



Biomarker characteristics of oils from Garmian Oil Fields and potential Jurassic source rocks, Kurdistan, NE Iraq: implications for oil-oil and oil-source rocks correlation

Diyar A. Saeed¹ and Ibrahim M.J. Mohialdeen¹

¹ Kurdistan Institution for Strategic Study and Scientific Research

¹ Department of Geology, School of Science, University of Sulaimani, Kurdistan

E-mail: ibrahim.jaza@univsul.edu.iq

Article info

Original: 11.07.2015
Revised: 02.11.2015
Accepted: 12.11.2015
Published online:
20.06.2016

Key Words:

*Kurdistan
Garmian
Sangaw
Sargelu
oil-source correlation
Biomarkers*

Abstract

The Middle Jurassic Sargelu Formation in Sangaw North -1 (SwN-1) borehole, Sangaw North Block, Garmian area, Kurdistan region, was used for geochemical analyses. Two crude oils from PLK-8 and Sarqala-1 wells in Pulkhana and Sarqala oil fields, one condensate from KM-3 well in Kor Mor gas field and seepage oil from ChiaSurkh oil field were chosen for organic geochemistry investigation, oil-oil and oil-source rocks correlation. Tectonically, the study area is located in the southeastern part of the Foothill Zone in Zagros Fold Belt.

The biomarkers ratios and molecular compound distributions showed that the oils, condensate and rock extracted sample of Sargelu Formation were derived from marine carbonate source rocks bearing marine algae and kerogen type II that deposited under reducing condition. Low presence of gammacerane indicated normal salinity condition during the depositions. The GC-FID traces of oils and condensate showed lack of any remarkable biodegradation, but rock-extracted of Sargelu Formations is strongly contaminated by polyethylene glycol according to the GC-FID chromatogram. Compositional similarity of sterane, hopane, isoperoid and n-alkane compounds among the crude oils and crude oils with extracted sample of Sargelu Formation suggested that the oils might be sourced from the same or similar source rocks that deposited under similar conditions. On the other hand, Sargelu Formation is supposed to be one of the sources of the generated crude oils. However, the maturity-related parameters showed no similarity between the crude oils and extracted sample of Sargelu Formation.

Introduction

The Kurdistan region of Iraq attracted many oil and gas companies for exploration and production of hydrocarbons (oil and gas). Currently, Kurdistan has been divided into many blocks or areas and most of them are under the exploration process. Recently, many boreholes drilled throughout the region, which are not studied in detail yet.

Oil fields in Northern Iraq are tectonically located in the Zagros Fold Belt and mainly within the Folded Zone extending between northeastern Thrust Zone and Khlesia uplift toward Mesopotamian Basin in the

southwest. The northeastern part of the Arabian plate including Kurdistan region was covered by dysoxic to anoxic environmental deposition condition during the Jurassic period that allowed preservation of high organic matter and development of the highest world oil and gas reserves (Murriss, 1980; Beydoun, 1998; Pitman et al., 2004; Al-Ameri and Zumberge, 2012; Mohialdeen et al., 2013; Abdula, 2015; Abdula et al., 2015; Hakimi et al., 2015). The rock units of this period are considered as generative hydrocarbon rock units by means of both optical and chemical methods in north Iraq (Mohialdeen, 2008; Al-Ahmad and Al-Gibouri, 2011; Al-Ameri et al., 2013).

The purpose of this study is to evaluate the biomarker characteristics of different oil types from Garmian oil fields and bitumen extracted from Sargelu Formation (Middle Jurassic) in SwN-1 well, in addition to applying oil-oil and oil-source rocks correlation of the selected oil fields.

Gologic Setting

A regional stratigraphic column of Early-Middle Jurassic period of Sangaw North-1 well (Figure-1) shows the presence of thick Jurassic sequence comprising of carbonates, shales and anhydrites beds. Lower Jurassic successions (Alan, Mus, Adaiyah and Butma formations) were deposited along the central Iraq and Foothill Zone within carbonate-evaporite inner shelf under lagoonal evaporitic condition (Jassim and Buday, 2006a).

The area of the present study is locating in Garmian area, Kurdistan region, North East of Iraq (Figure-2). It is bordered from the north by Sulaimani governorate, from the south by Diyala governorate, Hamrin structure located at the western side and the eastern part represented by Iranian border. Depending on tectonic subdivision of Iraq, the study area is located in the Low Folded Zone of Zagros Fold Belt. The Low Folded Zone is characterized by the deepest Precambrian basement. Buday and Jassim (1987) subdivided this zone into two longitudinal units, the Makhul-Hamrin subzone in the southwestern part and Butma-Chamchamal subzone in the northeastern side.

The Butma-Chamchamal subzone that included the SN-1 well is characterized by structurally highest part of the zone with lesser subsiding unit where the total thickness of Mesozoic-Tertiary sequence is in average 1-1.5km less than the Hamrin-Makhul subzone (Buday and Jassim, 1987). The Hamrin-Makhul subzone included other selected oil fields (Sarqala, Pulkhana, KorMor and Chia Surkh field). This unit was forming the deepest part of the Foothill Zone (ibid).

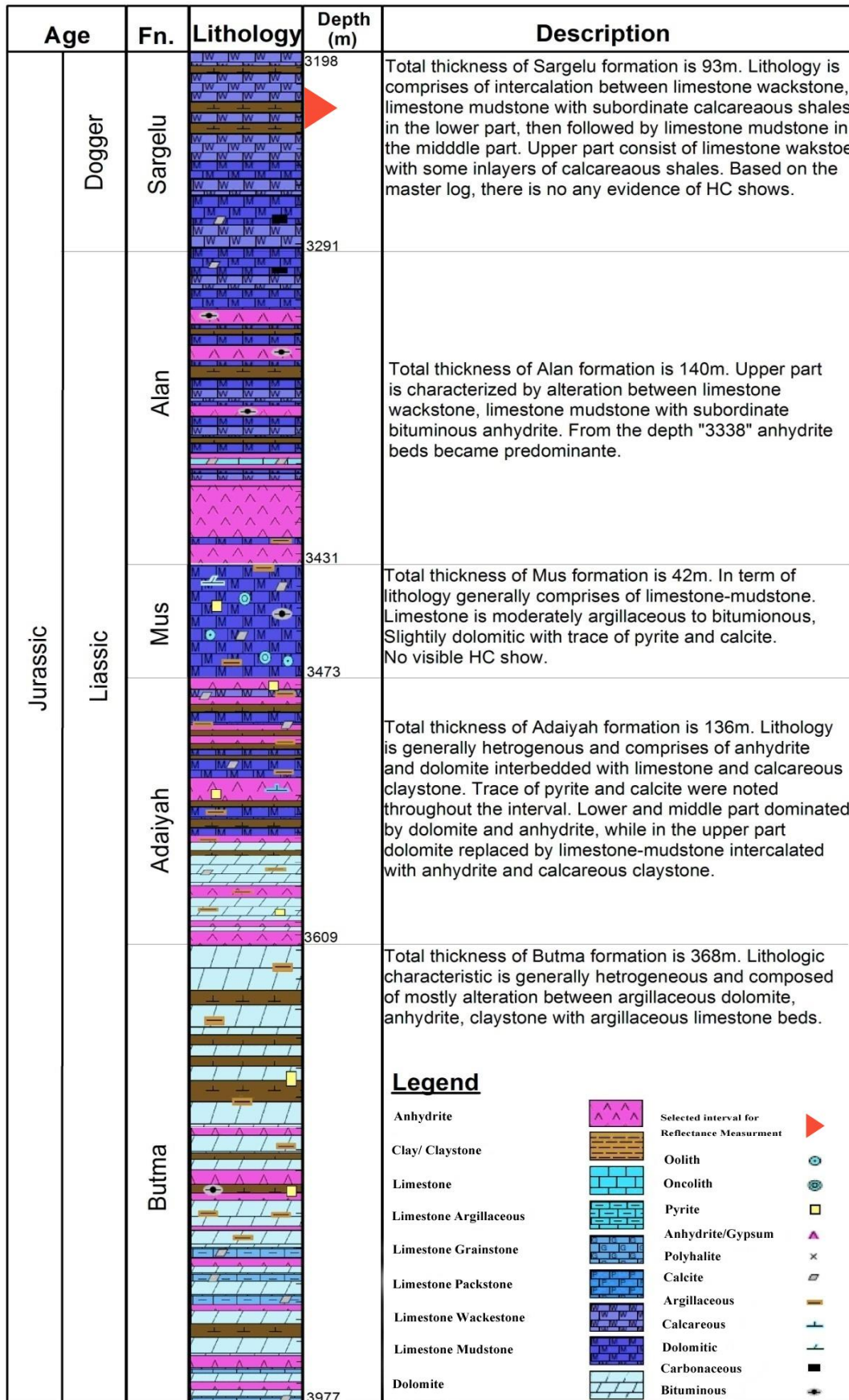


Figure-1: Stratigraphic column of Lower-Middle Jurassic succession in SwN-1 well. (Adapted from Well site Lithology of SwN-1 well).

Oil Fields in Garmian Area

Five oil fields were selected from the southeastern part of the Foothill Zone of Zagros Fold Belt (Figure-3). Two of the wells, SwN-1 and Sarqala-1, were drilled after 2005 and no studies were published on them.

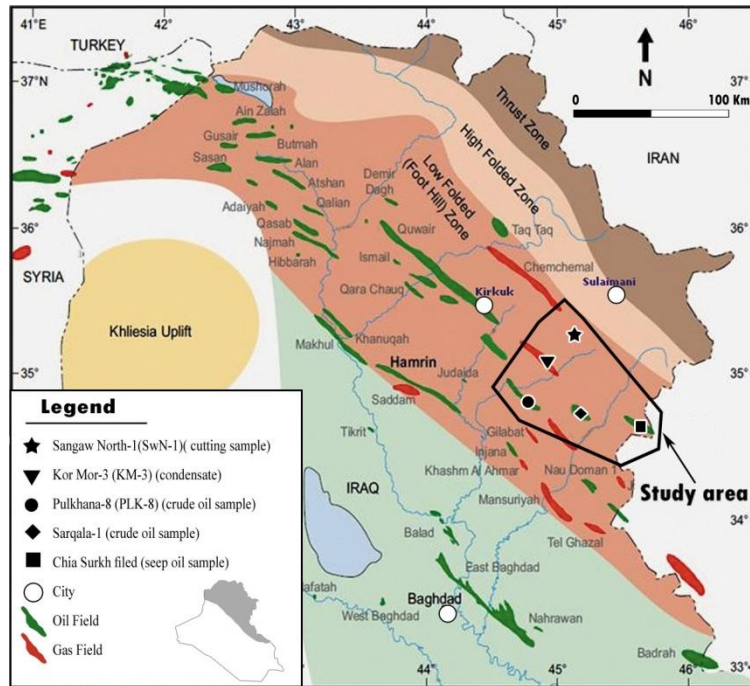


Figure-2: Location of the study area on tectonic map of north and northeastern parts of Iraq (Modified from Al-Qayim et al., 2010).

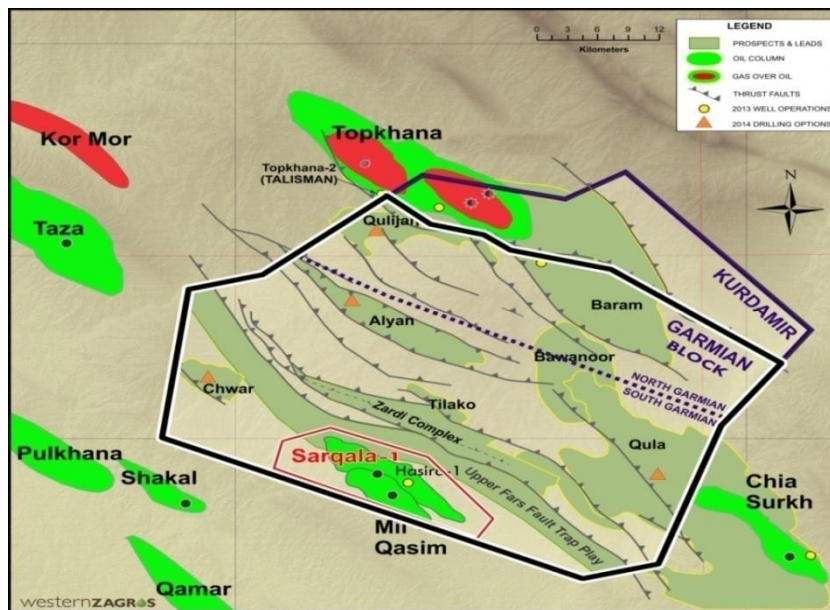


Figure-3: Structural map shows the location of Garmian Block in Garmian area, including Sarqala-1 well. (Cited from the Website of Western Zagros Oil Company).

Sargelu Formation

The Sargelu Formation was first described by Witzel in 1948, in Surdash anticline, Northeast Iraq. Depositional condition of Sargelu Formations was presumed by Bellen et al. (1959) as anoxic condition. Murriss (1980) considered Middle Jurassic as a period where major source rocks deposited under euxinic condition and became a source for generated hydrocarbon in the Middle East.

The Sargelu Formation according to Sharland et al. (2001) and Jassim and Buday (2006a) is a part of AP6 and AP7 Megasequences. The Middle Jurassic sequence (Sargelu Formation) is belong to (Middle-Late Jurassic) Megasequence AP7 (Jassim and Buday, 2006 c). Buday (1980) subdivided the stratigraphic units of Iraq into cycles in accordance with the main stages of the paleogeographic development of the areas. Early-Middle Jurassic sub stage belonged to the Upper Triassic-Middle Jurassic cycle. The paleogeographic and paleofacies development during the Early-Middle Jurassic period starts with a water transgression over the Stable Shelf. During Early Jurassic (Liassic) period the whole basins were filled by evaporitics facies with decreasing evaporate contribution to the northeast direction.

In the type section, the total thickness of Sargelu Formation is 115 m, composed of thin-bedded, black, bituminous limestones, dolomitic limestones and black papery shales, with stripe of thin black chert in the upper parts and similar lithology occurs in most outcrops (Balaky, 2004; Aqrawi et al., 2010; Abdula et al., 2015). Both contacts of the formation are conformable and gradational in type locality area. Upper contact with Naokelekan Formation and the underlying Formation is Sehkaniyan, (Bellen et al., 1959; Balaky, 2004). In the subsurface section, the lower boundary indicated with the last appearance of anhydrite bed at the top of Alan Formation (Jassim and Buday, 2006 c). This Formation has been deposited in distal, suboxic to anoxic basin (Al-Ameri et al., 2013) during Megasequence AP7 which is characterized by widespread transgression over the Iraqi territory during Middle Jurassic (Jassim and Buday, 2006 c).

The organic matter quality and quantity, hydrocarbon generation potentiality and thermal maturity of the Lower-Middle Jurassic formations that occurred in SwN-1 well were studied by Saeed et al. (2014) and Saeed (2015). They concluded that the maturities of Lower-Middle Jurassic formations in SwN-1 well are high (gas generation zone), ranged from 1.34%-2.10% based on Vitrinite Reflectance measurement.

Abdula et al. (2015) studied Sargelu Formation in north and northeast Iraq and the main outcomes of his research are the maturity of Sargelu mainly increases from west to the east direction, and Sargelu Formation mostly generates gas in the eastern part. Furthermore, based on biomarkers analysis, he discovered that Sargelu Formation has no any molecular contribution to the accumulated oil in Taq Taq oil field.

Fatah (2015) studied the formation in Miran Oil Field, close to Sulaimani City, from organic geochemical points of view. He concluded that the main kerogen type in Sargelu Formation is a mixed type II/III kerogen, and is thermally post mature and in the gas generation zone. The main expelled hydrocarbon at the present time is only gas, which means that the ability of Sargelu Formation in the SwN-1 well remains only for gas generation.

Samples and Methodology

Two groups of samples are used to accomplish the targets of the present research. The first Group, composed of four liquid samples, two crude oils is taken from Tertiary reservoirs through PLK-8 well in Pulkhana oil field and Sarqala-1 well in Sarqala oil field, one condensate sample from Tertiary reservoir is taken from Kor Mor-3 (KM-3) well in Kor Mor gas field and one oil seep sample taken from Chia Surkh oil field. All the liquid samples have been received from the concerning oil companies after getting permission from the Ministry of Natural Resources of KRG. The second type of samples is cuttings samples from the Sargelu Formation in SwN-1 well as also obtained from the stores of Ministry of Natural Resources of KRG.

The studied samples have been prepared by CSTJF center in France according to their procedures for GC-FID and GC-MS analysis. The GC-MS analysis was carried out with selected ion monitoring mode (SIM) in order to get information about the n-alkane and isoprenoids compounds and defining the distribution of most common biomarkers and the related compounds that are widely used to find out the maturities, sources of the oil samples and to establish a genetic relationship between the samples in order to categorize the oil families in the study area. For oil samples; the topping consists on evaporating an oil sample, in order to recover a C15+ fraction, by eliminating water, volatile hydrocarbons. The experimental conditions are the following: Water bath temperature: 50°C., Pressure: 20 mbars (Delta: ± 1 mbar)., Rotation speed: 100 trs/min. , and Evaporation time: 5 hours. For rock Samples; The Accelerated Solvent Extractor was used for extraction organic matter from rocks, the organic solvent used was dichloromethane. It allows evaluating the Extractable Organic Matter (EOM) (ratio between the extracted mass after ASE and the initial rock quantity). Second main step: Separation of Molten and Asphaltene; n-pentane is added in the C15+ fraction obtained in the first step (50 ml n-pentane per gram of fraction). The solution flask is placed in an ultra-sonic agitator. The solution is filtered (under vacuum, at ambient temperature) on a MILLIPORE filter (0.45 μ m, PTFE). The non-soluble compounds in n-pentane are retained on the filter (formation of a precipitate). They correspond to the asphaltene fraction. The asphaltenes are recovered by adding dichloromethane on the filter (dissolution of the precipitate). After evaporation of the solvent, the asphaltene fraction is weighed to provide its concentration (mass percent). The filtrate, soluble in n-pentane, corresponds to the molten fraction. It is recovered for ASPEC separation. Third main step: ASPEC preparation, the objective is to do a separation, both qualitatively and quantitatively, of the saturate and aromatic compounds, from the molten fraction recovered in pentane the second step. Before injecting 1 ml of the molten fraction in the ASPEC system, the fraction is concentrated by evaporation (objective: to obtain 3 ml of fraction for 100 mg sample (eq. sample containing asphaltenes)). The ASPEC preparation consists of: A first separation on a SPE column (retention of polar compounds). A second separation between the saturate and aromatic compounds on a chromatographic column. The collected fractions are concentrated by evaporation, before analyzing by GC-FID and GC-MS. The experimental conditions are the following: Mobile phase: n-pentane (first dried and filtered on a 0.22 μ m PTFE filter). Flow of mobile phase: 4 ml/min. Pressure: ~ 21 bars. SPE column: Lichroprep CN; 40-63 μ m, 60 Å. Inox LC Column: Lichrosorb SI; 250 x 10 mm; 5 μ m; 60 Å. Presenting the GC/MS method that have been used to analyze rock-extracted and oil samples by CSTJF center: Computerized gas chromatography/mass spectrometry (GC/MS) is utilized to evaluate biologically derived compounds in oils or rock extracts. The saturate fractions are injected into an *HP 6890* gas chromatograph coupled to an *HP 5973 PP* MSD in Selected ion monitoring (SIM) mode. GC/MS was equipped with a DB-5 column (60 m length, 250.0 μ m diameter, and 0.10 μ m film thickness). The samples are injected in split mode under constant pressure of carrier gas (Helium) flow at a rate of 35 cm/sec, at 70 eV ionization energy. The GC temperature program started at 40°C held isothermally for 6min, then heated at 2 °C/min to 300 °C (held 60 min).

Results and Discussion

Five samples consisting of rock-extracted sample from Sargelu Formation, two crude oils, condensate and seep oil that are selected from Sangaw North-1 well, Sarqala, Pulkhana, KorMor, and ChiaSurkh oil fields respectively, have been analyzed by GC and GC-MS. Concerning the selected rock extracted sample, it is realized that based on TOC wt% and Rock-Eval analysis for the cuttings samples (Saeed, 2015), the majority of rock samples do not include significant amount of organic matter as well as pyrolyzable hydrocarbon compounds S2. Accordingly, 100gm of rock-cuttings from the depth interval 3213m to 3237m of Sargelu Formation (Figure-1) is selected for characterizing its molecular distributions and performing correlations with the oil samples. The objective of selecting a large amount of the cuttings rock (100gm) is to obtain a proper amount of liquid extracted that is required for GC and GC-MS analysis.

In the present study, the GC-MS/SIM was used to monitor the ions with the mass/charge ratio (m/z) of 85, 191, and 217. Most of the peaks are indicated from their chromatograms and areas under the peaks have been used to account different parameters. In Figure-4, the m/z 85 of all the studied samples is presented with indicating the peaks of pristane and phytane.

From the mass chromatograms of m/z 191 it is possible to measure different parameters from the areas of tricyclics and pentacyclics compounds of the oil and rock extracted samples (Figure-5). Most of the peaks of the related tricyclics and pentacyclics compounds of the studied samples have been indicated by labels. The identification of peak labels that is used for calculating the parameters is submitted in Table-1. The mass chromatograms m/z 217 of sterane compounds (Figure-6) for the studied samples has been used to measure different parameters. (In Table-2, the identification of the peaks is summarized).

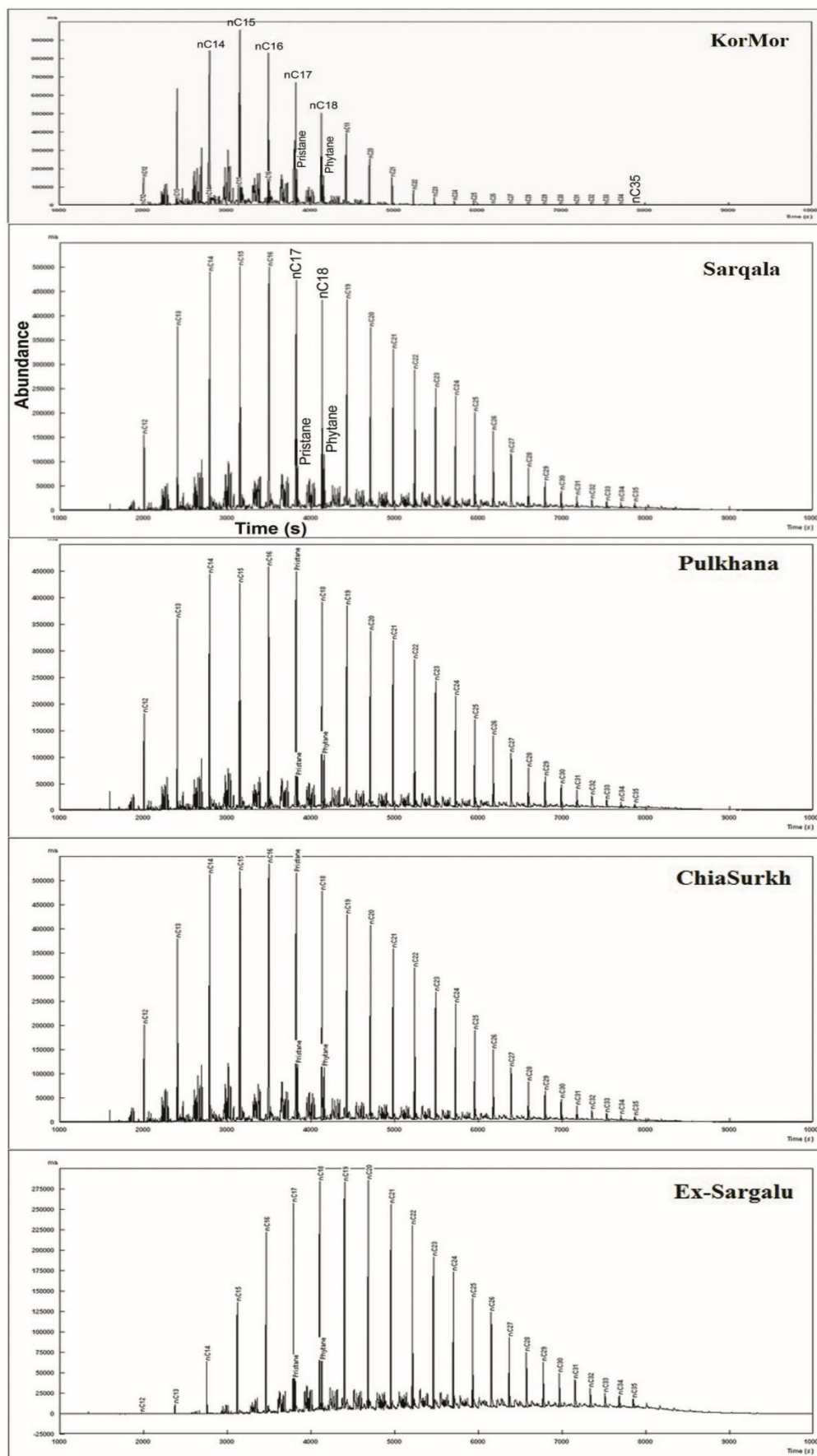


Figure-4: Mass chromatograms m/z 85 of the studied samples, including peaks of nC17, nC18, pristane and phytane and other n-alkanes compounds.

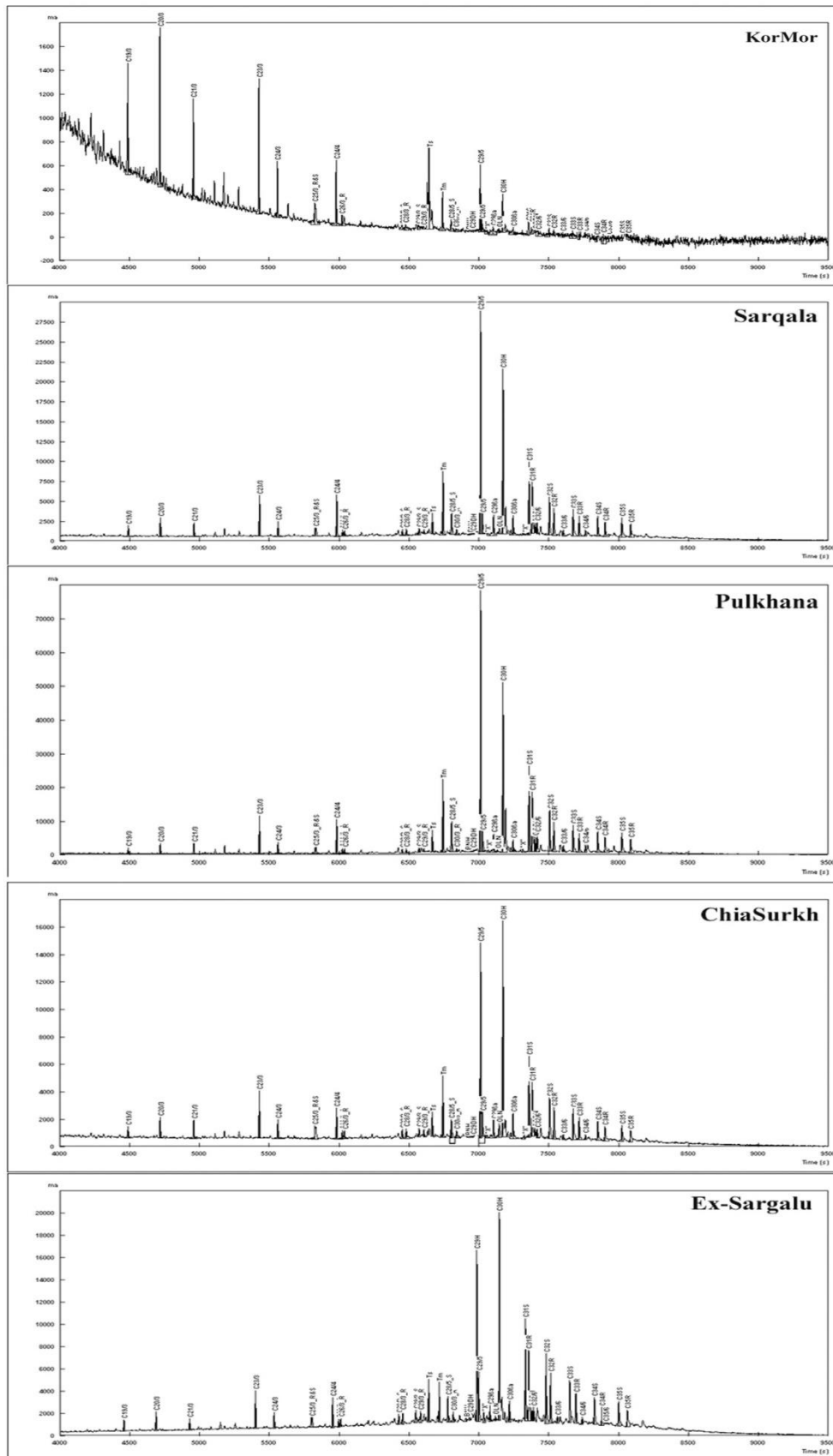


Figure-5: Mass chromatograms (SIM/GCMS Mode) for hopanes, m/z 191, of the studied samples. (Peaks identification in Table 1)

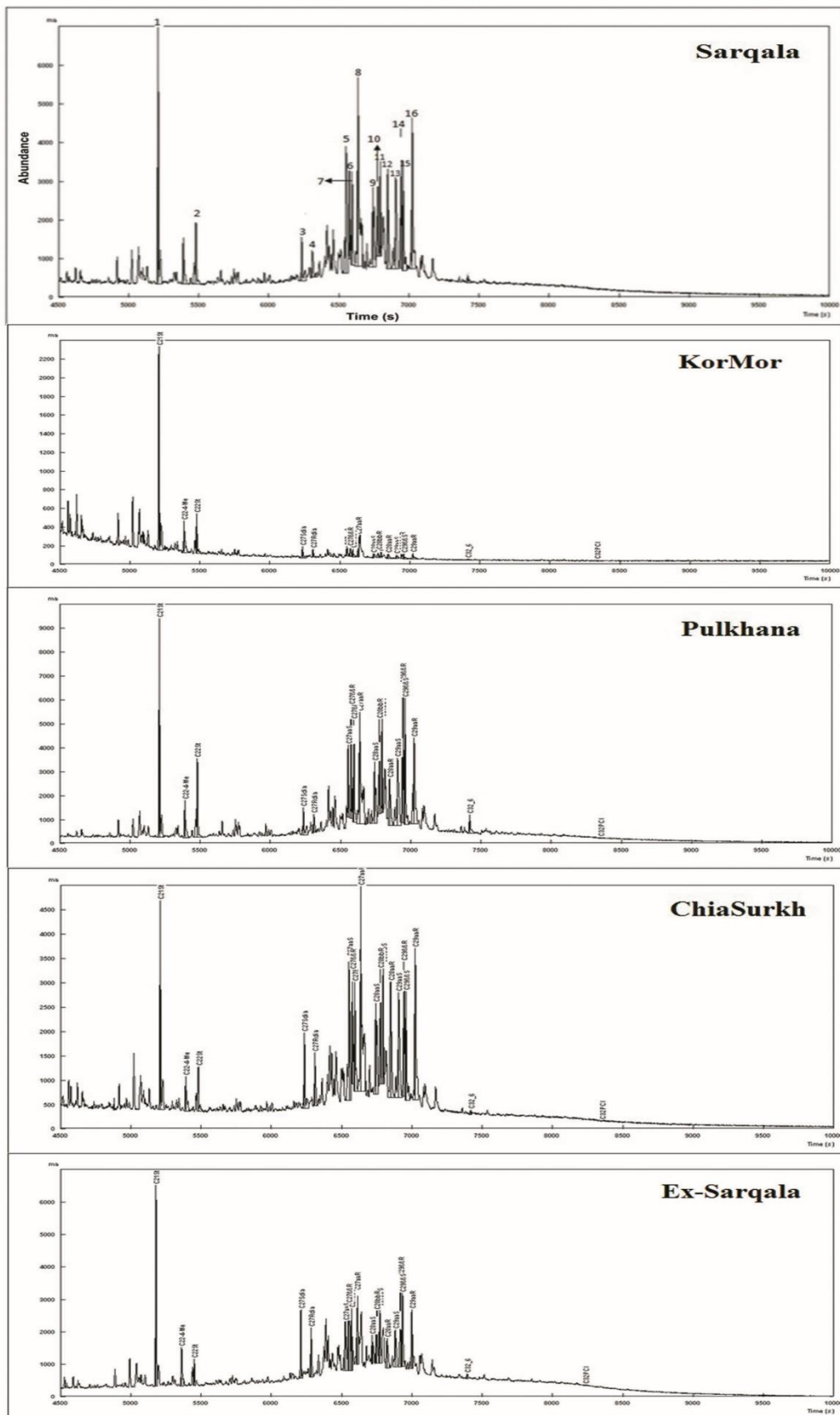


Figure-6: Mass chromatograms (SIM/GCMS Mode) for steranes, m/z 217, of the studied samples. (Peaks identification in Table 2).

Table-1: Showing the identification of most of the tricyclic and tetracyclics compound peaks of ion m/z 191 of Figure-5.

<i>Peak labels</i>	<i>Abbreviations</i>	<i>Identities</i>
1	C19/3	Tricyclic terpene
2	C20/3	Tricyclic terpene
3	C21/3	Tricyclic terpene
4	C23/3	Tricyclic terpene
5	C24/3	Tricyclic terpene
6	C25/3_R&S	Tricyclic terpene
7	C24/4	Teteracyclic terpene
8	C26/3_S	Tricyclic terpene
9	C26/3_R	Tricyclic terpene
10	C28/3_S	Tricyclic terpene
11	C28/3_R	Tricyclic terpene
12	C29/3_S	Tricyclic terpene
13	C29/3_R	Tricyclic terpene
14	Ts	18a(H)-trisnorneohopane
15	Tm	17a(H)-trishorehopane
16	C30/3_S	Tricyclic terpene
17	C30/3_R	Tricyclic terpene
18	C29H	17a(H), 21β(H)-norhopane
19	C29βa	17β(H), 21α(H)-normoretane
20	OLN	18α-Oleanane
21	C30H	17a(H), 21β(H)-hopane
22	C30βa	17β(H), 21α(H)-moretane
23	C31S	17a(H), 21β(H)-homohopane
24	C31R	17a(H), 21β(H)-homohopane
25	GCRN	Gammacerane
26	C32S	17a(H), 21β(H)-homohopane
27	C32R	17a(H), 21β(H)-homohopane
28	C33S	17a(H), 21β(H)-homohopane
29	C33R	17a(H), 21β(H)-homohopane
30	C34S	17a(H), 21β(H)-homohopane
31	C34R	17a(H), 21β(H)-homohopane
32	C35S	17a(H), 21β(H)-homohopane
33	C35R	17a(H), 21β(H)-homohopane

Table-2: Presenting the identification of regular and isomers of sterane compound peaks of Figure-6.

<i>Peak labels</i>	<i>Abbreviations</i>	<i>Identities</i>
1	C21 st	Short chain Sterane
2	C21 st	Short chain Sterane
3	C27Sdia	13 β (H), 17 α (H)-20S-Diasterane
4	C27Rdia	13 β (H), 17 α (H)-20R-Diasterane
5	C27 $\alpha\alpha$ S	5 α (H), 14 α (H), 17 α (H)-20S-Cholestane
6	C27 $\beta\beta$ R	5 α (H), 14 β (H), 17 β (H)-20R-Cholestane
7	C27 $\beta\beta$ S	5 α (H), 14 β (H), 17 β (H)-20S-Cholestane
8	C27 $\alpha\alpha$ R	5 α (H), 14 α (H), 17 α (H)-20S-Cholestane
9	C28 $\alpha\alpha$ S	5 α (H), 14 α (H), 17 α (H)-20S-24-
10	C28 $\beta\beta$ R	5 α (H), 14 β (H), 17 β (H)-20R-24-
11	C28 $\beta\beta$ S	5 α (H), 14 β (H), 17 β (H)-20S-24-
12	C28 $\alpha\alpha$ R	5 α (H), 14 α (H), 17 α (H)-20R-24-
13	C29 $\alpha\alpha$ S	5 α (H), 14 α (H), 17 α (H)-20S-24-Ethylcholestane
14	C29 $\beta\beta$ R	5 α (H), 14 β (H), 17 β (H)-20R-24-Ethylcholestane
15	C29 $\beta\beta$ S	5 α (H), 14 β (H), 17 β (H)-20S-24-Ethylcholestane
16	C29 $\alpha\alpha$ R	5 α (H), 14 α (H), 17 α (H)-20R-24-Ethylcholestane

Oil-Oil and Oil-Source Rock Correlation:

Correlations are considered as essential components in defining basin's petroleum system (Peters and Fowler, 2002). Defining the genetic relationships and connections between accumulated oils in an area and with their prospective source rocks is important for improving the exploration success and recognizing reservoir components to enhance production (Peters et al., 2005; Abeer et al., 2012).

The ratio of certain two biomarkers should be the same in the released oils from the same source rock if seriously not affected by extraneous factors (Hunt, 1996). Gases and condensates are related by preferential generation and accumulation mechanisms which may be different from those for oils. Moreover, condensate samples mostly included contaminated biomarkers rather than indigenous biomarkers that might adversely affect interpretation, including correlation (Tissot and Welte, 1984; Peters et al., 2005). Thus, in the present study the KorMor condensate sample has been excluded from the correlations processes in order to avoid any misinterpretations.

In the present study the biomarker ratios (Table-3) is utilized to perform correlation between selected samples (ChiaSurkh, Pulkhana, Sarqala oils and rock-extracted sample of Sargelu Formation).

n-Alkanes, Pristane and Phytane Compounds Distributions

From the m/z85 chromatograms of selected samples for correlation (Figure-4), it is deduced that there are strong similarities in molecular compounds distribution. Generally, they are characterized by predominance of light molecular weights ranged from C₁₅-C₂₀ over the heavy molecular compounds and the GC-MS trace's envelopes of the samples are unimodal and have front end biased distributions. The results of CPI and Pr/Ph ratios of the samples are close to each other and <1, including Sargelu-extracted sample (Table-3).

The cross plot of Pr/nC₁₇ versus Ph/nC₁₈ (Figure-7) shows similar depositional environments and organic contents of the source beds that released the oil samples and with the Sargelu-extracted sample. All these features indicated a great degree of compositional similarities between the origins of oil samples and Sargelu-

extracted sample. As a whole, based on n-alkane distributions including pristane and phytane compounds, it is concluded that the oil samples are supposed to have common source rocks and the properties of Sargelu-extracted sample is very close to the oil samples. Thus, the very good assumption is that the Sargelu Formation has molecular contributions to the studied oil samples. However, the Sargelu Formation based on vitrinite reflectance analysis is currently postmature ($R_o\%=1.4$) in Snagaw North-1 well (Saeed et al., 2015).

Table-3: Showing the biomarker ratios, as calculated from mass chromatograms, which are used in correlation processes.

Parameters	Sarqala	Pulkhana	Chia Surkh	Ex-Sargelu
CPI	0.98	0.98	0.98	0.99
Pr/nC17	0.18	0.15	0.21	0.24
Ph/nC18	0.37	0.42	0.31	0.36
Pr/Ph	0.63	0.48	0.84	0.60
C24Tet/C23T	1.01	0.99	0.77	0.81
Gr/C31RH	0.19	0.27	0.13	0.21
C29/C27St	0.96	1.05	0.87	1.03
C27diaS/C27 $\alpha\alpha\alpha$ R	0.23	0.24	0.37	0.94
St/Terpane	0.36	0.18	0.55	0.29
C27% $\alpha\alpha\alpha$ R	36.62	37.29	35.38	38.27
C28% $\alpha\alpha\alpha$ R	34.05	34.12	38.52	30.81
C29% $\alpha\alpha\alpha$ R	29.33	28.59	26.10	30.92

CPI: Carbon Preference Index; Pr: Pristane; Ph: Phytane; Tet: Tetracyclic; T:Tricyclic; H: hopane; Gr: gammacerane; St: Regular steranes; St/Terpanes= measured on total steranes (from C27S dia to C29 $\alpha\alpha\alpha$ R) and total terpanes (from Ts to C35RH); Ex: extracted rock sample. The used parameters were calculated from the peak area of some compounds that presented in Table 2 and Table 3.

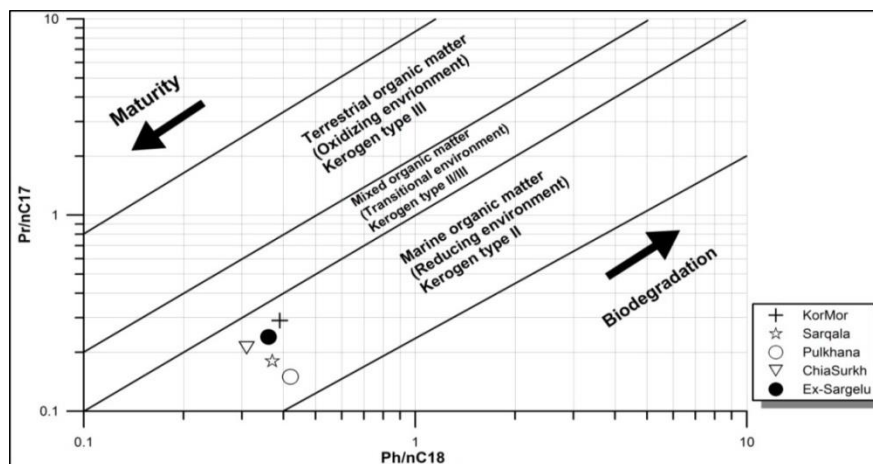


Figure-7: Cross plot of Pr/nC₁₇ versus Ph/nC₁₈, indicated marine organic matter sources for analyzed samples that deposited under reduced conditions. (The diagram after Hunt, 1996).

Terpane and Sterane Related Parameters

Terpane compounds distributions, generally show great similarities between the oil samples in one side and oil samples with the rock-extracted sample of Sargelu Formation in the other side (Figure-5). The most obvious differences between the m/z 191 chromatograms of the studied samples are the various intensities of C₂₉ and C₃₀ hopanes (peak 17 and 20, respectively) and Ts and Tm compounds (peak 14 and 15 respectively) (Figure-5). The later compounds are mostly maturity control, while hopanes are related to source materials (Adegoke et al., 2015).

The ChiaSurkh oil, genetically is much more similar to Sargelu Formation than Sarqala and Pulkhana crude oils since both Sargelu-extracted sample and ChiaSurkh oil pertained relatively higher abundance of C₃₀ than C₂₉ hopanes in contrast to Sarqala and Pulkhana crude oil, which is characterized by higher abundance of C₂₉ over C₃₀ hopanes. The intensity of Ts compound only in rock-extracted of Sargelu Formation is slightly higher than Tm compound, which is related to the high maturity of Sargelu Formation, as explained by Saeed (2014). On the other hand, in the oil samples Tm significantly is dominant over Ts compound, which is inferred relatively to similar maturities of the oil samples.

In spite of dissimilarity, there are many similarities between the oil samples in one side and oil samples with the rock-extracted of Sargelu Formation on the other side. All the studied samples included a complete series of tricyclic terpanes with predominant of C₂₃ compound (peak 4 in Figure-5). Tetracyclic terpane C₂₄ (peak 7 in Figure-5) is dominant in comparison to most of the tricyclic terpanes. All the samples included very low concentration of oleanane and gammacerane (peaks 19 and 24, respectively in Figure-5). The most interesting feature of the samples is their enrichment by complete series of homohopanes (peaks 22-32 in Figure-5), which is considered as the most characteristic evidence that prove anoxic depositional environment of source rocks for studied samples (Mohialdeen et al., 2013).

Based on various terpane related parameters that have been used to describe depositional conditions and source materials of the analyzed samples, the favored depositional environment of studied samples are marine that are enriched by carbonate materials and deposited with various degree under reducing conditions (Saeed, 2015).

Sterane biomarkers confirmed the similarity between the selected samples that are defined based on terpane (Figure-6). The characteristic feature that can be noticed from the steranes mass chromatograms is the abundance of diasteranes S and R (peaks 3 and 4, respectively in Figure-6) in Sargelu-extracted sample relative to the regular steranes, which relates to the high maturity of Sargelu Formation. In addition to, ternary plot of regular steranes $\alpha\alpha\alpha R$, expressed as C₂₇%, C₂₈% and C₂₉% (Table-3) is used to make comparison between the depositional environment and source materials of the studied samples (Bowden et al., 2006; Adegoke et al., 2015). The gross composition of regular steranes is used as a discriminated characteristic for classifying petroleum samples (Connan, 1993; Connan et al., 2006). Accordingly, the oil samples are genetically related and they are shown as strong affinity to Sargelu Formation since they are plotted as a one group on the sterane ternary plot (Figure-8). The samples including rock-extracted of Sargelu Formation are characterized by abundance of C₂₇ $\alpha\alpha\alpha R$ over C₂₈ $\alpha\alpha\alpha R$ and C₂₉ $\alpha\alpha\alpha R$ that deposited under marine environment, except for ChiaSurkh seep oil, where C₂₈ $\alpha\alpha\alpha R$ is relatively more abundant than C₂₇ $\alpha\alpha\alpha R$ and C₂₉ $\alpha\alpha\alpha R$ steranes.

Moreover, many cross plots between the values of different biomarkers ratios have been developed in order to provide detailed information concerning the correlation procedures either oil-oil or oil-source rock correlations (Mohialdeen, 2008; Mohialdeen et al., 2013; Adegoke et al., 2015). In the present study some of these biomarker ratios (Table-3) are used to show the genetic affinity of the selected samples to demonstrate further the connections between the oil fields of the studied area.

Table-3 listed those biomarkers ratios that are used together to draw various cross plot, such as Pr/Ph (Pristane/ Phytane) *versus* (C₂₉/C₂₇) regular steranes (Figure: 9), Gr/C₃₁R (Gammacerane/C31 homohopane R) *versus* C₂₄/4 / C₂₃/3 (C₂₄ Tetracyclic/ C₂₃ Tricyclic terpanes) (Figure: 10), and Sterane/Terpane *versus* C₂₇diaS/C₂₇ $\alpha\alpha\alpha R$ (Figure-11).

Consequently, based on the molecular distributions patterns, biomarkers ratios and the diagrams that are used to demonstrate the genetic relationships between the selected samples, it is concluded that there are strong connections between the oil samples in terms of depositional conditions, source organic matter and maturities and the possibility of generating from the common sources is too high. Regarding the oil-source rock correlations, also there are clear connections between the rock-extracted sample from Sargelu Formation and the oil samples in source related materials and depositional environment, but the current maturity of Sargelu Formation is completely different from the maturity stages of the oil samples. Nowadays, lower part of Sargelu Formation in Sangaw North-1 well is postmature according to vitrinite reflectance analysis and is not able to generate oil any more (Saeed et al., 2014).

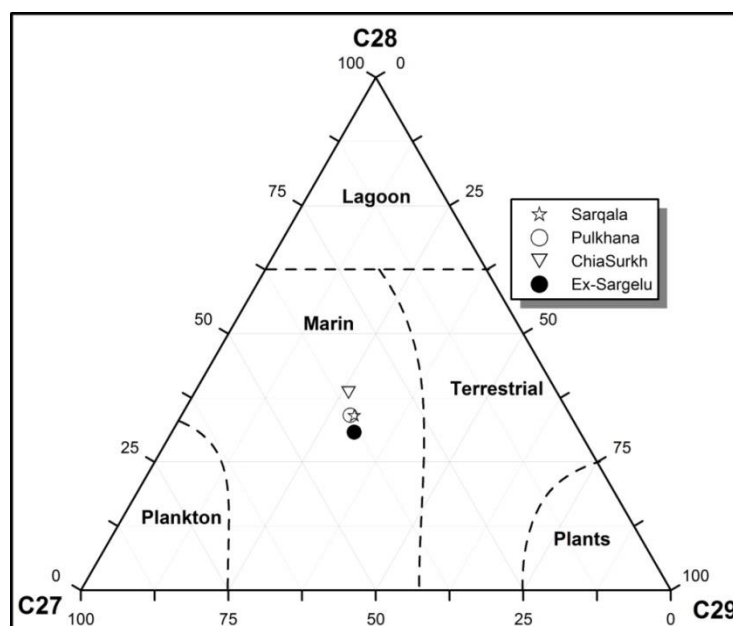


Figure-8: Steranes ternary diagram of C₂₇%, C₂₈% and C₂₉% ($\alpha\alpha\alpha$ R) concerning the selected samples, showing genetically relationships of the samples that deposited under marine environment (The diagram after Rabbani et al., 2005).

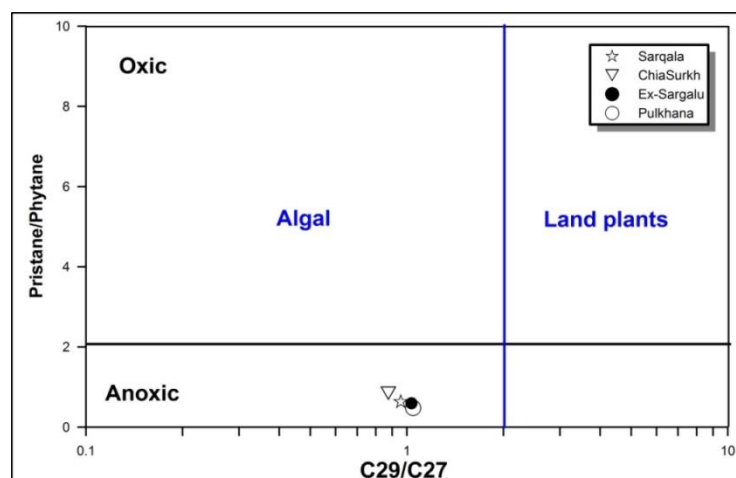


Figure-9: Cross plot of Pr/Ph versus C₂₉/C₂₇ regular steranes shows strong genetically relationships of the selected samples including rock-extracted of Sargelu Formation in terms of depositional environment and type of source materials, (The diagram after Othman et al., 2001)

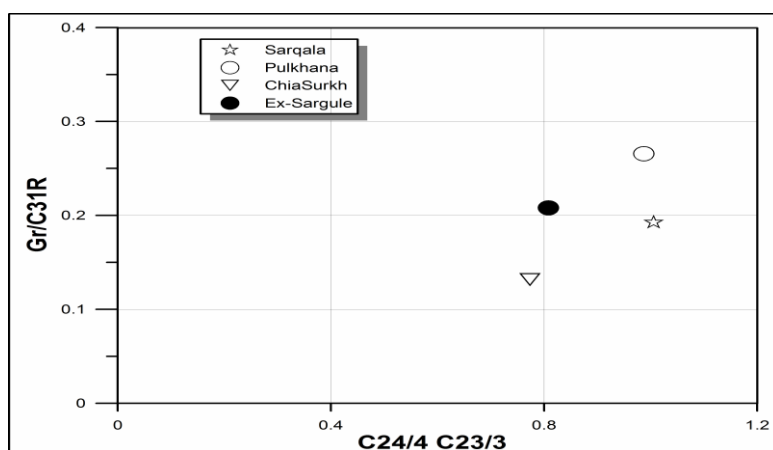


Figure-10: Cross plot of Gr/C₃₁R versus (C_{24/4}) / (C_{23/3}) shows close genetic affinity of the selected samples with each other, especially between Sarqala and Pulkhana crude oils separately and ChiaSurkh seep oil with rock-extracted of Sargelu Formation, (The diagram after Connan et al., 2006).

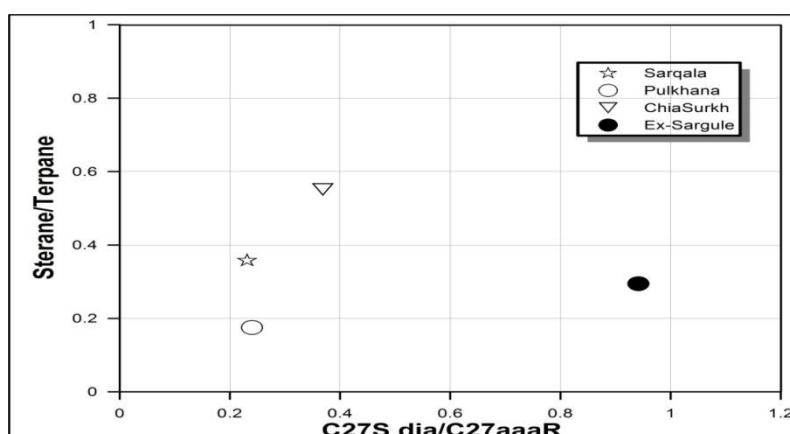


Figure-11: Cross plot of Sterane/Terpane versus C₂₇S dia/C₂₇aaaR shows close genetic relationships only between oil samples and no connections between oil samples and rock-extracted of Sargelu Formation due to higher maturity of Sargelu Formation, (The diagram after Connan et al., 2006).

Conclusions

According to molecular compounds and biomarkers analysis by GC/MS, crude oils, condensate and extract of Sargelu Formation are derived from marine algae and kerogen type II of a marine carbonate source rock that are deposited under reducing conditions. They are all characterized by low values of Pr/Ph, slightly even predominance of n-alkanes, high values of short over long chain n-alkanes and abundant C₂₇ regular sterane. Moreover, the geochemical results of tricyclics, tetracyclic and hopanes with high abundance of homohopanes series and low diasteranes/steranes ratio, altogether confirmed marine carbonate source rocks that are deposited under anoxic condition. Very low presence of gammacerane indicated normal salinity condition during the deposition.

The GC-FID traces of the crude oils and condensate approved lack of biodegradation effects on the samples, however ChiaSurkh seepage has been depleted from lighter hydrocarbon compounds (<nC₉).

The crude oils from different oil fields have similar molecular compound distributions and biomarker ratios suggest that there are strong genetic relationships between them and the possibility of generating from same or similar source rocks is too high. Sargelu Formation has molecular contributions to the crude oils based on similarities in biomarker ratios and compound distribution patterns. They are all characterized by similar depositional conditions and source materials, but the present maturity of Sargelu Formation is totally different and higher than the maturities of the crude oils.

Acknowledgments

The authors wish to acknowledge the financial support by the University of Sulaimani Research Grant. Sincere thanks are due to the Ministry of Natural Resources, Kurdistan Government, for supplying the samples and data for this research. Thanks to TOTAL Company for carrying out the geochemical analysis. The authors would also like to sincerely thank the anonymous reviewers for their careful and useful comments that improved the revised manuscript.

References

- Abdula, R. “*Petroleum source rock analysis of the Jurassic Sargelu Formation, northern Iraq*”, M.Sc. thesis (unpublished), Colorado School and Mines, United States, 106p. (2010)
- Abdula, R. “*Hydrocarbon potential of Sargelu formation and oil-source correlation, Iraqi Kurdistan*”, Arab. J. Geosci. DOI 10.1007/s12517-014-1651-0. (2015)
- Abeed Q., Leythaeuser D., and Littke R. “*Geochemistry, origin and correlation of crude oils in Lower Cretaceous sedimentary sequences of the southern Mesopotamian Basin, southern Iraq*”, Organic Geochemistry 46:113-126. (2012)
- Abdula, R.A., Balaky, S.M., Nourmohamadi, M.S., and Piroui, M. “*Microfacies Analysis and Depositional Environment of the Sargelu Formation (Middle Jurassic) from Kurdistan Region, Northern Iraq*”, Donnish Journal of Geology And Mining Research, Vol 1(1) pp. 001-026. (2015)
- Adegoke, A.K., Abdulla, W.H., and Hakimi, M.H. “*Geochemical and petrographic characterization of organic matter from the Upper Cretaceous Fika shale succession in the Chad (Bornu) Basin, northeastern Nigeria: Origin and hydrocarbon generation potential*”, Marine and Petroleum Geology, 61, pp. 95-110. (2015)
- Al-Ahmad, A.A. and Al-Gibouri, A. S. “*Geochemical and Palynological analysis in assessing hydrocarbon potential and palaeoenvironmental deposition, north Iraq*”, Journal of Petroleum Researches and Studies 190(2): 98-112. (2011)
- Al-Ameri T. K., Najaf A. A., Al-Khafaji A. S., Zumberge J., Pitman J. “*Hydrocarbon potential of the Sargelu Formation, North Iraq*”, Arab J Geosci. DOI: 10.1007/s12517-013-0875-8. (2013)
- Al-Ameri T. K., Zumberge J. and Markarian Z. M. “*Hydrocarbons in the Middle Miocene Jeribe Formation, Diyala Region, NE Iraq*”, Journal of Petroleum Geology 34(2): 199-216. (2012)
- Al-Qayim, B. Fuad Qadir, and Fawzi Al-Biaty “*Dolomitization and porosity Evaluation of the Cretaceous Upper Qamchuqa (Mauddud) Formation, Khabbaz oil field, Kirkuk area, Northern Iraq*”, GeoArabia 15(4): 49 –76. (2010)

- Aqrawi, A.A.M., Goff, J.C., Horbury, A.D., and Sadooni, F.N. “chapter 5: Middle Permian to Middle Jurassic” in *The Petroleum Geology of Iraq*, Beaconsfield, United Kingdom: Scientific Press Ltd, PO Box 21, Beaconsfield, Bucks, HP9 1NS, UK. (2010)
- Balaky, S.M.H. “Stratigraphy and sedimentology of Sargelu Formation (Middle Jurassic) in selected sections in Erbil and Duhuk Governorates–Iraqi Kurdistan”, M.Sc. thesis (unpublished), University of Salahaddin, Iraq, 109p. (2004)
- Bellen, R.C. van, H.V. Dunnington, R. Wetzel, and D.M. Morton, eds., *Lexique stratigraphic international*: Paris, v. III, Asie, Fascicule 10a Iraq, 333 p. (1959)
- Beydoun, Z. R. “Arabian plate oil and gas: Why so rich and so prolific?”, *Episodes* 21 (2): 74-81. (1998)
- Buday, T. “The regional geology of Iraq, v. 1, stratigraphy and paleogeography: Mosul, Iraq”, Dar Al-Kutub Publishing House, University of Mosul, 445p. (1980)
- Buday, T. and Jassim, S. Z. “The regional geology of Iraq: Vol.2: Tectonism, Magmatism, and Metamorphism. In I. I. Kassab and M. Abbas (eds.), Dar Al-Kutub Publication House, Mosul, Iraq, 325p. (1987)
- Connan J., Kavak O., Akin E., Yalc M. N., Imbus k. and Zumberge J. “Identification and origin of bitumen in Neolithic artefacts from Demirko`y Ho`yu`k (8100 BC): Comparison with oil seeps and crude oils from southeastern Turkey”, *Organic Geochemistry* 37: 1752-1767. (2006)
- Connan J. “Chapter I.7: Molecular Geochemistry in Oil Exploration”, in *Applied Petroleum Geochemistry*, edited by M. L. Bordenave, pp.177-203. (1993)
- Fatah, S.S. “Source rock characterization and biomarker distribution of Sargelu Formation (Middle Jurassic), Miran Oil Field, Sulaimani area, Kurdistan Region, NE-Iraq”, MSc thesis, Unpublished, University of Sulaimani, 140p. (2014)
- Hakimi, M.H., Mohialdeen, I.M.J., Abdullah, W.H., Wimbledon, W., Makeen, Y.M., and Mustapha, K.A. “Biomarkers and inorganic geochemical elements of Late Jurassic-Early Cretaceous limestone sediments from Banik Village in the Kurdistan Region, Northern Iraq: implications for origin of organic matter and depositional environment conditions”, *Arabian Journal of Geosciences*, DOI 10.1007/s12517-015-1863-y . (2015)
- Hunt, J.M. “*Petroleum Geochemistry and Geology*”, W.H. Freeman and Company, New York, 743 pp. (1996)
- Jassim, S.Z., and T. Buday “chapter 10: Late Toarcian-Early Tithonian (Mid-Late Jurassic) Megasequence AP7”, in *Geology of Iraq*, edited by Jassim, S.Z., and J.C. Goff, first edition: Brno, Czech Republic, Prague and Moravian Museum, pp.117-123. (2006) c
- Jassim, S.Z., and T. Buday “chapter 6: Units of the Unstable Shelf and the Zagros Suture”, in *Geology of Iraq*, edited by Jassim, S.Z., and J.C. Goff, first edition: Brno, Czech Republic, Prague and Moravian Museum, pp. 71-83. (2006) a
- Mohialdeen I.M.J. “Source rock appraisal and oil-source correlation for the Chia Gara Formation, Kurdistan-north Iraq”, PhD thesis, College of Science, University of Sulaimani, pp. 15–35. (2008)

- Mohialdeen I.M.J., Hakimi M.H., Al-Beyati F.M. “*Geochemical and petrographic characterization of Late Jurassic-Early Cretaceous Chia Gara Formation in Northern Iraq: palaeoenvironment and oil generation potential*”, *Mar Pet Geol* 43:166–177. (2013)
- Murris, R.J. “*Middle East-stratigraphic evolution and oil habitat*”, *AAPG Bulletin* 64 (5): 597-618. (1980)
- Othman, R., Arouri, K.H., Ward, C.R., and McKirdy, D.M. “*Oil generation by igneous intrusions in the northern Gunnedah Basin, Australia*”, *Organic Geochemistry* 32:1219-1232. (2001)
- Peters, K.E. and Fowler, M.G. “*Applications of petroleum geochemistry to exploration and reservoir management*”, *Organic Geochemistry* 33: 5-36. (2002)
- Peters, K.E., Walters, C.C., Moldowan, J.M. “*The Biomarker Guide*, vol. 2. Cambridge University Press, 1155 p. (2005)
- Pitman, J.K., D. Steinshouer, and M. D. Lewan “*Petroleum generation and migration in the Mesopotamian Basin and Zagros Fold Belt of Iraq, results from a basin-modeling study*”, *GeoArabia, Gulf PetroLink, Bahrain* 9(4): 41-72. (2004)
- Rabbani A. R. and Kamali M. R. “*Source Rock Evaluation and Petroleum Geochemistry , Offshore SW Iran*”, *Journal of Petroleum Geology* 28(4): 413-428. (2005)
- Saeed D. A. “*Organic geochemical characteristics of Lower-Middle Jurassic succession and crude oils from selected wells, Garmian area, Kurdistan Region, NE-Iraq*”, MSc thesis, Unpublished, University of Sulaimani, 144p. (2015)
- Saeed, D.A., Mohialdeen, I.M.J., and Kalaitzidis, S. “*Thermal maturity of Early-Middle Jurassic formations in Well Sangaw North-1 (SwN-1), Garmian, Kurdistan, NE Iraq: implications for petroleum generation*”, Poster for ICCP-2014 India, September 20-27, 2014. <http://iccp2014india.org/>. (2014)
- Sharland, P. R., Archer, R., Casey, D. M., Davies, R. B., Hall, S. H., Heward, A. P., Horbury, A. D., and Simmons, M. D. “*Arabian Plate Sequence Stratigraphy*”, *GeoArabia, Special publication 2, Gulf Petro Link, Bahrain*, 372p. (2001)
- Tissot, B.P. and Welte, D.H. “*Petroleum Formation and occurrence: A new approach to oil and gas exploration*”, 2nd ed.: Springer Verlag, Berlin, 699 p. (1984)

