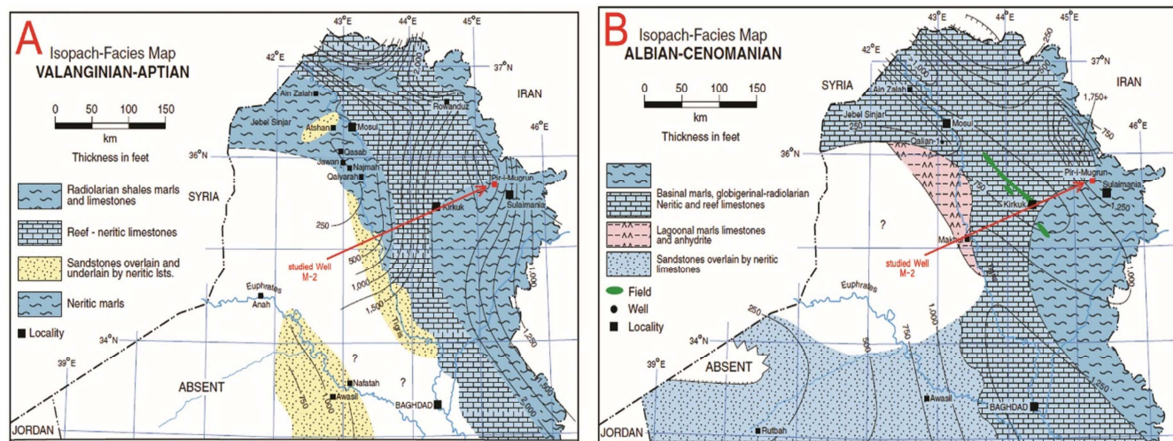


Fig. 3: Isopach–Facies Map of A: Valanginian-Aptian B: Albian-Cenomanian (Dunnington, 1958), with an indication of Sarmord Formation in studied well (M-2 Well).

Detailed petrographic examination of Sarmord Formation indicated that there are four main lithofacies: limestone, dolostone, siliceous, and shale. The rock unit also contains a variety of bitumen-rich lithologies, which can be seen as a bed, lamina, pore-filling, etc. Moreover, several diagenetic processes affected the Sarmord Formation, which prevents precise determination of the palaeoenvironment based on the mineralogical data (Basher and Al-Samarraie, 2012).

Aqrabi et al. (2010) claimed that the Cretaceous petroleum system in Iraq has great importance, it includes the AP8 and AP9 Megasequence, and the lower Cretaceous units considered the major part of this system. They also believed that the thick basinal units of the Garagu, Sarmord, and Balambo Formations act as a potential source rock for charging overlying fractured carbonate reservoirs. Sarmord Formation was divided into Lower Sarmord Formation and Upper Sarmord Formation by Buday (1980). He claimed that the exact boundary determination, as well as its exact lithological composition for this Formation needs future study. According to Jassim and Goff (2006) there is no Upper Sarmord Formation in its type section in the High Folded Zone of NE Iraq, and the Sarmord type section only represents the Lower Sarmord Formation. The latter authors believe that the proportion of limestone content of Sarmord Formation becomes higher towards the SW where it laterally passes into the Qamchuqa Formation. Moreover, Karim et al. (2013) precisely mapped Sarmord Formation and separated from Balambo Formation, for the first time, in Azmer-Goizha anticline.

Al-Qayim et al. (2016) made a correlation for surface and subsurface units in their study area. They claimed that there are general similarities in stratigraphic characteristics between outcropped studied units of Balambo, Sarmord, and Qamchuqa formations (in Zewe, Tabin, and Qamchuqa Gorge) to the subsurface sections of neighboring oil fields (especially in oil wells of Miran-1, Bazian-1, and Cahmchamal-2) for the same units, with presence of little differences. The rhythmic alternation of marl and marly limestone and/or limestone is the main diagnostic lithological characteristic of Sarmord Formation in Zewe, Sarmord-Sargelu, and Rania areas. This rhythmic alternation is mainly caused by Milankovitch cyclicity (Ahmed, 2007). Moreover, the outer shelf sediments of Sarmord Formation was conformably deposited over Balambo Formation during Hauterivian-Barremian (Ahmed et al. 2015). Recent attempt about organic geochemistry and petrophysical characteristics of Sarmord Formation in selected sections in Kurdistan region have been studied by Edilbi et al., (2019); The TOC wt.% and T_{max} values for their samples in subsurface and surface sections are 0.22 wt.%, 0.83 wt.% and 426 °C, 440 °C, respectively. Therefore, they concluded that the Sarmord Formation regarded as: poor organic carbon content, low maturity, and low capacity for hydrocarbon generation at subsurface section; while, fair to good organic carbon content, thermally mature, and poor to good potentialty for hydrocarbon generation was assigned for surface section.

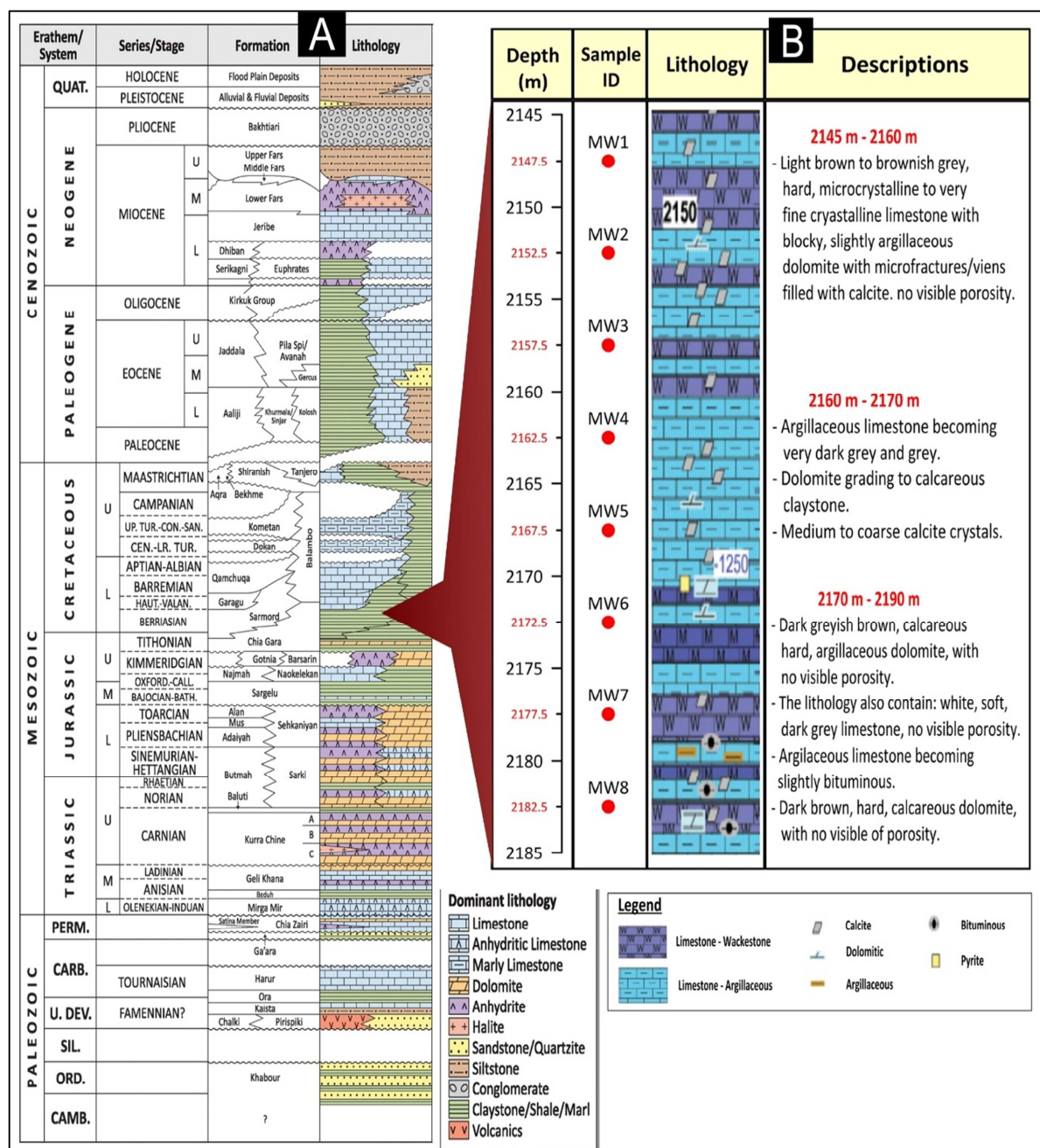


Fig. 4: Geological Column. A: General Stratigraphic column of Kurdistan Region-Iraq (after English et al, 2015). B: the stratigraphic column of M-2 Well with the sampling scheme (after Masterlog of M-2, by the Heritage oil company, 2012).

3. Samples and Methods

Eight cuttings samples were taken systematically every 5m from the lower part of Sarmord Formation in M-2 Well at depth range of 2185m – 2145m. The samples were obtained from the Geological Survey Storage in Erbil, Ministry of Natural Resources of Kurdistan Region. The samples were washed by distilled water. The washed samples were kept in the oven for 24 hours to dry at a temperature of 40 °C. The washed-out samples were crushed and grinded to a homogeneous powder, and then analyzed by Rock-Eval 6 in Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimani, Kurdistan Region-Iraq. The pyrolysis was performed with about 90-100 mg of crushed samples, which were heated to 800 °C in a helium atmosphere. The oven was held at 300 °C for 3 minutes and then increased at a rate of 25 °C/min. Several parameters such as TOC wt.%, S1, S2, S3 and the temperature of maximum pyrolysis yield (T_{max}) were measured (Table 1).

Organic petrographical examinations were carried out based on the International standards (ISO 7404-2, 2014), and samples examined by using a LEICA DMRX microscope at the Department of Geology, University of Patras, Greece. Maceral identification was performed in oil immersion under both white incident

light and blue-light excitation (ASTM D7708, 2014). The terminology of Macerl is based on the Stopes-Heerlen System as modified by ICCP System 1994 (ICCP, 1998; 2001; Sýkorová et al., 2005; Pickel et al., 2017), whereas for solid bitumens the classification of Jacob (1989) was followed. The equivalent of Vitrinite reflectance was measured according to ASTM D7708 (2014).

Sample preparation for Infrared analysis (concentrated Kerogen) has been done in the department of Geology, University of Sulaimani. The crashed samples were placed in a beaker with HCL (10%) included, then concentrated HCl (37%) is added. The acid then poured off, adding distilled water and standing overnight. HF acid (52%) is then added to the beaker. The acid then poured of, adding distilled water and standing overnight. Samples were then washed with distilled water multiple times until they were neutral. The residues are sealed with 10 µm nylon mesh, after that washed in a room temperature. The concentrated kerogens of selected samples were analyzed by Infrared instrument (IR) at the Department of Chemistry, University of Sulaimani. The pellets made through mixing with Potassium Bromide (KBr) and pressed under 20Kb pressure. The IR spectra were recorded on a Perkin-Elmer FT/IR spectrometer using KBr pellets (Vmax in cm⁻¹). The intensity of important peaks at wave numbers such as 1630 cm⁻¹, 1710 cm⁻¹, 2860 cm⁻¹, and 2930 cm⁻¹ have been measured (see section: Infrared Spectrometry) (Ganz and Kalkreuth, 1987).

4. Results and discussion

4.1. Rock-Eval analysis (pyrolysis)

The results of Rock-Eval analysis for tested samples are shown in table 1. The data have been filtered by using several screening parameters as shown in table 2, in order to eliminate those samples that have been contaminated by drilling fluids (English et al., 2015). Based on the screening conditions (Table 2), the values of Tmax for all the samples have been rejected, because either they have low Tmax (Tmax < 395) or low Tmax and high production index (PI) (Tmax < 435, PI > 0.2). Moreover, the values of PI for all samples (except sample #4) should be also rejected, because their genetic potential (GP) values are less than 2. The rest of the data are good and can be used for interpretation. By plotting the samples in figure 5, the contamination degree of the samples by drilling fluids can be assessed (Hunt, 1996). In this respect, all samples are considered as indigenous samples without any indication for contamination by drilling fluids (Fig. 5). This result suggests that the tested samples are untainted, and there are no any indications to be contaminated by free oil fluid.

Table 1: Rock-Eval pyrolysis data for samples of Sarmord Formation.

| Formation | Depth (m) | Sample ID. | TOC wt. % | S1 | S2 | S3 | PI | T _{max} | HI | OI | GP | S1/TOC | S2/S3 | PC wt. % |
|-----------------|-----------|------------|-------------|-------------|-------------|-------------|------|------------------|--------------|---------------|-------------|-------------|-------------|-------------|
| Sarmord | 2147.5 | 1 | 1.38 | 0.9 | 0.9 | 2.25 | 0.5 | 430 | 65 | 163 | 1.8 | 0.65 | 0.40 | 0.24 |
| Sarmord | 2152.5 | 2 | 0.88 | 0.55 | 0.66 | 2.23 | 0.45 | 434 | 75 | 253 | 1.21 | 0.63 | 0.30 | 0.19 |
| Sarmord | 2157.5 | 3 | 0.83 | 0.66 | 0.81 | 2.19 | 0.45 | 424 | 98 | 264 | 1.47 | 0.80 | 0.37 | 0.21 |
| Sarmord | 2162.5 | 4 | 1.5 | 1.09 | 1.28 | 2.59 | 0.46 | 312 | 85 | 173 | 2.37 | 0.73 | 0.49 | 0.3 |
| Sarmord | 2167.5 | 5 | 1.38 | 0.61 | 0.65 | 2.96 | 0.48 | 306 | 47 | 214 | 1.26 | 0.44 | 0.22 | 0.21 |
| Sarmord | 2172.5 | 6 | 1.34 | 0.67 | 0.75 | 2.63 | 0.47 | 306 | 56 | 196 | 1.42 | 0.50 | 0.29 | 0.22 |
| Sarmord | 2177.5 | 7 | 1.55 | 0.86 | 0.82 | 3.2 | 0.51 | 305 | 53 | 206 | 1.68 | 0.55 | 0.26 | 0.26 |
| Sarmord | 2182.5 | 8 | 1.27 | 0.75 | 0.71 | 2.72 | 0.51 | 301 | 56 | 214 | 1.46 | 0.59 | 0.26 | 0.22 |
| Average: | | | 1.27 | 0.76 | 0.82 | 2.60 | | | 66.88 | 210.38 | 1.58 | 0.61 | 0.32 | 0.23 |
| Minimum: | | | 0.83 | 0.55 | 0.65 | 2.19 | | | 47.00 | 163.00 | 1.21 | 0.44 | 0.22 | 0.19 |
| Maximum: | | | 1.55 | 1.09 | 1.28 | 3.20 | | | 98.00 | 264.00 | 2.37 | 0.80 | 0.49 | 0.30 |

Abriviations; S1: Free hydrocarbon (mg HC/gm rock); S2: Hydrocarbon potential (mg HC/gm rock); S3: CO₂ from organic source (mg CO₂/ gm rock); PI: Production Index (Transformation Ratio) {S1/(S1+S2)}; GP; Genetic Potential

(Petroleum Potential) (S1+S2); TOC: Total Organic Carbon (wt.%); HI: Hydrogen Index (100*S2/TOC); OI: Oxygen Index (100* S3/TOC); T_{max} : Temperature of maximum peak of S2 (C°); **Shaded Cell**: Rejected data based on conditions shown in Table 2.

Table 2: Rock-Eval screening parameters for filtering data modified from Peter and Cassa (1994) and Peters, 1986 by personal communication (from English et al., 2015).

| Condition | Action | Definitions |
|------------------------------------|---------------------------|---|
| TOC < 0.5 | Reject T_{max} , HI, OI | TOC: Total Organic Carbon (w%) |
| S2 < 0.5 | Reject T_{max} | S1: mg HC/g rock distilled by pyrolysis S2: mg HC/g rock cracked from kerogen during pyrolysis |
| T_{max} < 395 | Reject T_{max} | |
| GP < 2 | Reject PI | S3: mg CO2/g rock generated during pyrolysis |
| HI < 50 ; TOC > 1 | Reject T_{max} | T_{max} : temperature at maximum S2 peak |
| OI > 300 | Reject OI | HI (Hydrogen Index): mg HC/g TOC |
| T_{max} < 435; S1*1000/TOC > 300 | Reject T_{max} | HI= (S2/TOC)*100 |
| T_{max} < 435 ; (S1 /S2) > 0.3 | Reject T_{max} | OI (Oxygen Index): mg CO2/ g TOC |
| 435 < T_{max} < 445 ; PI > 0.3 | Reject T_{max} | OI=(S3/TOC)*100 |
| 445 < T_{max} < 460; PI > 0.4 | Reject T_{max} | GP (Genetic Potential) = S1+ S2 PI (Production Index) = S1/ (S1+S2) |

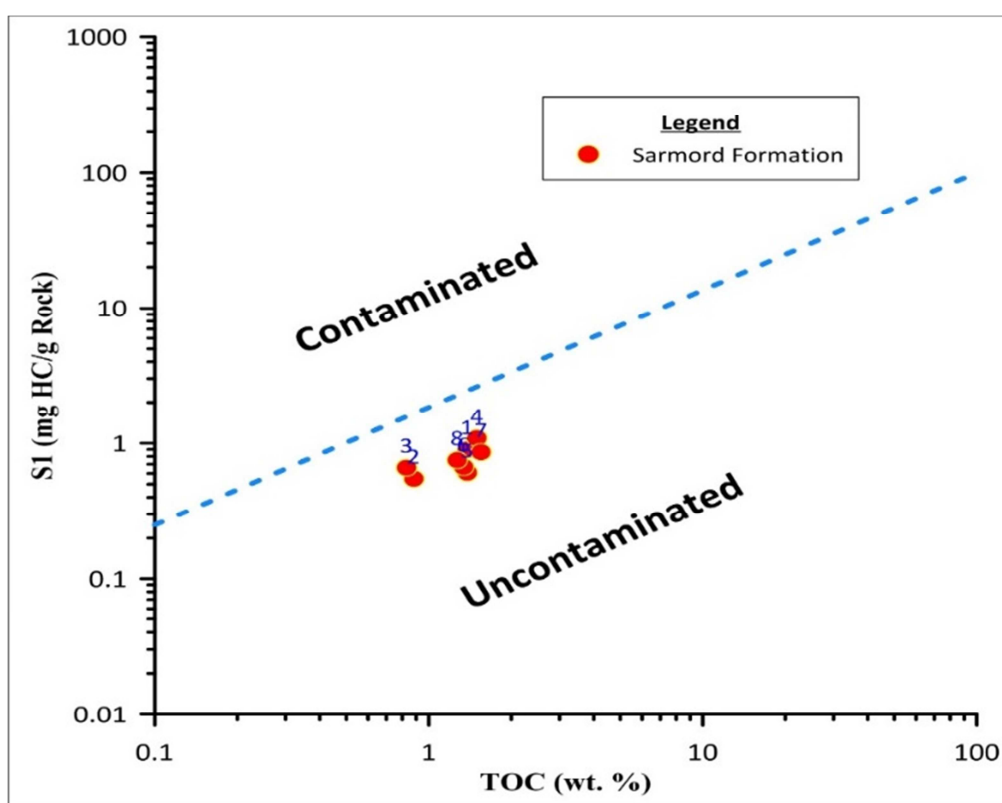


Fig. 5: Cross plot of TOC (wt.%) content vs. S1 (mg HC/g Rock) for determining contaminated samples (Hunt, 1996).

4.1.1 Quality of organic matter and hydrocarbon generation potential

The TOC content of a rock describes the quantity of organic matter (Peters et al., 2005), it includes both kerogen and bitumen (Peters and Cassa, 1994; Hunt 1996). The examined samples of Sarmord Formation contain 0.83, 1.55, and 1.27: minimum, maximum and average of TOC wt.%, respectively (Table 1). Thus, they are considered as a good source rock (Fig. 6). Although the presence of high TOC (wt.%) content in a rock sample increases its chance to become a good source rock (Tissot and Welte, 1984), but this factor is not sufficient indicator alone. Because part of the organic matter could be inert due to reworking, oxidation or

high levels of maturation, which results in low remaining petroleum generation potential (Espitalié et al., 1986; Dembicki, 2009). The values of TOC (wt.%) should be combined with the Rock-Eval parameters to get a suitable interpretation. In this study, the guidelines of Tissot and Welte (1978), Peters (1986), Peters and Cassa (1994), and Peters et al. (2005) were followed for source rock quality and hydrocarbon type assessment.

Based on Rock-Eval data, the analyzed samples of Sarmord Formation contain, relatively, significant amount of TOC content, but it is considered as a poor potential for generating hydrocarbon (Fig. 7). The same situation (high TOC and low potentiality) is also notable and confirmed by plotting Sarmord samples on the cross plot of TOC content vs S2 (Fig. 8). Based on the range and average values of S1, S2, GP (Table 1) and by regarding guidelines of prementioned authors, the Sarmord Formation is considered as a poor source rock that has no capacity for oil generation, but it has some potential for gas generation (Tissot and Welte, 1978). The high TOC content and low potentiality, at the same time, is also discussed in detail by Dembicki (2009).

The values of HI and S2/S3 ratio are used as a suitable parameter to determine the type of hydrocarbon, which can be generated by any source rock. Peters (1986) mentioned that if the value of HI and S2/S3 ratio is between 0-150, and 0-3, respectively, the source rock is only capable for gas generation. By comparing the values of the examined samples of Sarmord Formation (Table 1), it is noticed that the samples have the only potential for gas generation. The values of TOC are roughly equal to the residual part (RC) in the tested samples (Table 1, Fig. 9), that is why the pyrolysable part (PC) of TOC is very low.

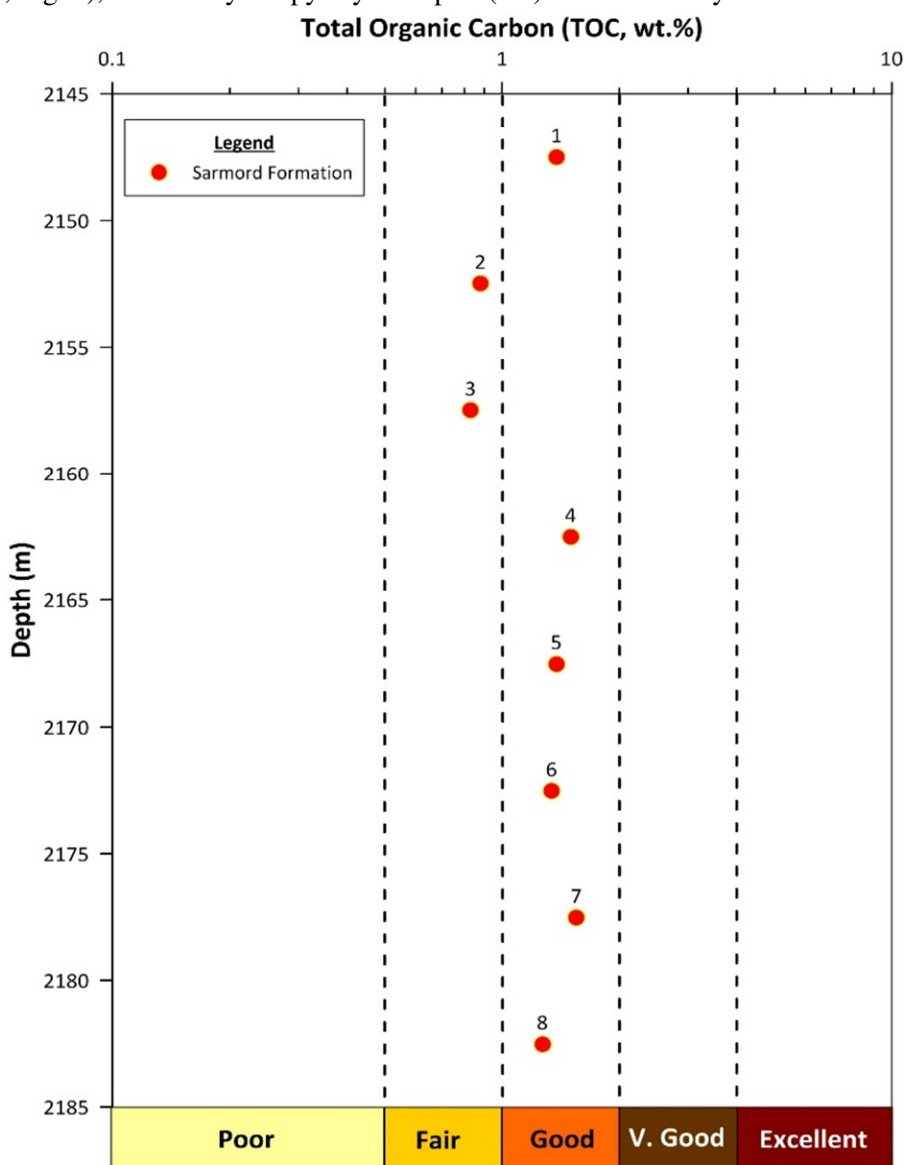


Fig. 6: Distribution of TOC (wt.%) content vs. Depth for analyzed samples of Sarmord Formation.

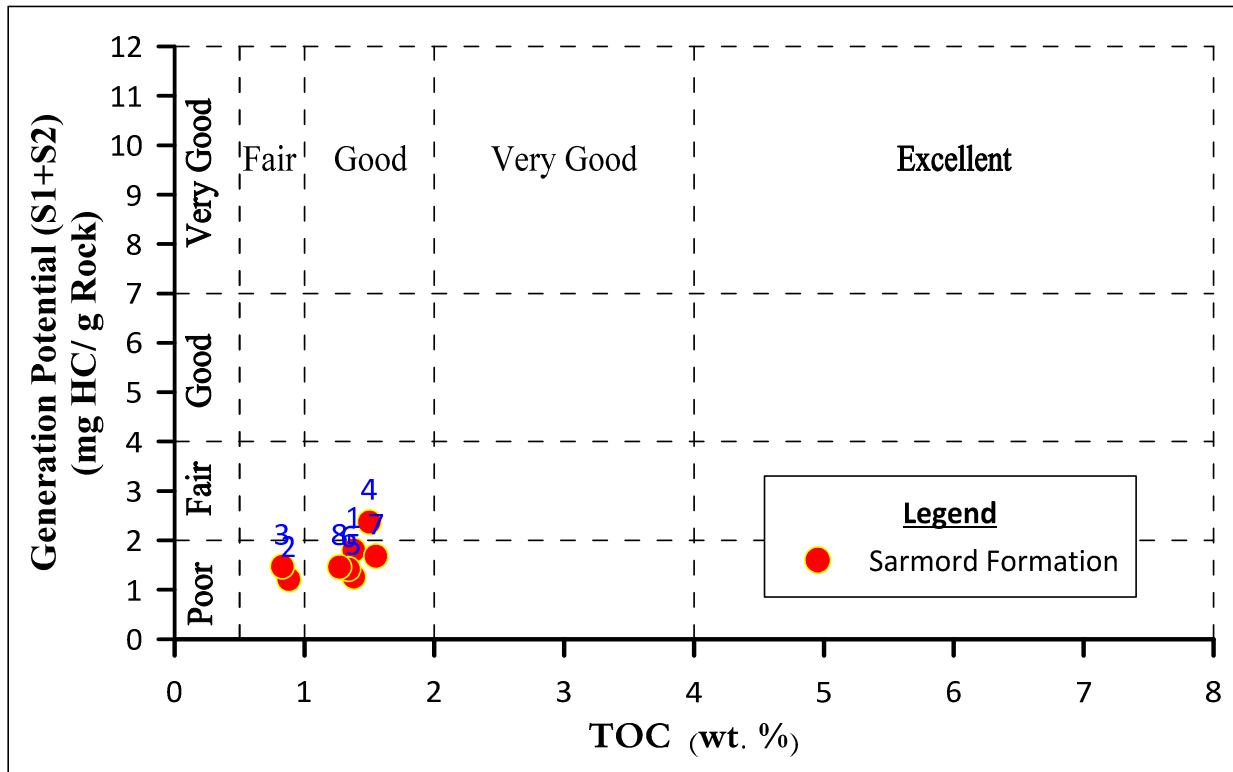


Fig. 7: Cross plot of TOC (wt.%) content vs. Generation Potential (S1+S2) (mg HC/g rock) for analyzed samples of Sarmord Formation (after Alaug et al., 2013).

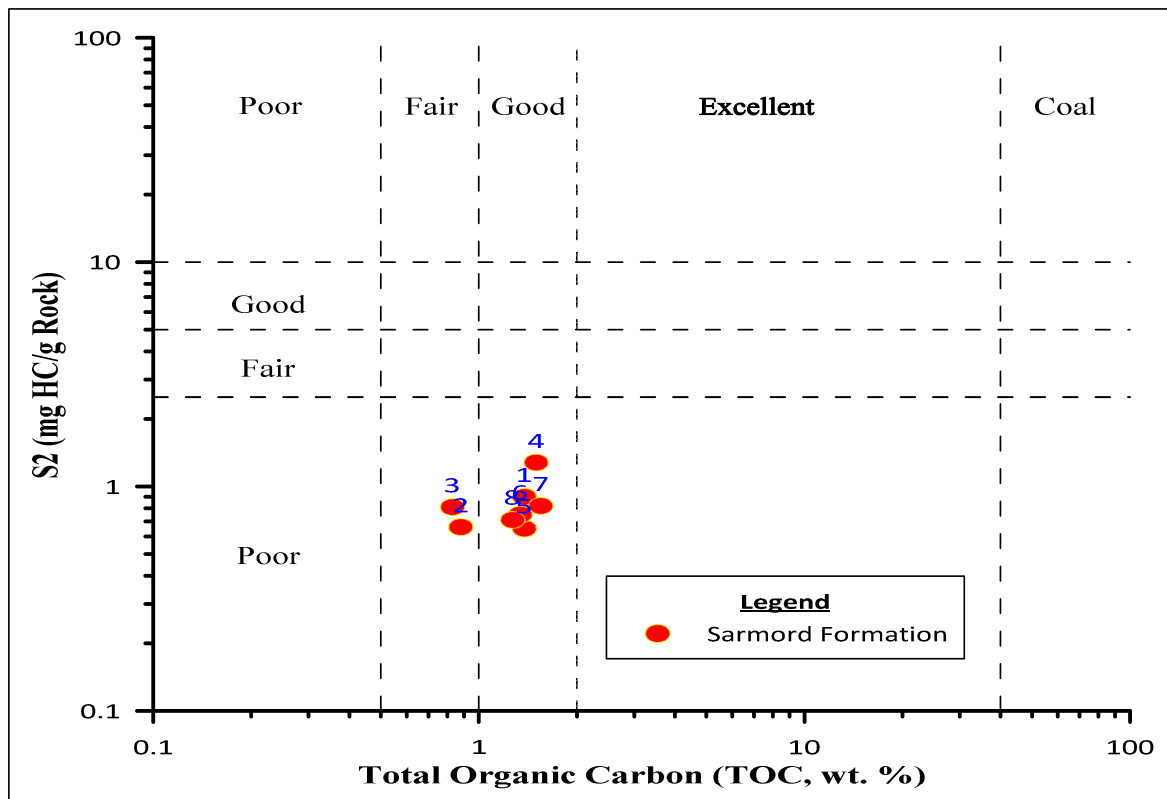


Fig. 8: Cross plot of Total Organic Carbon (TOC, wt.%) vs. S2 (mg HC/g Rock) for analyzed samples of Sarmord Formation (Dembicki, 2009).

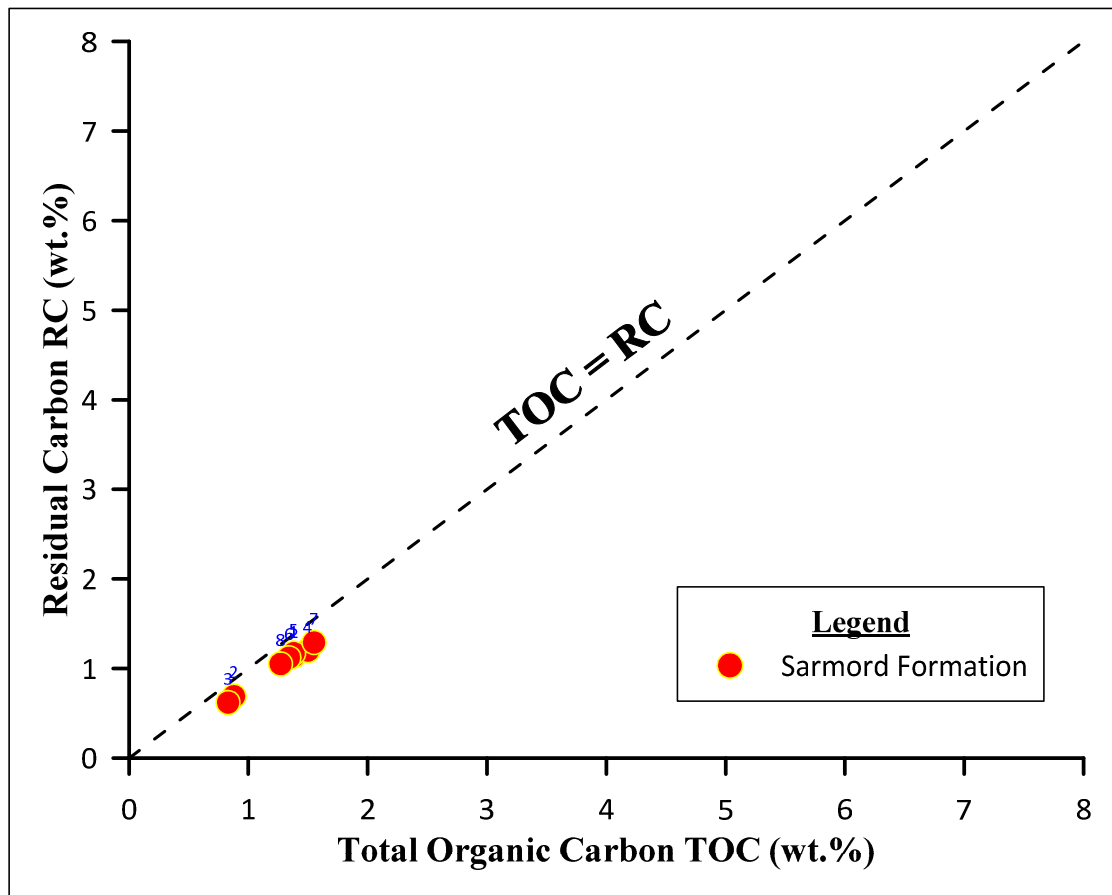


Fig. 9: Cross plot of TOC (wt.%) content vs. RC (wt.%) for analyzed samples of Sarmord Formation (Dembicki, 2009).

4.1.2. Kerogen type

As a routine of Rock-Eval data interpretation, the kerogen type has been determined based on the OI versus HI diagram (Figs. 10, 11). It is observed that nearly all samples have values of HI above 50 mg HC/g TOC and below 100 mg HC/g TOC (Table 1), indicating Type III kerogen (Figs. 10, 11) (except sample #5, with HI=47 that indicates Type IV kerogen). The values of OI display relatively great variability, from the low value of OI (sample #1, OI= 163 mg CO₂/g TOC) to high value (sample #3, OI= 264 mg CO₂/g TOC), but there is no clear indication for any oxidation trend regarding to their lithology and depth. Oxygen index (OI) and Hydrogen index (HI) are not only related to kerogen type, but also kerogen quantity (Peters, 1986). In case of OI, the high value of OI in samples #2, and #3 (Table 1) might be related to the low values of TOC, and S1 for the samples (Fig. 10).

By plotting the examined samples on the diagram between TOC (wt. %) and S2 (mg CO₂/g TOC) the same results are obtained concerning kerogen type (Kerogen Type III) (Fig. 12).

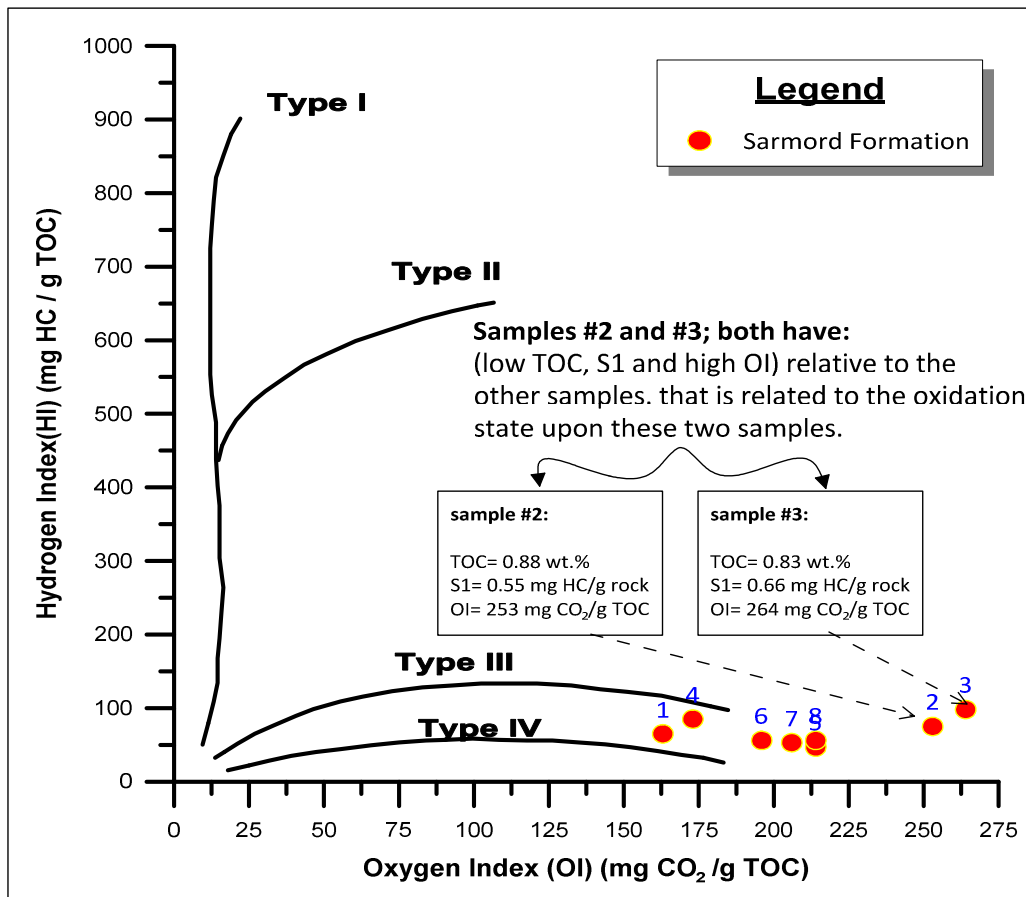


Fig. 10: Projection of analyzed samples of Sarmord Formation on pseudo van Krevelen diagram (Hunt, 1996). Look the text on the figure for more detail about the reason for high OI for samples #2 and #3.

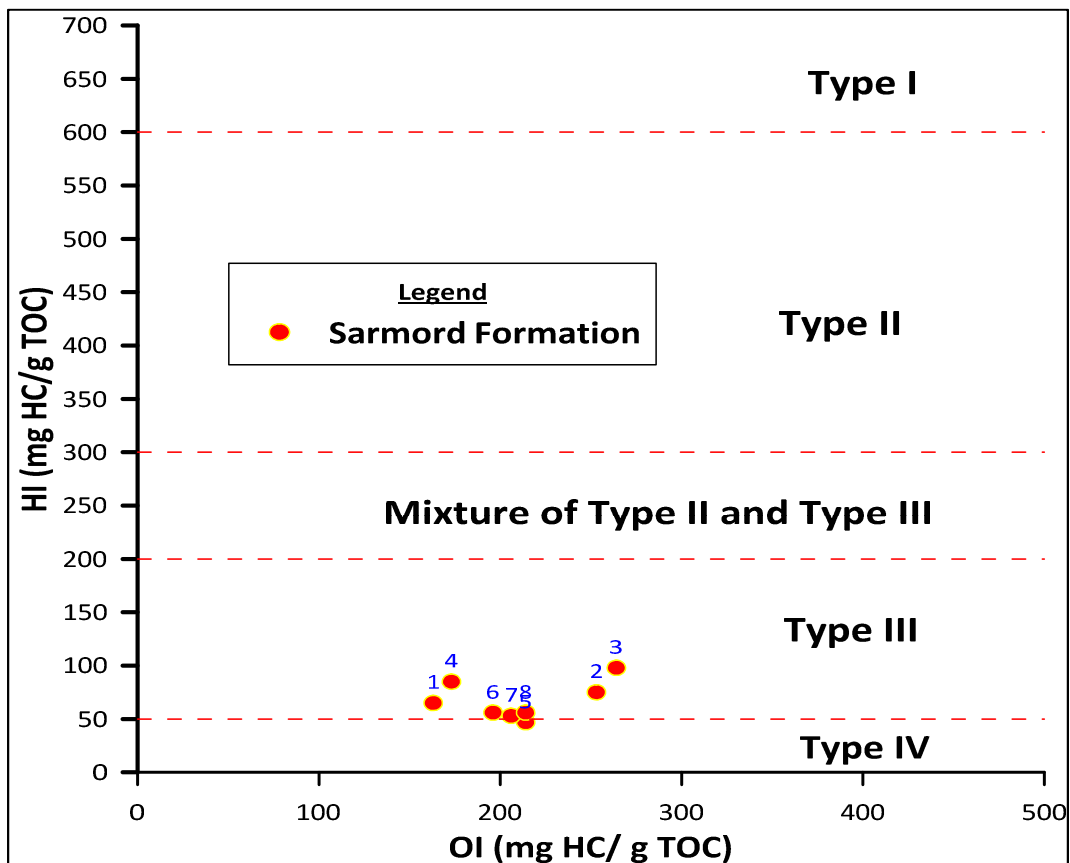


Fig. 11: Relation between oxygen index (OI) and hydrogen index (HI) for samples of Sarmord Formation (after Abdula, 2017).

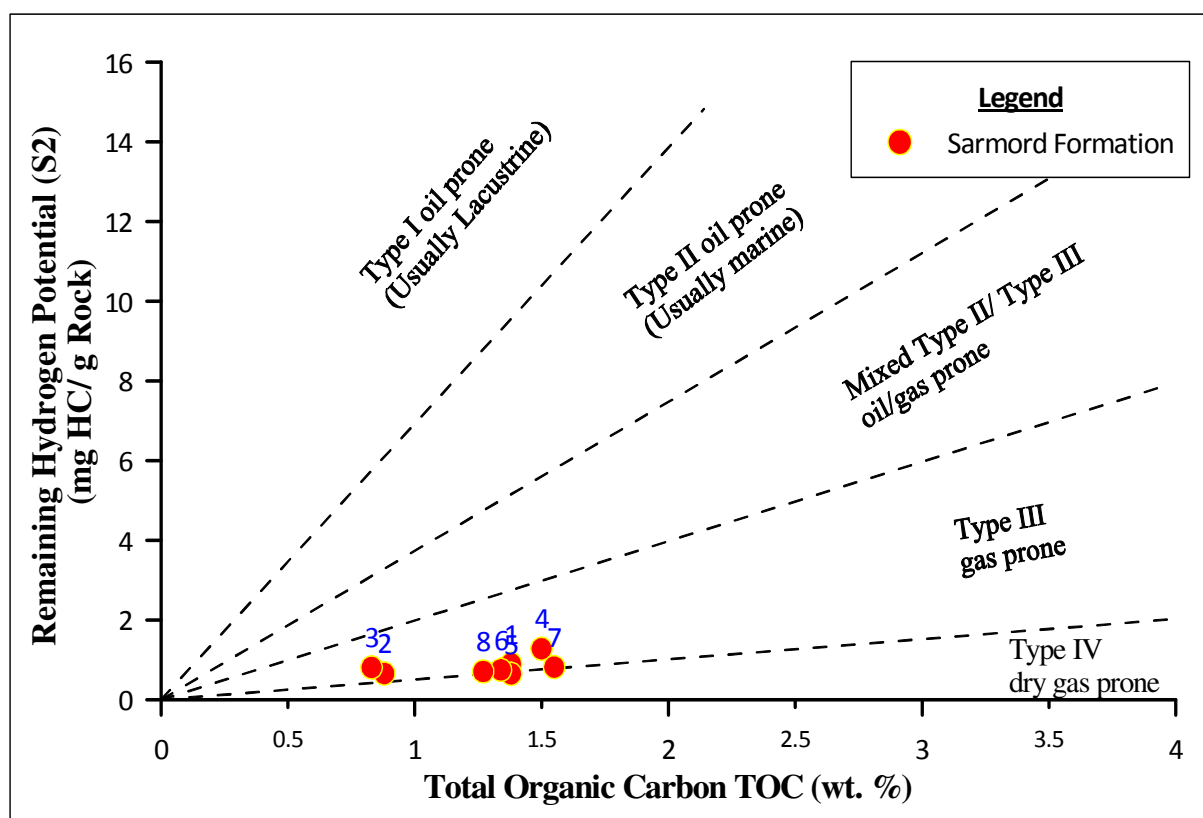


Fig. 12: Relation between remaining hydrogen potential (S2) (mg HC/g Rock) versus TOC (wt.%) (Akinlua et al., 2005), for tested samples of Sarmord Formation.

4.1.3. Thermal maturity of organic matter

In this study, the maturity assessment based on the values of T_{max} and PI are restricted, because the mentioned parameters are not fulfilling the reasonable conditions that are mentioned in table 2. Therefore, to determine the maturity level of Sarmord Formation, we focused on other techniques such as vitrinite reflectance measurement and Infrared spectroscopy.

4.2. Organic Petrographical Features

In terms of maceral and other organic particles, samples contain mostly bituminite in the "schlieren" form (Kus et al., 2017) which is disseminated predominantly within the clayey particles; additionally alginite has been observed, although rarely, as well as macerals of humic origin (i.e. macerals of the huminite group), the latter is quite weathered and degraded and are regarded as contamination from drilling mud. Furthermore, in most of the samples, microgranular solid bitumens are frequent with the homogenous solid bitumens occurring subordinately. Solid hydrocarbons are mainly associated with the clay-rich particles and less with the carbonates-rich particles (Fig. 13). It is noteworthy also to mention that pyrite is a common mineral being regularly associated with the organic particles.

A thorough determination of the reflectance values of various organic particles revealed the following distribution (of average values in each sample): bituminite 0.18-0.19%, huminite 0.38-0.43%, microgranular solid bitumens 0.22-0.25%, homogenous solid bitumens 0.53-0.67% (Table 3). Among these particles the ones that correspond closely to the maturation of the samples are the homogenous solid bitumens (Table 3) (Jacob, 1989), since the huminites are most probably originating from the drilling mud. By applying the Jacob (1989) equation to the homogenous solid bitumens, the equivalent vitrinite reflectance for the studied section ranges between 0.73-0.81%, with the values close to 0.80% being more accurate as were measured in smooth surfaces. The obtained values indicate maturation is within the oil window.

Table 3: Reflectance values (R%) in various organic particles of Sarmord Formation.

| Sample No. | Bituminite R% | Hum. Contamination | Microgranular SB R% | Homogenous SB R% | Eq. V. McSB | Eq. V. HSB |
|------------|---------------|--------------------|---------------------|------------------|-------------|-------------|
| 1 | 0.18 | 0.38 | 0.22 | 0.55 | 0.54 | 0.74 |
| 5 | 0.19 | 0.43 | 0.24 | 0.65 | 0.55 | 0.80 |
| 6 | 0.19 | 0.43 | 0.24 | 0.67 | 0.55 | 0.81 |
| 8 | 0.19 | 0.43 | 0.25 | 0.53 | 0.55 | 0.73 |

Abriviations; SB: Solid bitumen; Hum: Huminite; Eq.V.McSB: equivalent vitrinite of microgranular solid bitumen; EqV. HSB: equivalent vitrinite of homogenous solid bitumen.

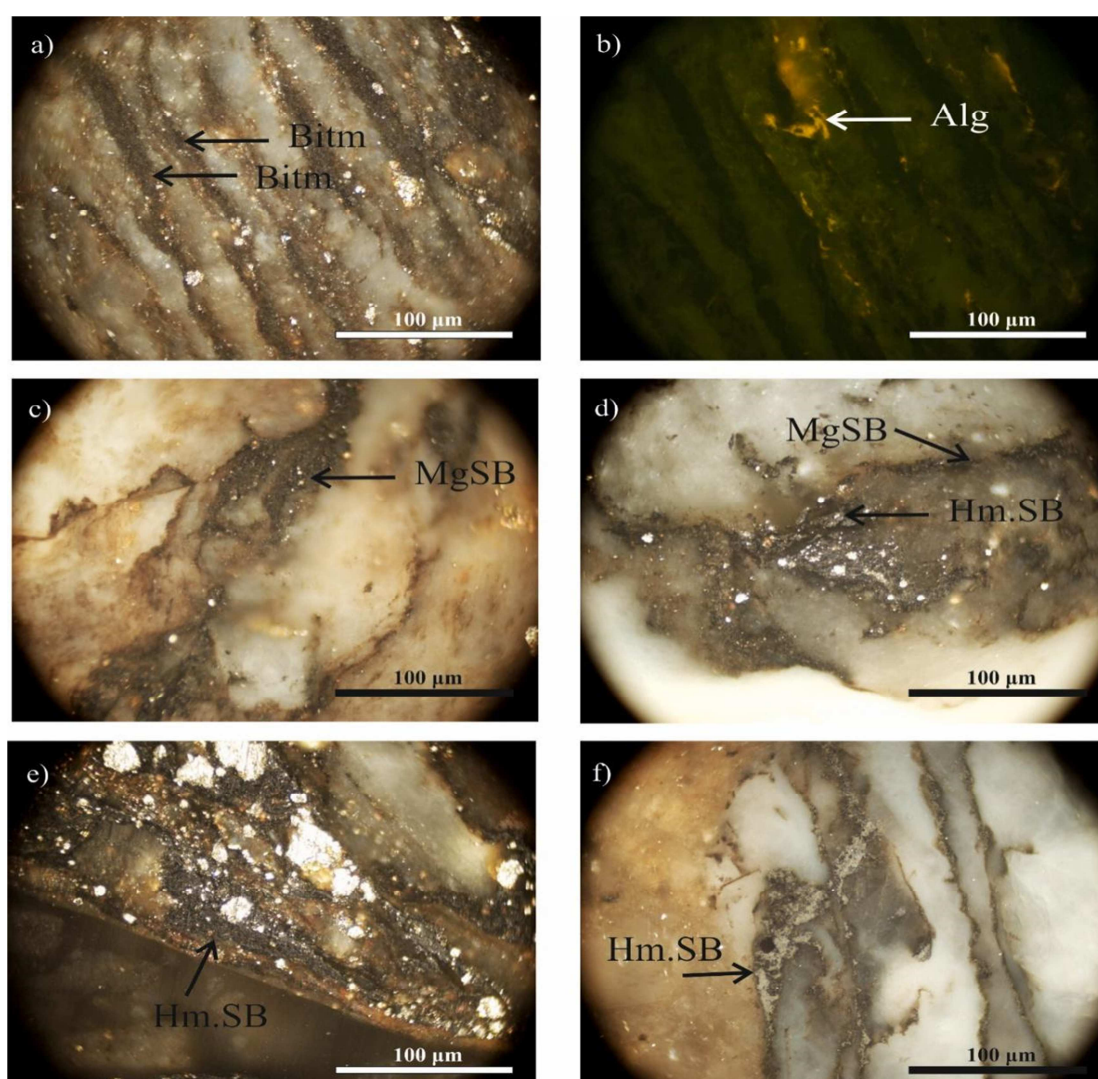


Fig. 13: Photomicrographs of the samples of the lower part of Sarmord Formation. Samples were taken under oil immersion objective, X500; a. b: under fluorescence mode c-f: under white reflected light and; Alg: alginite, Bitm: bituminite, MgSB: microgranular solid bitumen, HmSB: homogenous solid bitumen.

4.3. Infrared spectrometry

Infrared spectroscopy is one of the old techniques used in source rock assessment (Ganz and Kalkreuth, 1986; Thompson and Dembicki, 1986). This method is simple and of low cost, and also it can be used effectively for grouping source rock to oil-prone and/or gas-prone categories, but still is supported by data of Rock-Eval pyrolysis and/or kerogen microscopy (Ganz and Kalkreuth, 1986). The spectra of infrared displayed aliphatic group at 2860 cm^{-1} (CH_2), 2930 cm^{-1} (CH_3), and carboxyl and carbonyl group at 1710 cm^{-1} , while the aromatic compound ($\text{C}=\text{C}$) is detected at 1610 cm^{-1} . Kerogen type and maturation level can be interpreted through determining the change of the aliphatic peak and carboxyl/carbonyl peak relative to the aromatic peak (Ganz and Kalkreuth, 1986).

The infrared spectra for demineralized kerogen for all samples of Sarmord Formation are shown in figure 14. The shape of each spectrum is compared with those described by Thompson and Dembicki (1986) to determine kerogen type. The readings of Intensity (T %) for each peak have been calculated and tabulated in table 4, following the procedure and calculations defined by Ganz and Kalkreuth (1987). Furthermore, the samples are plotted on the C-factor *versus* A-factor diagram (Fig. 15) in order to determine kerogen type and state of thermal maturation.

The response of aliphatic and aromatic fractions are very small for samples #5, #6, #7, and #8. Thus, these samples are not discussed further, because they have low peak intensity, that prevent further measurement or calculations. While, the rest of the samples (samples #1, #2, #3, and #4) are used for further evaluation. Based on Thompson and Dembicki, (1986), all samples belong to type B and C, which are considered as gas-prone kerogen type. The plotted samples on diagram of C-factor *versus* A-factor show that the Sarmord samples are more close to the evolution path Type III kerogen (Fig. 15). Therefore, it is considered as Type III kerogen.

Regarding the thermal maturity, the examined samples are between 0.80 to 1.10 of virinite reflectance equivalent grid (Fig. 15). Thus, the state of thermal maturation for Sarmord Formation is considered above the oil window.

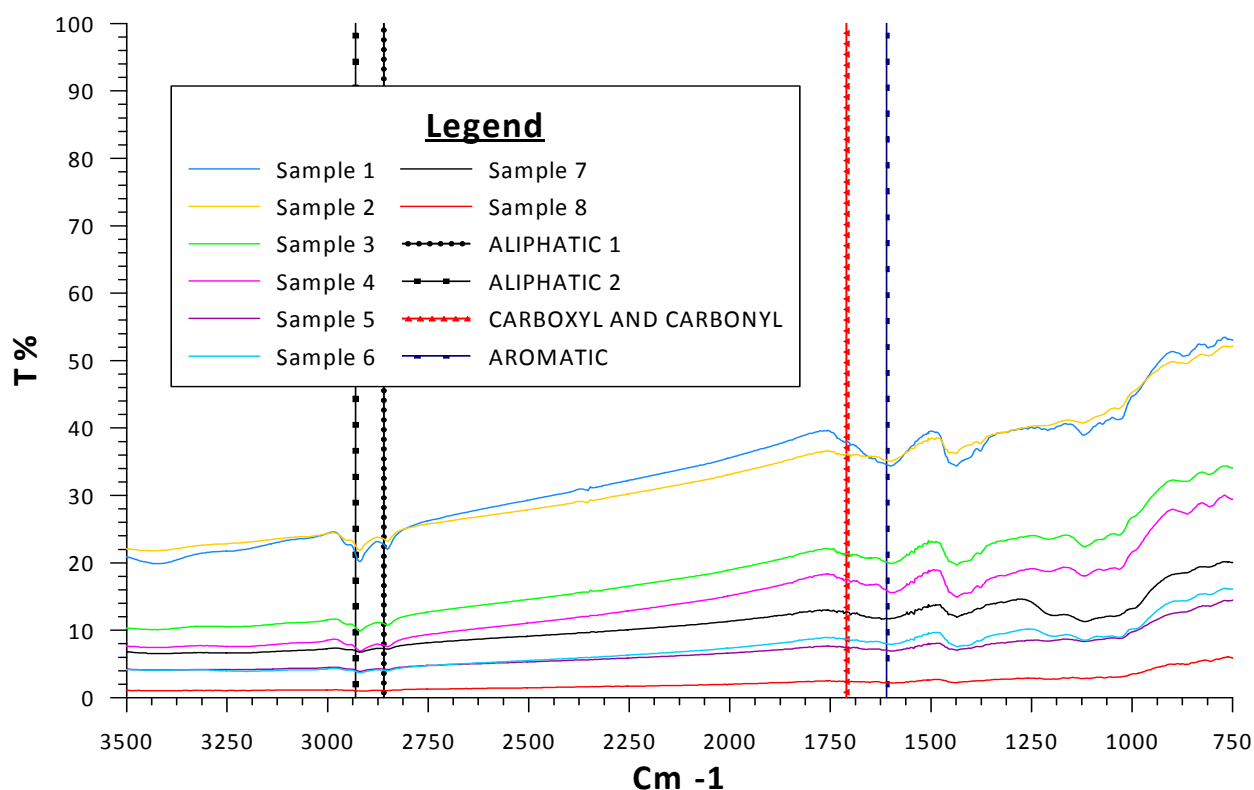


Fig. 14: The Infrared spectra for the studied samples of Sarmord Formation. The position of aliphatic, carboxyl and carbonyl group, and aromatic are shown on the diagram (look electronic version for color coded legend).

Table 4: The result of analysed samples by Infrared spectra. The samples #5, #6, #7, and #8 do not have the sufficient peak for reading. The rest samples are suitable.

| Sample number | Aliphatic at 2930 cm^{-1} | Aliphatic at 2860 cm^{-1} | carboxyl and carbonyl group at 1710 cm^{-1} | Aromatic group at 1630 cm^{-1} | C- factor (1710)/(1710+1630) | A-factor (2930+2860)/(2930+2860+1630) |
|---------------|------------------------------------|------------------------------------|--|---|------------------------------|---------------------------------------|
| 1 | 2.2 | 3 | 1.8 | 5 | 0.26 | 0.51 |
| 2 | 1.7 | 1 | 1 | 2.7 | 0.27 | 0.50 |
| 3 | 2 | 1.3 | 1.2 | 3 | 0.29 | 0.52 |
| 4 | 1.7 | 1.2 | 1.4 | 3.1 | 0.31 | 0.48 |
| 5 | NA | NA | NA | NA | NA | NA |
| 6 | NA | NA | NA | NA | NA | NA |
| 7 | NA | NA | NA | NA | NA | NA |
| 8 | NA | NA | NA | NA | NA | NA |

NA: not available.

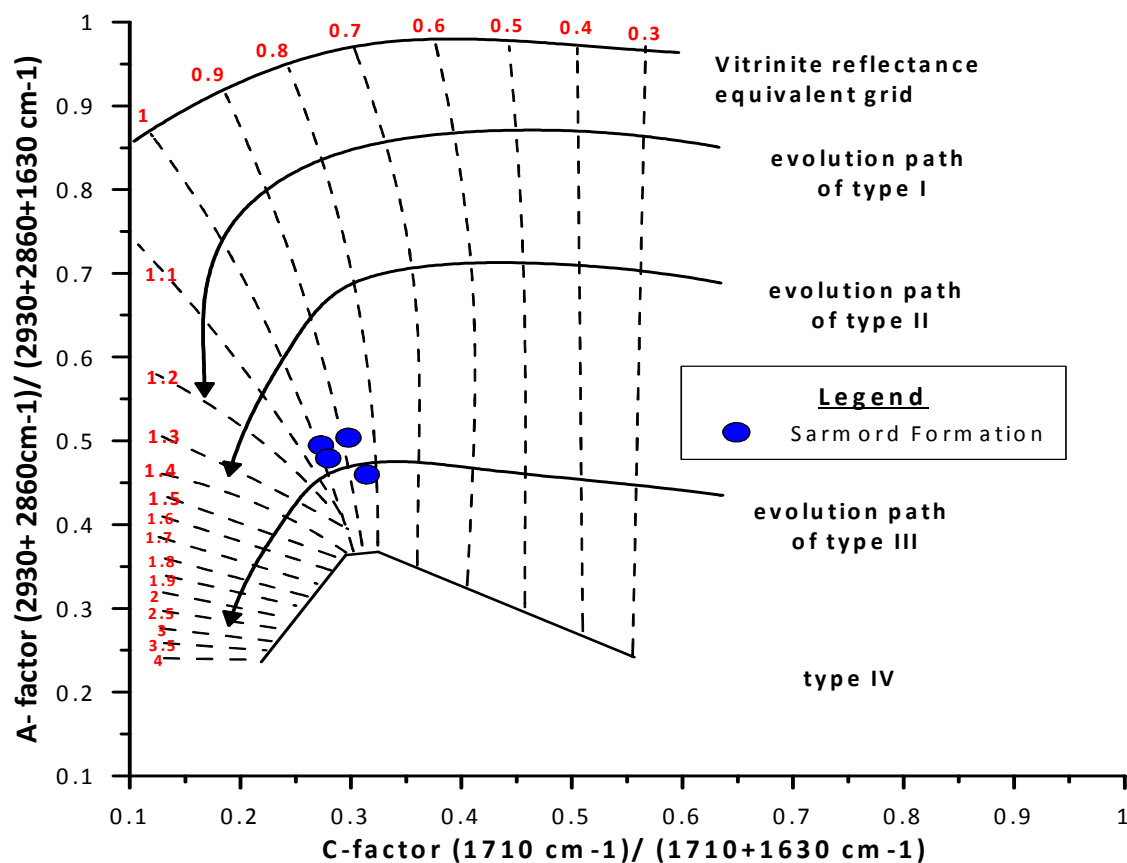


Fig. 15: The result of Infrared spectra for the studied samples of Sarmord Formation as plotted on the A-Factor versus C-factor diagram (Ganz et al., 1987).

4.4. Connecting Rock-Eval data to the petrographical and spectroscopical analysis

Before concluding about: (i) the quantity, quality of organic matter, (ii) hydrocarbon potentiality, and (iii) state of thermal maturation, it is very important to co-evaluate and link all the data that were obtained from the above presented techniques (Rock-Eval pyrolysis, optical microscopy, infrared spectroscopy) in order to get a comprehensive view. The following points can be considered:

- The analysed samples of lower part of the Sarmord Formation contain enough amount of TOC to be classified as a good source rock, but with low potentiality (section 4.1.1). The TOC content of the samples are resembling the residual carbon (RC), (TOC roughly equal to RC) meaning that the majority of organic matter lost its ability to generate hydrocarbon. For petroleum to be formed, it is necessary to have enough hydrogen content accompanied with carbon. In Sarmord Formation, the hydrogen content of the tested samples are very low, that is why we got a low amount of HI (and this is reflected in low values of HI). The major organic matter in the samples is solid bitumens, which indicates that the expulsion of hydrocarbon is already took place. This situation (expulsion) leads to the decreasing potentiality and increasing residual part (RC) of organic matter.
- The graphical presentation of Rock-Eval data and Infrared spectroscopy assigned as Type III kerogen of the studied samples; however, apart of the huminite macerals that denote contamination, the Type III kerogen assignment refers more to the solid bitumens than to the existence of any terrigenous originated vitrinite.
- The huminite particles are observed under the microscope. They have low reflectance and are belonging to mud additives (contamination). These particles are leading to a slight increase of the real TOC values, but can also have an impact on the unreliable T_{max} values (forming double loob of S_2 peak).
- The occurrence of bituminite and almost lack of any vitrinite and inertinite macerals provide indications that the depositional environment was a marine setting.
- Maturation assessment based on petrographical technique is roughly consistent with the results of infrared spectroscopy (mature with oil window); however, the infrared microscopy of the tested samples exhibit a bit higher maturation, probably attributed to the minor pyrobitumens that occur in the samples.

5. Conclusions

The examined samples of the lower part of Sarmord Formation from M-2 Well contain a satisfiable amount of TOC content, but the organic matter is not considered as an effective source rock, because it contains less amount of potential hydrocarbon content. The samples contain additives of drilling mud, with low reflectance values, which caused unreliable readings of T_{max} . The organic matter is represented mostly by solid bitumens, which are residual products of hydrocarbons expulsion *insitu* and/or migrated. Type II kerogen is the predominant kerogen type, which is considered as oil-prone kerogen type, but the kerogen lost nearly all its potentiality to generate hydrocarbon. The vitrinite equivalent reflectance for the studied samples ranges between 0.73 and 0.81%, indicated oil window and slightly above oil window, pointing to mature to early post mature.

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